PROCEEDINGS OF THE NATIONAL CONFERENCE OF THE NIGERIAN SOCIETY OF ENGINEERS [NSE]

"COAL CITY 2021"

HELD AT THE INTERNATIONAL CONFERENCE CENTRE
FEDERAL CAPITAL TERITORY
ABUJA

6TH – 10TH DECEMBER, 2021

ISBN 978-978-971-073-7

The Nigerian Society of Engineers

Conference Proceedings

2021 NATIONAL ENGINEERING CONFERENCE AND ANNUAL GENERAL MEETING

"COAL-CITY 2021"

THEME:

EXPANSION OF THE ENERGY MIX FOR NATIONAL ECONOMIC GROWTH

"COAL CITY 2021" CONFERENCE PROCEEDINGS

FOREWARD

PROCEEDINGS OF 2021 NSE ANNUAL CONFERENCE-TAGED COAL-CITY

The Nigerian Society of Engineers (NSE) is once again organizing its Annual National Engineering Conference and AGM at ICC, Abuja. As usual Engineers, Researchers, Academia, Industrialists, Local and Foreign Investors, Policy makers, Legislators, Development Partners, and experts from all works of life would converge in Abuja the Capital City of Nigeria between 7th –9th December 2021 to deliberate on this year's conference with theme titled " EXPANSION OF THE ENERGY MIX FOR NATIONAL ECONOMIC DEVELOPMENT”.

The objectives of the conference include: analyze the current policy direction, efforts in the provision of energy on a sustainable basis utilizing the abundant and diverse renewalable sources with the support of the relevant infrastructure. Strategies on how to promote the sustainable expansion of energy mix to address the energy needs and revive industrial growth and facilitate the development of rural economies, increase in job creation, and reduce poverty across the country would be scrutinized.

The conference was successfully held as scheduled where a total of 53 well researched scientific articles were presented and discussed. This included six (6) commissioned papers and keynote speech from eminent personalities that addressed the main theme of the conference.

The conference ran four (4) concurrent technical sessions where it interrogated the prospects and challenges of utilization of Coal, Natural Gas and Hydro (Water) for sustainable power generation and provision of competitive energy in Nigeria. The use of environment friendly technologies for sustainable expansion of energy mix was equally reviewed due to its critical importance within the scheme of climate change.

The conference was able to examine the options of upgrading of technological capabilities of the power sector to address the ever-evolving challenges surrounding deployment of Technology Innovations to promote Renewable Energy Systems and enhance the nation competitiveness.

The conference interrogated and characterized the competitiveness of the Mini/Smart Grid Development and its Integration with Clean Energy for mass adoption to enhance the reliability and performance of the power sector; reviewed the opportunities and risks for investments in energy mix promotion using PPP approach as well as energy mix financing and regulations.

The conference attempted to probe the requisite human and institutional capacity development plan to drive the expansion of energy mix; design and promote an integrated and coordinated approach that would stimulate sector synergy; develop framework for resolving energy crisis, carbon capture and storage technologies for climate change mitigation and proposed strategies to encourage the private sector to lead in monitoring, evaluation, and feedback mechanism.

Most of the presentations and discussions centered around the principle of energy mix. In order to meet its energy needs, each country uses the types of energy available to it, in different proportions. As the national population grows, countries become more energy sensitive translating to higher demands.

Discussants at the conference were able to provide a clearer understanding of the term “energy mix” as the blending of several primary sources of energy designed to meet a country’s energy needs. This normally comprise of fossil fuels such as oil, natural gas, coal, nuclear energy and other sources of renewable energy. The other sources of renewable energy identified during the deliberations at the conference include wood, other bio-energies, hydro, wind, solar and geothermal.

Panellists at the conference advanced the argument that composition of the energy mix varies greatly from one country and can change significantly from time to time. This position points to the fact that variables affecting such changes include: i) the availability of usable resources domestically or the possibility of importing them, ii) the extent and type of energy needs to be met, and iii) policy choices determined by historical, economic, social, demographic, environmental and geopolitical factors.

Verifiable global data on energy consumption was presented by participants where statistics on the consumption of primary energy, for instance in 2018, amounted to the equivalent of about 13.86 billion metric tons of oil, compared to about 11.27 billion tons in 2006. Primary energy comprises of commercially traded fuels, includes modern renewable energy sources used to generate electricity. The largest share of primary energy consumption worldwide is attributed to oil, followed by coal and natural gas. Nuclear energy has fallen out of favour over the last decade in some countries, while hydropower has become increasingly popular.

Experts informed the participants at the conference that with the present accelerated erosion of the ozone layer caused by global warming, the World is approaching a critical time in human history where decision on either to continue burning fossil fuels and contributing to climate change or to switch to clean energy have to made consciously, making the role of renewable energy sources more and more important.

Scientists and industrialist present at the conference opined that in other environments particularly in developed countries, energy mix points to all direct uses of energy, such as transportation and housing. It important to note that the phrase energy mix should not be confused with power generation mix, which refers only to generation of electricity. In Nigeria, however, there is a thin line between energy mix and power generation mix.

Participants deliberated on the subject matter of energy mix in Nigeria from the perspectives of outlined in the sub-themes of this conference with emphasis on renewable energy because developing this subsector would go a long way in achieving optimal energy mix.

The commissioned speakers pointed to the fact energy supply in Nigeria (especially electricity and refined petroleum) has been inadequate and unreliable in spite the country's rich endowment in hydrocarbon resources and its heavy reliance on them. This, in their opinion, has transformed Nigeria into an energy deficient nation compelling widespread dependence on diesel-based generators by different classes of electricity consumers. Currently only 40% of urban and 10% of rural residents have access to electricity. Per capita consumption of energy in Nigeria stands at about 212 kWh is one of the lowest in the world. The consequences of this on business competitiveness and the social lives of the people have been enormous.

Researchers pointed out that deficient supply of modern fuels has also forced a heavy reliance of households on biomass resources such as fuel wood, corn stocks, animal dung, among others, for domestic energy use despite their inefficiencies and health risks. Modern fuel scarcity in the economy and failing electricity supply create a dual energy crisis for Nigeria. Studies reported at the conference indicated that small scale businesses suffer the most from Nigeria's energy poverty. Such businesses spend a large proportion of their capital (about 20-25% of their investment) on back-up generating facilities thus turning the Nigerian economy into a generator economy. The economic cost of inadequate and unreliable electricity to the Nigerian economy is huge.

The conference was informed of the nation's Renewable Master Plan projections. According to the projections, the Nigeria's electricity demand will reach 116GW (gigawatts) by 2030. The estimates put the demand at 45GW as at 2020. The Energy Commission of Nigeria also projected increase in electricity demand from 51GW in 2020 to 119GW by 2030. On the supply side, Nigeria has 25 grid-connected Power Generating Plants with a total installed capacity of 12.56GW. Unfortunately, these plants can only boast of an available capacity of 3.88GW. This is because a number of these plants are unavailable for evacuation to the national grid because of the peculiarity of Nigeria's system – for instance lack of maintenance and repair requirements, trip offs, faults and leakages. Most of these plants are fired by fossil (natural gas) thermal power (85%, i.e., 22 Gas Plants generating 10,632MW) whilst the remaining 15% are accounted for by 3 hydroelectric power plants – Jebba, Kainji and Shiroro Power Stations generating 1,930MW (Africa-EU RECP, 2016).

The conference established that renewable energy (RE) resources hold great potential for meeting the energy needs of Nigeria, a country that is aptly described as an energy deficient nation. With a huge RE resources such as biomass, strong winds, unlimited solar potentials, hydro and geothermal resources, it is believed Nigeria has sufficient RE resources that could potentially provide a significant proportion of the country's expanding energy needs. For example, the country has a solar radiation of between 3.5 kWh/m²/day at the coastal areas and 9.0 kWh/m²/day at the northern boundary. This presents a great opportunity for Nigeria to get RE at low cost as well as minimize her dependence on fossil fuels.

Looking at the current electricity situation in Nigeria, participants at the conference concluded that the demand for electricity greatly outstrip the supply and further observed that to bridge this gap, the country needs to develop its renewable energy potentials.

The proceedings of the 2021 NSE is structured along the main theme and ten (10) sub-themes to make it reader friendly and easy reference material. The sub-themes include: i) prospects and challenges of utilization of coal, natural gas and hydro (Water) for sustainable power generation and provision of competitive energy in Nigeria, ii) appropriate energy mix to facilitate rural development and poverty alleviation, iii) deployment of technology innovations to promote renewable energy Systems, iv) opportunities and risks for investments in energy mix promotion, v) energy mix financing and regulations, vi) public private partnerships (PPP) as a veritable tool for sustainable energy mix, vii) energy mix research and its applications to address current energy crisis, viii) leveraging on energy mix to transit the nation to clean energy environment, ix) mini/smart grid development and its integration with clean energy for mass adoption and x) energy crisis, carbon capture and storage technologies for climate change mitigation.

The proceedings captured the silent contributions of the key organizations and lead speakers leading to a consensus to develop a road map charting a direction on how Nigeria can achieve sustainable expansion of energy mix. The conference further resolved to show how the former translate in increased energy generation efficient use, competitiveness, profitability, etc to enhance private sector participation.

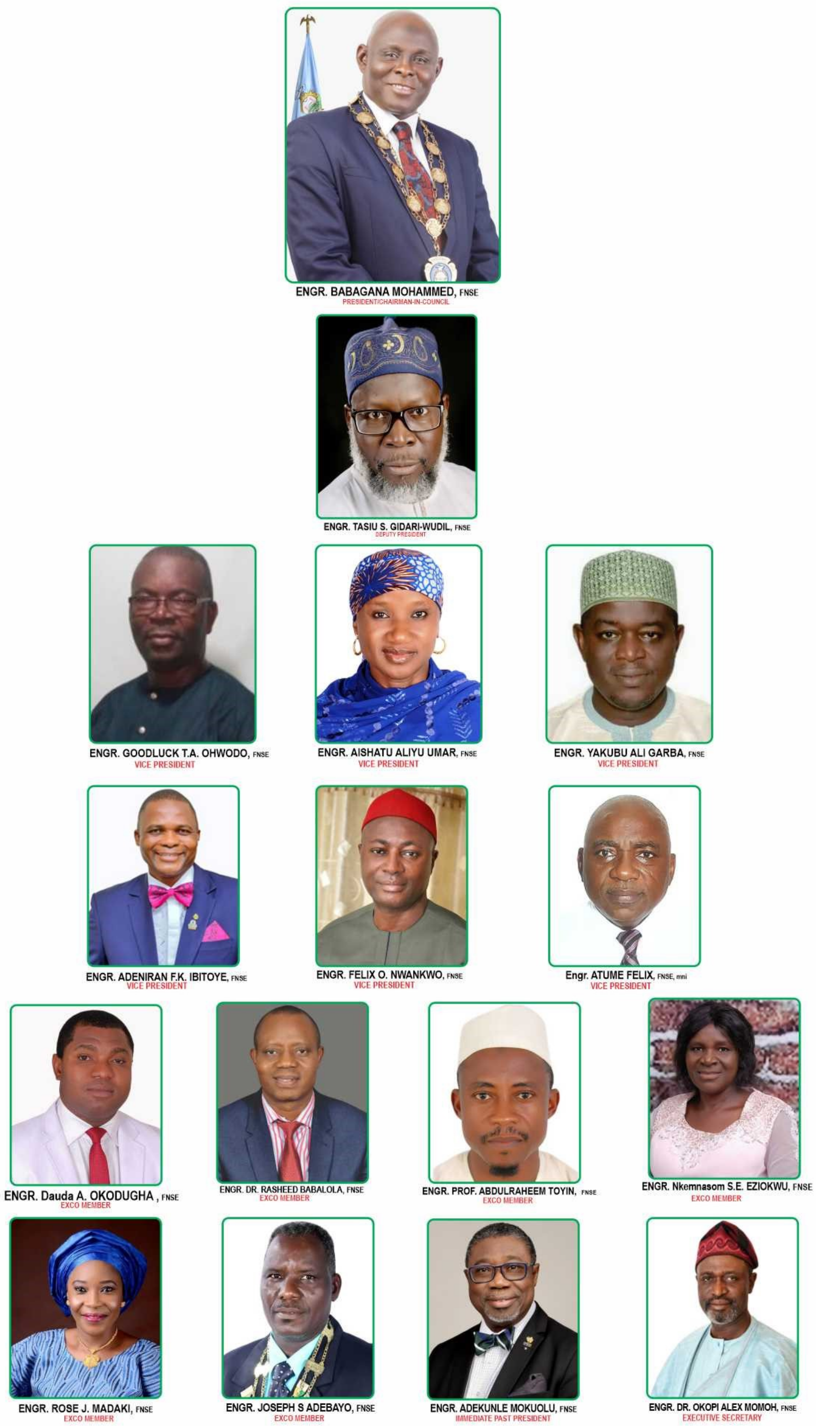
The conference underscored that these transformations in the power sector is expected to trigger changes in the availability, accessibility, affordability of energy and its alignment with the different energy demands from the diverse sectors. The resultant effect is more uptake of relevant technologies by the industry to improve their efficiencies and quality of products as well as services. More opportunities and enhancement of lifestyles of the citizens which directly affect the entrepreneurship and rural economy.

It is our expectation that the conference proceedings would serve as a rich reference material for the diverse target users cutting across the academia, industry, operators, regulators, etc.

On behalf of the 2021 NSE National Executive Committee, the Conference Planning Committee (CPC) and Technical Committee (TC), I thank all for coming and participating in the 2021 NSE Conference making remarkable contributions. Wishing all pleasant reading and purposeful use of the materials complied in the proceedings.

Engr. Prof. Sadiq Z. Abubakar, FNSE, FNIAE
Chairman, Technical Sub-Committee

LIST OF 2021 NATIONAL EXECUTIVE COMMITTEE



LIST OF 2021 CONFERENCE PLANNING COMMITTEE

2021 CONFERENCE PLANNING COMMITTEE

1. Engr. Etido Inyang, FNSE - Chairman
2. Engr. Robbie James Owivry, FNSE - Member
3. Engr. Ojekunle Ezekiel O., - Member
4. Engr. Joan Nweke, MNSE - Member
5. Engr. Fatima M. Kaigama, MNSE - Member
6. Engr. Mrs. Kori Shettima, MNSE - Member
7. Engr. Mustapha Garba, MNSE - Member
8. Mr. Abdulkadir Aliyu - Secretary
9. Engr. Musa Ibrahim Musa, MNSE - Asst. Secretary

SUB-COMMITTEES

Local Organizing Committee

1. Engr. Lady Uchenwa Ujam, FNSE - Chairman
2. Engr. Abdulbari Abdulmalik, FNSE - Member
3. Engr. Dipo Mabogaje, FNSE - Member
4. Engr. Halimat Adediran, FNSE - Member
5. Engr. Abdulrahman Mohammed, FNSE - Member
6. Engr. Chukwuocha Emake.J., MNSE - Member
7. Engr. Nweze Fidelis King, MNSE - Member
8. Engr. Olufemi Ojo, MNSE - Member
9. Engr. Dr. Odinaka Victor Okonkwo, MNSE - Member
10. Engr.Obumneme C. Onyedum, MNSE - Member
11. Engr. Dr. E.C. Okoroigwe, MNSE - Member
12. Engr. Egiuzo Ikechukwu Davidson, MNSE - Member
13. Engr. Dr Eze Innocent Ochiagha, MNSE - Member
14. Engr. Gerald Ibe Okwe, MNSE - Member
15. Engr. Godwin Ihegboro, MNSE - Member

16. Engr. Nnamdi Cyprian Nwasuka, MNSE - Member

Registration/Materials

1. Engr. James Owivry, FNSE - Chairman
2. Engr. Lola Adetona, MNSE - Member
3. Engr. Fausat B. Dare Bello, MNSE - Member
4. Engr. Ahmed Tijjani Abubakar, MNSE - Member

Venue and Accommodation

1. Engr. Joan Nweke, MNSE - Chairman
2. Engr. Akpan Akin, MNSE - Member
3. Engr. Lawal Salisu, MNSE - Member
4. Engr. Stephen Paul Gyang, MNSE - Member

Exhibition

1. Engr. Ezekiel Ojekunle, FNSE - Chairman
2. Engr. Chibuike Onyejietu, MNSE - Member
3. Engr. Gladys I. Okoro, MNSE - Member
4. Engr. Abraham Aghadike, MNSE - Member

Transportation

1. Engr. Kori Shettima, MNSE - Chairman
2. Engr. Abdulrahman Mohammed, FNSE - Alternate Chairman
3. Engr. Bashir Shettima, MNSE - Member
4. Engr. Aji Agbu, MNSE - Member
5. Engr. Nsikak Afia, MNSE - Member

Entertainment/Souvenir

1. Engr. Fatima Kaigama, MNSE - Chairman
2. Engr. Usman Abubakar, FNSE - Member
3. Engr. Mrs. Ogho Etaghene, MNSE - Member
4. Engr. Murtala Olanrenwaju A. MNSE - Member
5. Engr. Ibrahim Kawuwa, MNSE - Member

Fund Raising

1. Engr. Etido Inyang, FNSE - Chairman
2. Engr. Ekpenyong U. Ekpenyong, MNSE - Member
3. All Members of the CPC

Security

1. Engr. Akaninyene Akpan, MNSE - Member
2. All Members of the NSE Security Committee

LIST OF 2021 TECHNICAL COMMITTEE

1. Engr. Prof. Sadiq. Z. Abubakar, FNSE	-	Chairman
2. Engr. Prof. James Gbenga Aribisala, FNSE	-	Vice Chairman
3. Engr. Prof. O.A.U. Uche, FNSE	-	Member
4. Engr. Joshua Aboyeji Adeoye, FNSE	-	,,
5. Engr. Prof. Anyansi Francis, FNSE	-	,,
6. Engr. Prof. Akindele Folarin Alonge, FNSE	-	,,
7. Engr. Prof. David Esezobor, MNSE	-	"
8. Engr. Prof. Lateef Olorunfemi Onundi, MNSE	-	,,
9. Engr. Prof. Joshua O. Olaoye, MNSE	-	,,
10. Engr. Prof. Baba El-Yakub, MNSE	-	,,
11. Engr. Dr. Uche Chinweoke Ogbuefi, MNSE	-	,,
12. Engr. Kunduli Mustapha, MNSE	-	,,
13. Engr. Dr. Kolawole Adisa Olonade, MNSE	-	,,
14. Engr. Dr. Robinson Ejilah, MNSE	-	,,
15. Engr. Dr. Eyitayo Afolabi, MNSE	-	,,
16. Engr. Arifa Haq, MNSE	-	,,
17. Engr. Ya'u Shuaibu Haruna, MNSE	-	,,
18. Ajayi Olubunmi	-	Secretary
19. Amaka Jideofor	-	Asst. Secretary

EDITOR IN CHIEF AND CHAIRMAN TECHNICAL COMMITTEE

PROF. SADIQ Z. ABUBAKAR
NIGERIAN SOCIETY OF ENGINEERS
NATIONAL ENGINEERING CENTRE
OFF LABOUR HOUSE ROAD – NATIONAL MOSQUE
CENTRAL BUSINESS DISTRICT
FCT, ABUJA

TABLE OF CONTENTS

THEME FOCUS: PROSPECTS AND CHALLENGES OF UTILIZATION OF COAL, NATURAL GAS AND HYDRO (WATER) FOR SUSTAINABLE POWER GENERATION AND PROVISION OF COMPETITIVE ENERGY IN NIGERIA

THEME FOCUS: APPROPRIATE ENERGY MIX TO FACILITATE RURAL DEVELOPMENT AND POVERTY ALLEVIATION

PLENARY SESSIONS

EXPANSION OF THE ENERGY MIX FOR ELECTRICITY GENERATION IN NIGERIA

Prof. Abubakar S. Sambo, ***OON, NPOM***
BEng (ABU), DPhil (Sussex), Regd Engr (COREN)
FAS, FAEng, FNSE, FSESN, FNAEE, FNIMechE, FRAESON, FNIM, FNIPE, FEI(UK)
Faculty of Engineering & Env. Design, Usmanu Danfodiyo University, Sokoto

ABSTRACT
The major economic sectors of industry, transport, services and households in Nigeria are greatly restrained from the expected growth due to the grossly inadequate energy supplies. Electrical power of 4,000 – 5,000 MW is grossly inadequate for a population of more than 200 million people. Recent energy demand projections show that for a GDP growth rate of 7% the required electrical power will be about 31,000 MW in 2020; 63,000 MW in 2030; and 103,000 MW in 2040. This can be achieved by the significant expansion of the energy mix for electricity generation from the current mix of gas and hydro to also include nuclear, solar and wind. Expansion of the energy mix will ensure enhanced energy security of supply, which investors always look for, before they establish branches outside their countries of origin.

Over the years the increasing effect of global warming leading to climate change complications arising largely due to the combustion of fossil fuels, along with other issues, made the United Nations to come up with Sustainable Development Goals (SDGs) to be attained by 2030. Nigeria signed the SDGs in 2015 and ratified it in 2017. Earlier on, the United Nations Framework Convention on Climate Change (UNFCCC) convinced African nations that climate change problems are also African problems and the African Union adopted agenda 2063 mandating its member states to produce their National Determined Contributions (NDCs) for abating climate change.

The International Energy Agency (IEA) after noting that the implementation of the SDGs, worldwide, will not limit global temperature rise to 1.5 degrees Centigrade came up with 2050 Net Zero Agenda for substantial reduction of CO2 emissions which was the major topic of discussion at the November 2021 Glasgow Climate Change Conference where President Muhammadu Buhari's address conveyed the Government's decision to end the use of gas by 2040 and to attain Net Zero CO2 emission by 2060. Earlier, at the United Nations General Assembly in New York in September 2021 the President presented Nigeria's Energy Compact for energy transition.

A new Electricity Generation Expansion Plan (EGEP) for Nigeria was developed, based on the energy demand projection produced by the Energy Commission of Nigeria. EGEP was also produced by integrating the new policy statements on energy transition and on reduced emissions but with expanded energy mix. If the Nigerian Society of Engineers will want to recommend use of gas beyond 2060 and also the use of coal then it will be necessary for a detailed study to be conducted on development of more gas fields, on mining of coal and processing it, on the entrenchment of circular carbon economy, on job creation potentials as well as a detailed cost benefit analysis of the whole matter.

Contents

Introduction

- Reasonable standard of living and also of economic growth both require adequate, reliable and affordable energy supplies for the households, services, transport and industrial sectors of all national economies.
- Fossil type energy resources, like oil and natural gas and also coal which have been the dominant sources of energy for electrification, transport and industrial production are highly polluting and exhaustible. Electricity generation from renewable energy resources of solar energy, wind, hydro and biomass/biofuels as well as from nuclear power plants produce negligible pollution.
- It should noted that 87% of the CO2 emissions from human sources arise from the combustion of fossil fuels and it has 4 major components:

- Electricity generation	41%
-Transportation	23%
- Industry	20%
- Others	16%

- Global temperature rise arising largely from combustion of fossil fuels is the principal cause of global warming which if not curtailed will lead to climate change in general with the following outcomes:
  - Melting of the glaciers
  - Massive global floods
  - Droughts
  - Increased fire threats
  - Weed and pest invasions, amongst others.

- In order to address climate change complications and other development challenges, Nigeria and the overwhelming majority of nations signed and ratified the United Nations Sustainable Development Goals (SDGs). Nigeria signed it in 2015 and ratified it in 2017.

- SDG7 in particular is for all nations to provide universal access to modern energy services to its citizens by 2030 as well as to significantly increase the uptake of renewable energy and doubling of energy efficiency.
- The International Energy Agency (IEA) after monitoring the implementation of the SDGs concluded that the world will not limit temperature rise at 1.5 °C and thereafter came up with the 2050 Net Zero Agenda which aims at a situation of zero CO_2 emission by use of renewable energy, electric vehicles and carbon capture techniques in addition to developing forestry plantations to serve as carbon sinks.
- In 2013 the African Union (AU) adopted Agenda 2063 after recognizing Climate Change as a key challenge to the continent's development and agreed that member states should produce their Nationally Determined Contributions (NDCs) for abating Climate Change complications.
- While the nation's energy supply should fully align with the SDGs and in particular SDG7 as well as the NDCs for abatement of Climate Change complications, there is the need for the nation's power supply to also be based on:

- Nigeria's Energy Compact Template, reflecting the nation's commitments to the global energy transition, presented at the United Nations General Assembly (UNGA) in September 2021

- Nigeria's commitment at COP26 namely: Gas will be used up to 2040 and Nigeria will attain Net Zero CO_2 emissions by 2060.

- The implementation of these policies for the provision of adequate and reliable electricity will necessitate the expansion of the energy mix from the current mix of mainly two (gas and hydro) to five (gas, hydro, solar, wind and nuclear).
- Expansion of the energy mix for electricity supply from two to five will ensure enhanced level of security of electricity supply which is a major factor that international manufacturing plants consider before they establish branches outside their countries of origin.

Electricity Generation Technologies

- Power supply systems can currently be categorized into four:

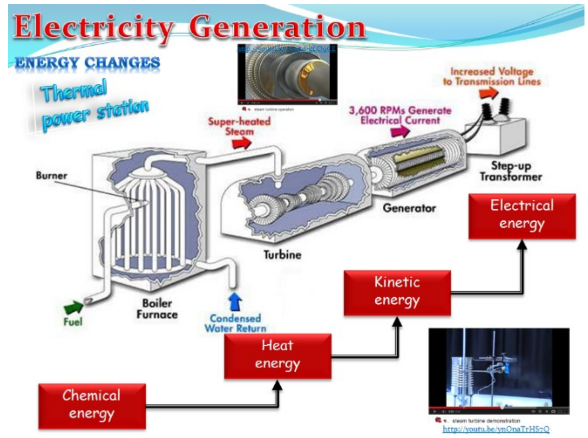
- Fossil Fuel Plants which include coal plants, gas plants, diesel/oil plants

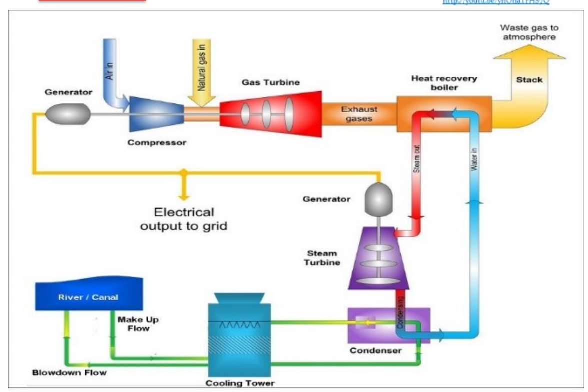
- Nuclear Power Plants

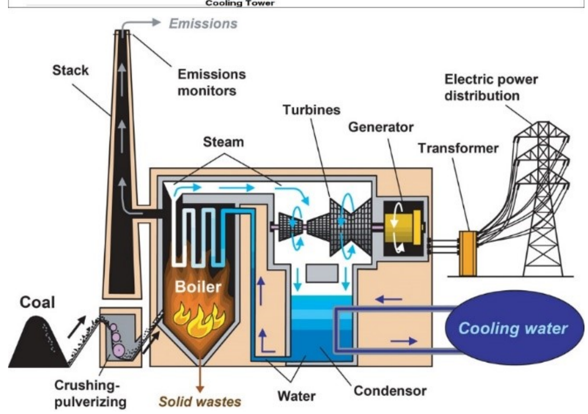
- Renewable Power plants of solar, wind, hydro, geothermal and others

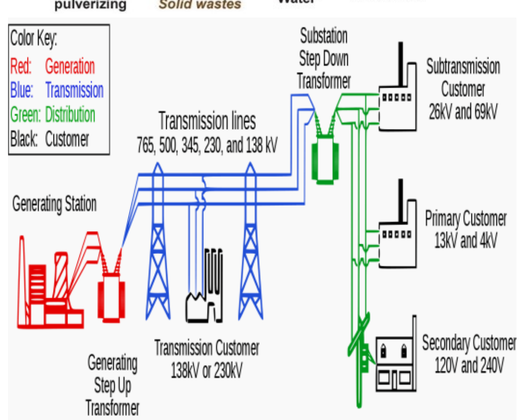
- Emerging Technologies of Hydrogen/Fuel Cells

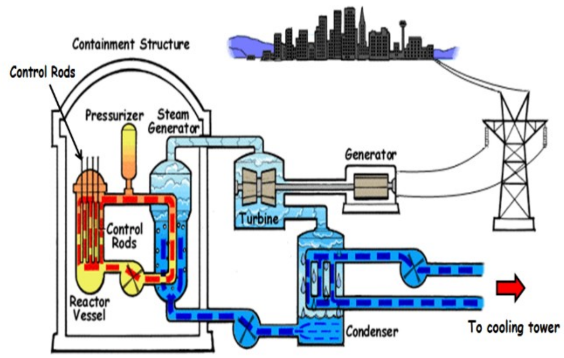
- ❑ Climate Change considerations are globally making nations to minimize CO_2 emissions in the power and transport sectors and this is moving the world considerably towards renewable energy power systems and to electric vehicles.
- ❑ To refresh and update our understanding of the subject matter, and to carry Engineers not conversant with power systems along, there is need to begin with a brief discussion of the major conventional and renewable energy power generation technologies and the emerging ones.

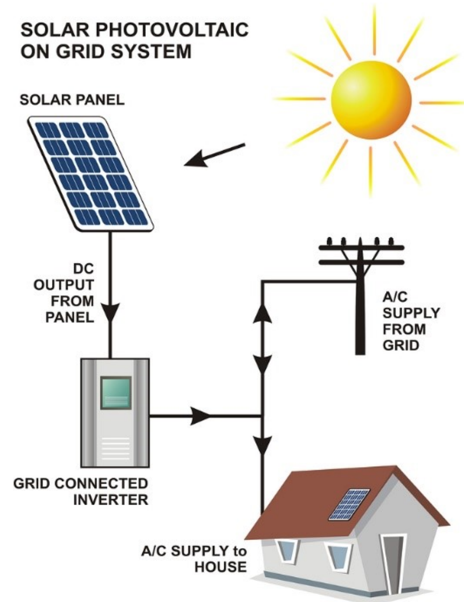


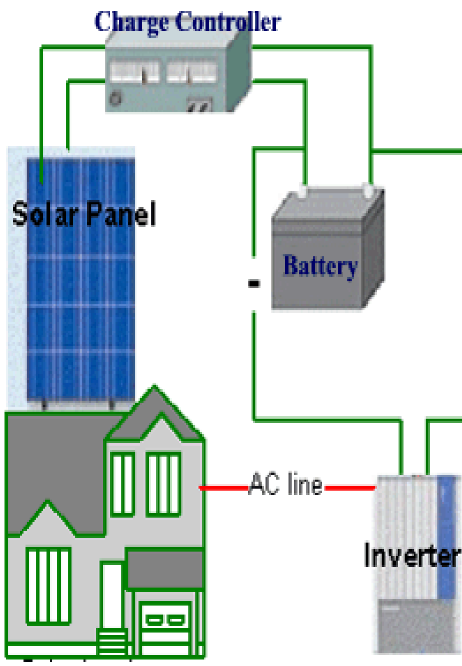


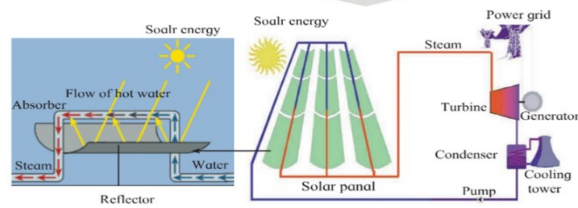


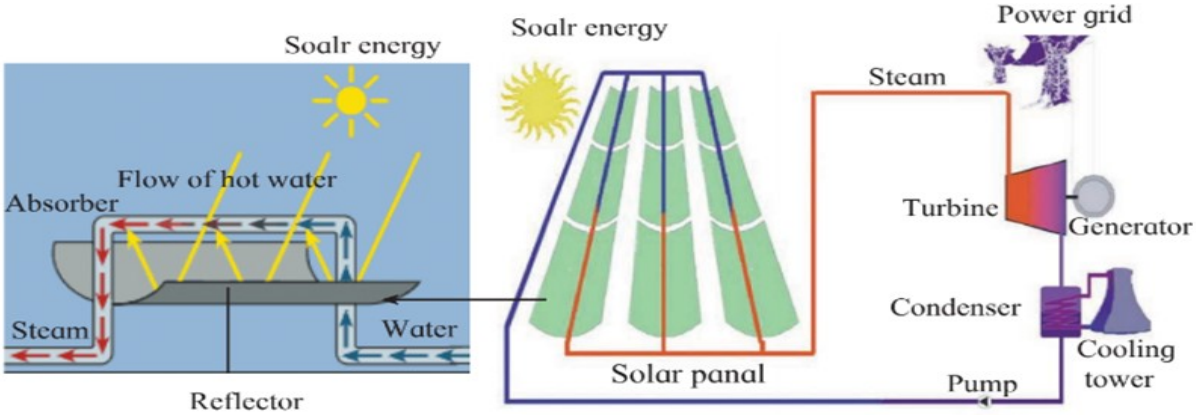


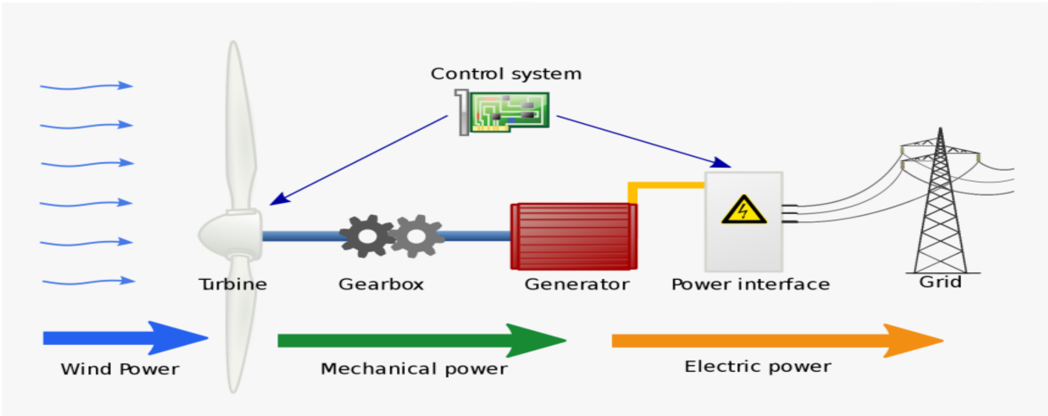

Containment Structure
Control Rods
Pressurizer
Steam Generator
Generator
Turbine
Control Rods
Reactor Vessel
Condenser
To cooling tower

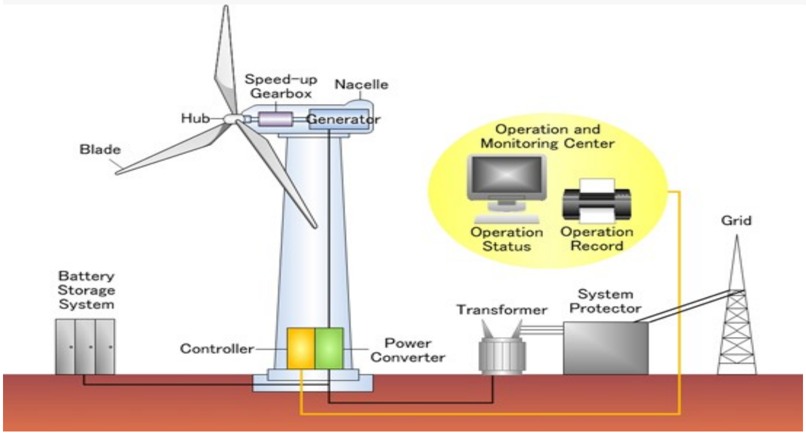

SOLAR PHOTOVOLTAIC
ON GRID SYSTEM
SOLAR PANEL
DC OUTPUT FROM PANEL
A/C SUPPLY FROM GRID
GRID CONNECTED INVERTER
A/C SUPPLY to HOUSE

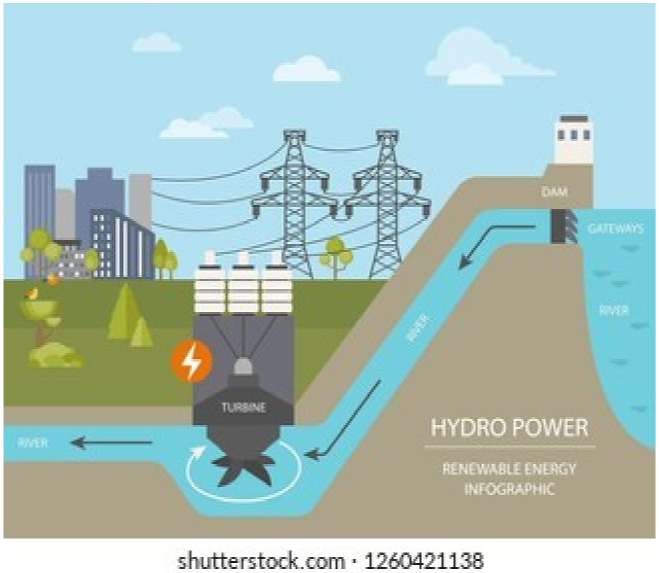

Charge Controller
Solar Panel
Battery
-
+
AC line
Inverter

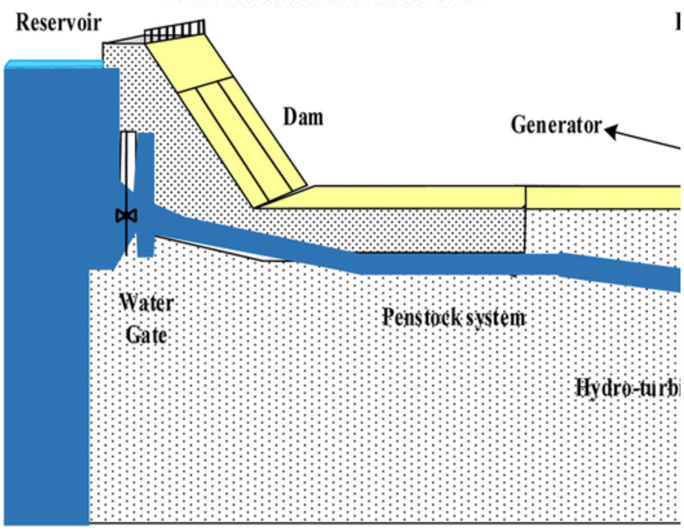

Soalr energy
Flow of hot water
Absorber
Steam
Water
Reflector
Soalr energy
Steam
Power grid
Turbine
Generator
Condenser
Cooling tower
Pump
Solar panal


Soalr energy
Flow of hot water
Absorber
Steam
Water
Reflector
Soalr energy
Power grid
Steam
Turbine
Generator
Condenser
Cooling tower
Solar panal
Pump


Control system
Turbine
Gearbox
Generator
Power interface
Grid
Wind Power
Mechanical power
Electric power

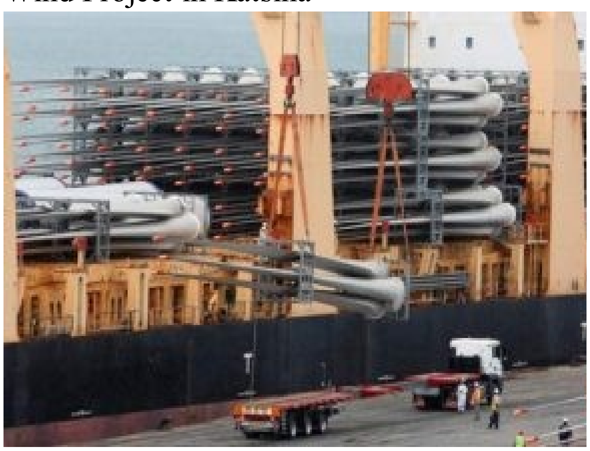

Speed-up Gearbox
Nacelle
Hub
Generator
Blade
Operation and Monitoring Center
Operation Status
Operation Record
Grid
Battery Storage System
Transformer
System Protector
Controller
Power Converter


DAM
GATEWAYS
RIVER
RIVER
TURBINE
RIVER
HYDRO POWER
RENEWABLE ENERGY INFOGRAPHIC
shutterstock.com · 1260421138


Reservoir
Dam
Generator
Water Gate
Penstock system

- Compare this with the

10 MW Wind Project in Katsina

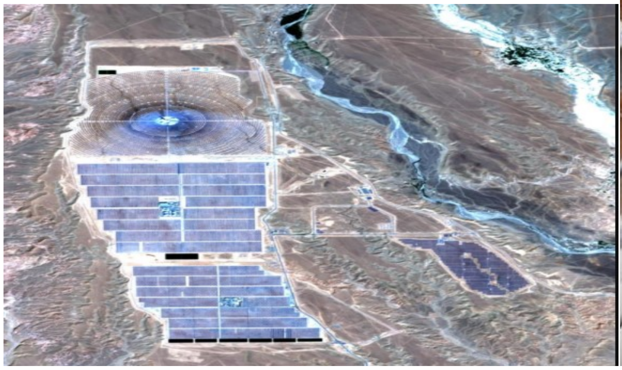


State

-

Finland is known as the largest biomass plant in the world. The plant produces 550 MW of heat, 240 MW of electricity and 160 MW of steam

The 580 MW CSP Solar Plant in Ouarzazate, Morocco
- Location has annual solar radiation intensity of 2,635 kWh/sq m
- Developed in 3 phases as Noor I, II and III covering an area of 2,500 hectares
- The three phases were grid connected in 2018 and they offset 760,000 tonnes of carbon dioxide per annum



- There is need to mount very serious measures to conserve the consumption of electricity nationwide by entrenching energy efficiency and energy conservation measures.
- There is need to locally produce, within Nigeria, the commonly consumed components of power plants like transformers, feeder pillars and many others.
- In the same vein there is need for the local production of solar panels, and the balance of system components, in Nigeria, through adoption of appropriate policy frameworks and incentivisation schemes.
- Assembly plants should also be attracted to produce requisite number of deep cycle rechargeable batteries, inverters, charge controllers etc. The first step is the completion and expansion of the solar panel production plants of NASENI, UDUS and Borno State Government before new ones are established.
- Involvement of ECOWAS, AU and the AfDB in establishing the production plants of the solar panels and the balance of systems component in Nigeria will facilitate the patronage of the items by other African nations in executing their energy transition pathways.

Before ending this presentation, I wish to bring up the apprehension of many Engineers on the two new policies of ending gas utilisation by 2040 and on attaining Net Zero emissions by 2060 and to say that policies are not static and that the NSE can propose some amendments. However, a detailed study is essential. For use of gas and also coal up to and beyond 2060 the study should:

- Produce estimates of undeveloped gas fields in all the potential basins as well as the estimates of the coal deposits in the 14 states of the Federation.

- Produce an estimate of the economic implications, including job creation potentials, of developing new gas fields and coal mines and coal processing plants.
- Produce a roadmap for entrenching a circular carbon economy to capture and use as much of the CO2 emissions as possible and bury the un-used components.
- To come up with innovative financing schemes for these new projects in addition to producing a comprehensive cost benefit analysis bearing in mind the economic disadvantage of stranding the gas assets by 2040.

Conclusion

- With the subsisting Government position expressed at COP26 there is need to focus on gas, renewable energy sources and nuclear power systems for significant expansion of the energy mix for electricity generation in the country.
- An Electricity Generation Expansion Plan with expanded energy mix will provide enhanced energy security of supply which the private sector seeks and which general socio-economic growth also desires.
- The massive investment requirements can be largely secured, especially for the renewable energy plants by adoption of the South African Renewable Energy Independent Power Procurement Programme (REIPPP) and partly from the facilitation of the African Development Bank (AfDB).
- Electricity access rate, similar to those of North African countries, can be realized in Nigeria with good policies, regulations and with political will at the highest levels.
- The NSE can conduct a comprehensive study and subsequently propose amendments of the new energy policies to pave way for the possible use of gas and coal beyond 2060.
- The NSE study should also highlight the need for proposing the financing of emission mitigation projects of circular carbon economy and forestry plantations along with the proposals for the new gas and coal projects.

DEPLOYMENT OF ALTERNATIVE GENERATING RESOURCES FOR SUSTAINABLE SOLUTION TO NIGERIAN POWER SECTOR CHALLENGE

Engr. Prof. Mohammed Sani Haruna
(Faeng, Fnse, Fiet, Fnate, Fsesn, Fnipe, Fnieee)
Executive Vice Chairman/Chief Executive
National Agency for Science And Engineering Infrastructure (Naseni)

ABSTRACT

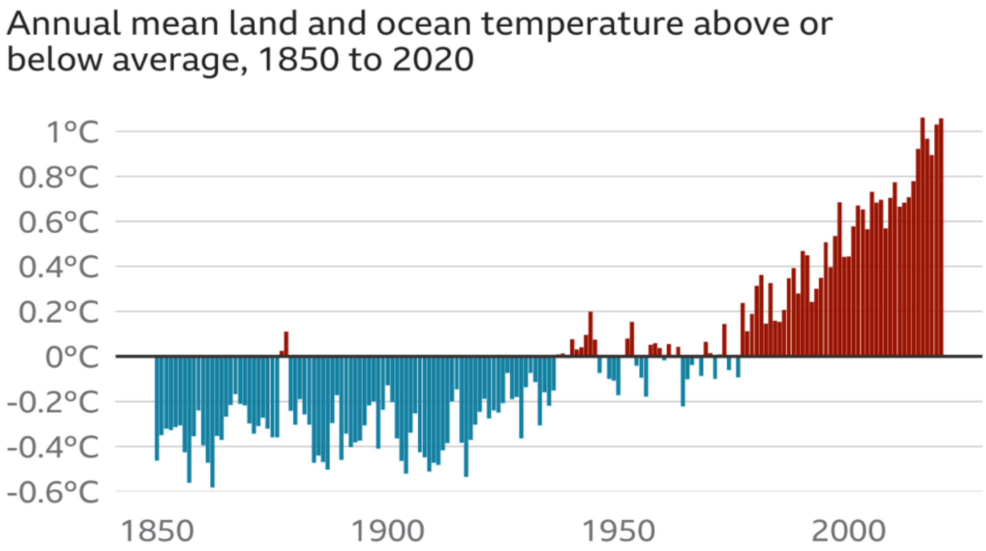
The Nigerian Electricity Supply Industry has been undergoing significant and irreversible changes aimed at repositioning the sector that has been very unreliable. The privatization of Power Holding Company of Nigeria (PHCN) in 2013 led to the formation of eleven (11) electricity Distribution Companies (DISCOs) and six (6) Generation Companies (GENCOs) while government retained 100% ownership of Transmission Company of Nigeria (TCN) as part of the strategy for socio economic transformation. The thermal/hydro generation dominated sector installed capacity now of about 12,522MW is not only inadequate for a population of over 200 million but the less than 50% being generated is hardly fully evacuated and distributed. Among the significant target of the privatization was to allow for competition; to arrest constant power outages; to improve quality and quantity of power delivery to consumers and increase efficiency of affordable energy supply. None of these can be said to have been achieved despite huge internal and external funding. These of course includes grants and foreign borrowings. There are tendencies to abandon coal, nuclear, and fossil fuel sources of power generation in an effort to meet climate change targets at the detriment of inadequate generation, transmission and distributing capacities. So far majority of developed and developing countries are still maintaining mixed power generation even where excess capacity and energy output exist. The sector reform plan/roadmap, equipment production, supply and installation are painfully foreign with minimum local contents. This paper therefore analyses current programmes and the remedial measures being implemented and advocate home grown technical and managerial solutions as well as deployment of all available natural resources of conventional and renewables for electricity generation in Nigeria as the only guarantee for sustainable solution to power sector predicament.

- Nigeria needs to utilize all alternative generating resources (renewable and conventional) including coal for electric power sufficiency before anything else.
- Efficient and affordable power supply in Nigeria is dependent upon developing and deployment of home-grown solution including capability and capacity for production of power equipment and machineries
- There is no patronage for locally produced component of solar electricity and small hydroturbine in Nigeria. Hence missing opportunities

- for employment generation and creation/development of SMEs.

2021 UNITED NATIONS CLIMATE CHANGE CONFERENCE COMMONLY REFERRED TO AS 26TH CONFERENCE OF THE PARTIES (COP26)

- Climate Change has been a subject of discuss globally for a couple of decades
- The discuss centers on carbon (IV) oxide emission and its effect on global warming which said to bring about devastating/unfavorable climate condition
- The United Nation has identified Climate Change as an issue of concern and has been advocate for developing measures to curb its effect on the environment



- COP26 is the most recent annual UN climate change conference which was held in Glasgow, United Kingdom from 1 – 12 November 2021
- COP26 was organized in order to get nations to commit to the the following:
    - End fossil fuel subsidies
    - Phase out coal
    - Put a price on carbon
    - Protect vulnerable communities
    - Deliver $100 billion climate finance commitment
- The outcome was a new global agreement – The Glasgow Climate Pact
- Emissions
    - It was agreed countries will meet next year to pledge further cuts to emissions of carbon dioxide (CO_2) – a green house gas which causes climate change
- Developing Countries
    - The agreement pledged to significantly increase money to help poor countries cope with the effect of climate change and make the switch to clean energy
- Fossil Fuel Subsidies
    - World Leaders agreed to phase-out subsidies that artificially lower the price of coal, oil or Natural gas
- COAL

- The plan to reduce the use of coal – which is responsible for 40% of annual CO_2 emission

WHAT WAS IN THE COP26 AGREEMENT?
(THE GLASGOW CLIMATE PACT) – KEY DECISIONS

- Emissions
  - It was agreed countries will meet next year to pledge further cuts to emissions of carbon dioxide (CO_2) – a green house gas which causes climate change
- Developing Countries
  - emission
  - The agreement pledged to significantly increase money to help poor countries cope with the effect of climate change and make the switch to clean energy
- Fossil Fuel Subsidies
  - World Leaders agreed to phase-out subsidies that artificially lower the price of coal, oil or Natural gas
- COAL
  - The plan to reduce the use of coal – which is responsible for 40% of annual CO_2

COAL – CONTROVERSIAL PHASE OUT VS PHASE DOWN

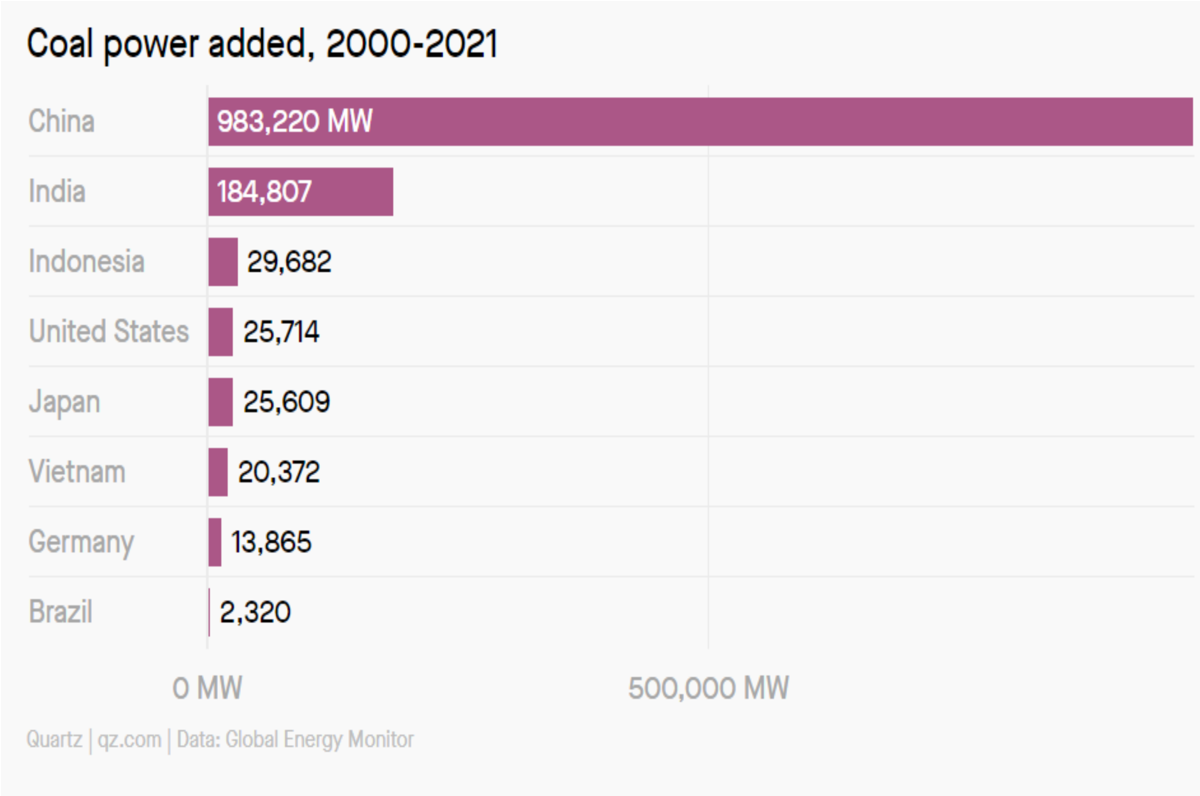
- All representatives initially agreed to "*phase out coal by year 2030*" at the start of the conference
- At the last minute (end of 2 weeks), China and India opposed the commitment to "phase out" coal while negotiating the final agreement.
- It proposed thereafter that the phrase "phase out unabated coal" in the final draft text of the agreement be replaced with "phase down coal"
- Countries had to agree to a weaker commitment to "phase down" rather than "phase out" coal

The Reasons

- CHINA -countries have different capacities to fight climate change because they are in different stages of economic development.
- INDIA - How can anyone expect that developing countries make promises about phasing out coal and fossil fuel subsidies? Developing countries still have to do deal with their poverty reduction agenda

THE POSITION OF CHINA AND INDIA AT COP26 WAS INSPIRATIONAL - DEPLOYMENT OF ALTERNATIVE GENERATING RESOURCES IS A MUST INSTEAD OF ONLY RENEWABLE SOURCES

After China, India accounts for about 11% of the world's coal use, followed by the US at 6%.



THESE TWO COUNTRIES ARE AMONG THE TOP FASTEST GROWING ECONOMIES

NIGERIA POSITION AT COP26

- President Buhari's speech criticized rich countries (major emitters) for making promises towards climate finance that to date, have remained hollow
- He also pointed that these developed world who have somewhat reached the goal of energy self-sufficiency impose standards that would clearly stunt development in countries such as Nigeria.

"May I recall that the phenomenal growth of industrial economies has been driven by

access to a stable and abundant supply of relatively cheap energy,"

GLASGOW CLIMATE PACT – NOT LEGALLY BINDING

- Countries like Nigeria, Palau, the Phillipines, Chile and Turkey all said that although there were imperfections, they broadly supported the text
- Although It has been said that the agreement will set the global agenda on climate change for the next decade, GLASGOW CLIMATE PACT is not legally binding
- Only a few countries are making their pledges legally binding
- Most commitments made at COP will have to be self-policed
- FACT IS SOME AFRICAN AND LATIN AMERICAN COUNTRIES FELT THAT NOT ENOUGH PROGRESS WAS MADE TO PROVIDE FINANCIAL ASSISTANCE TO POOR COUNTRIES
- DEVELOPING COUNTRIES WILL EMBARK ON ECONOMIC ACTIVITIES THAT WILL REQUIRE GENERATION OF POWER FROM LOCALLY AVAILABLE SOURCES

NIGERIA SHOULD NOT BE FULLY COMMITTED TO GLASGOW CLIMATE PACT FOR NOW – THE REALITY

- Some many years have gone by since the Paris Agreement and United Nation Framework Convention on Climate Change. Richer countries have not fulfilled their promises to aid poorer countries accordingly
- Developing countries will still have to be self reliant in solving their energy predicaments
- Nigeria's power supply crisis
  \- average electricity consumption per inhabitant is only 150 kWh per capita, one of the lowest in the world.
    - Almost 50 percent of the population does not have access to grid electricity.
    - Those who do have access are subject to unreliable supply in most areas.
- **NIGERIA IS NOT EVEN CURRENTLY UTILIZING COAL AS A SOURCE OF ENERGY DESPITE RESERVE POWER CAPACITY OF ABOUT 54,000MW**

THERE IS ALSO THE ISSUE OF SUSTAINABLE DEVELOPMENT GOAL (SDG) N0: 7

SDG NO. 7 - Ensure access to affordable, reliable, sustainable and modern energy for all BY 2030

- Investment in traditional centralized power plant alone wont deliver UN-SDG by 2030.

REASONS?

- The median duration of Centralized electricity investment projects is nine years, based on World Bank results (Powerforall.org, 2016)
- They rarely serve significant numbers of rural communities, as power plants and electrical grids consistently fail to reach those who live far from the existing infrastructure.
- Some terrain and geographical locations and hamlets illustrate non-commercial viability of extending grid infrastructure

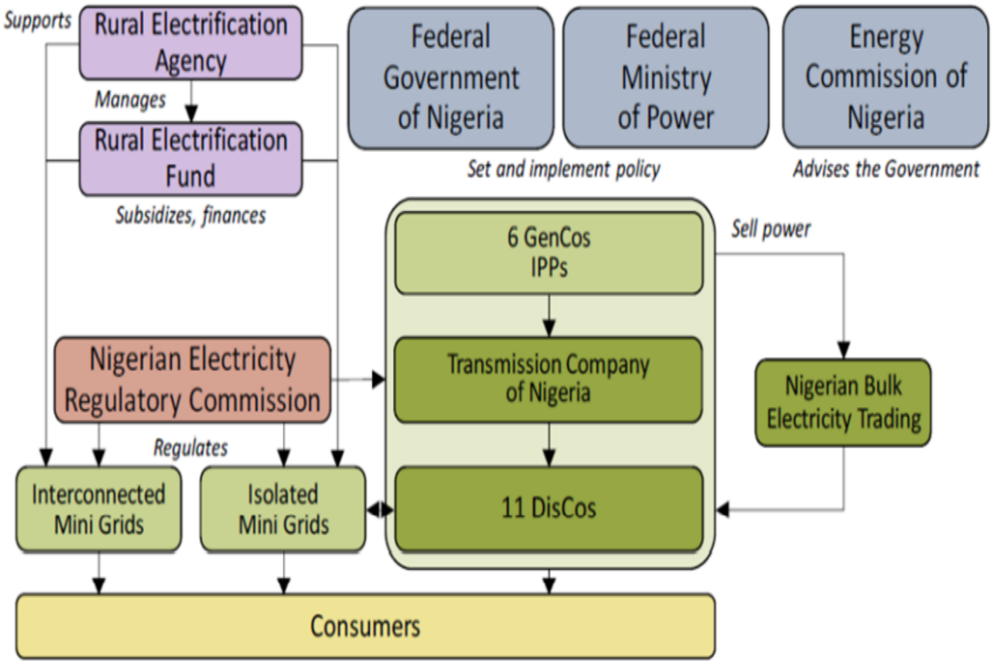
CURRENT ENERGY SITUATION IN NIGERIA

- Nigeria's power generation is mostly thermal and hydro with installed capacity of about 12,522 MW. This is not adequate for a population of over 200 million. We need over 18GW.
- The less than 50% being generated is hardly fully evacuated and distributed.
- Currently, only 45% of Nigeria's population is said to be connected to the national grid while power supply difficulties are experienced about 85% of the time and almost non-existent in certain regions.
- Power supply difficulties has crippled and impeded the nation's economic development efforts in major sectors (agricultural, industrial and mining)
- Manufacturing Firms rely on self generated electricity to power their operations
- The negative effects of insufficient power supply on businesses can only be imagined

POLICIES AND PROGRAMMES OF THE FEDERAL GOVERNMENT TO REFORM AND REPOSITION THE POWER SECTOR FOR BETTER SERVICE DELIVERY

- The Electric Power Sector Reform Act 2005 (EPSRA) was established.
- The Federal Government had privatized Power Holding Company of Nigeria (PHCN) in 2013
- The Government had raised about $2billion from the unbundling of Power Holding Company of Nigeria (PHCN), creating a number of distribution and generation companies.
- Six (6) Generation Companies (GENCOs)
- Eleven (11) Electricity Distribution Companies (DISCOs)
- One (1) Transmission Company of Nigeriam (100% Government ownership

THE STRUCTURE OF NIGERIAN POWER SECTOR



In Nigeria, all grid-connected power are conventional power plants, basically, gas turbine-based power plants and hydropower plants

The sector has failed to live up to expectations, becoming a burden to taxpayers as most Nigerians are with unstable or without power supply.

EIGHT (8) YEARS AFTER UNBUNDLING OF PHCN

- The electricity power supply situation has not shown any signs of improvement as it has continued to fluctuate due to multi-faceted and long-standing challenges.
- According to the data, supply fell by 22.9% from a peak generation of 4,115 Megawatts to 3,172 Megawatts on Saturday, June 12, 2021.
- African Energy published **the Nigeria Power Report 2021/22** in 2021 and reported that Nigeria's installed capacity will reach 18.3GW by 2025 but with available generation likely to be constrained to just 7.6GW, supply will continue to lag far behind demand
- The report forecasted that the challenges facing the power sector are likely to continue in the medium-term.

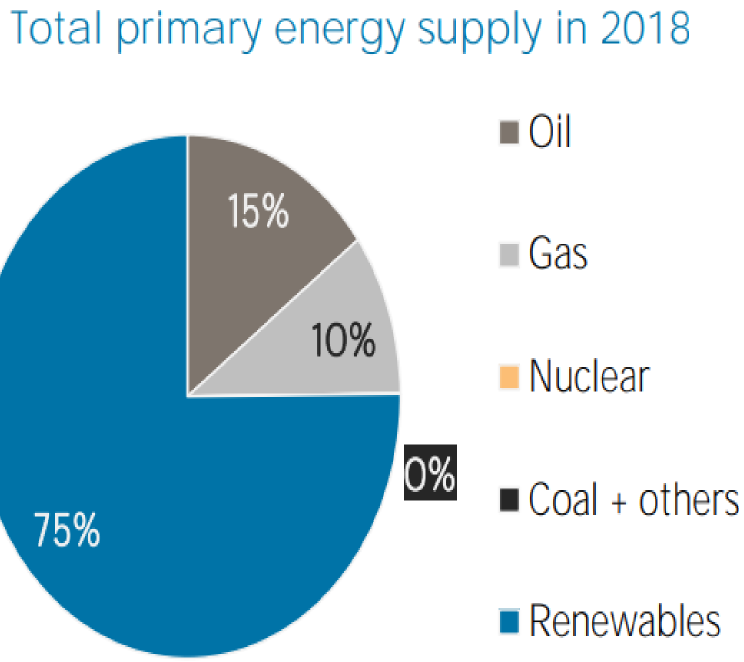
THE SOLUTION TO NIGERIA POWER CHALLENGES LIES IN ITS ABUNDANT ENERGY RESOURCES

- Nigeria is blessed with both renewable and non-renewable power generation options.
- Its enormous natural resources include
    - **Crude oil and natural gas,**
    - **coal,**
    - arable land,
    - solar (particularly in the north),
    - hydropower (incl. 277 small hydro identified sites with a

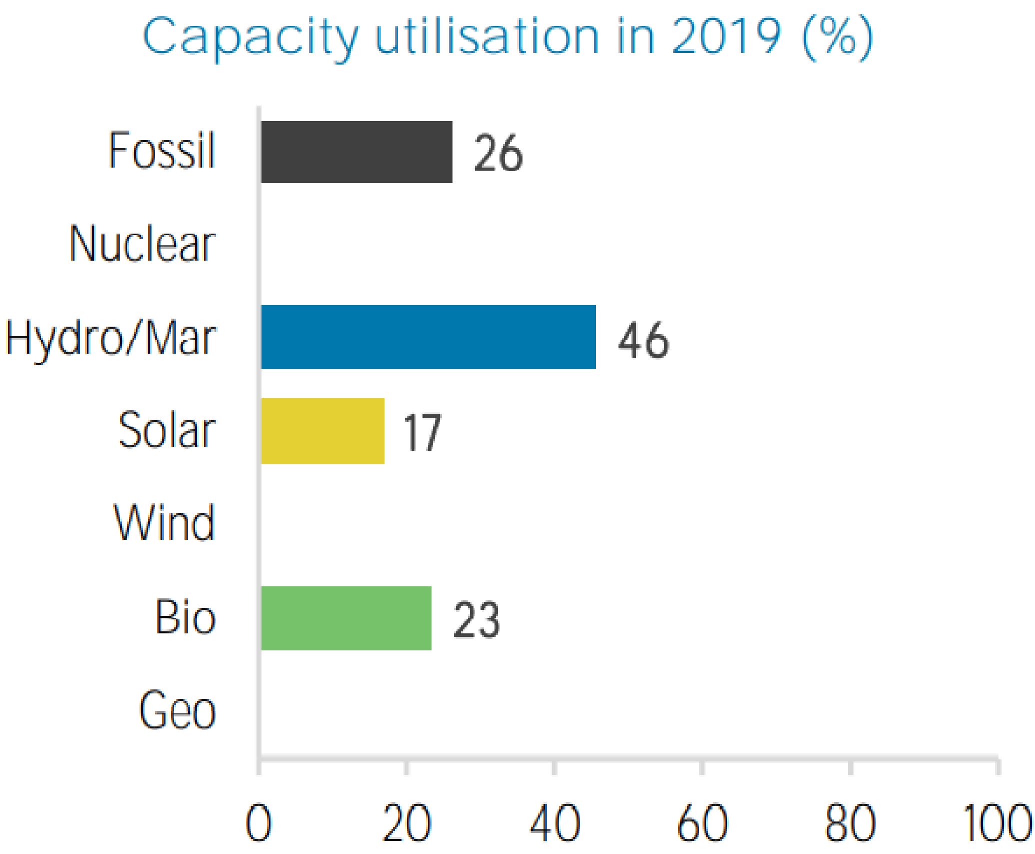
cumulative potential of 3,500 MW) and

- wind (mainly in the north and along the coastal line

NIGERIA ENERGY PROFILE BY INTERNATIONAL RENEWABLE ENERGY AGENCY

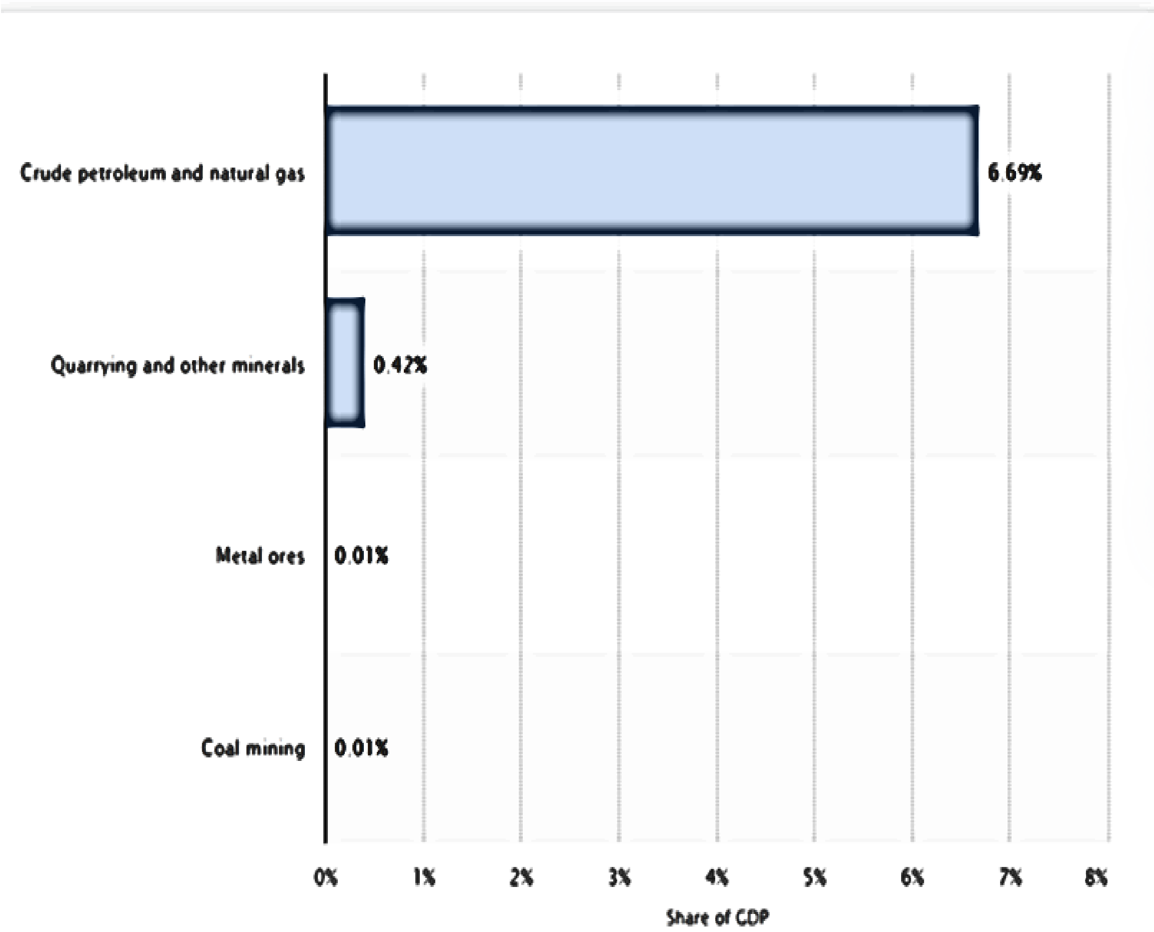


(2021)



NON-RENEWABLE POWER GENERATION OPTIONS

- Nigeria is the sixth oil producing country in the world
- Large reserve of natural gas
- Mineral resources -Uranium for Nuclear Power
- Coal is one of seven priority minerals that has been identified by the Federal Ministry of Mines and Steel Development for focused development due to the commerciality of the estimated deposits and their capacity to accelerate overall economic development through industrial linkages.

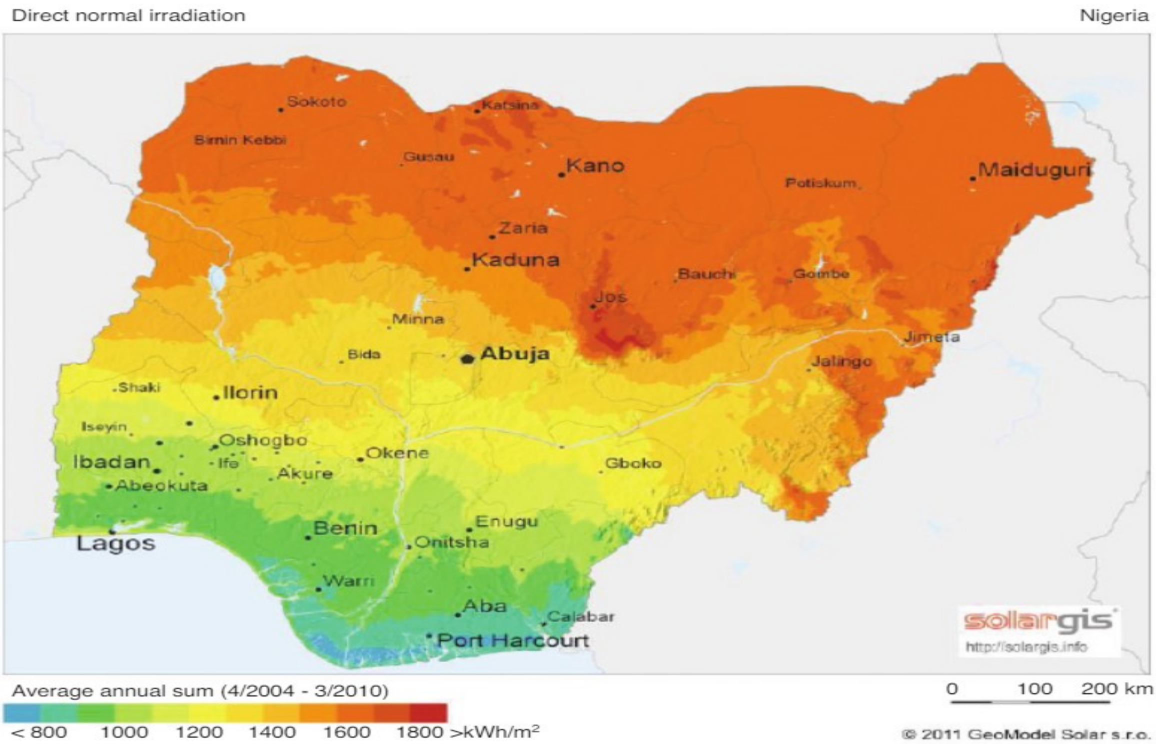


COAL RESERVES ALONE CAN GENERATE 53,900MW BY 2030 – GUARDIAN NEWSPAPER

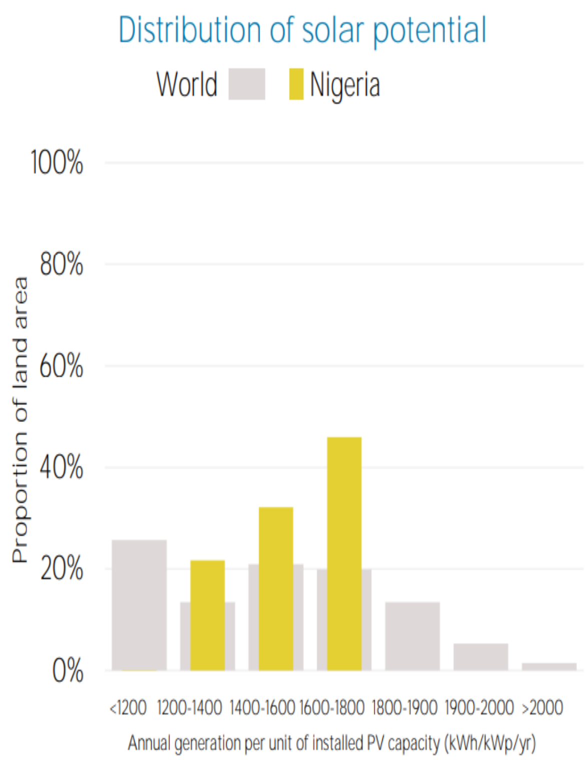
- Nigeria currently boasts of about one billion metric tonnes of coal reserves which have not been fully exploited and developed in the electricity energy mix.
- Coal contributed 0.04% to Nigerian electricity in 1972 but
- attained its peak of 2.27% in 1973, and
- thereafter declined to 0% today.
- 2015
    - 9.9% = 1,200MW
- 2020
    - 13.8% = 4,400MW
- 2025
    - 15.3% = 15,400MW
- 2030
    - 15.6% = 53,900MW

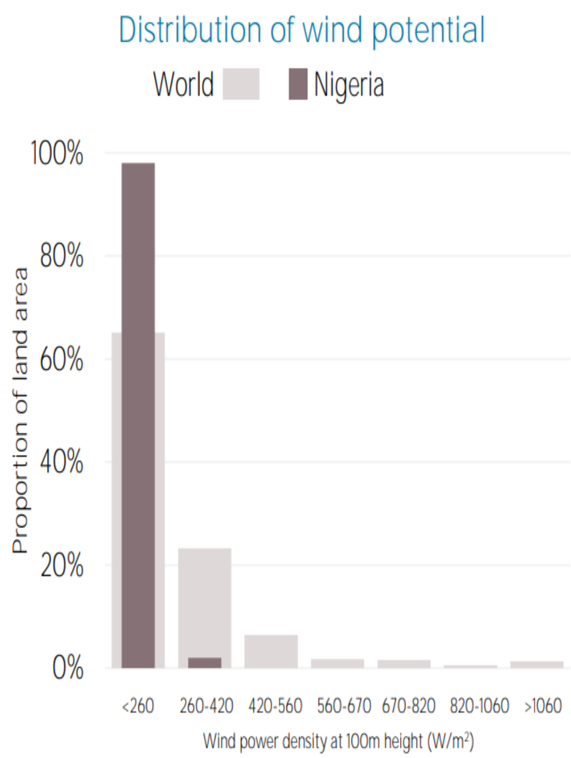
RENEWABLE ENERGY POTENTIAL OF NIGERIA	
ENERGY RESOURCES	**ESTIMATED RESERVE**
Large Hydropower	**11,250 MW**
Small Hydropower (<30 MW)	**3500 MW**
Fuel Wood	**11 million hectares of forest and woodland**
Municipal Waste	**30 million tonnes/year**
Animal Wastes	**245 million assorted animals in 2001**
Energy Crops and Agricultural Residue	**72 million hectares of agricultural land**
Solar Radiation	**3.5-7.0 kW h/m2/day**
Wind	**2-4 m/s at 10 m height** **Wind speeds in Nigeria range from a low 1.4 to 3.0m/s in the Southern areas, except for coastal line and 4.0 to 5.1m/s in the North. The Plateau area particularly interesting.**

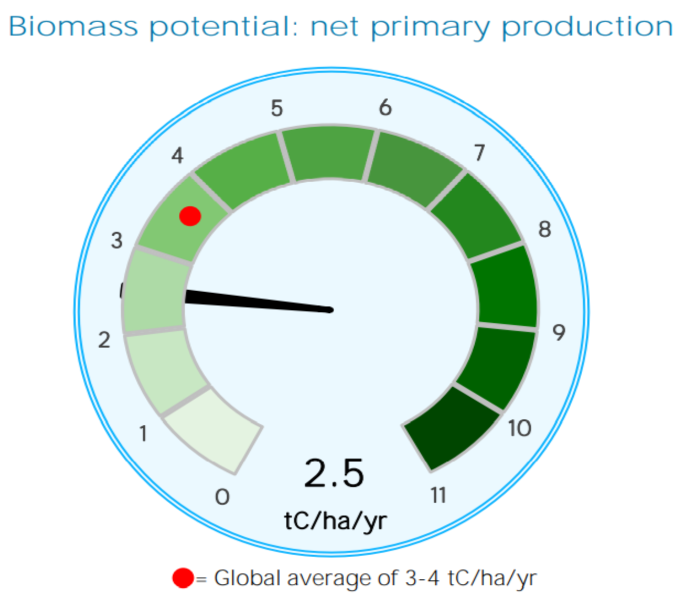
MAP OF NIGERIA SHOWING DIRECT NORMAL IRRADIATION



PROPORTION OF NIGERIA RENEWABLE ENERGY IN COMPARISON TO GLOBAL DISTRIBUTION







DECENTRALIZED ENERGY SYSTEM/ALTERNATIVE GENERATING RESOURCES

- Centralized power supply is becoming out of tune with modern practice in advanced economics liberalized by commercialization and privatization of the industry.
- Decentralized Energy paradigm is occurring worldwide reflecting the fundamental shift in the way the world produces and uses energy.
- More and more cities, regions, and industries find themselves operating with a mix of centrally-generated and distributed energy resources, which sometimes represent a mix of energy technologies as well, from solar and

wind to gas and even nuclear (GE Power, 2018).

FASTER APPROACH TO UN-SDG 7 TARGET OF YEAR 2030 - DISTRIBUTED (DECENTRALIZED) POWER SYSTEM

A faster approach is the deployment of distributed system which can be designed specifically for places the grid will not easily or cost-effectively reach, where majorities of those without energy access now reside.

COMPLEX PROBLEM

POSSIBLE SOLUTION

FASTER APPROACH TO UN-SDG 7 TARGET OF YEAR 2030 - DISTRIBUTED (DECENTRALIZED) POWER SYSTEM

- Constructed around renewables, this energy generation method is more environmentally friendly and addresses actual local demand for energy.
  - *A wide range of distributed generation and decentralized renewable energy solutions—including*
    - pay-as-you-go solar home systems,
    - multi-technology (wind, hydro, solar, biomass) mini-grids, and
    - mobile solar farms

DECENTRALIZED ENERGY POLICY IN NIGERIA

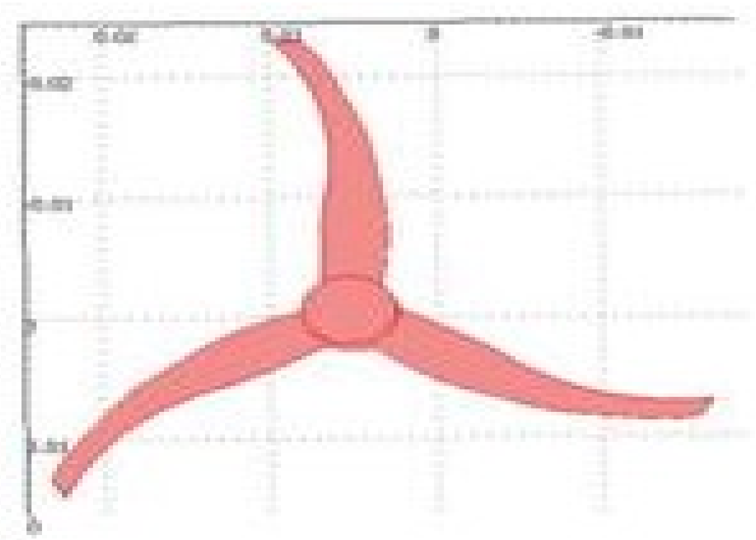
- The Federal Government of Nigeria launched a National Solar Program in 2017.
- the Federal Government recently approved an integrated energy mix targets under Electricity Vision 30:30:30 which targets generation of 30 GW in 2030, with 30 per cent from renewable energy sources.
- The approval and finalization of the country's Rural Electrification Strategy and Implementation Plan which lays out amongst other things a holistic plan for rural and off-grid electrification.
- The Bank of Industry (BOI) launched a one-billion-naira solar fund ($3.3 million) to catalyse the use of decentralized solar energy, including rooftop systems and mini-gridsion for last mile and underserved communities across rural Nigeria.
- The International Finance Corporation (IFC), and the UK Department for International Development (DFID), joined together to facilitate the deployment of off-grid and embedded solar systems in Nigeria's commercial and industrial sectors,
- The Nigerian Electricity Regulatory Commission released a draft Mini-Grid regulation,
- The Nigerian National Petroleum Corporation started consultation on a new bio-fuel policy.

DEVELOPMENT OF LOCAL CONTENT IN POWER THROUGH SCIENCE, TECHNOLOGY AND INNOVATION

- The role of S&T is to lead national development and to support socio-economic needs.
- The priority areas that have been identified are:
- - Development of key technologies to increase the international competitiveness of existing Korean industries.
- - Development of technologies related to resources, energy, and food for social and economic stability.
- Development of technology in the area of health care, environmental protection, and social information systems to improve the quality of life and social benefits.
- Fostering of creative basic research to promote scientific advancement and to expand sources of technological innovation.

NASENI WIND ENERGY PROJECT (NAWEP)

- At 10m height, imported wind turbine blades cannot perform optimally in this country since they are built to operate at the speed of at 8m/s and above
- At the same height, the wind speed in Nigeria is between 3 – 5m/s.
- NAWEP is aimed at developing wind turbine blades for optimal wind energy conversion for Nigerian wind regime of 3 – 5m/s
- The wind turbine blade was designed based on R & D on the wing of the "swift" bird



ADVANCES IN ENERGY TECHNOLOGIES ARE TAKING PLACE ON A DAILY BASIS

Solar cell innovation produces a thousand times more power

- New materials, such as ferroelectrics like barium titanate, a mixed oxide made of barium and titanium.

- "Ferroelectric means that the material has spatially separated positive and negative charges,"
- Unlike silicon, ferroelectric crystals do not require a so-called pn junction to create the photovoltaic effect
- in other words, no positively and negatively doped layers.
- This makes it much easier to produce the solar panel

CONCLUSION

- The current operation and agreement to DISCOs need to be revisited as the company's services falls below expectation
- All candidate rivers, streams and dams should be utilized for deployment of micro to small hydro-turbine, solar and biomass where applicable in mini and off grid systems to boost energy for improved socioeconomic activities in the rural areas.
- Non-renewable options should be in the energy mix of Nigeria

REFERENCES

- Ebigenibo Genuine Saturday (2021) Nigerian Power Sector: A new structure required for effective and adequate power generation, transmission and distribution, Nigerian Power Sector: A new structure required for effective and adequate power generation, transmission and distribution (gjeta.com)
- Sambo, A.S. (2005) "Renewable Energy for Rural development: The Nigerian perspective". ISESCO: Science and Technology Vision, Vol. 1, May, 2005, http://www.isesco.org.ma/ ISESCO_Technology_Vision/NUM01 /doc/A.S.Sambo.pdf
- Haruna M. S. (2015) Science, Technology and Innovation in Nigeria https://www.researchgate.net/publication/353039216_Science_Technology_and_Innovation_in_National_Development
- https://www.trade.gov/country-commercial-guides/nigeria-electricity-and-power-systems
- https://guardian.ng/business-services/coal-reserves-can-generate-53900mw-by-2030/
- https://energypedia.info/wiki/Nigeria_Energy_Situation
- Nigeria Power Report 2021/22 | African Energy (africa-energy.com)
- https://www.bbc.com/news/science-environment-56901261

MAXIMIZING THE POTENTIALS OF HYDROPOWER GENERATION RESOURCES IN NIGERIA: CHALLENGES, PROSPECTS AND OPTIONS FOR SUSTAINABILITY

Prof. Eli Jidere Bala
Director-General/CEO
Energy Commission of Nigeria, Abuja
Email: dg@energy.gov.ng

ABSTRACT

Hydropower is a renewable energy resource, which should be fully exploited to promote sustainable energy supply for national development and for mitigation of global warming. Nigeria is endowed with hydropower potentials estimated at 27.5 GW with about 5.8GW only being exploited, including the Mambilla and Zungeru projects. Consequently, only a paltry 21% of the nation's hydropower potential is being realized. Presently, Nigeria's installed grid-connected electricity generation's capacity is about 13GW, for a population of about 200 million, and has about 15% of the capacity from hydropower, while 85% is from natural gas. It is estimated that about US$40 billion would be required to maximally exploit the yet unutilized hydropower power potential in Nigeria. Adequate policies, legal and regulatory as well as institutional frameworks are imperative in order to attract private investments in a Public-Private Partnership (PPP) model in this sub-sector. The Nigeria Electricity Industry is liberalized and deregulated via the Electric Power Sector Reform Act (EPSRA) of 2005.

1.0 Introduction

Energy is fundamental to the quality and security of our lives. Nowadays, humanity is totally dependent on uninterrupted supply of energy in the form of fuels and electricity for socio-economic development. It is a key ingredient in all sectors of modern economies. Energy is technically defined as the capacity to do work. From thermodynamics point of view, when work is done on or by a system, the state of the system changes. Thus, energy may be viewed as an agent of change or transformation.

Adequate supply of energy in a nation prompts economic development expressed by the Gross Domestic Product (GDP) as well as social development expressed by the Human Development Index (HDI). The higher the energy consumption per capita of a nation, the higher its GDP and HDI.

Renewable energy is energy derived from energy source that can be regenerated naturally within a relatively short time frame. For example, solar radiation, wind, hydropower, biomass, geothermal, sea waves and tide.

Unlike fossil type energy source of crude oil, natural gas and coal, which have been formed over millions of years ago and are therefore depletable at any rate of consumption; renewable energy sources are more or less non-depletable due to its regenerative nature within relatively short time. They are also environmentally friendly sources of energy.

Hydropower is a renewable energy resource which exists mainly in the form of potential energy of water, which is transformed into mechanical energy through turbo machinery principles. The mechanical energy is then transformed into electrical energy through an electric generator. Also, in a new concept of hydro kinetics, the kinetic energy of flowing stream is transformed in a similar manner like that in a wind energy conversion system into mechanical energy and then to electricity.

2.0 Hydropower Resources in Nigeria and Africa

Nigeria has abundant reserves of hydropower with potentials of about 28GW made up of 24GW large hydropower and 3.5GW of small hydropower. In Nigeria, hydropower capacities of less than 30MW are referred to as small; while, those above 30MW are said to be large. Out of these potentials, less than 6.0GW of large hydropower and 0.1GW small hydropower are being exploited. See Table 1.

Table 1. Hydropower Utilization in Nigeria

S/N	Project	Installed Capacity (MW)	Status
1	Kainji Hydropower	760	Operational
2	Jebba Hydropower	578	Operational
3	Shiroro Hydropower	600	Operational
4	Zungeru Hydropower	700	Near Completion
5	Kashimbila Hydropower	40	Awaiting Commissioning
6	Dadin-kowa Hydropower	40	Completed
7	NESCO Hydropower	30	Operational
8	Gurara I Hydropower	30	Completed, waiting for evacuation infrastructure
9	Tunga Dam SHP (Taraba State)	0.4	Operational (UNIDO)
10	Mambilla Hydropower	3,050	Work yet to fully begin
11	Waya Dam, Bauchi State	0.175	Completed and Operational (UNIDO)
12	Ezioha Mgbowo, Enugu	0.030	By UNIDO but vandalized

The first hydropower station to be operated in Nigeria is the NESCO hydropower plant in Kurra Falls, Jos, which commenced operation in 1929 with installed capacity of 8MW. The turbines, were made of Pelton Wheels and Francis Turbine. The power plants are still operational. See Figure 1.

Figure 1. NESCO Power Plant, Kurra (8MW). Established in 1929.

According to IRENA in 2015, Africa has an estimated hydropower potential of 350GW. Also, according to 2021 Hydropower Status Report by the International Hydropower Association (IHA), Hydropower remains the Africa's primary renewable resource in Africa at over 38 GW of installed capacity, with 971 MW added in 2020. It accounts for over 70% of the renewable electricity share and about 16% of the total electricity share. Hydropower's share of total electricity is predicted to increase to more than 23% by 2040 following efforts to achieve universal access and a low carbon energy transition. Table 2 reveals installed hydropower capacities of some African countries.

Table 2. Hydropower in some select African countries

S/N	Country	Hydropower Installed Capacity (MW) 2019
1	DR Congo	2,760
2	Ethiopia	4,074
3	Egypt	2,876
4	South Africa	3,596
5	Kenya	837
6	Ghana	1,584
7	Uganda	1,040
8	Zambia	2,400
9	Morocco	1,770
10	Angola	3,836
11	Mozambique	2,216

Source: IHA, 2021

3.0 Costs of Hydropower Schemes

IRENA (2015) has reported that hydropower offers the most economical solution for large-scale renewable electricity generation, as technology is mature and the resources are large in comparison with current Africa's demand. Costs can be as low as USD 0.03/kWh, and the average of about USD 0.1/kWh. A weighted average installed cost for large scale hydrower in Africa is about USD 1.4 million/MW.

The report also indicated that the implementation of SHP plants is a cost-effective off-grid solution for rural areas. Capacity factors can be high and generation costs relatively low with an average LCOE of about USD 0.5/kWh. The weighted average capacity installation costs is about USD 3.8/MW.

Consequently, for Nigeria to fully exploit the yet to be exploited hydropower potential of 18,300MW of large hydropower at USD 1.4 million/MW and 3,400MW of SHP at USD 3.8 million/MW, would require about USD 40 billion.

Figure 2 shows the LCOE from utility-scale renewable power generation technologies, 2010 – 2020 from IRENA (2021).

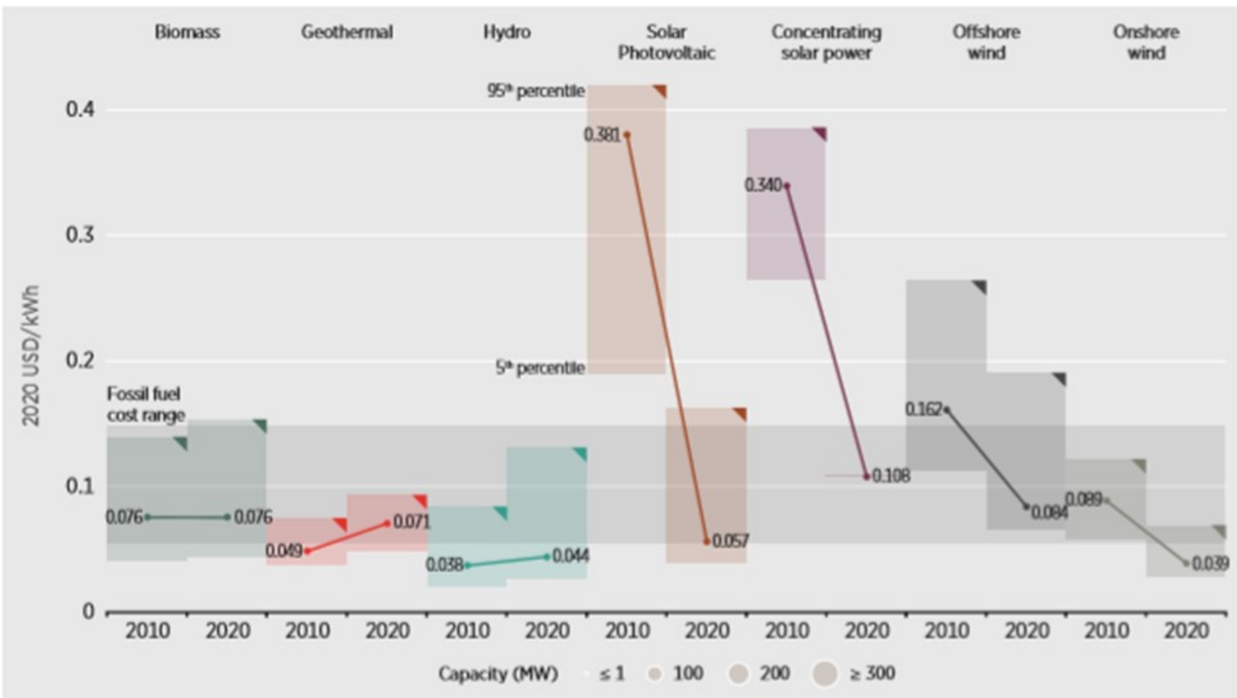


Figure 2. Levelized Cost of Energy (LCOE) from Utility-scale Renewable Power Generation Technologies, 2010 – 2020 (Source: IRENA)

4.0 Hydropower Policy in Nigeria

The National Energy Policy, approved by the Federal Executive Council (FEC) in 2003, as the omnibus integrated energy policy that gives the direction that the government wants to develop its energy sector, has these policy statements on hydropower:

a. The nation shall fully harness the hydropower potentials in the country for electricity generation.
b. The nation shall pay particular attention to the development of SHP schemes for the growth of the rural economy.
c. The nation shall exploit hydropower resources in an environmentally sustainable manner.
d. The nation shall actively promote private sector and indigenous participation in hydropower development.
e. The nation shall support research and development activities for local

adaptation of hydropower plant technologies.

Similarly, the policy objectives have been stated and the short, medium and long-term strategies to enable achievement of the policy objectives are proffered.

5.0 Increasing the Utilization of Hydro potentials in Nigeria

There are efforts on-going aimed at exploiting the hydroelectric potentials of the Country. The Federal Government has been demonstrating political will towards increasing the share of hydropower in the electricity generation mix of the nation. The Zungeru 700MW plant is due for completion soon and the Kashimbila 40MW Project has been completed, awaiting commissioning. Furthermore, the construction of the 3,050MW project in Mambilla, Taraba state is due to take off in earnest with a target completion year of 2030.

Furthermore, in promoting small hydropower development in Nigeria, the United Nations Industrial Development Organization (UNIDO) in 2015, with the support of the Global Environment Facility (GEF) and the government of Nigeria launched the project "Scaling up small hydropower (SHP) in Nigeria". The main objective of the project is to promote investment in SHP technology and strengthen local manufacturing of small hydropower turbines in Nigeria. The project comprises of four (4) major components including "Human and institutional capacity building". This project is expected to deliver additional 3.1MW of Hydropower to the nation when completed. It was under this project that the 400kW small hydropower project in Kakara, Taraba state was implemented and the plant is currently serving the electricity needs of Highland Tea factory in Taraba State. This is in addition to a 30 kW SHP plant and 150kW SHP were also established in Ezioha Mgbowo in Enugu and Waya Dam in Bauchi, respectively in collaboration with respective River Basin Authorities, before 2003. Other sites are still being worked on, under this project.

However, the need for participation of the organized private sector in the development of hydroelectric potentials of Nigeria cannot be over emphasized. There are sites already identified as investable hydropower sites in studies conducted by UNIDO and another by the Federal Ministry of Power. Private investors are therefore needed in order to drive increase in utilization of hydropower in Nigeria in line with the Electric Power Sector Reform (EPSR) Act 2005.

6.0 Challenges Confronting Hydropower

The development of hydropower, like any infrastructural facility in Nigeria, is majorly hampered by lack of sustained investment as a result of weak policy implementation and foreign exchange challenge. Generally, rivers flow through different countries giving rise to management challenges. Climate change is also negatively affecting hydropower development.

Furthermore, the construction of large hydroelectric plant may involve displacement of people from their natural habitats and destruction of species of plants and animals with attendant impacts on immediate environment. Inadequate human and manufacturing capacity is also a challenge as most of the personnel on, and equipment for, hydroelectric projects in Nigeria are foreign. Security of recent, is another cause for concern as it regards development in general in Nigeria.

7.0 Prospects and Way Forward

As a nation, good policies on hydropower and renewable energy development in general have been put in place. Our challenge has always been implementation of such policies.

Nigeria's National Energy Policy (NEP) articulates for the optimum development of Nigeria energy resources in an environmentally friendly manner and with the active participation of the private sector.

Hydropower certainly has a significant role in meeting the energy needs of the country, as presented in the National Energy Policy, for driving sustainable economic and social prosperity of the country.

Other challenges earlier mentioned must therefore be overcome in order to accelerate the development of hydropower in Nigeria. The government's role is majorly to create an enabling environment through adequate policies and incentives backed by legislations that will attract and guarantee investment into the sub-sector. There must be concerted efforts to complete all on-going hydroelectric power projects in the Country especially the Mambilla Project which will be the biggest hydroelectric project in the country. Investments on SHP should be incentivized in order to enhance electricity access in the rural areas. Local capacity must be built so that indigenous Engineers will be fully involved in the design, construction and maintenance of hydroelectric projects in Nigeria. This will be in line with Executive Order 5 for planning and execution of projects, promotion of Nigerian content in contracts of science, engineering and technology. Our security situation as a nation also needs to improve so that hydroelectric projects can go on without any hindrance.

8.0 Conclusion

Electricity access in Nigeria still about 60% and even much lower in the rural areas. The huge unexploited hydropower potentials, need be exploited in order to increase energy access and also serve as a climate change mitigation measure as it is renewable. The National Energy Policy states that the nation shall fully harness the hydropower potential available in the country for electricity generation and pay particular attention to the development of small hydropower schemes. It further states that the exploitation of the hydropower resources shall be done in an environmentally sustainable manner and private sector and indigenous participation in hydropower development shall be actively promoted. It is time to vigorously pursue what is in our policy document on hydropower in order to increase its utilization and provide adequate and cost-effective energy to Nigerians in a sustainable manner. There should be continuity in policy implementation to enable sustainability and benefits to the nation.

References

1. IHA (2021): 2021 Hydropower Status Report
2. IRENA (2021): LCOE from Renewable Power Technologies 2010 - 2020
3. Bala, E. J. (2021): Renewable Energy and Human Security in Nigeria: An Assessment. A Paper Presented at National Defence College, November 2021
4. Vanguard Newspaper (https://www.vanguardngr.com/2021/10/2022)
5. This Day Newspaper (https://www.thisdaylive.com/index.php/2021/09/28)
6. TCN (2020): Annual Technical Report 2019
7. ECN (2018): National Energy Policy; Draft Revised Edition
8. ECN (2003): National Energy Policy

CAPACITY BUILDING FOR EFFECTIVE MAINTENANCE OF POWER SUPPLY INFRASTRUCTURE IN NIGERIA

Ahmed Bolaji Nagode D

irector General, National Power Training Institute of Nigeria (NAPTIN)

Email: abnagode@naptin.gov.ng

Abstract

Harnessing the energy of our environment for economic activity is intrinsically reliant on Power Supply infrastructure. Without well developed and maintained Power Supply infrastructure, the objectives of National Economic Growth by economic handlers of our country cannot be realistically implemented.

Government involvement in development related activities, has all the antecedents for stakeholders in the privatized power sector to cast aspersion on its motives and intentions. However, by continuously engaging relevant stakeholders, jettisoning old ways and adopting time-tested methodologies that are the norm in the modern business of Generating, Transporting and Distributing electricity, the implementing arms of the government can utilize capacity building to impact individuals and organizations who are reliant on Power Supply Infrastructure for their benefit. In the advent of the privatized power sector, some of these benefits include safety of life and equipment, profitability of Generation, Transmission and Distribution assets owing to good overall design in consonance with veritable maintenance strategies, prevention of cascading faults propagating the entire system, and a data driven approach to making decisions on utilization of both public and private resources.

The focus of this Paper is Capacity Building for Effective Maintenance of Power Supply Infrastructure in Nigeria. This paper seeks to enlighten the reader on insights into the programmes and methodologies that have been adopted by the government for ensuring that there is sustained Human Capacity in the Nigerian Power Sector. It also identifies the problems of Power Supply Infrastructure and touches on existing opportunities for capacity development in the maintenance of Power Supply Infrastructure as a solution to these problems. The paper further underscores the challenges encountered by the government in setting up Capacity Development Frameworks and acquiring funding for Capacity Development.

In conclusion, this paper will recommend several approaches that can embed Capacity Development in the attitude and psyche of Power Sector-facing agencies of government. The adoption of Capacity Development as fundamental to sustainability of Power Supply Infrastructure, is the much-needed paradigm shift in the approach to delivering realistic milestones for National Economic Growth. By embracing Capacity Development as fundamental to sustainability of the Sector, challenges of the sector in the area of maintenance of Power Supply Infrastructure can be approached from a perspective of growth. Further recommendations will also be made on structures that can secure the buy-in of private sector players towards the overall goal of National Economic Growth.

Keywords: Nigerian Power Sector, Funding for Capacity Development, Maintenance Strategies, Power Supply Infrastructure, Attitude to Capacity Development, Sustainabilit

INTRODUCTION

With Africa in focus, Nigeria is the largest economy on either side of the Sahara Desert. Supplying the Nigerian economy at three times its current size would require less energy demand if the energy mix were to be diversified. (IEA, 2019) Today, 80% of on-grid power generation in Nigeria comes from gas; most of the remainder comes from oil, with Nigeria the largest user of oil-fired back-up generators on the African continent. (IEA, 2019). The prevalence of oil-fired back-up generators is as a result of the erratic nature of on-grid power supply across Nigeria. Several categories of electricity consumer who are dependent on stable power supply, have their economic activity affected by the stability of grid supply.

Small and Medium-Scale Enterprises (SMEs) cannot thrive solely on unstable energy from the grid so they must rely on alternative energy sources to keep their operations afloat. Without considering manufacturing capacity of SMEs, the scenario is similar for residential areas, the highest grid energy consumption category in Nigeria (GIZ, 2015), where electricity from the grid is utilized for daily running of household activities. Another category of electricity consumer, even though catered to by the Eligible Customer Regulation 2017 (Oduntan, 2021), must also plan for back-up captive power on the odd day that grid electricity through unconventional electricity market routes becomes unreliable.

One of the reasons advanced for power sector reform was the participation of private sector participants who would inject funding into the NESI for expansion and development of power supply infrastructure, as failing and inadequate power supply infrastructure constantly led to interruptions in power supply to all categories of electricity consumer. (Adoghe et al., 2009)

There are two ingredients that fundamentally support the effectiveness of Power Supply Infrastructure, (1) Qualified Personnel who will carry out maintenance programs that are designed to keep Power Supply interruptions to a minimum (2) Regularly scheduled inspection, testing and servicing of equipment (NFPA 70B, 2002). As the apparent reality of energy demanded by the various categories of electricity consumer is anything but univocal, it is therefore rational to expect that an undiversified energy mix in combination with, energy demand outstripping supply and insufficiently maintained power supply infrastructure by Qualified Personnel, will pose a problem to economic growth. The barriers to economic growth are detailed in numerous research papers and documents for national economic development.

Vision 20:2020, as a planning and strategy programme for national economic development, identifies unreliable power supply, poor and decaying infrastructure, and high dependence on the oil sector as significant barriers to national economic development. It goes further to propose targets for development of the energy sector. Measures to achieve the set targets in Vision 20:2020 also resonate with other planning and strategy documents for national economic development. Some commonalities in the measures are capacity development (GIZ, 2015), Research and Development (NREEEP, 2015), promotion of alternative technologies such as solar, to diversify the energy mix (REMP, 2012) and so on. While it is undeniable that the country has experienced various levels of success in achieving the various targets for the measures aimed at expanding the energy mix, the mechanisms and methods for assessing the impact of capacity building measures for power supply infrastructure development and maintenance is non-existent or lagging behind by comparison. Given the process-driven nature of capacity building, it is important to have systems that will enable the tracking of results along the processes, so as to demonstrate concrete results and trace evidence. (Lawal, 2018) Some systems that are deep-seated in the modern methods of business development for the electricity value chain are equally relevant for capacity building along the chain. Specifically, Quality Management Systems (QMS) and Data driven systems are key to evidence-based decision making towards assessing the impact of capacity building for development and maintenance of Power Supply Infrastructure.

From a perspective of economic growth, making data driven decisions is crucial to both modern business development and capacity building for Power Supply Infrastructure maintenance. With the right data management systems, behaviour of stakeholder groups like policy makers, service providers, and beneficiaries can be accurately monitored for the application of a training product/market fit that ensures a positive trend for adequacy of the ingredients that support Power Supply Infrastructure which will help to solve the problems of the target market in ways that are superior to the alternatives. (Dickson, 2021) The resulting positive trend is important for responding to the growth of beneficiaries' expectations which ultimately results in the robustness of Power Supply Infrastructure. The robustness of Power Supply Infrastructure is an economic development objective that is important to all stakeholder groups in the NESI, and thus, capacity building for Power Supply Infrastructure maintenance has to grow in a manner that corresponds to the needs of all stakeholders who are reliant on Power Supply Infrastructure for their benefit.

The 2030 Agenda for Sustainable Development Goals lists several measures required for implementation of the goals and targets. These measures include mobilization of financial resources, capacity building, and the transfer of environmentally sound technologies to developing countries. This paper takes a look at capacity development as a solution to problems of Power Supply Infrastructure, evidence-based decision making for capacity development, the risks to Power Supply Infrastructure associated with lack of capacity in NESI career aspirants and career employees, and the benefits of employing modern methods to capacity building aimed at Power Supply Infrastructure maintenance. The paper proposes several approaches that may help to improve stakeholder cooperation and ensure sustained capacity building towards maintenance of Power Supply Infrastructure.

OVERVIEW OF CAPACITY BUILDING FOR THE POWER SECTOR

Nigeria's Privatized Electricity Sector has come a considerable way; It has been thirteen (13) years since the sector was subjected to reform in order to improve efficiency of Power Supply to Nigerian citizens. Many of the driving forces behind the global electricity reform were equally at play in the Nigerian scenario: Capital Scarcity, Persistent Poverty, Debt and Deficits, and Economic Inefficiencies. (Adoghe et al., 2009) In adopting the pathway offered by reform, Nigeria signified its intent to solve the problems created by state owned monopolization of the electricity sector. Understandably, one of the hallmarks of troubled reforms is neglecting the need for targeted Capacity Building to support the reform. (Wamukonya, 2005) For the most part, this is due to the advancement of new structures which the handlers of the reform lacked the capacity to address. (Adoghe et al., 2009) (Vlahinić, 2011)

In the case of electricity, it was envisaged that, amongst other challenges, the companies that emerged from the privatization exercise would experience obstacles in staffing at the different organizational levels. (Adoghe et al., 2009) This new staffing structure would require training unlike what was obtainable in the erstwhile monopoly, where capacity building and training of both technical and accounts and finance personnel in the electricity sector was sufficient. In order to wholly support the reform, a desk study was carried out and the initial recommendation was for the enactment of a comprehensive training policy which would be in tune with the changing scenarios of the sector. (Nigeria Infrastructure Advisory Facility, 2008)

The NIAF was the instrument for the setting up the National Power Training Institute of Nigeria (NAPTIN) and its initial recommendation paved the way for the National Power Sector Training Policy (NPSTP). This policy is currently awaiting validation at the next National Council on Power (NACOP).

The Nigerian Power Sector has been the beneficiary of a number of Donor funded Capacity Building Initiatives which are all targeted at strengthening the Capacity of organizations like NAPTIN for training delivery and ultimately tackling the aforementioned forces responsible for the reform in order to create a thriving and sustainable electricity supply industry which will support economic growth. Some Programmes by Donor Financial Institutions (DFI) include NESP I & II by GIZ, Enhancing Vocational Training Delivery for the Power Sector in Nigeria by French Agency for Development, Scholarship Training programmes executed by ANCEE and financed by AfDB and AFD, USAID Meter Installation and Maintenance Training of Trainers, and Improving the performance of Electricity Distribution Companies by JICA. Notable in the NESP is the training course on Maintenance of Transformers and Switchgear that was a result of the Training Market Assessment in Nigeria conducted in 2013 and a competence analysis evolved together by GOPA-intec and NAPTIN. The Training Market Assessment itself was another such Capacity Development activity in GIZ's NESP which, as one of its objectives, sought to build capacity in the methods of conducting such an assessment for future replication. The Man Power Audit of the Power Sector which may cover other power sector entities not covered by the NESP's Training Market Assessment, is being worked on by NAPTIN and NERC and is testament to the success of DFIs capacity building interventions for the Nigerian Power Sector.

DFIs have also directly trained entities and Power Sector Stakeholders other than NAPTIN in order to achieve quick wins towards advancing the themes of their development programmes for Nigeria's promising power sector. Stakeholders like the TCN have also reintroduced one-year pupillage training programs where new engineers get the necessary practical experience before they are exposed to the hazards of high voltage network. (TCN, 2017/2018) TCN has also played a key role in putting NAPTIN on the path of setting up a QMS and certifying its processes through ISO 9001:2015.

The Federal Government of Nigeria's vision to achieve 30,000 megawatts of electricity by the year 2030, with at least 30% from renewable energy sources (Electricity vision 30-30-30) has also seen various capacity building initiatives in the sector. Worthy of Note is the Energizing Education Programme which is coordinated by the Rural Electrification Agency.

Until the 90 million Nigerian people who at present remain disconnected to the mainstream grid supply, become acquainted with sustainable electricity supply, the drive to build capacity and continuously train stakeholders must be pursued relentlessly. The value proposition of capacity building and training for power sector stakeholders in this regard is the sustainability of efforts for making electricity accessible to all Nigerian citizens

PROBLEMS WORKING AGAINST CAPACITY BUILDING FOR MAINTENANCE OF POWER SUPPLY INFRASTRUCTURE IN THE SECTOR

Despite the strengthening of NAPTIN by DFIs and the Federal Government of Nigeria, there is still a massive skills deficit in the sector, exacerbated by the demands of the newly reformed companies who cannot afford the luxury of extensive pupillage programs. (NESP - UNIT 4, 2014) In order to aggressively meet the demands of the newly formed companies, NAPTIN has contracted Adjunct Faculty who have the requisite industry experience to deliver trainings within the time frames that can be afforded by the newly reformed companies.

NAPTIN has also offered customized training courses and the flexibility to customize its training courses to suit the training policies of power sector entities.

Another problem experienced by capacity building for the sector is the perception of capacity building by all Power Sector stakeholders and this is highly consequential in the extent of adoption of the NPSTP and the fidelity of the Man Power Audit of the Sector. The different entities in the sector have a myriad of diverse motivations for their participation in the sector which introduces complexities in the ways that they wish to structure training and capacity building into their bottom lines.

The current state of operations and control of the Nigerian Power system as described by USAID reports that service providers do not plan maintenance properly or in line with international best practices (NPSP, 2020). The lack of capacity to properly plan maintenance is an issue that can be addressed through developing the capacity of Service Provider's (SP) staffing to include planning experts to establish maintenance planning criteria to improve maintenance practices and therefore, improve system security and economics. This presupposes that there should be maintenance planning coordination among service providers.

PROBLEMS OF MAINTENANCE OF NIGERIAN POWER SUPPLY INFRASTRUCTURE

Nigeria is the largest economy in sub-Saharan African with a population of over 200 million people and experiencing obstacles in the power sector that are constraining national economic growth. The country is blessed with gas reserve, oil, solar, wind, biomass and hydro resources with potential to generate over 14,000MW of electricity from existing generation plants. However, it is only able to delivered slightly above 4,000 MW which is insufficient for the population and sustaining the desired growth. The NESI experiences broad challenges related to gas supply, electricity policy enforcement, generation, transmission and distribution constraint, power sector planning shortfalls, lack of adequate maintenance and human capacity development that have kept the industry from reaching commercial viability.

Generally, the populace sees lack of electricity as a result of low generation capacity, however the breakdown of the generation, transmission and distribution due to lack of adequate maintenance is directly or indirectly linked to supply interruptions and sometimes even system collapse.

The maintenance of Power Supply Infrastructure or any engineering infrastructure consists primarily with the responsibility of detecting, diagnosing, correcting, replacing and verifying failure of components or equipment while ensuring optimal performance of the equipment through scheduled periodic preventive maintenance and sustained repairs carried out on faulty equipment. The importance of effective maintenance practices cannot be overlooked because it assists in extending the useful life of equipment, safety of personnel, reduces system downtime and ensures availability of the equipment when the need arises. (T.C Madueme) The cost of a major breakdown which will result in downtime is between four to fifteen times higher compared to the cost of regular maintenance based on a recent survey.

The Nigerian Electricity Supply Industry (NESI) has undergone changes with the intention of repositioning the industry to function efficiently over the past few years with notable government reforms, programme and policies being implemented in order to encourage the development of the sector. However, these reforms and policies are tailored towards incremental generation, upgrading transmission and distribution infrastructure with little or no policy to institutionalize capacity building as one of the components for the effective maintenance of the aforementioned Infrastructure. It should be recalled that NESI has suffered decades of lack of investment, ageing manpower and infrastructure, and little or no effective maintenance plan which becomes the major factor for influencing failure of the industry. The poor state of maintenance of Nigerian Power Infrastructure could be attributed to the stakeholder's attitude towards maintenance, obsolete equipment, unskilled manpower or workforce, lack of adequate training and poor funding. (Y. O Lawal)

For years, NESI stakeholders' attitude towards maintenance has been treated with neglect, as unnecessary, and often overlooked. Emphasis is placed on getting the best productivity from power supply infrastructure equipment but it is not recognized as a part of the operation that produces revenue which requires well-structured maintenance policy. (OK Ekwum). Effective Maintenance is a very vital component of any grid system or power supply infrastructure and our poor maintenance culture has affected power stability in Nigeria.

In order to achieve a seemingly energy mix development for National Economic growth, there is a need for the government and other stakeholders to take steps to establish and implement a National Maintenance Policy (NMP) on NESI infrastructure aimed at addressing maintenance challenges, which must encapsulate human capacity building of the industry players as one of its fundamental components to ensure effective maintenance and sustainability of power supply infrastructure so as to get the NESI performing at its optimal potential.

CAPACITY DEVELOPMENT AS A SOLUTION TO PROBLEMS OF MAINTENANCE OF NIGERIAN POWER SUPPLY INFRASTRUCTURE

Capacity building is a nucleus of development policy. Capacity Development is "the process whereby people, organizations and society as a whole, unleash, strengthen, create, adapt, and maintain capacity over time in order to achieve development results". Capacity development can be classified into three major levels namely: Individual, organizational and enabling environment which completely are interdependent and mutually strengthening.

Individual capacity development: This is achieved by improving individual vocational knowledge, performance and skills through training, mentoring, experiences, motivation and incentives. It allows each personnel to perform.

Organizational capacity development: This can be realized by improving organizational performance through plans, rules, strategies and leadership, partnerships, structures, and strengthening processes as well as systems. It is the internal policies, procedures and structure that determine the effectiveness of an organization.

Enabling environment: The need to develop and improve policy framework to address socio-economic, environmental, political, financing, labour markets, and class structures. The enabling environment set the general scope for capacity development. (Otoo)

The development of human and institutional capacity in NESI is vital because it helps society develop and sustain economic growth through training, education and mentoring, and most importantly it motivates and inspires industry practitioners to improve their living standard while carrying out effective maintenance of power supply infrastructure.

THE IMPACT OF CAPACITY DEVELOPMENT IN THE PRIVATIZED POWER SECTOR (BENEFITS AND SOLUTIONS)

Lack of maintenance has become a major concern that is affecting Power Supply Infrastructure in most developing countries. Maintenance is an inconsequential action in developing countries hence, due to insufficient knowledge about maintenance concepts, it is not prioritized. However, because the management of

Transmission Company of Nigeria (TCN) realized the benefits and solution that is associated with capacity development, the company engaged NAPTIN on aggressive human capacity development by training over five hundred (500) personnel in the year 2018 and has since continued to do that on an annual basis which has led to reduction of system disturbance. Shown below in Table 1 is a data for a Summary of System Disturbance for Generation and Transmission Company of Nigeria from 1990 to 2019 as published by TCN as Grid System Operations 2019, Annual Technical Report.

TABLE 1: SUMMARY OF SYSTEM DISTURBANCES. (JANUARY 1990 - DECEMBER 2019)

	TOTAL	DISTURBANCES CAUSED BY GENERATION FAULTS		DISTURBANCES CAUSED BY TRANS. FAULTS		PARTIAL GRID COLLAPSE			TOTAL GRID COLLAPSE			DISTURBANCES DUE TO INDERTERMINATE CAUS			
YEAR	NO. OF DISTURBANCE	ACTUAL NUMBER	% OF TOTAL	ACTUAL NUMBER	% OF TOTAL	GEN. CAUSED	TRX. CAUSED	TOTAL	GEN. CAUSED	TRX. CAUSED	TOTAL	TOTAL COLLAPSE	PARTIAL COLLAPSE	TOTAL	% OF TOT
2019	11	2	18.18%	8	72.73%	0	1	1	2	7	9	1	0	1	9.09%
2018	13	1	7.69%	12	92.31%	0	1	1	1	11	12	0	0	0	0.00%
2017	24	4	16.67%	20	83.33%	0	9	9	4	11	15	0	0	0	0.00%
2016	27	8	29.63%	19	70.37%	0	5	5	8	14	22	0	0	0	0.00%
2015	10	0	0.00%	10	100.00%	0	4	4	0	6	6	0	0	0	0.00%
2014	13	2	15.38%	10	76.92%	0	4	4	2	7	9	1	0	1	7.69%
2013	24	2	8.33%	22	91.67%	0	2	2	2	20	22	0	0	0	0.00%
2012	23	1	4.35%	19	82.61%	0	8	8	1	11	12	2	1	3	13.04%
2011	19	0	0.00%	17	89.47%	0	5	5	0	12	12	0	2	2	10.53%
2010	42	9	21.23%	29	69.05%	2	17	19	7	12	19	4	0	4	9.52%
2009	39	8	20.51%	31	79.49%	3	17	21	5	14	19	0	0	0	0.00%
2008	42	8	19.05%	32	76.19%	5	10	16	3	22	26	1	1	2	4.76%
2007	27	3	11.11%	24	88.89%	1	7	9	2	16	18	0	0	0	0.00%
2006	30	8	26.67%	22	73.33%	2	8	10	6	14	20	0	0	0	0.00%
2005	36	15	41.67%	21	58.33%	4	11	15	11	10	21	0	0	0	0.00%
2004	52	20	38.46%	32	61.54%	7	23	30	13	9	22	0	0	0	0.00%
2003	53	14	26.42%	39	73.58%	9	30	39	5	9	14	0	0	0	0.00%
2002	41	19	46.34%	22	53.66%	18	14	32	1	8	9	0	0	0	0.00%
2001	19	9	47.37%	10	52.63%	1	4	5	8	6	14	0	0	0	0.00%
2000	11	2	18.18%	9	81.82%	0	6	6	2	3	5	0	0	0	0.00%
1999	9	2	22.22%	7	77.78%	1	4	5	1	3	4	0	0	0	0.00%
1998	18	2	11.11%	16	88.89%	2	11	13	0	5	5	0	0	0	0.00%
1997	20	0	0.00%	20	100.00%	0	13	13	0	7	7	0	0	0	0.00%
1996	10	3	30.00%	7	70.00%	2	6	8	0	2	2	0	0	0	0.00%
1995	11	0	0.00%	11	100.00%	0	10	10	0	1	1	0	0	0	0.00%
1994	5	4	80.00%	1	20.00%	1	3	4	0	2	2	0	0	0	0.00%
1993	19	0	0.00%	19	100.00%	0	14	14	0	5	5	0	0	0	0.00%
1992	1	0	0.00%	1	100.00%	0	1	1	0	0	0	0	0	0	0.00%
1991	6	1	16.67%	5	83.33%	0	1	1	1	4	5	0	0	0	0.00%
1990	14	11	78.57%	3	21.43%	0	0	0	11	3	14	0	0	0	0.00%

Source: TCN Grid System Operation 2019 Annual Technical Report

Analysis of the table

The impact of TCN effective maintenance practice after over five hundred (500+) Engineers, Technologist, Technicians and Non-Technical personnel trained by NAPTIN through sponsorship of Associations of Power Utilities of Africa (APUA) in the year 2018 has resulted in successive reduction of system disturbances, prompting the company to operate efficiently based on Grid System Operations 2019, Annual Technical Report.

From the table above, Transmission related faults caused Eight (8) and ten (10) system disturbances that occurred in 2018 and 2019 respectively, while Generation faults caused Two (2) of the collapses. Compared to 2017 before the capacity development, twenty (20) Transmission related faults occurred.

Analyses of the diverse events precipitating the System Disturbances generally reflected inadequate routine maintenance of the rights-of-way of grid transmission and sub transmission circuits. This led to over-growth of bushes along these rights-of-way and, consequently, the incessant fouling of the high voltage circuits by all types of encumbrances such as vegetation. Other causes were unreliable protection schemes, aged equipment, poor relay coordination etc.

Over the years, it has been noticed that restoration after system disturbance has often been through the same faulted circuits, after resetting the relays that operated. This pointed to the fact that the faults, more often than not, were only temporary (transient) and may have been avoided. These circuits are being patrolled and maintained in a thorough and effective manner. Also, some of the disturbances were traceable to protection problems; especially lack of proper coordination of distance relays, spurious operations and outright failures of relaying schemes.

Supported by the investigation of the table, it is evident that the rationale behind inadequate maintenance at utilities is principally due to lack of capacity development. Hence, capacity development/ training is required in order to improve maintenance practice at utilities thus improving maintenance performance. The maintenance training program/courses curriculum offer in NAPTIN include policy makers and investors because NAPTIN is a parastatal under the Federal Ministry of Power established as part of the privatization process. In order to institutionalize the culture of maintenance in both organizational and corporate level of NESI, NAPTIN designed its cutting-edge maintenance training programme curriculum involving investors and policy makers through curriculum validation.

The benefits and solutions of Capacity development deduced from the analysis of the table can be stated as follows

It builds up knowledge, confidence, and resources; skills that grow from capacity development efforts on a project has enhanced TCN's ability to envisage and take measures on other projects.

Capacity development procedures intentionally minimize dependence on experts outside the organization as sources of maintenance solutions, knowledge, and resources to TCN issues. It encourages the TCN professionals to take measures on maintenance problems.

Capacity development encourages TCN professionals to become maintenance process owners and they are thus empowered for future development which helps them to gain control over the process.

These efforts are conscious to the TCN organizational culture and environment, as a result, often lead to more practicable and applicable maintenance solutions than techniques that are driven without capacity development

THE RISKS TO POWER SUPPLY INFRASTRUCTURE ASSOCIATED WITH LACK OF CAPACITY IN CAREER ASPIRANTS AND CAREER EMPLOYEES

Capacity development in Nigeria Electricity Supply Infrastructure (NESI) challenges and tensions are not limited to Nigeria or other developing nations but may have more severe consequence on these nations since their resilience to deal with the issues is usually lower. The risk to power supply infrastructure associated with lack of Capacity in career aspirants and employees can be notice from Table 1 that between year 2016 and 2017 the disturbance caused by both Generation Companies and Transmission Company of Nigeria fault is high because the level of their investment in capacity development is low which impacts on the productivity and morale of their career employees.

FRAMEWORKS FOR CAPACITY DEVELOPMENT (NSQF) AND SKILLS ORGANIZATION

A strong Nigerian electricity supply industry needs well-trained and properly inspired employees. As seen with all sectors of the Industry, in the last fifteen (15) years, there has been no significant investment in specialized training, and investments in capacity building have been inadequate. Indeed, much of the trained employees are aging and nearing retirement age.

The Federal Government of Nigeria recognizes this and is developing a broad strategy to strengthen the existing employees competency through skill enhancement and professional development programs. This strategy will guarantee that an effective workforce is recruited, trained, and retained to carry out the government's vision for the power industry. As part of this approach, the government has made the National Power Training Institute of Nigeria (NAPTIN) fully operational, ensuring that the government pays particular attention to the sector's training infrastructure, developing of National Power Sector Training Policy (NPSTP) and bearing the mandate of Power Sector Skills Council responsible for Institutionalization of the Nigerian Skills Qualifications Framework (NSQF) in Nigeria.

NSQF is a system for the development, classification and recognition of skills, knowledge, understanding and competencies acquired by individuals, irrespective of where and how training or skill was acquired. The system gives a clear statement of what the learner must know or be able to do whether the learning took place in a classroom, on-the-job, or less formally. The framework championed by National Board for Technical Education (NBTE), indicates the comparability of different qualifications and the methods of progression from one level to another. The framework is the structure within which the NSQF operates, aimed at promoting lifelong learning and providing quality assurance and recognition. The objectives of NSQF are to ensure the quality, status, relevance, and provision of the availability of Technical and Vocational Education and Training (TVET), reduce complexity and ambiguity of selecting a competent person by industry, and narrowing the gaps between what TVET graduates know and can do and the skills and knowledge that employees say they need.

APPROACHES FOR ENSURING THAT THERE IS SUSTAINED HUMAN CAPACITY DEVELOPMENT TOWARDS MAINTENANCE OF POWER SUPPLY INFRASTRUCTURE

Growing the capacity building initiatives for power sector stakeholders means an increase in the number of qualified stakeholders who are desirous of moving the current state of power supply infrastructure towards sustainability. By lending urgency to the coordination of stakeholders and stakeholders capacity building, the appreciation of many of the problems found in power supply infrastructure maintenance and its effects on economic growth will become more mainstream rather than specialized information which is perceived as the preserve of a privileged few, a hallmark of the pre-reform era.

Stakeholders also need to be active in assessing the gap in their skills and what trainings they need to have to be considered qualified in their respective fields. By empowering the stakeholders to know in detail their levels of competency, they are motivated to look for more tools and training to enhance their productivity towards ensuring the robustness of power supply infrastructure for the sector.

Through prioritization of the following approaches, capacity building for maintenance of power supply infrastructure will have the intended consequences of economic growth:

The need for collection of data on skills in the sector has never been more in need than right now. By continuously sensitizing stakeholders on the need to collect data on available skills and making such data easily accessible to stakeholders, the results from a Man Power audit for the power sector becomes easily supported by all concerned and the problems of power supply infrastructure maintenance becomes more easily defined in our economic space. An example of this is the effect of data collected on metering which assists all stakeholders in understanding the metering gap.

The NPSTP needs to be constantly on the agenda for all engagements that concern power sector stakeholders. Until stakeholders claim ownership of the policy, many of the projected successes of the reform will remain out of our reach.

Quality Management System (QMS) for service providers needs to become more mainstream for streamlining activities and improving the processes involved in power supply infrastructure maintenance; without a basic incentive to improve processes of SPs, the sector runs the risk of continuously falling behind expectations.

If given consideration, the National Maintenance Policy (NMP) should be coordinated with other relevant policies in the power sector.

The Health and Safety of personnel directly concerned with maintenance needs to be given proper attention as this will reassure them that their contributions to economic growth does not go unnoticed. Legislation to this effect is highly recommended.

CONCLUSION

Capacity Building for Power Supply Infrastructure development and Maintenance and its concomitant effects on National Economic Growth needs to become a staple in the post-reform Power Sector Agenda. In adopting a knowledge economy as a way to diversify Nigeria's economic activities, it is poignant to remember that the speed of the economy moves at the speed of proliferation of stakeholders' knowledge and skills. The adoption of Capacity Development as fundamental to sustainability of Power Supply Infrastructure, is the much-needed paradigm shift in the approach to delivering realistic milestones for National Economic Growth. By embracing Capacity Development as fundamental to sustainability of the Sector, challenges of the sector in the area of maintenance of Power Supply Infrastructure can be approached from a perspective of growth.

REFRENECES

A NEW MAINTENANCE STRATEGY FOR POWER HOLDING COMPANY NIGERIA TO CONTEST THE CURRENT POWER DEMAND PROBLEM

OK Ewulum

Dissertation submitted in partial fulfillment of the requirements for the degree Master of Engineering at the Potchefstroom Campus of the North-West University, November 2008

Adoghe, A., Odigwe, I., Igbinovia, S. (2009) Power Sector Reforms-Effects on Electric Power Supply Reliability and Stability in Nigeria. International Journal of Electrical and Power Engineering 3 (1): 36-42, 2009

Dickson, Ben. (17/09/2021). Boston Dynamics' Spot robot is securing its position in a niche market. (Online), 26/09/2021. https://bdtechtalks.com/2021/09/17/boston-dynamics-spot-update/

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). (2015). The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. https://www.giz.de/en/downloads/giz2015-en-nigerian-energy-sector.pdf

Lawal, Abdulkareem. (24/04/2018). Measuring the impacts of capacity development: four things to consider. (Online), 22/09/2021. https://www.itad.com/article/measuring-the-impacts-of-capacity-development-four-things-to-consider/

MAINTENANCE CULTURE IN ELECTRICAL POWER INDUSTRY IN NIGERIA: CASE STUDY OF AFAM POWER STATION

T.C. MADUEME

Faculty of Engineering

University of Nigeria, Nsukka

Nigerian Journal of Technology, Vol. 21, No. 1, 2002

United States Agency for International Development (USAID). (March, 2020) NIGERIA POWER SECTOR PROGRAM (NPSP) CURRENT STATE ANALYSIS OF TCN SYSTEM OPERATION PROCESSES

Nigeria Infrastructure Advisory Facility. (2008). E89 Review of Training Needs and Provision in the Power Sector, Initial Blueprint

Oduntan, Sunday. (30/08/2021) Facts on suspension of eligible customer regulation. (Online), 23/09/2021.

https://m.guardian.ng/opinion/facts-on-suspension-of-eligible-customer-regulation/

Otoo S., Agapitova, S. and Behrens, J., The Capacity Development Results Framework, World Bank

Institute, 2009

POOR MAINTENANCE CULTURE; THE BANE TO ELECTRIC POWER GENERATION IN NIGERIA

O.S. Onohaebi 1* and Y.O. Lawal 2

Journal of Economics and Engineering, ISSN: 2078-0346, May, 2010

TCN Milestones, February 2017 – February 2018

Vlahinić, Nela Effects of Privatization in Electricity Sector: The Case of Southeast European Countries. https://www.researchgate.net/publication/236121975_The_Effects_of_Privatization_in_Electricity_Sector_The_Case_of_Southeast_European_Countries

Wamukonya, N. (2005, December 10) Power Sector Reforms in Sub-Saharan Africa: Some Lessons. Economic and Political Weekly, Vol. 40, No. 50 (Dec. 10-16, 2005), pp. 5302-5308 (7 pages) https://www.jstor.org/stable/4417522

PUBLIC PRIVATE PARTNERSHIP AS A VERITABLE TOOL FOR SUSTAINABLE ENERGY MIX FINANCING IN NIGERIA

by
INFRASTRUCTURE CONCESSION REGULATORY COMMISSION

Abstract: *Nigeria since independence has witnessed increases in the rate of urbanization and growth in the transport sector and industry mainly propelled by fossil fuel (coal – oil). As energy demand assuredly increased, supply became grossly inadequate. The challenge of meeting present energy demand in Nigeria is colossal in the sense that while seeking for sustainable energy supply and making energy choices, the environmental problems of fossil fuels need to be considered. Hence, in solving our energy supply constraints, options in a prospective energy mix should equally be environmentally friendly, sustainable and efficient (conserving energy for more work). PPPs in the energy sector come in different shapes, sizes and structures and are used mainly in generation and transmission. The methodology used varies, depending on the place, the government and the specifics of the operation; therefore, each one is tailored to the needs and circumstances given at the time when the partnership is created.*

1. INTRODUCTION

Building modern, sustainable, and reliable infrastructure is critical for meeting the rising aspirations of billions of people around the globe. Infrastructure investment helps raise economic growth rates, offers new economic opportunities, and facilitates investment in human capital. In this paper, our concentration is on the Energy Sector Infrastructure and how Public Private Partnership is a veritable tool for sustainable Energy Mix Financing in Nigeria.

2. MAIN BODY

Sustainable finance plays an essential enabling role in the energy transition and innovation. Meeting a future global increase in energy demand in a sustainable way while reducing emissions from existing infrastructure will require trillion dollars of investment. However, there is currently a gap of many hundreds of billions of dollars between existing investments and what is required. Nigeria currently spends 9-10 billion USD per annum on infrastructure. (source: NIP; AFDB; States Infrastructure & Regional development TWG; Governors forum). With the COVID-19 crisis also rippling through the energy sector, a new lens through which to view the energy transition has emerged. Renewable energy sources have strengthened their position in the global electricity mix as a result of changed energy production and consumption patterns during the pandemic. However, the economic downturn might cause the sustainable funding gap to widen, as private sector investments may be deferred and government budgets are strained. In developing countries, governments may not have the financial means for generous stimulus packages. Hence, the need for Public Private Partnership (PPP) as a financing option for one of the United Nations Sustainable Development Goals (SDG) also known as Global Goals I.e. Affordable and Clean Energy.

The term "energy mix " refers to the combination of the various primary energy sources used to meet energy needs in a given geographic region. It includes fossil fuels (oil, natural gas and coal), nuclear energy and the many sources of renewable energy (hydro, wind, solar and geothermal). These primary energy sources are used, for example, for generating power, providing fuel for transportation and heating and cooling residential and industrial buildings. To meet energy needs, each country uses the types of energy available to it, in differing proportions. This is what is called the energy mix. While the figures vary significantly from one country to another, fossil fuels dominate the energy mix at the global level, accounting for over 80% of the total. Whether large or small, ideas and initiatives aimed at enhancing energy efficiency and use of Energy Mix, as well as improving energy access, will need Public-Private Partnerships to be successful.

- Public-private partnerships (PPPs) can be a tool to get more quality infrastructure services to more people. When designed well and implemented in a balanced regulatory environment, PPPs can bring greater efficiency and sustainability to the provision of public services such as energy, transport, telecommunications, water, healthcare, and education. PPPs can also allow for better allocation of risk between public and private entities. PPPs have become more common not only in the aftermath of the 2008 financial crisis, as governments are eager to leverage scarce public funds but have seen a rise in developing countries over the last two decades. More than 134 developing countries apply PPPs, contributing about 15–20 percent of total infrastructure investment. PPPs may refer to informal and short-term engagements of nongovernmental organizations, the private sector and/or government agencies that join forces for a shared objective; to more formal, but still short-term private sector engagements for the provision of specific services, to more complex contractual arrangements, such as build, operate, transfer regimes, where the private sector takes on considerable risk and remains engaged long term; or to full privatizations

3. RESULTS

In Nigeria, the agency responsible for regulating all PPP projects entered into by the Government in Nigeria is called Infrastructure Concession Regulatory Commission (ICRC). The Commission was established in 2008. As at date, there are 73 post-contract PPP projects under implementation at the ICRC Projects Disclosure Portal (www.ppp.icrc.gov.ng or www.icrc.gov.ng). The portal is the first disclosure portal in the world, established in collaboration with the World Bank in 2017.

As at 30th June 2021, there were 164 pre-contract projects at various stages of Development and Procurement phases on the ICRC website (www.icrc.gov.ng). However, below is a list of all Energy Sector PPP projects regulated by the ICRC.

SN	MDA	PROJECT TITLE	SECTOR
1	**Federal Ministry of Water Resources**	**Gurara 2 Greenfield Multi-Purpose Dam** The Concession of the Gurara 2 Greenfield multi-purpose Dam, Niger State includes 300MW of hydropower components of the dam.	Energy
2	**Federal Ministry of Water Resources**	**Owena Multi-Purpose Dam water supply (Unsolicited Proposal)** The project will provide about 1.5kwh of electricity to the national grid.	Energy
3	**Federal Ministry of Water Resources**	**Development of 9MW Oyan Dam Unsolicited** This involves the Operations and Maintenance of 9MW hydroelectric power.	Energy
4	**Federal Ministry of Water Resources**	**Development of 220MW River Mada Medium hydropower plant in Nasarawa State** This involves the Operations and Maintenance of 220MW hydroelectric power.	Energy
5	**Federal Ministry of Water Resources**	**Other PPP Projects:** i. Development of Tede Dam for Hydro power and other purposes. ii. Concession of Oturkpo Dam for Hydro Power and other purposes. Development of Dasin Hausa Dam for Hydro power and other purposes.	Energy
6	**Federal Ministry of Mines and Steel**	**Ajaokuta Steel company Ltd & National Iron Ore Mining Company (NIOMCO)** Rehabilitation, completion, management and operation of Ajaokuta Steel Company and National Iron Ore Mining Company (NIOMCO) through PPP Concession agreement.	Energy
7	**Federal Ministry of Power/Nigerian Electricity Management Services Agency (NEMSA)**	**Transformer Repair Services** The project is an unsolicited proposal submitted by Kilowatt Electrics Limited (KWEL) to the NEMSA. KWEL is proposing a joint venture partnership with NEMSA to operate the transformer repairs workshop in Ijora Lagos and construction of transformer repair workshops in Port Harcourt and Kaduna centers. The partnership will also include the role of electrical inspection, testing and certification of all electrical installation hitherto performed by NEMSA.	Energy

8	**Federal Capital Territory/ Abuja Infrastructure Investment Center (AIIC)**	**Small Hydropower Embedded Power from the Wupa Water Treatment Plant Effluent Discharge** Wupa Water Treatment Plant Project on a Build Operate and Transfer (BOT) PPP model to produce electric power from the effluent discharge from the plant. Power generation capacity is estimated at 3,346.29kW/day which would power the WWTP and also provide the input for the production of fertilizer and plastics. The power plant is expected to sell excess power to the national grid.	Energy
9	**Federal Ministry of Power**	**Concession of 1.2MW Grid Connected PV Solar Power Plant** Concession of 1.2MW Grid Connected PV Solar Power Plant at Lower Usuma Dam, Abuja under the Japanese Grant-In-Aid to the FGN	Energy
10	**Federal Ministry of Petroleum Resources**	**NNPC Refineries Rehabilitation Project** The project will involve the rehabilitation of refineries across the country.	Energy
11	**Federal Ministry of Petroleum Resources**	**Construction Of LPG And Ethanol/Methanol Plants At Emede Uzere Delta State (On Public Private Partnership (PPP) Basis)** The construction of an LPG and Ethanol/Methanol Plant at Emede Uzere, Delta State from Everlinksourcing Ltd to the Ministry of Petroleum Resources. Identification of Public Private Partnership projects for Petroleum Equalization Fund,	Energy
12	**Federal Ministry of Petroleum Resources/NNPC**	FMoP have sent concept notes to the Commission and are keen to develop the following projects; i. Concession and development of 25MW Katsina Wind Farm ii. Concession and development of 215MW Kaduna Power Plant iii. Concession and development of 10MW lake Chad Basin Development Authority, Borno. Concession and development of 1.2MW Solar facilities at Lower Usuma Dam.	Energy
13	**Federal Ministry of Power**	**University of Benin 15MW Solar Project (Unsolicited Proposal)** The project is a 15MW PV Solar power to be sited on a 30Hectare parcel of land at the University of Benin Ugbowo Campus.	Energy
14	**Federal Ministry of Water Resources**	**Solar Power Off-Grid Rural Electrification** The project involves the provision of off-grid solar power to the remote rural communities in Taraba, Gombe, Niger, Kogi, Ebonyi, Oyo, Ogun, Edo, Akwa Ibom, Katsina and Kebbi states	Energy
15	**Federal Ministry of Power/ Electrification Agency**	**40 MW Kashimbila Dam Hydropower Station** Kashimbila Dam is a 32m high composite dam with a 40 MW hydropower station located on the Katsina-Ala River, Taraba State, a tributary of the Benue River, approximately 20 km downstream of the Nigeria-Cameroon border. It comprises a zoned rockfill embankment with a central mass gravity ogee spillway, an outlet works which consist of multi-level intakes and outlet structure.	Energy

16	**Federal Ministry of Power**	**<u>Makurdi Hydropower Project</u>** The Makurdi Hydropower Project (Makurdi HPP) was originally conceived as part of the Plan for Electric Power System Development issued by the then National Electric Power Authority [NEPA] in 1974. The planned dam site is located on the Benue River, the primary tributary of the Niger River in Nigeria, about 10 ~ 15 km upstream of Makurdi, the capital of Benue State.	Energy
17	**Federal Ministry of Water Resources**	Development of Hydroelectric power from existing 6 Small & Medium from dams across the Country Federal Executive Council (FEC) gave an approval on the 30th November 2016 for 6 dams. 1. Bakolori Dam, Zamfara State 2. Omi-Kampe Dam, Kogi State 3. Doma Dam, Nasarawa State 4. Jibiya Dam, Katsina State 5. Zobe Dam, Katsina State 6. Ikere Gorge Dam, Oyo State	Energy
18	**Federal Ministry of Power(Power)/ Federal Ministry of Water Resources**	**<u>Development of Small, Medium and Large Hydropower Project Phase 2</u>** Development of hydroelectric power from existing small, medium & large hydro dams in twelve (12) locations nationwide. As shown below: **Lot 3A** • 7MW Girmi Earth Hydropower Plant, Kaduna State (Brownfield) • 1.2 MW Lower Usuma Hydropower Plant FCT (Brownfield) • 9MW Oyan Hydropower Plant, Ogun State (Brownfield) **Lot 3B** • 138MW Dasin Hausa Hydropower Plant, Adamawa State (Greenfield) • 40MW Kashimbilla Hydropower Plant, Taraba State (Brownfield) • 92MW Garin Dalli Hydropower Plant, Benue State (Greenfield) **Lot 3C** • 182MW Bawarku Hydropower Plant, Benue State (Greenfield) • 136MW Manya Hydropower Plant, Taraba State (Greenfield) • 109MW Katsina Ala Hydropower Plant, Benue State (Greenfield) **Lot 3D** • 700MW Oguma Hydropower Plant, Kogie State (Greenfield) • 1500MW Makurdi Hydropower Plant, Benue State (Greenfield) • 441MW Onitsha Hydropower Plant, Anambra State (Greenfield)	Energy

4. CONCLUSION AND RECOMMENDATION

The choice of Public Private Partnership (PPP) in the delivery of these projects were made deliberately by the various

Ministries, Departments and Agencies to accelerate investment in new infrastructure and facilitate the rejuvenation of existing assets to a satisfactory standard that meets public's needs and aspirations; To also achieve worthwhile and value for money investment that is affordable and beneficial to the government; To increase the capacity and diversity of the private sectors participation in infrastructure development. These projects have a huge potential in bridging Energy Infrastructure Gap in Nigeria. And We at ICRC strongly believe that PPP's have a great potential in Nigeria as long as the Government develops bankable projects.

References:

https://www.planete-energies.com/en/medias/close/what-energy-mix

Private_Partnerships_in_the_Nigerian_Energy_Sector_Banks%27_Roles_and_Lessons_of_Experience
https://www.researchgate.net/publication/263662241_Public-

https://www.researchgate.net/publication/233952340_THE_ROLE_OF_ENERGY_MIX_IN_SUSTAINABLE_DEVELOPMENT_OF_NIGERIA

https://www.globalelectricity.org/content/uploads/2nd_edition_strengthening_ppps_-_joint_report_gsep-un-energy_20123.pdf
https://www.weforum.org/agenda/2020/09/four-tools-for-increasing-sustainable-energy-financing/

https://www.worldbank.org/en/topic/publicprivatepartnerships/overview

https://ieg.worldbankgroup.org/sites/default/files/Data/reports/chapters/ppp_chap1_0.pdf

https://ppp.worldbank.org/public-private-partnership/sector/energ

MANAGING REGULATION IN NIGERIA: CHALLENGES AND OPTIONS FOR IMPROVEMENT

Prof. Frank. N. Okafor FNSE, FAEng.
Commissioner, Engineering, Performance & Monitoring,
Nigerian Electricity Regulatory Commission.

ABSTRACT

In any country, lack of adequate Power supply has cascading and dire impacts on the Economy and all interdependent critical infrastructure network. When contextualized, this means that a nation's power sector can only be said to be sustainably developing if it is effectively positioned to support the economic and human development needs of today's people, while primed to meet the energy needs of future generations. Nigeria with over 200 million people is still abjectly trapped with Grid Power hovering around 4,500 - 5,000MW while Off-Grid power Generation which is delivered at prime cost is about 7 times the quantity of Grid Power. This paper looks at the implication of this scenario that saddles the Regulator with the onerous responsibility of trying to balance the expectations of the Government which is increased access to electricity at affordable cost, the expectation of the consumers (the rich and the Poor) which is improved quantity and quality of Power supply and that of investors in the industry which is primally to make reasonable returns on their investments. All these pressures on a regulator challenged by a system with predominantly obsolete Infrastructure, low level of Automation, and even poor Revenue Assurance occasioned by metering penetration of less than 40%.

Managing Regulation in Nigeria: Challenges and Options for Improvement

Contents

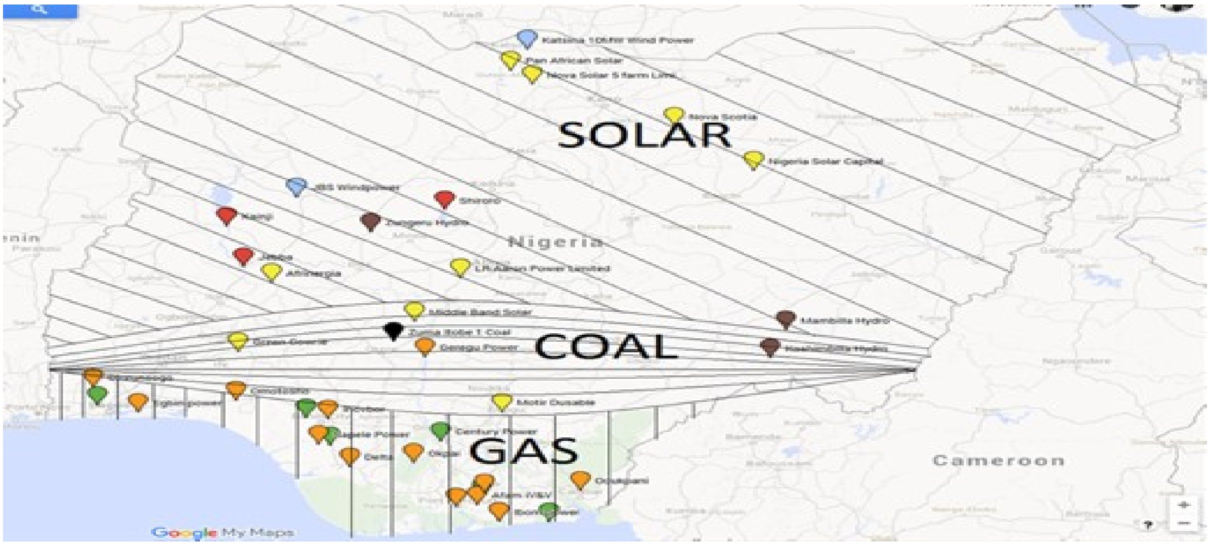
Introduction

- In any country, lack of adequate power and sustainable energy sources and delivery has cascading and dire impacts on the Economy and all

- interdependent and critical infrastructure networks;
- Trends in the world economies and increasing national demands will put additional burdens on meeting the self-sufficiency and security goals in these areas of national development;
- When contextualized, this means that a nation's power sector can only be said to be **sustainably developing** if it is effectively positioned to support and anchor the economic and human development needs of today's people, while primed to meet the energy needs of future generations;
- Nigeria with over 200 million people is still abjectly trapped and hovering around 4,500 - 5,000MW;
- Therefore, all Stakeholders in the Nigeria Electricity Supply Industry (NESI) must work hard to bridge the widening gap between available generation capacity and demand.

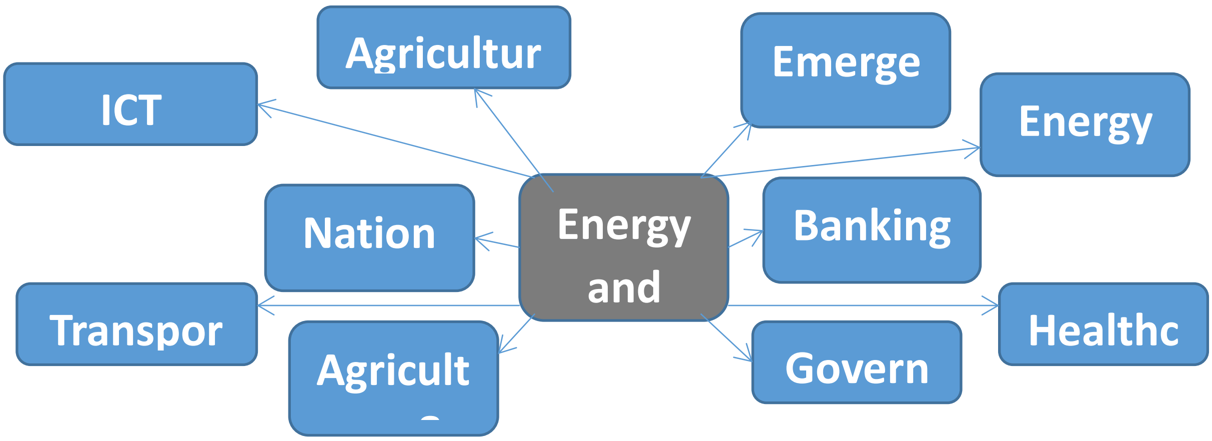
Nigeria In Focus

Energy Resources Potentials In Nigeria



Energy Source			
Existing Hydro Power Plants	Prospective Hydro Power Plant	Solar Power Plant	Wind Power Plants
Existing Gas Power Plants	Prospective Gas Power Plant	Prospective Coal Power Plant	

Dependency Of Other Economic Sectors On Power



ABOUT THE NIGERIAN ELECTRICITY REGULATORY COMMISSION AND Power Sector Stakeholders' Expectations

Objects of The Commission

a) Section 32(1)(a) of the EPSR Act, 205 empowers the Commission to create, promote and preserve efficient industry and market structures, and to ensure the optimal utilization of resources for the provision of electricity services.

b) Section 32(1)(b): The Commission is also empowered to maximize access to electricity services, by promoting and facilitating consumer connections to distribution systems in both rural and urban areas.

c) Section 32(1)(c): The Commission shall ensure that adequate supply of electricity is available to consumers.

Section 32(2)(g) further empowers the Commission to undertake such other activities which are necessary or convenient for the better carrying out of or giving effect to the objects of the commission.

Stakeholders' Expectations and Deliverables

Stakeholder	Expectation	Deliverables
Customers	• **Metered Supply; Reliable service, Customer care**	• **Timely settlement of bills**
Disco	• **Cost-reflective tariffs** • **Stable regulatory environment** • **Reliable and predictable grid supply** • **Timely Settlement of Bills** • **Settlement of MDA Debts**	• **Deployment of meters** • **Reduce losses** • **Reliable services** • **Posting of bank guarantees on contracts** • **Timely settlement of upstream invoices** • **Compliance with licence terms and conditions**
TCN	• **Cost Reflective tariffs** • **Stable regulatory environment** • **Payment for available capacity** • **Timely settlement of invoices by Discos** • **Bank guarantees for contracted services**	• **Delivery of contracted capacity;** • **Available and reliable contracted capacity** • **Compensation for non-availability** • **Compliance with licence terms and conditions**
NBET	• **Timely settlement of invoices by Discos** • **Bank guarantees on vesting contracts** • **CPs for full activation PPAs** • **LDs for non availability by Gencos**	• **Timely settlement of Genco Invoices** • **Posting of guarantees to Gencos on PPA** • **Compliance with licence terms and conditions**

Issues and Challenges impacting the power sector

Issues Of the Power Sector in Nigeria

- Infrastructure
    - Gas supply issues
    - Generation capacity and Energy Mix
    - Transmission and Distribution Capacities
    - Reliability and Quality of Supply;
    - Interface Challenges
    - Rehabilitation and Expansion
    - Metering, Communications and SCADA/EMS
    - Integrated & Operational Planning
    - Technical, Safety, and Security Issues
- Commercial
    - Illiquidity Issues
    - Investments & Funding
    - Market Reflective Tariffs
    - Succession plan
    - Tools and training infrastructure e.g. Training Simulators, software applications etc.
    - Partnerships and R&D

Illiquidity Crisis of The Power Sector

- The major challenge that had hindered progress in terms of the performances of the DISCOs and GENCOs is the inability of the DISCOs to pay their bills as expected.
    - Market Remittances
    - Markets Contracts
    - ATC&C Losses Reduction
- Policy & Regulatory
    - Consistency of Policy Direction & Sector Coordination
    - Sound Regulatory Oversight
    - Effective and Efficient Electricity Market
    - Creation of New Markets and Competition
    - Implementation of Power Sector Recovery Plan (PSRP)
    - Implementation of Performance Improvement Plans (PIPs) by DiCos
    - Adequacy, Safety, Security, Reliability, Resilience and Affordability of Electricity.
    - Grid Discipline
- Capacity Development
    - Dearth in human capacity
    - Continuous capacity development

- This has been identified as the fundamental crisis of the sector which if not addressed can destroy all the gains we had achieved in the transition from the public and private sector.
- Non-cost reflective tariffs: electricity tariffs are set well below what is needed to recover costs, often requiring heavy government subsidies to make up the loss and creating significant financial challenge across the entire power sector value chain. If utilities cannot recover their costs, they cannot make much-needed

investments in infrastructure maintenance or modernization.

- This has been caused by critical events, which can be attributed to the lack of coordination, clear policy direction, weak regulation & enforcement and indiscipline.

Funding The Power Sector

- In the case of Nigeria, after privatization we all went to sleep and implemented policies that scared national and international bankers. The difficulty of securing cheap and low-term infrastructure financing is a major challenge that all actors along the value chain are experiencing and that explains one of the reasons why the anticipated progress of changing the technical status of the Distribution Companies is moving at a slow pace.
- The experience of countries that were courageous enough to travel the path of reform is that of knowing that after the corporatization of the companies, unbundling, setting up the requisite institutional and regulatory environment and ultimately privatization, the Government still needed to provide its own part of the funds that will sustain the sector. `
- With the current financial status of the country, securing funding is becoming more challenging and most of the equipment of the power sector still have to be imported.
- It must be acknowledged that FGN is making frantic efforts to provide soft loans to the TCN and Discos. However, this is for a limited scope and time. The Sector needs a sustainable means of funding!

Infrastructure: Fuel Company (Fuel-cos)

- Gas is the predominant fuel for power generation in the Nigerian power sector accounting for 83% of the installed capacity of over 13,000MW with available capacity of about 7,800MW;
- **Inadequate gas pipeline infrastructure:** The capacity of the gas pipeline infrastructure is insufficient to reliably meet the gas demands of the existing power plants operating at the full installed capacity;
- **Gas supply constraints and Vandalism**: Most of the gas supplied to the power plants is on a "best endeavour" basis. Vandalism of oil and gas delivery infrastructure has also shut down gas production which resulting in another 1,000MW of constrained generation in recent years.
- This has been compounded by power producers' large payment arrears that it is unable to settle (total gas supply indebtedness of power plants. As such supply has been erratic and low resulting in about 2,000MW of constrained generation;

Infrastructure: Fuel Company (Fuel-cos)

- ❑ Since the launch of the master plan in 2008, there has not been any significant improvement in Gas supply situation in the domestic market.

This could be attributed to:

- ✓ Inadequate Gas production facilities and supply infrastructures.
- ✓ Lack of commercial Gas pricing framework.
- ✓ Non-payment for gas consumed by power plants.

- ✓ Lack of credit worthy off takers.

- ❑ Efforts should be intensified by Government to look into all the challenges associated with Gas supply to the domestic market especially the above.

The issue of a cost reflective tariff in the Nigeria Electricity Supply Industry should also be looked into. The price paid for electricity consumed and the amount remitted by the Discos to the Market have direct relationship with the ability of the Gencos to pay fully and promptly for the Gas

- **Some of the key challenges of power generation are:**
  - Inadequate Generation Capacity;
  - Maintenance issues: No maintenance culture, lack of adequate spare parts;
  - Grid Reliability issues;
  - Stability of units;
  - Market issues: Non-payments for energy generated;
  - Fuel (gas) supply interruption and quality issues;
  - Inadequate gas pipeline infrastructure and vandalism;
  - Poor Dispatch Strategy (Economic Merit Order Dispatch).

- **Infrastructure: Generation Companies (Gencos)**

Power Plant Type	POWER PLANT	INSTALLED CAPACITY (MW)	PLANT INHERENT CONSTRAINED CAPACITY (MW)	EFFECTIVEAVAILABLE CAPACITY (MW)	
				MW	%
HYDRO POWER PLANTS (HPP)	Kainji	760	280	440	57.89
	Jebba	570	120	450	78.95
	Shiroro	600	0	600	100.00
	SUB-Total HPP	**1930**	**400**	**1490**	**78.95**
THERMAL PLANTS	Shell Afam VI	650	150	500	76.92
	Okpai (Agip)	480	0	370	77.08
	Azura	450	0	450	100.00
	Olorunsogo (PAPALANTO)	335	31	304	90.75
	Omotosho I	335	31	304	90.75
	Ibom Power	190	75	115	60.53
	Omoku	150	50	100	66.67
	Rivers IPP	180	20	160	88.89
	Trans Amadi	136	51	75	55.15
	Transcorp (Delta)	972	402	510	52.47
	Egbin	1320	440	880	66.67
	Sapele I	1020	900	120	11.76
	Geregu I	414	124	290	70.05
	Afam I-IV & V	977	872	150	15.35
	SUB-TOTAL THERMAL	**7,609**	**3,146**	**4,328**	**65.93**
NIPP PLANTS	Odukpani (Calabar) NIPP	560	110	450	80.36
	Sapele -NIPP	450	225	225	50.00
	Gbarain NIPP	225	112.5	112.5	50.00
	Alaoji NIPP	1074 576 (phase 1)		240	22.35
	Geregu II NIPP	435	145	290	66.67
	Ihovbor NIPP	450	112.5	337.5	75.00
	Olorunsogo II NIPP	675	425	250	37.04
	Omotosho II NIPP	450	90	360	80.00
	SUB-TOTAL NIPP (MW)	**4,319**	**1,220**	**2,265**	**57.68**
	NATIONAL TOTAL (MW)	**13,858**	**4,766**	**8,083**	**67.52**

Infrastructure: Generation Companies (Gencos)

- The problem of incessant gas supply to the gas power plants across the Southern part of Nigeria is a clear case in point. Considering the fact that we are still hovering around 5,000MW all these years, a lot more needs to be done.
- The ***Peak Actual Generation*** ever attained is about **5,801MW *on 01/03/2021***.
- Lack of effective Market Contracts and Obligations is key contributor to the Power Generation problems.
- Poor Dispatch of power plants.
- DisCos' Low Power Off-take/ Load Rejection behavior also contributes immensely to Low Generation Profile.

Infrastructure: Transmission Company Of Nigeria (TCN)

- The transmission network, a critical link in the electricity value chain, under the government ownership and control is in dire need of attention;
- Fragile Electricity Transmission System: The network is weak, radial and lacks redundancy facility. In the event of significant increase in actual generation, the transmission network would **NOT** be capable of supporting such output;
- Presently the state of the national electricity transmission network transformation capacity is at about 8,000MW but Transfer Capability is far below. Beyond this value, the integrity of the network will be threatened;
- Extremely Poor Projects Management;
- There are at least **140 projects** that are ongoing presently across the 6 geopolitical zones of the country. These projects include majorly, transmission lines (330kV and 132kV), substations s/s (330kV S/S, 132kV S/S and 330/132kV S/S). Others are Line Bays, capacitor banks and rehabilitation projects. Some of these Projects have been lingering for years attracting **huge** variations from the Contractors;
- Payment for Right of Way acquisition (RoW) – WAYLEAVE: This is a very serious drain pipe for TCN. One cannot image that some Wayleave Compensation Payments are more than the total cost of projects. This is unacceptable!!!

Infrastructure: Transmission Company of Nigeria (TCN)…2

- **More Challenges:**
  - The contractual service obligations are not maintained. Contracts are unnecessarily extended attracting Huge Variations;
  - Lack of adequate transmission lines and sub-stations capacities;
  - Very weak ISO – Grossly Ill-equipped to manage the Grid. Inadequate Operational Tools and Infrastructure;
  - Networks are not properly operated within Statutory Limits (Voltage and Frequency);
  - The right of way (RoW) violations;
  - Congestion issues (available transfer capability at some T&D interface points);

- The issue of coordination between different partitions: regional transmission organizations (RTO) and independent system operator (ISO);
- Poor Relay Protection Coordination leading to Reliability Issues;
- Frequent system outages (Collapses);
- Commercial Issues concerning payments of wheeling charge.
-

Infrastructure: Distribution Companies (Discos)

- Poor Revenue Collection and Market Remittances;
- Inadequate Distribution Lines and Transformation Capacities;
- Poor Reticulation of Distribution Networks;
- Inadequate Feeders Metering & Customers Metering;
- Lack of AMI/AMR Infrastructure;
- Low DisCos' Load Off-take;
- Load Rejection by DisCos;
- Very high ATC&C Losses;
- Constraints at the interfaces with transmission and at various other points;

Poor Customers Complaints Handling by DisCos.

Non-payment Of MDA Debts

- At the time when the privatization program had been worked out there was a tacit agreement that the FGN would put in place a mechanism for debts of Ministries and agencies to be paid to the companies. The Government even issued a directive that the accountant General would deduct the debts of MDAs at source. The total MDAs debts as of March this year is captured in the table below:
- As of today, this debt has increased to over N93 Billion, including interest. No mechanism has been put in place to address this issue and has also contributed to the financial crisis of the Discos. Most of the debts are those of military and security establishments and experience has shown that collecting revenue from these facilities to be a daunting task.

Market/System Indiscipline

- ❑ Indiscipline is a very big challenge that if not quickly addressed it will strangulate the market. The two types of indiscipline threatening the existence of the market are:
  - ✓ Market transaction indiscipline
  - ✓ Grid Operations Indiscipline
- ❑ Poor remittances from the Discos to the market and the more frequent system collapses What we are experiencing are the results of the two-indiscipline mentioned above. The only way to deal with these types of indiscipline are:
  - ✓ Effective contracts - in a developed market.
  - ✓ Effective Administrators – in a developing market (SO/MO).
- ❑ OPTIONS FOR IMPROVING for the POWER SECTOR
- ❑ There should be leadership and direction on the Implementation of PSRP to address sector liquidity challenges and the following:

- ✓ infrastructure constraints associated with gas, generation, transmission and distribution limiting access and options to safe and reliable electricity services;
- ✓ insufficient end user tariffs to fund operating costs;
- ✓ significant sector revenue shortfalls and liquidity crisis threatening viability of the sector;
- ✓ ineffective contracts limiting accountability of operators and enforcement activities of the Regulator (NERC); and
- ✓ sector governance and transparency challenges.

- ❑ FMoP and NERC to ensure effective coordination and regulation of the Sector respectively;
- ❑ Institutionalization of proper System Planning to avoid Gold Plating of Projects;
- ❑ Removal of all T&D Interface Bottlenecks within the shortest possible time (Maximum of 2 years);
- ❑ Development of a credible Merit Order for effective and efficient Dispatch of power;
- ❑ Ensure independence of the System Operator and adequate tooling;
- ❑ Promotion of 'New Markets' – Mini-grids, Franchising, Eligible Customer;
- ❑ Provide cost reflective tariffs over a reasonable period;
- ❑ Ensure full settlement of Market Invoices by the DisCos.

Focus Areas…2

- Gradual activation of Market Contracts to enhance accountability, enforcement actions and full payment for energy off-take by the Discos;
- Full payment for electricity Bills by MDAs;
- Rollout of other 'New-Markets' initiatives and facilitate implementation of existing Regulations such as Eligible Customer, Mini-Grid, IEDN, Embedded Generation etc;
- Strict compliance monitoring and enforcement of Rules, Regulations, Codes and Safety/Technical Standards to address Grid Indiscipline;
- Close Monitoring of the Implementation of TCN SLA Interface Projects and Performance Improvement Plans (PIPs) by the Distribution Companies to eliminate operational bottlenecks and increase energy off-take (Inter-Agency Teams should be encouraged);
- Deduction at Source for all outstanding MDA electricity Bills;
- Generally enhance Compliance Monitoring and Enforcement;
- Diversification of Generation Mix Options to ensure security of supply;
- Partnerships with Universities/Research Institutes to enhance Capacity Development and address Industry Challenges.
-

Focus Areas...3
Transmission COMPANY OF NIGERIA (TCN)

- ❑ Institutionalization of World Class Project Management in TCN to ensure

Effective and efficient completion of projects;

- Note that acquisition of Right of Way (RoW) and Wayleave Compensation Payment for transmission projects constitute one of the most difficult issues leading to **serious corruption**, **extremely high costs of projects** and **delay in completion of projects also leading to Variations**. A surgical operation should be carried out on the management of Wayleave Compensation Payments by TCN. It is worthy of note that some of the Wayleave compensations amount to more that the total project costs. This can only happen in Nigeria;
- There is need to expedite the completion of all Transmission Projects between now and 2023. I recommend **renegotiation** of all outstanding Contracts with a view to reducing the costs and payment for outstanding works. This was done in the past;
- Appointment of Board for TCN is imperative;
- Funding of Transmission Projects through Government Interventions, Private Sector participation and the use of NIPP power plants sales proceeds;
- Fast track the implementation of a new Independent System Operator (ISO) structure that is autonomous from TCN;
- Siemens Intervention Projects should be expedited.

Focus Areas ...4
Creation of New Markets, Technologies and ENHANCE private sector participation

There should be traction on activities involving measurements, monitoring and verification, development of new regulations to **open up the market space** for more private sector participants to engender competition, improve power supply and access to electricity, ensure full metering of customers, improve reliability of supply, improve market liquidity, improve market discipline, controlled licensing process, etc.

Conclusion

- Solving Energy Challenges in Nigeria is solving about 50% of the Nation’s Problems:
  - ✓ Promoting Job creation and empowerment for the teeming youths.
  - ✓ Addressing Security Challenges.
  - ✓ Promotion of energy for economic development in the North which will promote support for emerging economies in water supply, access to school, access to health, access to roads and improved manufacturing capacity, ICT, transportation, agriculture etc.
- The socio-economic development of this great nation depends on a large extent, on the functionality of the Market. Therefore, all hands must be on deck to ensure that the challenges identified and recommendations made are looked into with a view to addressing and implementing them, for the Growth and Development of the Market in Nigeria and with clear Agenda to also empower the Northern Nigeria.
- Note the commendable successes recorded by this administration in the Power Sector is in serious jeopardy

except urgent actions are taken to address major lingering challenges.

- Note from the resolve of the present Administration, it is evident that the Policy thrust is to ensure that Nigeria has an electricity supply industry that can meet the needs of its citizens in the 21st century; and to modernize, expand electricity coverage to support national economic and social development. However, to achieve this noble objective, certain anomalies in the Sector as highlighted in this presentation must be corrected immediately.

THEME FOCUS:

PROSPECTS AND CHALLENGES OF UTILIZATION OF COAL, NATURAL GAS AND HYDRO (WATER) FOR SUSTAINABLE POWER GENERATION AND PROVISION OF COMPETITIVE ENERGY IN NIGERIA

CHARACTERIZATION OF MAIGANGA, GOMBE COAL

Kiman Silas[a], Hyelachidari Abdu Hassan[a] and Habiba D. Mohammed[a]

[a]Department of Chemical Engineering, University of Maiduguri, Maiduguri, Borno State.

ABSTRACT:
To readily attract prospective investors, it is pertinent to readily make available the properties of Nigerian's coals that are critical. The physicochemical properties and functional group analysis of the Maiganga coal of Gombe State were investigated. The moisture content of 5.8%, ash content 8%, volatile matter 43.91%, fixed carbon 42.16%, sulphur content 0.134% and calorific value 5179.80 (kcal/kg) were found. The volatile matter was greater than 31 wt.% typically classified as Sub-Bituminous B coal. The caloric value of 5179.80 (kcal/kg), Ash content of 8.0%, Carbon (69.486 %) and hydrogen (5.22249 %) are the major combustible constituents of coal, and both of them are high in the coal sample. The organic compounds having oxygen functional groups found in the coal include phenols, alcohols and carboxylic acid. Properties of the Maiganga coal is best suited for cement and power electricity production due to its low-rank coal (LRC) categorization.

Keywords: Maiganga coal, physicochemical properties, functional groups analysis, power generation

1. INTRODUCTION

Power generation in any country is very essential to its economic grow (Adeojo and Osinibi, 2016). Although generation of energy from coal is accompanied by the emission of greenhouse gases, the development of clean coal technologies has helped to reduce this emission (Alhassan *et al.,* 2020). Coal, as a solid fuel is composed primarily of carbon along with variable quantities of other elements, chiefly hydrogen, sulphur, oxygen, nitrogen as well as trace amounts of other elements, including mineral matter (Ryemshak *et al*., 2016). It is a formation process that is both biological and geological in nature, which take place over a long period of time where dead plant matter is converted into peat, and in turn converted into lignite, sub-bituminous coal, bituminous coal, and lastly anthracite (Meshram *et al*., 2015). Coal consists of combustible substance that are both organic and inorganic compounds or elements which make it a major energy source worldwide. Coal contains mostly carbon (C), but it also has hydrogen (H), oxygen (O), sulfur (S) and nitrogen (N), as well as some inorganic constituents (minerals) and water (H_2O) (Ryemshak *et al*., 2016).

In the five major coal ranks (from peat to anthracite), organic constituents such as carbon, hydrogen and oxygen are rank dependent variables but the major inorganic elements (nitrogen and sulphur) contents depend on chemistry of the area of occurrence and precursory plant of the coal (Janković *et al*., 2020; Kamble *et al*., 2019). All these inorganic compounds affect the efficiency of the blast furnace as well as other boilers, and so choice of low content inorganic coal is very crucial for fuel making. Since the discovery of petroleum in Nigeria, the use of coal for electricity generation, cooking, heating up houses in the cold period to create warmth, etc., has been neglected in spite of its abundance in the country (Oyedepo, 2014). This resulted to constant failure in power supplies, political and economic instability due to insufficiency and increase in price of petroleum product (Olujobi *et al*., 2021). Therefore, against the backdrop of abundant proven reserves of coal, analyses of coal properties for their suitability in power generation can significantly contribute to Nigeria's energy mix. To readily attract prospective investors, it is pertinent to readily make available the properties of Nigerian's coals that are critical for electricity generation. There are only a few experimental investigations on the combustion profile of Nigerian coals and investigating their slagging potentials are even rarer (Musa *et al*., 2016). An in-depth understanding of the characterization and ash chemistry of the Nigerian coals is necessary in order to assess indigenous coal combustion efficiency, also to avail engineers and policymakers with the comprehensive data required to effectively develop and strategically implement plans for future power plants and or the industrial applications of coal resources in Nigeria. The main objective of the study is to characterize the Maiganga, Gombe coal by proximate analysis, ultimate analysis and FTIR analyses and recommend its suitability as solid fuel for combustion in power generation.

2. MATERIALS AND METHODS

2.1 Coal samples preparation

The coal sample was obtained from Garin Maiganga located within the Gombe Formation in Maiganga village, Akko local government area of Gombe state, Nigeria. All samples were initially crushed and pulverized. The coal samples were sieved to a particle size of 150 micrometer in preparation for further analysis. The coal sample is prepared using both the mechanical and manual methods so as to meet the desired analytical specifications using an array of sample preparation equipment. Crushing of the samples from a top-size of about 500 - 600mm, to a suitable size distribution range of 30.5 – 100mm was carried out manually through the use of hammer. A pulveriser was then used to prepare samples from a top size of 6mm down to a suitable size distribution range of 150 – 250μm. An automatic sieve shaker, was used for sieving the samples to the desired size distribution required for each test.

2.2 Proximate and Ultimate Analysis

2.1.1 Moisture content

The air-oven method was used to analyze for moisture content. Coal samples passing a 212µm test sieve was stored in the proximate analysis room for 30 minutes before the start of the test. Crucibles with lids were heated for 1.5 hours before the start of the test. The crucibles and lids were cooled for 10 minutes and then put in a desiccator cabinet for 10 minutes. An electronic balance was then used to weigh the crucibles before uniformly spreading 1.000g of conditioned sample and recording the mass of the crucibles and contents. The crucibles and contents were then loaded into the air oven at a temperature of 105°C for 1.5 hours, and such that the atmosphere or flow within the oven was changed at a rate five times per hour. This was as specified in ASTM D3173.

2.1.2 Volatile matter

Coal samples passing a test sieve with an aperture of 212µm was stored in the proximate analysis room for at least 30 minutes before commencement of the test. The crucibles and lids (crucibles uncovered) were placed in the volatile furnace. When the furnace attained a temperature of 905 °C, the crucible and lids were removed and allowed to cool for 60 minutes to room temperature. 1.000g of coal samples were put into each crucible. Each crucible was lightly tapped on a clean hard surface a few times to form an even layer on the bottom.

2.2.3 Ash content

Ash is simply the non-combustible inorganic residue which remains after coal is completely burned. Coal samples passing a test sieve with an aperture of 212µm sieve size was stored in the proximate analysis room for 30 minutes before the test commenced. After the crucibles and lids were conditioned in the furnace and allowed to cool to room temperature, 1.000g of coal samples were placed into each crucible. The crucibles were loaded into the furnace equipped with a preprogrammed temperature controller. The furnace temperature was ramped to 500°C over a period of 60 minutes; held at 500°C for 30 minutes; ramped to 815°C over a period of 60 minutes; and held at 815°C for 60minutes. The temperature was verified with an external type-K thermocouple when the furnace stabilized at 815°C. This was in accordance with the ISO 1171:1997.

2.2.4 Fixed carbon

The fixed carbon content can be calculated from the expression; this was calculated from the formula: %Fixed Carbon= 100 – (%Moisture+ %Ash+ %Volatile matter. % of carbon – (% moisture + % Ash + volatile matter) (1)

2.3 Ultimate Analysis

Coal passing through a sieve having an aperture of 212µm was used for this analysis. Ultimate analysis was carried out making use of the TRUSPEC CHN Elemental determinator. The equipment was supplied with a reference material with known ultimate analysis result. This reference material (Prox-Plus) was used to determine the accuracy of the CHN Elemental determinator before commencing the tests. 1.0g of sample was loaded into porous crucibles and subjected to combustion in an oxygen-rich environment. Typical run duration was about 10 minutes. The system converts the coal catalytically to Nitrogen, CO_2 and water, which are separated with a gas chromatographic column and detected through a sensor. The results were displayed on the computer monitor in terms of

percentage carbon, hydrogen and nitrogen on an air-dried basis. This was based on ISO 12902 – CHN instrumental method. Oxygen was calculated by difference on an air-dried basis as follows:

$$O_2\ (\%) = 100 - (C + H_2 + N_2 + Ash + Moisture) \quad (2)$$

2.4 Fourier Transform Infra-Red Spectroscopy (FTIR) Characterization

The FTIR analysis was carried out on a Perkin Elmer 100 series, Universal ATR accessory spectroscopy. This is for the purpose of identification and comparison of the functional groups present in each sample. Samples were oven dried at a temperature of 100 °C and crushed with mortar and pestle before analysis.

3. RESULTS AND DISCUSSION

Results of the analyses conducted on the Maiganga coal in order to determine its properties using the proximate and ultimate analyses are presented.

3.1 Proximate Analysis Result

Results of the proximate analyses were used to establish the rank of coal and show the ratio of combustible to incombustible constituents. The proximate analysis of the test samples was carried out in accordance with the ASTM D 3172-73(84) standard. The results of the proximate analysis of the Maiganga coal is shown in Table 3.1.

Based on the results of proximate analysis of the Maiganga coal sample, the moisture content is 5.8%, ash content is 8%, volatile matter is 43.91%, fixed carbon is 42.16%, sulphur content is 0.134% and calorific value is 5179.80 (kcal/kg). Moisture content is a significant parameter of coal since all coals are mined wet. Chemically and physically bound water can contribute to total moisture. The moisture content decreases with maturity and ranking of coal due to the decrease of porosity (Wang *et al*., 2020). Musa *et al*., (2016) reported the Maiganga coal moisture content of 5.17%. The moisture content of below 10% for coal sample is within the acceptable limits for electric power generation (Nyakuma *et al*., 2021). Low moisture content is an indication that the coal is of a high rank and good quality, possibly the rank of bituminous grade whose content also represents a significant improvement in coal's quality because moisture affects the calorific value, the concentration of other constituents, decreases system capacity and increases operational cost. Based on its fuel properties, the coal can be classified as a Sub-Bituminous B, the results indicate that the coal is potentially suitable for future utilization in electric power generation and the manufacture of cement and steel. These finding are similar to the works of Nyakuma and Aliyu, (2016), Nyakuma, (2015) and Nyakuma, (2012).

Table 3.1: Results of proximate Analyses of the Maiganga coal samples.

% Proximate Analysis	Maiganga Coal
Moisture content	5.80
Ash content	8.00
Volatile matter	43.91
Fixed carbon	42.16
Sulphur content	0.134

It has been reported that, coal samples with volatile matter (VM) greater than 31 wt.% are typically classified according to calorific or higher heating value (Nyakuma, 2012). Hence, on the basis of this result, Maiganga coal could be identified as Sub-Bituminous B coal and is best suited for cement and power electricity production due to its low-rank coal (LRC) categorization and could be suitable for electrical power generation on account of its minimum calorific value of 3,500.00 cal/g (Ryemshak and Jauro, 2013). In the light of the foregoing findings, and report of studies conducted by Nyakuma and Aliyu, (2016), Maiganga coal sample may be suitable for power generation since its caloric value is 5179.80 (kcal/kg).

3.2 Ultimate Analysis Result

Ultimate (i.e., elemental) analysis is dependent on quantitative analysis of various major elements present in the coal. It is essential to know the elemental composition of solid fuel in order to determine its rank as well as grade for evaluation of its suitable application as a chemical feedstock or as a fuel in power generation. The elemental composition of carbon, hydrogen, nitrogen, sulphur and oxygen in the coal samples are shown in Table 3.2.

Table 3.2: Ultimate Analysis of Maiganga coal sample.

Element	Elemental composition (%)
Carbon	69.486
Hydrogen	5.22249
Oxygen	10.5693
Nitrogen	1.2218

Sulphur	0.1340

The result revealed high proportions of the elements; Carbon, C (69.486 %) and hydrogen, H (5.22249 %). Carbon and hydrogen are the major combustible constituents of coal, and both of them are high in the coal samples. The higher the carbon content, the higher the calorific value and the better the quality of the coal for power generation (Chukwu *et al*., 2016). The Odagbo coal sample with carbon (62.18%) and hydrogen (5.87%) were reported to have high carbon and hydrogen contents (Chukwu *et al*., 2016). Oxygen content in the samples is 10.5693%, the high content of oxygen is characteristic of low rank coals, while the decreased concentration is typical of low rank coals. More oxygen a coal contains the easier it to burn to ignite (Rasheed *et al*., 2015). Table 3.3 shows the variation of selected coal properties with coal rank.

Table 3.3: The variation of selected coal properties with coal rank (Rasheed *et al*., 2015).

	< ----------Low Rank------------->		< ----------High Rank--------->	
Rank:	**Lignite**	**Sub-bituminous**	**Bituminous**	**Anthracite**
Age:	------------------------------Increase------------------------------>			
% Carbon:	65-72	72-76	76-90	90-95
% Hydrogen:	~5-----------------------------decreases----------------------------- ~2			
% Nitrogen:	< ------------------------------ ~1-2 ------------------------------>			
% Oxygen:	~30----------------------------decreases----------------------------- ~1			
% Sulphur:	~0-----------------increase---------- ~4 ---------- decreases----------------- ~0			
% Water:	70-30	30-10	10-5	~5
Heating value (BTU/lb) :	~7000	~10,000	12,000-15,000	~15,000

The increased content of hydrogen (i.e 5.22249%) is normally more characteristic of low rank coal while the decreased values are commonly more typical of higher-rank coals as shown in Table 3.3. The increased contents of Nitrogen are normally more characteristic of higher-rank coals, while the decreased values of this element are commonly more typical of lignites, while the increased content of Sulphur is more characteristic of lignites (Rasheed *et al*., 2015). Nitrogen content of almost all coals is in the range of 1 – 2% (Nyakuma, 2015). In this study, the Nitrogen content is 1.2218% which is fair enough as it falls within the reported range.

3.3 Functional Groups Result

The FTIR method, being able to reveal carbo-hydrogenated structures (aromatic and aliphatic) and heteroatomic functions (mainly oxygenated), as well as to detect the presence of minerals, is currently one of the most powerful techniques for coal characterization and thus is of paramount importance in the various utilization procedures of coal (Balachandran, 2014; Manoj, 2016; Manoj and Elcey, 2015). FTIR spectra may be used for the identification of minerals associated in the coal structures also, the functional groups of coal and its derived products provide an insight into the structure of coal (Manoj and Elcey, 2015). A typical FTIR study on coal was reported by Odeh, (2015). However, the quantity of different functional groups on the FTIR spectra in the 4000–1000 cm^{-1} band of the raw coal is presented in Figure 3.1.

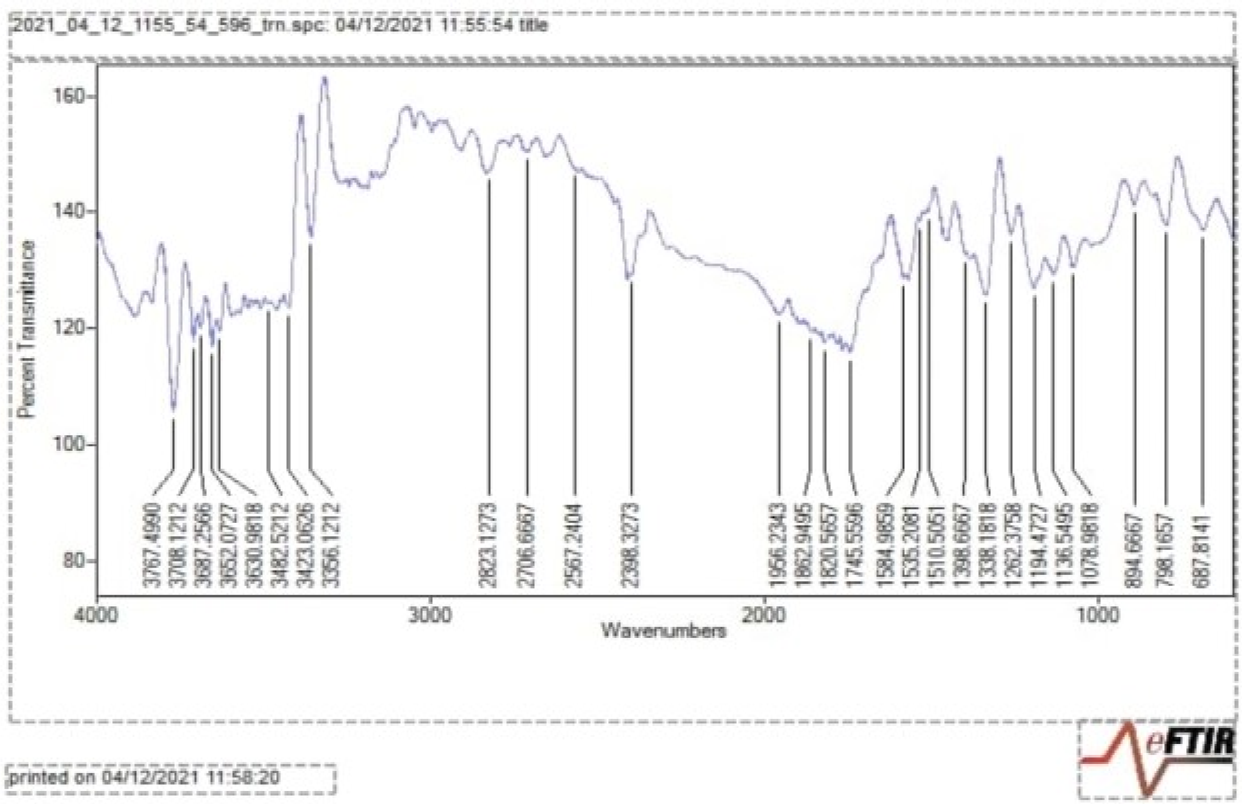


Figure 3.1: Functional groups on the FTIR spectra in the 3800–1000 cm^{-1} band of the raw coal.

The peak positions on the spectra illustrates the presence of a certain functional group with the form of vibration it exhibits. Table 3.4 shows the functional groups in 3800–1000 cm^{-1} peak positions and its vibration forms.

Table 3.4: Functional groups in 3800–1000 cm^{-1} and its vibration form.

Peak position (cm^{-1})	Functional groups	Vibration form	Reference
3800– 3200	—OH and—NH	Stretching vibrations	(Lin *et al*., 2019; Sonibare *et al*., 2010)
3600	O—H groups	Stretching vibrations	(Lin *et al*., 2019; Sonibare *et al*., 2010)
1770–1720	Aliphatic anhydride C=O	Stretching	(Lin *et al*., 2019)
1715–1690	COOH	Stretching	(Lin *et al*., 2019)
1690–1660	Quinone C= O	Stretching	(Lin *et al*., 2019)
1605–1595	Benzene ring C= C	Stretching	(Lin *et al*., 2019)
1480–1465	—CH_2	Antisymmetric deformation	(Lin *et al*., 2019)
1460–1435	—CH_3	Antisymmetric deformation	(Lin *et al*., 2019)
1410-1310	O—H groups	Stretching vibrations	(Lin *et al*., 2019)
1385–1370	—CH_3	Symmetrical bending	(Lin *et al*., 2019)
1338–1260	Ar—O—C	Stretching	
1250– 1000	Si— O	Bending vibration	(Manoj and Elcey, 2015)
1160–1120	C— O— C	Stretching	(Lin *et al*., 2019)

900–700	Aromatic —CH	out of plane structure.	(Manoj, 2016; Manoj and Elcey, 2015)
690	C—S		(Saikia *et al*., 2007)

The organic compounds having oxygen functional groups found in coal include phenols, alcohols and carboxylic acid also, the –OH groups in raw coal could also be associated with either clay minerals such as kaoline, quartz, illite, montmorillonite, halloysite containing absorbed/interlayer water/structural OH groups or other minerals containing water of crystallization such as gypsum, rozenite, mirabilite, etc (Manoj, 2016; Saikia *et al*., 2007; Sonibare *et al*., 2010). Hence, the FTIR result of the Maiganga coal revealed, it contained either clay minerals, or other minerals containing water of crystallization.

4. CONCLUSION

Rank and type of coal are fundamental factors that control coal characteristics. This includes; the cooking properties and suitability for application for power generation. The results of proximate analysis of the Maiganga coal samples, showing the moisture content (5.8%), ash content (8%), volatile matter (43.91%), fixed carbon (42.16%), sulphur content (0.134%) and calorific value (5179.80 kcal/kg) reveal the potential of the coal samples in engineering application. Consequently, coals with volatile matter (VM) greater than 31 wt.% are typically classified is as Sub-Bituminous B coal and is best suited for cement and power electricity production due to its low-rank coal (LRC) categorization. From the FTIR result, the coal sample is known to have appreciable amount of clay minerals or other minerals containing water of crystallization with the caloric value of 5179.80 (kcal/kg). The properties of the Maiganga coal exhibited high proportions of combustible chemical elements for thermal energy utilization and non-coking application.

REFERENCES

Adeojo, O. O., and Osinibi, O. M. (2016). Assessing the intersections between renewable energy, sustainable development and the challenges of environmental justice in Nigeria. *Interdisc. Environ. Rev.*, *17*(2), 148-149. https://doi.org/10.1504/ier.2016.076184

Alhassan, F., Thomas, S., Aminu, R., Barau, J., Oyeleke, O., and Abdullahi, R. (2020). Combined cycle power plant technology: Prospects in boosting Nigeria’ s electricity production. In *IEEE Xplore* (pp. 8–12). IEEE.

Balachandran, M. (2014). Role of infrared spectroscopy in coal analysis — An investigation. *Amer. J. Anal. Chem.*, *5*, 367–372.

Chukwu, M., Folayan, C. O., Pam, G. Y., and Obada, D. O. (2016). Characterization of some Nigerian coals for power generation. *J. Comb.*, 1–12. https://doi.org/10.1155/2016/9728278

Iyayi, S. E. (2007). Diversifying Nigeria' s petroleum industry. *Int. J. Phy. Scie.*, *2*(10), 263–270.

Janković, M., Janković, B., Marinović-Cincović, M., Porobić, S., Nikolić, J. K., and Sarap, N. (2020). Experimental study of low-rank coals using simultaneous thermal analysis (TG–DTA) techniques under air conditions and radiation level characterization. *J. Ther. Anal. And Cal.*, *142*(2), 547–564. https://doi.org/10.1007/s10973-020-09288-5

Kamble, A. D., Saxena, V. K., Chavan, P. D., and Mendhe, V. A. (2019). Co-gasification of coal and biomass an emerging clean energy technology: Status and prospects of development in Indian context. *Int. J. Min. Scie. And Technol.*, *29*(2), 171–186. https://doi.org/10.1016/j.ijmst.2018.03.011

Lin, S., Liu, Z., Zhao, E., Qian, J., Li, X., Zhang, Q., and Ali, M. (2019). A study on the FTIR spectra of pre- and post-explosion coal dust to evaluate the effect of functional groups on dust explosion. *Proc. Saf. And Environ. Prot.*, *130*, 48–56. https://doi.org/10.1016/j.psep.2019.07.018

Manoj, B. (2016). A comprehensive analysis of various structural parameters of Indian coals with the aid of advanced analytical tools. *International J. Coal Scie. & Technol.*, *3*(2), 123–132. https://doi.org/10.1007/s40789-016-0134-1

Manoj, B., and Elcey, C. D. (2015). Demineralization of sub-bituminous coal by fungal leaching : A structural characterization by X-ray and FTIR analysis. *Res. J. Chem. Environ*, *17*(8), 11–15.

Meshram, P., Purohit, B. K., Sinha, M. K., Sahu, S. K., and Pandey, B. D. (2015). Demineralization of low grade coal - A review. *Ren. And Sus. Ener. Revi.*, *41*, 745–761. https://doi.org/10.1016/j.rser.2014.08.072

Musa, U., Ishaq, K., and Onoduku, U. S. (2016). Characterization and ash chemistry of selected Nigerian coals for solid fuel combustion. *Pet. And Coal*, 1–20.

Nyakuma, B. B., and Aliyu, J. (2016). Physicochemical characterization and thermal decomposition garin Maiganga coal. *GeoScie. Eng.*, (3), 6–11.

Nyakuma, B B. (2015). Physicochemical, thermokinetic and tank classification of Garin Maiganga Coal. *J. Ener. & Environ.*, 1–15. Retrieved from www.uniten.edu.my/jee

Nyakuma, Bemgba B., Jauro, A., Akinyemi, S. A., Faizal, H. M., Nasirudeen, M. B., Fuad, M. A. H. M., and Oladokun, O. (2021). Physicochemical, mineralogy, and thermo-kinetic characterisation of newly discovered Nigerian coals under pyrolysis and combustion conditions. *Internat. J. Coal Scie. And Technol.*, 1–20. https://doi.org/10.1007/s40789-020-00386-1

Nyakuma, Bemgba Bevan. (2012). Oxidative thermal analysis of Nigerian coals. *J. Ener. & Environ.*, 2–5.

Odeh, A. O. (2015). Qualitative and quantitative ATR-FTIR analysis and its application to coal char of different ranks. *J. Fuel Chem. And Technol.*, *43*(2), 129–137. https://doi.org/10.1016/s1872-5813(15)30001-3

Olujobi, O. J., Ufua, D. E., Olokundun, M., and Olujobi, O. M. (2021). Conversion of organic wastes to electricity in Nigeria: legal perspective on the challenges and prospects. *Inter. J. Environ. Scie. And Technol.*, 1–12. https://doi.org/10.1007/s13762-020-03059-3

Rasheed, M. A., Rao, P. L. S., Boruah, A., Hasan, S. Z., Patel, A., Velani, V., and Patel, K. (2015). Geochemical characterization of coals using proximate and ultimate analysis of Tadkeshwar coals, Gujarat. *Geosciences*, *4*, 113–119. https://doi.org/10.5923/j.geo.20150504.01

Ryemshak, Solomon A, and Jauro, A. (2013). Proximate analysis, rheological properties and technological applications of some Nigerian coals. *Inter. J. Ind. Chem.*, *4*(7), 1–7.

Ryemshak, Solomon Akila, Jauro, A., Putshaka, J. D., and Sori, R. M. (2016). Ultimate Analysis of some Nigerian coal: Ranking and Suitable Application. *Inter. J. Eng. And Appl. Scie. (IJEAS)*, *3*(10), 31–35.

Saikia, B. K., Boruah, R. K., and Gogoi, P. K. (2007). XRD and FTIR investigations of sub-bituminous Assam coals. *Bul. Mat. Scie.*, *30*(4), 421–426.

Sonibare, O. O., Haeger, T., and Foley, S. F. (2010). Structural characterization of Nigerian coals by X-ray diffraction, Raman and FTIR spectroscopy. *Energy*, *35*(12), 5347–5353. https://doi.org/10.1016/j.energy.2010.07.025

Wang, F., Yao, Y., Wen, Z., Sun, Q., and Yuan, X. (2020). Effect of water occurrences on methane adsorption capacity of coal: A comparison between bituminous coal and anthracite coal. *Fuel*, *266*, 1–12. https://doi.org/10.1016/j.fuel.2020.117102

OPTIMAL ECONOMIC DISPATCH IN MICRO-GRIDS USING FIREFLY ALGORITHM

Gwaivangmin, B.I., Bakare, G.A., Haruna, Y.S and Amoo A.L

Electrical and Electronics Engineering Department
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University Bauchi
Correspondence: bgwaivangmin@gmail.com

ABSTRACT

Globally the power sector is faced with critical challenge of increased power demand as a result of exponential growth of world population; thus, the need to search for alternative energy sources is paramount. Despite the continuing rapid growth in renewable energy sources, a variety of different technologies and fuels including hybridized energy systems are likely to be required. This study presents economic dispatch of committed Photovoltaic (PV), Micro-Pumped Hydro Energy Storage (MPHES) and Diesel Generator (DG) to minimize the total operating cost in the electricity supply of the University of Jos subject to optimal constraints using Firefly Algorithm (FFA). It is expected that the operational cost of power supply for the institution would be minimized.

Keywords: Committed, Economic Dispatch, Firefly Algorithm, Hybridised, Optimal, Renewable

1. INTRODUCTION

With the prevailing global economic challenges, the Engineer is faced with the challenge of ensuring that the cost of production is at its minimum, and this can be achieved by minimizing operating cost, or the production cost (raw materials or input cost). To achieve the task of minimizing production cost via power supply operation Economic load dispatch (ELD) which is the process in which power supply systems are coordinated such that the lowest operating cost generators are used for more hours while the highest operating cost generators are used for less hours.

According to Saxena (2014) Economic load dispatch problem is actually a constrained problem and engineers have come up with several principles and methods towards solving these problems. ELD has become a significant function in operation and control of power system.

Economic load dispatch problems can be solved using several deterministic optimization approaches including linear programming, gradient method, lamda iteration method, non-linear programming etc. unfortunately these methods require lots of efforts in terms of computation. As a result of the complexities of computing using deterministic methods, artificial intelligence methods have been developed to find optimal solutions among which are; evolutionary programming, artificial bee colony, particle swarm optimization, genetic algorithm, bacterial

foraging and sometimes hybrid method like Bio-inspired meta-heuristic algorithm etc.
For this work firefly algorithm (FFA) which is also an artificial intelligence method is used.

2. LITERATURE REVIEW

2.1 Hybrid systems

Hybrid systems, as the name implies, combine two or more modes of electricity generation together, usually using renewable technologies such as solar photovoltaic (PV), wind turbines and pumped storage hydropower e.t.c. Hybrid systems provide a high level of energy security through the mix of generation options, and often will incorporate a storage system (battery, fuel cell) or small fossil fueled generator to ensure maximum supply reliability and security.

Udayakanthi (2015), in his study gave an insight into the energy situation and renewable energy potential of Sri Lanka. It was identified that Sri Lanka has economically feasible power generation potential of wind and solar energy. Southern part of southern coastal belt and western coastal belt are very suitable for utility scale wind and solar power generation. Using HOMER simulation software a grid tied wind-solar hybrid power generation system was modeled for a selected location in the Kirinda area of Sri Lanka, located on the southern coastal belt near Hambantota. Through the simulation process, installation of 8 numbers of 850kW wind turbines and 1MW solar PV array was identified as economically most feasible design to supply average 3MW load connected to grid where payback period of the design is 3.4 years.

Ceran *et al.* (2016) worked on an the supply and economical analysis of a hybrid power generation system (HPGS) which utilizes photovoltaic modules, wind turbines, fuel cells and an electrolyzer with hydrogen tank working as the energy storage. It was discovered that the cost of energy generated from the configurations was more economical with the Photovoltaic Modules. The price can be very beneficial and suitable for long-term investments particularly with partial governmental support.

Mehang et al. (2016) performed a study on the potential of renewable energy to improve the electricity supply duration in the Ngadu Ngala sub-district, Sumba Island, Indonesia to prolong the supply duration from 6 hours to 24 hours daily. They used three alternatives of system configuration; no supply shortage was found based on the simulation performed by HOMER software. According to the analyses, the hybrid diesel generator-PV system would likely be the most suitable for the observed area considering technical as well as economic point of view, for the long run. The analyses result also revealed the comparative benefits of hybrid diesel generator-PV system over the existing system in terms of the cost of energy and the penetration rate. The use of a hybrid system that would use the diesel generator as a back-up may give a better cost per kWh considering the increasing cost of diesel.

Yang *et al.*(2016)proposed a wind-solar-gas complementary energy power generation system based on micro-turbine hybrid, and calculated the performance parameters of wind power, photovoltaic power and gas turbine power generation according to the corresponding affecting parameters, the results showed that: The established complementary energy power generation system achieved the purpose of power complementary of regional electricity net; the capacity factors of wind power, photovoltaic and gas turbine power generation were approximately equal to 1, and provided a theoretical basis for technical analysis and economic analysis to realize regional power grid.

Chadel *et al.* (2017) undertook a study on a method to determine the size and optimization of a photovoltaic – wind hybrid system for medium power. They presented a comparative study of two sizing methods of hybrid PV/wind power systems, in order to choose the method which has the best reliability with an optimal cost to avoid under sizing or over sizing of the system. The results showed that the use of a wind system as a back-up system with a photovoltaic system increased the cost of the hybrid system for the site of Tlemcen and there was a favorable economic trend for the photovoltaic system to use on wind energy, because solar energy dominates wind energy to the site of Tlemcen. Using wind as a back is not a good choice since weather conditions could affect both solar and wind in certain time resulting into poor power supply.

Jiang *et al.* (2018) undertook a study on sensitivity analysis and Bayesian prediction (SABP) method for the optimized design of hybrid photo-voltaic wind energy system. They used the actual data to analyze and compare the main, optimized and desired scenarios of hybrid energy systems (HES) designs. The results showed that optimized design can minimize the cost of the energy generated while reliably matching local electricity demand. The sensitivity analysis and Bayesian prediction system helped to eliminate the dependence on traditional energy resources, reduced transition costs by purchasing electricity and decreased the high cost of energy of the city. The work did not consider a back up for the hybrid system which is essential for stable power supply.

Opara *et al.* (2018), evaluated various micro-grid models which included solar PV, micro hydro turbine, wind turbine, diesel generator, battery and converter models to ascertain the most suitable model for the Federal University of Technology Owerri Campus environment, it was discovered that the most feasible option for providing power to the student's hostel was the micro hydro power plant from Otamiri. It showed that it was both economically and technically viable and

being a clean source of electrical power and would pose no environmental challenge and will equally save cost of diesel being used to back-up power to utility supply. The micro hydro power may not meet up with the power demand during dry season, an addition of PV or wind may help provide a stable power throughout the year.

Ceran *et al.* (2019) presented an analysis of unit cost of electricity generation in hybrid power generation system (HPGS). The analyzed hybrid system consisted of wind power, photovoltaic panels and energy storage electrolyzer – fuel cell. The analysis was carried out for the six variants. Variant I – the source of electricity in the hybrid system is wind, variants II, III, IV, V – electricity is generated by wind turbines and solar panels, variant VI – the source of electricity in the hybrid system is only photovoltaic installation. For all the cases, the price of one kilowatt-hour in a hybrid system is almost two and a half times higher than the average energy price currently borne by municipal recipients. The currently analyzed hybrid system can only be used in situations where costs do not play a role, i.e., military applications or pilot installations for research purposes. The work cannot be used for the generality of the consumers of electricity. The addition of a pumped storage hydropower system may give a better result and reduce cost per kWh.

Nengroo *et al.* (2019) proposed an optimized strategy for a hybrid photovoltaic (PV) and battery storage system (BSS) connected to a low-voltage grid. In the study, a cost function was formulated to minimize the net cost of electricity purchased from the grid. The charging and discharging of the battery were operated optimally to minimize the defined cost function. Half-hourly electricity consumer load data and solar irradiance data collected from the United Kingdom (UK) for a whole year were utilized in the proposed methodology. Five cases were discussed for a comparative cost analysis of the electricity imported and exported. The proposed scheme provided a techno-economic analysis of the combination of a BSS with a low-voltage grid, benefitting from the feed-in tariff (FIT) scheme. The electricity cost could be reduced if an addition renewable energy system is integrated to the network.

2.2 Economic load dispatch (ELD)

The main aim of the power utilities is to provide electrical energy to the consumers with an assurance of minimum cost of generation. Hence in order to achieve economic operation of system, total demand must be appropriately shared among all the generators. Economic load dispatch is one of the major and challenging issues in power system. It is mainly an optimization problem with a goal of obtaining generation with a minimum cost along with the satisfaction of the constraints.

According to Panigrahi *et al*. (2015) the new meta-heuristic and swarm-based firefly algorithm was a very effective and powerful technique and was used for the optimization of the cost of economic load dispatch problem. It is a simple method and is easy to implement. In their work, they demonstrated and tested the algorithm to optimize the problem of minimization of cost function. Firefly algorithm proved itself to be efficient in cost minimization of thermal generators and thus a strong tool for economic load dispatch.

Attai (2015) investigated a PSO based economic load dispatch on two sample networks (a 6-bus IEEE test system and 31-bus Nigerian grid system).The results showed that PSO can minimize total production cost and also compute transmission losses. The penetration of renewable posed a major challenge to power utility's planning and operations as a result of their intermittence and uncertainty nature. Therefore, further ELD research should emphasize on larger networks with renewable penetration in power systems.

Farsadi *et al*. (2015) solved the economic dispatch problem in a distribution network between the grid, diesel electric generators, and wind turbines. The scenario tree method to solve the economic dispatch problem was used. Their power probabilities were calculated by using their cost functions. Powers injected by diesel generators and wind turbines reduced the power request of the grid and the cost of electricity consumption. In addition, wind turbines and diesel electric generators were placed near the consumers, which resulted into reduced line losses. Modeling and simulation of diesel electric generators and wind turbines in the 33 ADN distribution network and a local distribution network was performed. The Weibull probability distribution function was used to determine the wind speed of wind turbines.

Ma *et al* (2015) proposed a dynamic economic dispatch and control method to minimize the overall generating cost for a stand-alone microgrid in DongAo Island, which was integrated with wind turbine generator, solar PV, diesel generator, battery storage, the seawater desalination system and the conventional loads. A new dispatching strategy was presented based on the ranking of component generation costs and two different control modes, in which diesel generator and battery storage acted alternately as the master power source to follow system power fluctuation. The optimal models and GA-based optimization process were given to minimize the overall system generating cost subject to the corresponding constraints and the proposed dispatch strategy. The effectiveness of the proposed method was verified in the stand-alone microgrid in DongAo Island, and the results provided a feasible theoretical and technical basis for optimal energy management and operation control of stand-alone microgrid.

Obaro *et al*. (2018) used two energy dispatch strategies which included mixed integer nonlinear programming (MINLP) and the proposed combined dispatch strategy was considered in the optimization of hybrid power system to minimize daily operating cost of decentralized hybrid power system (DHPS). The Minimum operation efficiency of DG was proposed using Quasi-Newton method in order to optimize operational and maintenance costs. The excessive DGs on/off control which characterized previous works were normalized. The results obtained showed that the DHPS can significantly minimize daily fuel consumption cost as well as improve supply reliability when compared to DG-single system using both strategies. The result further showed that both the combined dispatch strategy and the MINLP optimization techniques brought about a significant daily operation cost reductions as well as reduce DG's operation duration compared to the single DG system. The efficacy of the combined dispatch strategy further demonstrated that an improvement of approximately 15.1% and 37.14% savings in daily operational cost was achieved using the dynamic household and community daily load demands respectively over the MINLP optimization technique. It was recommended that the system's life cycle cost be analyzed to determine the overall power system cost. In the studies, the dispatch techniques presented immensely benefited system engineers in the integration of DHPS, as a solution to reduce over-dependence on the conventional power system, minimize operation cost and improve supply reliability.

Ivanova and Pasechnikov (2019) carried out a study on construction of a solar-diesel power plant to the consumers of the village of Nerkha in the Nizhneudinsk Area of the Irkutsk Region. The schedules of the calculated power generation by the photovoltaic modules on the basis of the data of the local meteorological station were compared with the actual consumption schedule. The actual data of power generation by the diesel power plant and photovoltaic modules for five months of operation were presented. The calculated and actual indices were compared. The comparative analysis of the calculated data from the study and the actual data on solar-diesel power plant operation in the village of Nerkha of the Nizhneudinsk Area revealed the comparability of indices.

According to the data of the study, the photovoltaic modules were planned to generate 65.7 thousand kWh of power for the period from December through April, in practice their generation was estimated at 45.13 thousand kWh. The economic effect for 5 months amounted to 4,045,032 Naira owing to the substitution of 14.2 tons of diesel fuel.

Sarker *et al*. (2019) demonstrated a novel stochastic optimization approach named gravitational search algorithm (GSA) to solve the convex and non-convex economic load dispatch (ELD) problems that was with and without valve point loading effects and transmission loss. GSA optimization technique was applied to solve ELD problems for test systems having 3, 5 and 6-units. The obtained results of the proposed GSA method was compared and found better result in comparison with conventional optimization technique as well as recently published papers. This comparison results revealed the effectiveness, robustness, high quality solution, feasibility, stable convergence characteristics and good computation efficiency of the proposed GSA technique.

Vallem and Kumar (2020) Integration of renewable energy sources provide energy security, substantial cost savings, and reduction in greenhouse gas emissions, enabling nation to meet emission targets. Microgrid energy management (MGEM) is a challenging task for microgrid operator (MGO) for optimal energy utilization with penetration of renewable energy sources, energy storage devices, and demand response. In their work, optimal energy dispatch strategy was established for grid-connected and stand-alone microgrids integrated with photovoltaic, wind turbine, fuel cell, microturbine, diesel generator, and battery storage system. Techno-economic benefits were demonstrated for the hybrid power system considering uncertainty of load and generation. So far, MGEM problem had been addressed with the aim of minimizing operating cost only. However, the issues of power losses and emission-related objectives needed to be addressed for effective MGEM. In the work, MGEM was formulated as mixed-integer linear programming, and a new multi-objective solution was proposed for MGEM. Demand response was also included in the optimization problem to demonstrate its impact on optimal energy dispatch and techno-commercial benefits. Simulation results were obtained for the optimal capacity of each component, charging/discharging scheduling, state of charge, power import from main grid, net present cost, cost of energy, initial cost, operational cost, fuel cost, and cost of emissions taking care of seasonal load variation throughout the year. Simulation results obtained with the proposed method had been compared with various evolutionary algorithms to verify its effectiveness.

3. OBJECTIVE

The main objective of this work is providing a stable uninterrupted power supply to the 11 kV dedicated feeder of the University of Jos. This requires that the economic operation of the system and the total demand on the feeder must be shared among the units to ensure no excess power is realised. Renewable energy sources have been included to share load with the diesel generating units and the public power supply to reduce load from the two sources. The major constrain is electricity production cost minimisation.

For this work the supply architecture as shown in Figure 1, it is made up of the Solar PV, Micro-pumped hydro energy storage, diesel generators and supply from the distribution company grid.

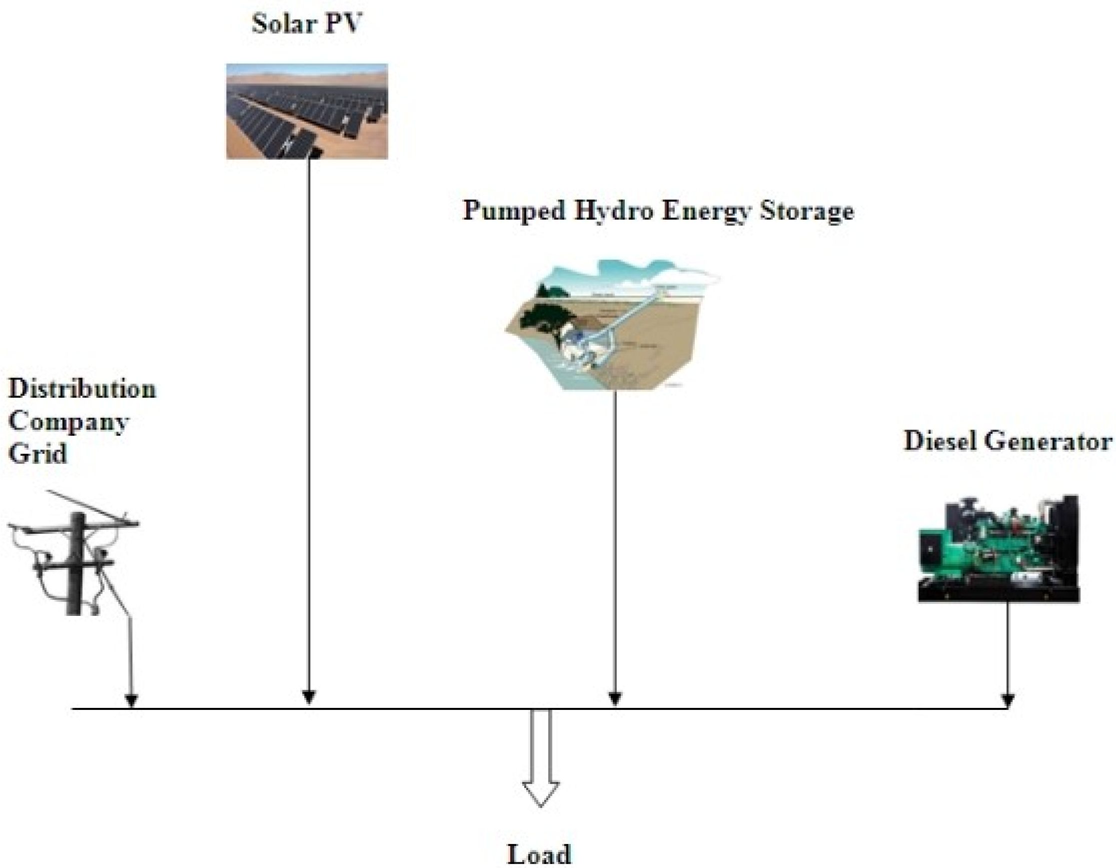


Figure.1. Hybrid Energy System

4. Economic Load Dispatch

The economic load dispatch problem is an important aspect in deciding the allocation of the generation of the generating units. In this work we assume that micro-pumped hydro energy storage system and the Solar PV are near the centre so neglecting the transmission losses by the power generated from the renewable sources and the diesel generation sources are also considered to have no transmission losses. The cost function includes the operating cost of the diesel generating units, micro-pumped hydro energy storage system and PV plants and penalty cost due to imbalance between the actual and the scheduled power outputs of the micro-pumped hydro energy storage power and the PV plants. The weighted cost method is considered in the formulation.

The objective function of the ELD problem with the renewable sources can be described as;

$$\text{Minimise } F_t = \sum_{i=1}^{N} OC\left(P_{gi}\right) + \sum_{j=1}^{M} OC\left(P_{PHj}\right) +$$

Subject to

$$P_D + P_L - \sum_{i=1}^{N} P_{gi} - \sum_{j=1}^{M} P_{PHj} - \sum_{k=1}^{S} P_{PVK} = 0$$

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \quad (3)$$

$$0 \leq P_{PHj} \leq P_{PHrj}^{max}$$

(4)

$$0 \leq P_{PVK} \leq P_{PVrk}^{max} \quad (5)$$

The first term of equation (1) is the operating cost of the diesel generating units $OC(P_{gi})$, second term is the operating cost of the micro-pumped hydro storage system $OC(P_{PHj})$, and the last term is the operating cost of the PV system $OC(P_{PVK})$. Also P_{gi}^{min} and P_{gi}^{max} are the minimum and maximum limits of the i^{th} diesel generating units, P_{Hj} and P_{PHrj} are the scheduled and rated power generation of the j^{th} micro-pumped storage, similarly P_{PVK} and P_{PVrk} are the scheduled rated power generation of the k^{th} solar system.

5. CONCEPT OF FIREFLY OPTIMIZATION

According to Balachennaiah *et al.* (2015) Fireflies use flash signals to attract other fireflies for potential mates. Based on this behavior a meta-heuristic algorithm was developed. All the fireflies are considered

unisexual and their attraction is directly proportional to the intensity of their flash. Therefore if a firefly particle had the choice of moving towards either of two fireflies, it will be more attracted towards the firefly with higher brightness and moves in that direction. If there are no fireflies nearby, the firefly will move in a random direction. The brightness of flash is associated with the fitness function.

The firefly algorithm has three particular idealized rules which are based on some of the major flashing characteristics of real fireflies. These are the following:

(i) All fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.

(ii) The degree of attractiveness of a firefly is proportional to its brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not a brighter or more attractive firefly than a particular one, it will then move randomly.

(iii) The brightness or light intensity of a firefly is determined by the value of the objective function of a given problem. For maximization problems, the light intensity is

(iv)

(v) proportional to the value of the objective function.

Attractiveness:

In the firefly algorithm, the form of attractiveness function of a firefly is the following monotonically decreasing function:

$\beta(r) = (\beta_o^* \exp(-\gamma r^m)$),with m≥1, (6)

Where, r is the distance between any two fireflies, β_0 is the initial attractiveness at r =0, and γ is an absorption coefficient which controls the decrease of the light intensity.

Distance:

The distance between any two fireflies i and j, at positions xi and xj, respectively, can be defined as a Cartesian or Euclidean distance as follows:

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2}$$

Where $x_{i,k}$ is the kth component of the spatial coordinate x_i of the ith firefly and d is the number of dimensions we have, for d = 2, we have

$$r_{ij} = j\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

(8)

However, the calculation of distance r can also be defined using other distance metrics, based on the nature of the problem, such as Manhattan distance or Mahalanobis distance.

Movement:

The movement of a firefly i which is attracted (i.e., brighter) firefly is given by the following equation:

$x_i = x_i + \beta_o * exp(-\gamma r_{ij}^2) * (x_j - x_i) + a * (\text{rand} - \frac{1}{2})$, (9)

Where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones.

4.1 Table 1. Parameters of Firefly Algorithm

Parameter	***Notation in Algorithm***
Brightness	Objective function

Beta (β)	Attractiveness parameter
Alpha (α)	Randomisation parameter
Gamma (γ)	Absorption coefficient
Number of generations	Iterations
Number of fireflies	Population
Dimension	Problem dimension
R	Radius, time interval etc. (depends on application

In firefly algorithm, parameter alpha (α) controls exploration and parameter gamma (γ) controls exploitation. These parameters describe the variation of the attractiveness and its value is responsible for the speed of firefly algorithm convergence.(Panigrahi and Mishra,2015)

The coefficient α is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0, 1]. As we will see in this implementation of the algorithm, we will use β_o= 1.0, α = [0, 1] and the attractiveness or absorption coefficient γ =1.0, which guarantees a quick convergence of the algorithm to the optimal solution.

The different steps involved in the FA are as follows:

Step 1: Initialization of the FA.

(i) The dimension of the problem.

(ii) The number of fireflies.

iii) The maximum number of iterations.

(iv) The values of α, β, γ and δ are chosen.

(v) Iteration counter i =0.

Step 2: Increment the iteration counter i =i+1.

Step 3: Calculate the fitness of the fireflies in every iteration by using the fitness function and associate the light intensity of each firefly to the same.

Step 4: Sort the fireflies based on their light intensities and find the best firefly in each iteration.

Step 5: Vary the light intensity perception of all other fireflies based on the distance between them.

Step 6: Move the fireflies based on attraction which depends on their light intensities and also the control parameters.

Step 7: If the stopping criteria are not reached go back to step 2 else go to step 8.

Step 8: Display the results with the firefly particle of highest light intensity.

6. RESULTS AND DISCUSSION

For this work the following Firefly parameters were used

Table. 2 Firefly numeric parameters

Maximum Number of Iterations	Maxit = 1000
Number of Fireflies (Swarm Size)	npop =25
Light Absorption Coefficient	γ = 1
Attraction Coefficient Base Value	β =2
Mutation Coefficient	α = 0.2
Mutation Coefficient Damping Ratio	α damp = 0.98
Uniform Mutation Range	Δ = 0.05
m	2

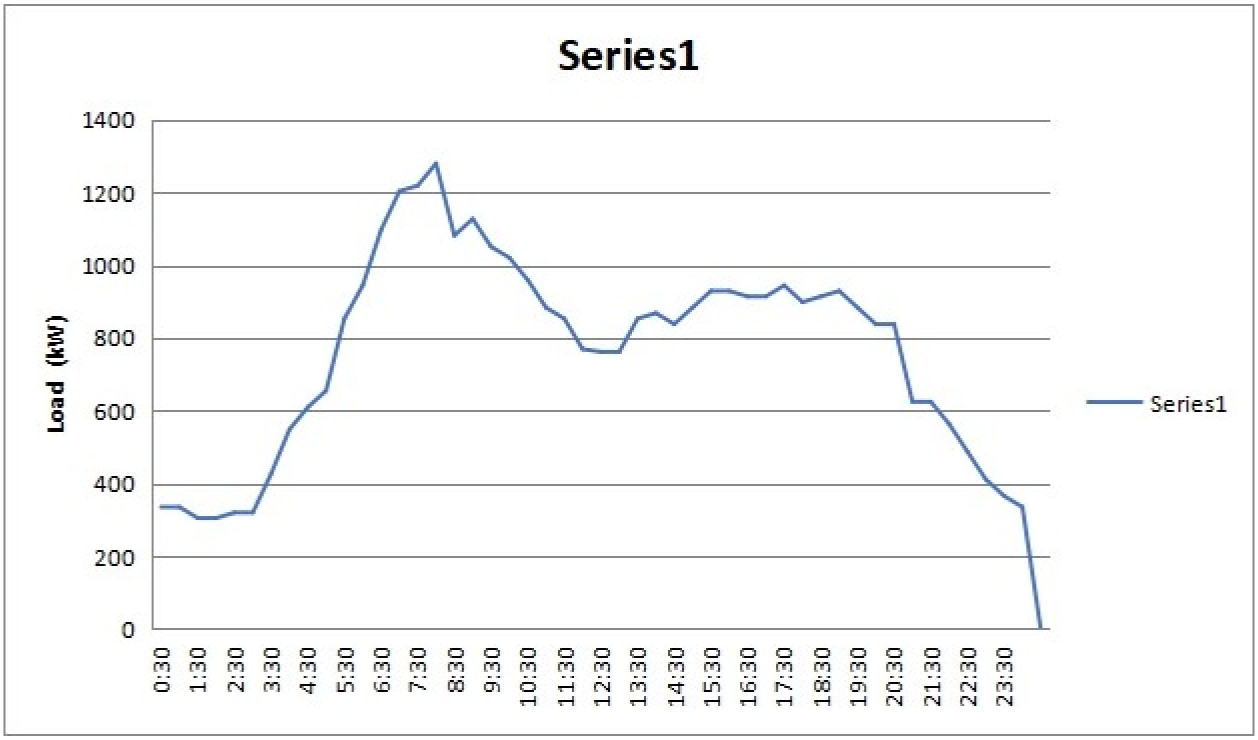
We shall be discussing problems based on six cases with and without the inclusion of renewable sources of power in consideration. Our discussion would be based on cost per kWh.

Table 3. Load Forecast for the next 24 Hours

Time (Hours)	Load (kW)
0:30	335.33
1:00	335.33
1:30	304.84

2:00	304.84
2:30	320.01
3:00	320.01
3:30	426.78
4:00	548.71
4:30	609.68
5:00	655.41
5:30	853.55
6:00	945.01
6:30	1,097.43
7:00	1,204.12
7:30	1,219.36
8:00	1,280.33
8:30	1,082.19
9:00	1,127.92
9:30	1,051.70
10:00	1,021.22
10:30	960.25
11:00	884.04
11:30	853.56
12:00	769.82
12:30	762.10
13:00	762.10
13:30	853.56
14:00	868.80
14:30	838.31
15:00	884.04
15:30	929.77

16:00	929.77
16:30	914.52
17:00	914.52
17:30	945.01
18:00	899.28
18:30	914.52
19:00	929.77
19:30	884.04
20:00	838.31
20:30	838.31
21:00	624.92
21:30	624.92
22:00	563.96
22:30	487.75
23:00	411.54
23:30	365.81
24:00	335.33



(Hours)

Figure 2. Forecast load demand for the 24 Hours of the 11kV dedicated feeder

Table 4. Micro-Grid Components Data – Turn on and Off Status

Time (Hours)	PHES KW	G1 KW	G2 KW	G3 KW	PV KW	Grid KW
00:30	0	0	0	0	0	335.33
01:00	0	0	0	0	0	335.33
01:30	0	0	0	0	0	304.84
02:00	0	0	0	0	0	304.84
02:30	0	0	0	0	0	320.01
03:00	0	160.005	160.005	0	0	0
03:30	0	213.39	213.39	0	0	0
04:00	0	0	274.355	274.355	0	0
04:30	0	0	304.84	304.84	0	0

05:00	0	0	327.705	327.705	0	0
05:30	0	284.517	284.517	284.517	0	0
06:00	0	0	0	0	945.01	0
06:30	0	0	0	0	1,097.43	0
07:00	0	0	0	0	1,204.12	0
07:30	0	0	0	0	1,219.36	0
08:00	0	0	0	0	1,280.33	0
08:30	0	0	0	0	1,082.19	0
09:00	0	0	0	0	1,127.92	0
09:30	0	0	0	0	1,051.70	0
10:00	0	0	0	0	1,021.22	0
10:30	0	0	0	0	960.25	0
11:00	0	0	0	0	884.04	0
11:30	0	0	0	0	853.56	0
12:00	0	0	0	0	769.82	0
12:30	0	0	0	0	762.10	0
13:00	0	0	0	0	762.10	0
13:30	0	0	0	0	853.56	0
14:00	0	0	0	0	868.80	0
14:30	0	0	0	0	838.31	0
15:00	0	0	0	0	884.04	0
15:30	0	0	0	0	929.77	0
16:00	0	0	0	0	929.77	0
16:30	0	0	0	0	914.52	0
17:00	0	0	0	0	914.52	0
17:30	0	0	0	0	945.01	0
18:00	0	0	0	0	899.28	0
18:30	914.52	0	0	0	0	0

19:00	884.04	0	0	0	0	0
19:30	838.31	0	0	0	0	0
20:00	838.31	0	0	0	0	0
20:30	624.92	0	0	0	0	0
21:00	624.92	0	0	0	0	0
21:30	624.92	0	0	0	0	0
22:00	563.96	0	0	0	0	0
22:30	487.75	0	0	0	0	0
23:00	411.54	0	0	0	0	0
23:30	0	0	0	0	0	365.81
24:00	0	0	0	0	0	335.33

Table5: Truth Table of the Micro-Grid

Time (Hours)	PHES KW	G1 KW	G2 KW	G3 KW	Pv KW	Grid KW
00:30	0	0	0	0	0	1
01:00	0	0	0	0	0	1
01:30	0	0	0	0	0	1
02:00	0	0	0	0	0	1
02:30	0	0	0	0	0	1
03:00	0	1	1	0	0	0
03:30	0	1	1	0	0	0
04:00	0	0	1	1	0	0
04:30	0	0	1	1	0	0
05:00	0	0	1	1	0	0
05:30	0	1	1	1	0	0
06:00	0	0	0	0	1	0

06:30	0	0	0	0	1	0
07:00	0	0	0	0	1	0
07:30	0	0	0	0	1	0
08:00	0	0	0	0	1	0
08:30	0	0	0	0	1	0
09:00	0	0	0	0	1	0
09:30	0	0	0	0	1	0
10:00	0	0	0	0	1	0
10:30	0	0	0	0	1	0
11:00	0	0	0	0	1	0
11:30	0	0	0	0	1	0
12:00	0	0	0	0	1	0
12:30	0	0	0	0	1	0
13:00	0	0	0	0	1	0
13:30	0	0	0	0	1	0
14:00	0	0	0	0	1	0
14:30	0	0	0	0	1	0
15:00	0	0	0	0	1	0
15:30	0	0	0	0	1	0
16:00	0	0	0	0	1	0
16:30	0	0	0	0	1	0
17:00	0	0	0	0	1	0
17:30	0	0	0	0	1	0
18:00	0	0	0	0	1	0
18:30	1	0	0	0	0	0
19:00	1	0	0	0	0	0
19:30	1	0	0	0	0	0

20:00	1	0	0	0	0	0
20:30	1	0	0	0	0	0
21:00	1	0	0	0	0	0
21:30	1	0	0	0	0	0
22:00	1	0	0	0	0	0
22:30	1	0	0	0	0	0
23:00	1	0	0	0	0	0
23:30	0	0	0	0	0	1
24:00	0	0	0	0	0	1

Table 6. Micro-Grid Components Specifications

SPECIFICATIONS	PHES KW	G1 KW	G2 KW	G2 KW	PV KW
RATED POWER	1000	300	300	300	1500
COST ($/KW)	0.05	69.2	69.2	69.2	0.06
MAX (KW)	930	855	855	855	1280
MIN (KW)	0	0	0	0	0

Table.7 Classical Economic Load Dispatch Results

SPECIFICATIONS	**PHES** **KW**	**G1** **KW**	**G2** **KW**	**G2** **KW**	**PV** **KW**
RATED POWER	1000	300	300	300	1500
COST ($/KW)	0.05	69.2	69.2	69.2	0.06
MAX (KW)	930	855	855	855	1280
AV.Total Load(kW)	681.319	**219.304**	**260.802**	**297.854**	**41,724.049**
Electricity Cost ($/H)	**7.57**	**6,070**	**7,219**	**13,741**	**208**

Firefly Implementation

Using MATLAB R2015a, the FFA economic load dispatch was implemented using the parameters in Table 2. Using the codes developed by Yapiz et al.(2015). The results are as shown in Table.8.

Firefly Algorithm (FA) in MATLAB for Economic load dispatch

```
clc;
clear;
close all;
%% Problem Definition
CostFunction = @(x) Rosenbrock(x);        %
Cost Function
nVar = 5;               % Number of Decision
Variables
VarSize = [1 nVar];      % Decision Variables
Matrix Size
VarMin = -10;           % Decision Variables
Lower Bound
VarMax = 10;            % Decision Variables
Upper Bound
%% Firefly Algorithm Parameters
MaxIt = 1000;        % Maximum Number of
Iterations
nPop = 25;           % Number of Fireflies
(Swarm Size)
gamma = 1;           % Light Absorption
Coefficient
beta0 = 2;           % Attraction Coefficient Base
Value
alpha = 0.2;         % Mutation Coefficient
alpha_damp = 0.98;    % Mutation Coefficient
Damping Ratio
delta = 0.05*(VarMax-VarMin);     % Uniform
Mutation Range
m = 2;
if isscalar(VarMin) && isscalar(VarMax)
   dmax = (VarMax-VarMin)*sqrt(nVar);
else
   dmax = norm(VarMax-VarMin)
```

Table 8 Economic Load Dispatch using FFA

SPECIFICATIONS	PHES KW	G1 KW	G2 KW	G2 KW	PV KW
RATED POWER	1000	300	300	300	1500
COST ($/KW)	0.05	69.2	69.2	69.2	0.06
MAX (KW)	930	855	855	855	1280
Average Load(kW/H)	681.319	219.304	260.802	297.854	41,724.049
Electricity Cost ($/H)	**7.04**	**5,989**	**6,898.07**	**13,059**	**203.54**

From Tables 7 and 8 it can be seen that the cost of production of kw /h for the three generators, PHES and Solar PV from the Firefly economic dispatch is cheaper than that of the classical economic dispatch. Hence FFA gives optimal values than the classical iteration method. This shows that FFA is more efficient in cost minimization in economic dispatch.

7. CONCLUSION

The economic dispatch of committed Photovoltaic (PV), Micro-Pumped Hydro Energy Storage (MPHES) and Diesel Generator (DG) has minimized the total operating cost in the electricity supply of the University of Jos using Firefly Algorithm (FFA). It is expected that investment into micro-hydro pumped storage system and Solar PV will ensure stable and sustainable power supply in the University.

REFERENCES

Attai.A.U (2015) Power System Economic Load Dispatch Using Particle Swarm Optimization. *International Journal of Advanced Engineering Research and Technology.Vol.3.Issue 6.pp202-205*.

Balachennaiah, P.,Suryakalavathi,M And Nagendra, P (2015) Firefly Algorithm Based Solution to Minimize the Real Power Loss in A Power System.*AIN Shams Engineering Journal. Vol. 9, 89–100*

Ceran, B .,Hassan, Q.,Jaszczur , M and Sroka, K (2016) An Analysis of Hybrid Power Generation Systems for a Residential Load. *Energy and Fuels.pp 1-10.*

Ceran. B and Szczerbowski. R (2019) Energy cost analysis by hybrid power generation system.*2nd International Conference on the Sustainable Energy and Environmental*

Development. 14-17 November, Krakow, Poland.

Chadel. A., Chadel . M.,Aillerie . M and Benyoucef .B (2017)Technical and economic analysis of hybrid solar/wind energy source for the site of Tlemcen-Algeria. International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES17, Beirut Lebanon.

Farsadi.M.,Sadighmanesh.A., Sahir.F.M.,Heris.F.N (2015) Economic Dispatch Problem for Distribution Network including Wind Turbines and Diesel Electric Generators. 9th International Conference on electrical and Electronics Engineering.

Ivanova,I and Pasechnikov,T (2019) Experience of Solar-Diesel Power Plant introduction in the Village of Nerkha of the Irkutsk Region. E3S Web of Conferences 77,04004.

Ma.Y.,Yang.P.,Guo.H and Wang.Y (2015) Dynamic Economic Dispatch and Control of a Stand Alone Microgrid in DongAo Island.Journal of Electrical Engineering Technology.Vol.10. No.4.

Mehang, T.S, Tanoto, Y and Santoso, M (2016) Potential of Small Size Hybrid Diesel-Photovoltaic to Improve Sub-District Supply Duration in East Sumba, Indonesia. *International Journal of Renewable Energy Research. Vol.6, No.3.*

Nengroo, S.H . ,Ali, M.U., Zafar,A., Hussain,S., Murtaza, T., Alvi. M. J, Raghavendra,.K.V.G and Kim, H.J (2019)An Optimized Methodology for A Hybrid Photo-Voltaic and Energy Storage System Connected to a Low-Voltage Grid. *Elecronics.www.mdpi.Com/Journal/Electronics.*

Obaro, A.Z., Munda, J.L., Siti. M.W and Yusuff, A.A (2018) Energy Dispatch of Decentralized Hybrid Power System. International Journal of Renewable Energy Research.Vol.8.No.4. pp1231-1245.

Opara. R.O., Onojo J.O., Ononiwu. G.C., Nosiri.O.C and Ekwueme .E (2018) Feasibility Study and Analysis of a Micro-Grid Scheme for Federal University of Technology, Owerri, Imo State, Nigeria. *International Journal of Advances in Scientific Research and Engineering. Vol 4 (11).*

Panigrahi,P.,Mishra,S and Pani,S.R (2015) Implementation of Firefly Algorithm on Economic Load Dispatch. International Journal of Engineering Research and Technology.Vol.4 Issue04.pp376-380.

Sarker,K., Roy,B., Sarker,J and Santra.D (2019) A solution Procedure to the Economic Load Dispatch Problem through the Gravitational Search Technique. International Journal of Engineering Science and Technology.Vol.11 No.1 pp 10-21.

Saxena,N (2014) Economic load dispatch Using Firefly Algorithm, M.Eng.Thesis, Thapar University Patiala,Punjab,India.

Saxena,N and Ganguli,S (2015) Solar and Wind Power Estimation and Economic Load Dispatch Using Firefly Algorithm.4th International Conference on Eco-friendly Computing and Communication system,ICECCS.pp.688-700.

Servert, J., San Miguel, G And Lopez, D (2011) Hybrid Solar - Biomass Plants For Power Generation; Technical And Economic Assessment

Udayakanthi, M.V.P.G (2015) Design of a Wind-Solar Hybrid Power Generation System in Sri Lanka. Master of Science,Thesis. School of Industrial Engineering and Management Energy Technology, Division o f Heat & Power SE-100 44 Stockholm.

Vallem, V.V.S.N.M and Kumar, A (2020) Optimal Energy Dispatch in Microgrids with Renewable Energy Sources and Demand Response.Electrical energy Systems. Wiley online Library.

Yapiz et al. (2015) Implementation of Firefly Algorithm (FA) in MATLAB. Yarpiz, http: www.yarpiz.com

PROSPECTS AND CHALLENGES OF NIGERIA'S ENERGY RESOURCES: A REVIEW

*[a] Okorafor O.O., [b]Nwaobi A.F., [c]Ugwah V.N.

[a,b,c] Department of Agricultural and Bioresources, Federal University of Technology Owerri,

PMB 1526, Owerri, Imo State.

ABSTRACT:

This study presents a review on the energy status of the nation, Nigeria which is Africa's largest economy with only 60% of its population having access to electricity in 2018, despite the abundance of diverse energy resources in the country. It was observed that the energy demand of the entire nation can be met if only 0.1% of the total solar energy radiant on her land area is harnessed with an efficiency of 1%. Also, Nigeria has over 200.4 trillion cubic feet (Tcf) of proven natural gas reserve and a great prospect for hydropower owing to the availability of abundant water resources. Coal energy resources stand at about 1-2.175 billion tons which if optimally harnessed, could sufficiently supply the remaining megawatts of energy needed in Nigeria. Considering accessibility, even distribution, sustainability, cost-effectiveness, and renewability, the most suitable energy-mix required for optimum performance of the economy would be a blend of solar energy and hydropower alongside the already existing crude/natural gas resources.

Keywords: Hydropower, Solar Energy, Natural Gas, Coal Power, Renewable Energy.

1. INTRODUCTION

Energy and its prerequisites are very important tools for a sustainable economy to impact growth and development at all facets. Every aspect of any existing economy needs and requires energy for it to meet its economic demands and expectations. According to Oyedepo (2012), energy plays the most vital role in the economic growth, progress and development as well as poverty eradication and security of any nation. Also, from Asghar (2008) energy is a key source of economic growth because many production and consumption activities involve energy as basic input. The energy industry is undoubtedly an engine of growth, as its products serve as inputs into nearly all goods and services imaginable (Liko, 2019). The abundance and availability of energy/energy resources create the framework and platform required in determining the strength and viability of any economy for sustainability and balance. Chow et al., (2003) reiterates also that energy is the lifeblood of any technological and economic development; according to Okorafor et al, (2013) the greatest indicator of development and independence in any nation's gross domestic product (GDP) is measured by the quality and quantity of power (energy to do work) it generates to meet the requirements of manufacturing, production, distribution and consumption. Widespread development and elevated progress that leads to poverty eradication, sustainability in the economy, and growth are dependent on the increase and adequate management of energy resources. In the present dispensation, any economy that cannot support the demands of its economy by meeting up to the requirement of the production of goods and services would be one facing challenges of poor energy base and unavailable energy resources. The demand for energy will continue to increase as long as there is an increase in the population of the world. According to a survey from WEC (2013) it is expected that at least 80% of the increase in energy demand is expected to come from the increasing population of developing countries. The main objective of this paper is to present a review of the global, continental, and national energy resources scenario; observing the prospects and challenges of energy resources in Nigeria and proffering some safe solutions to the energy problem of the country.

1.1 Global and Continental Energy Status. With reference to Shell (2017), the total world energy comes from 80% fossil fuels, 10% biofuels, 5% nuclear and 5% renewable (hydro, solar, wind, geothermal) and only 18% of this total energy is in the form of electricity while most of the other 82% are used for heat and transportation. Global energy consumption draws from six (6) primary sources: 44% of petroleum, 26% natural gas, 25% coal, 25% hydroelectric power, 2.4% nuclear power and 0.2% non-hydro renewable energy (Chow et al, 2003). As conservative as these figures may seem, the only factor responsible for increase in the demand of energy still remains an ever-increasing population growth and this is reported by UNDESAPD (2019), that the world's population is expected to grow to around 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100. This projection will also require that energy requirements be made to meet with the teaming population. Furthermore, IEA (2019) has projected that world energy demand is expected to increase by 19%. Presented in Tables 1.0 and 2.0 is an overview of the worlds' total energy reserve and consumption as at 2019 while Figure 1 shows the global energy sources from 1978 to 2018 as detailed by Kober et al., (2020).

Table 1.0: World Total Energy Reserves as at 2019

Continents	Natural Gas (Trillion m^3)	Crude Oil (Thousand Million Barrels)	Coal (Million Tonnes)	Renewable Power (TWH)
Central America	8.0	317.0	13689	184.1
Europe	3.4	157.8	135109	836.6

CIS	64.2	714.9	190655	3.3
Middle East	75.6	1417.4	1203	13.3
Africa	14.9	399.1	14837	45.1
Asia Pacific	17.7	361.8	456813	1146.2
North America	15.0	1116.5	257330	576.9
Total	198.8	41484.5	1069636	2805.5

(Source: British Petroleum, 2020)

Table 2.0 World Energy Consumption as at 2019

Continent	**Natural Gas (Billion m^3)**	**Nuclear (Exajoules)**	**Crude Oil (Exajoules)**	**Coal (10^8 Joules)**	**Renewable Energy (Exajoules)**	**Primary Energy (Exajoules)**
North America	1057.6	8.59	44.78	12.41	6.70	116.58
Central America	165.5	0.22	11.86	1.48	2.73	28.61
Europe	554.1	8.28	30.40	11.35	8.18	83.82
CIS	573.7	1.88	8.37	5.53	0.03	36.68
Middle East	558.4	0.06	17.80	0.40	0.12	38.78
Africa	150.1	0.13	8.28	4.47	0.41	19.87
Asia Pacific	869.9	5.77	71.54	122.22	10.81	257.56
Total	3929.2	24.92	193.03	157.86	28.98	583.90

(Source: British Petroleum, 2020)

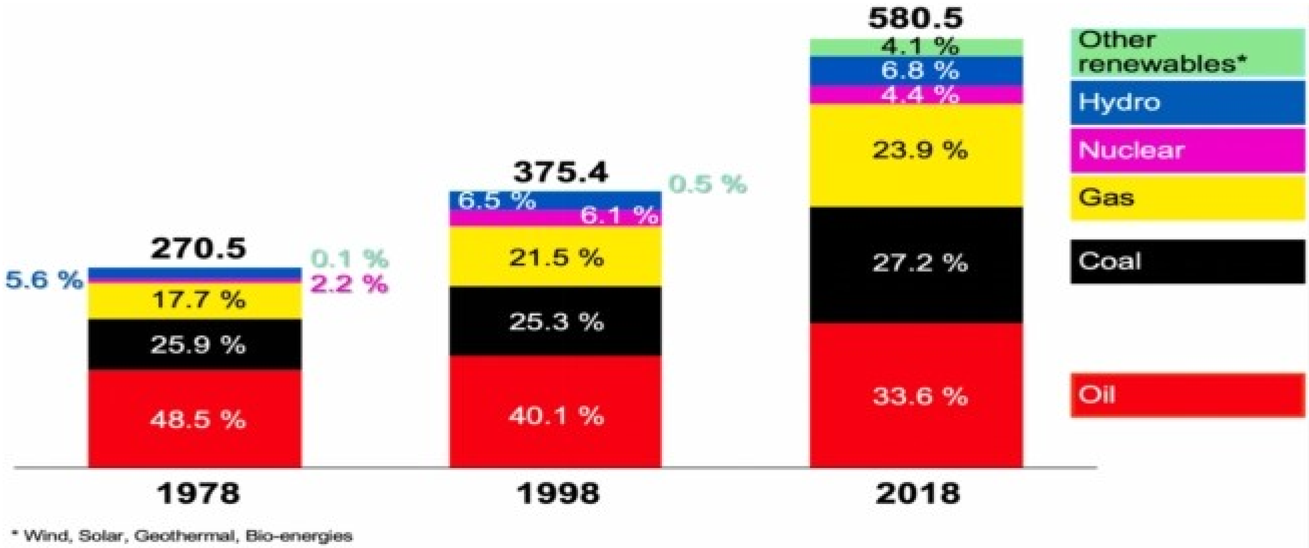


Figure 1: Global Energy Sources from 1978 - 2018. (Source: Kober et. al., 2020)

According to UNEP (2017), the energy resources/reserves and consumption of Africa as a continent is presented as follows;

- Africa has the world's largest per capita energy consumption; with 16% of the world's population (1.18 billion out of 7.35 billion populates), it consumes about 3.3% of global primary energy.
- Of all the energy sources, Africa consumes most (42% of its total energy consumption) followed by gas (28%), Coal (22%), hydro (6%), renewable (1%), and nuclear (1%).
- Africa has 7.5% of the World's proven natural gas reserves, it produces about 6% and consumes 3.19% of global reserves respectively.
- Africa produces 9.1% of total global oil production and accounts for 42% of total global oil consumption.
- South Africa is the world's 7th largest producer and accounts for 94% of Africa's coal production.
- Africa's renewable energy resources are diverse, unevenly distributed and enormous in quantity, almost unlimited solar potential 10(TW), abundant hydro (350 GW), wind (110 GW) and geothermal energy sources (15 GW).
- Energy from biomass accounts for more than 30% of the energy consumed in Africa and more than 80% in many Sub-Saharan African countries.
- Sub-Saharan Africa has undiscovered but technically recoverable energy resources estimated at about 115.34 billion barrels of oil and 21.05 trillion cubic meters of gas.

Africa is indeed blessed and endowed with a lot of energy resources which have been either untapped or unused and this brings to bay that the continent has not actively contributed to the global energy base since most of the production activities are not fully operational due to power outages and unstable power generation. (IEA, 2017).

Table 3.0: Power Consumption per capita in selected African Countries.

Country or Region	Consumption per capita (kWh/capita)
North Africa	1,442
SSA	200
Angola	346
Democratic Republic of Congo	94
Ethiopia	85
Ghana	320
Kenya	168
Mozambique	507
Nigeria	144
Tanzania	98
Zimbabwe	510
South Africa	4,148
World—High income countries	9,086
World—Low- and middle-income countries	1,933

(Source: IEA, World Energy Statistics, 2017).

2. ENERGY RESOURCES AND UTILIZATION IN NIGERIA

Nigeria is a country endowed with both mineral and natural resources which are expected to drive the nation beyond its present economic condition but due to poor handling, mismanagement and improper implementation of finances and policies pertaining to energy resources, the gross domestic product (GDP) and general standard of living of the population are still

within the poverty range of global calculation. In all hemispheres/aspects, Nigeria is indeed endowed with both renewable and non-renewable energy sources and is considered the continent's largest economy while only 60% of the population had access to electricity in 2018 (EIA, 2020). However, despite the potentials of these abundant and diverse energy resources (hydropower capacity of 14,750 MW, 2.0 – 4.0 m/s wind speed, 3.7 – 7.0 kWh/m^2 - day solar radiation, biomass potential of 144 million tonnes/year and 150,000TJ/yr. of wave and tidal energy), the country's economic progress is still hampered by energy crises (Ohimain, 2014).

2.1 Coal

Coal was discovered in Enugu, Nigeria in 1909 and remains the oldest non-renewable source of energy. Coal is a resource primarily used for electric power generation, and currently supplies 41% of global electricity needs. Significant quantities of coal are also employed in metallurgical processes, gasification, cement industries, and as raw materials for activated carbon and many common and industrial chemicals, as well as for heat for the wallboard, aluminum, and cement industries (Shifeng and Robert, 2018). Nigeria has proven coal reserves of 639 billion tonnes consisting approximately of 49% sub bituminous, 39% bituminous and 12% lignite coals (Chukwu et al., 2016). About 95% of Nigerians coal production has been consumed locally usually for transport, industrial heat and cement production (Sambo et. al., 2010).

Coal power contributed 0.04% to Nigerian electricity in 1972, attained its peak of 2.27% in 1973, and thereafter declined to 0% today as is depicted in Figure 2 (IEA, 2020). Coal production was at its peak between 1950 and 1960 in Nigeria (Ohimain, 2014), but was abandoned as other power sources (hydro, thermal, and gas) gained emergence and has proven to be more efficient. The Nigerian Civil War (1967-1970) also negatively impacted coal production as many mines were abandoned during the war (Odesola et al., 2013). Since then, Nigeria's Coal-to-power has failed drastically. However, with some new robust policies enacted to support the coal-to-power project, there were projections that these projects could supply a total of 4,800MW to the national grid and could double Nigeria's electricity generation. It is however saddening that some of these projects never came to be thus stifling the coal power sector of the country. Figure 2 shows the percentage of electricity generation from coal from 1972-2012.

2.2 Natural Gas

Natural gas refers mainly to the natural occurring gaseous mixture of hydrocarbon gasses found underground in reservoirs. Nigeria as a nation is blessed with many of such reservoirs, not only is the quality of the natural gasses found in the many reservoirs rich with no Sulphur content and with high liquid (condensate) content consisting of about 70% to 95% of methane making it one of the world's purest natural gas, it is equally highly sought after.

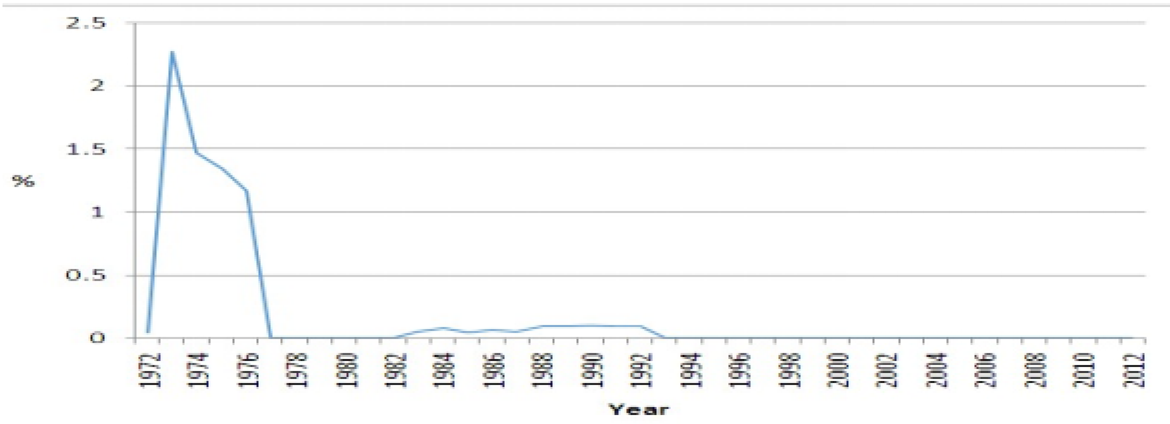


Figure 2: Percentage Electricity Generation from Coal from 1972-2012. *(Source:* Ohimain, 2014)

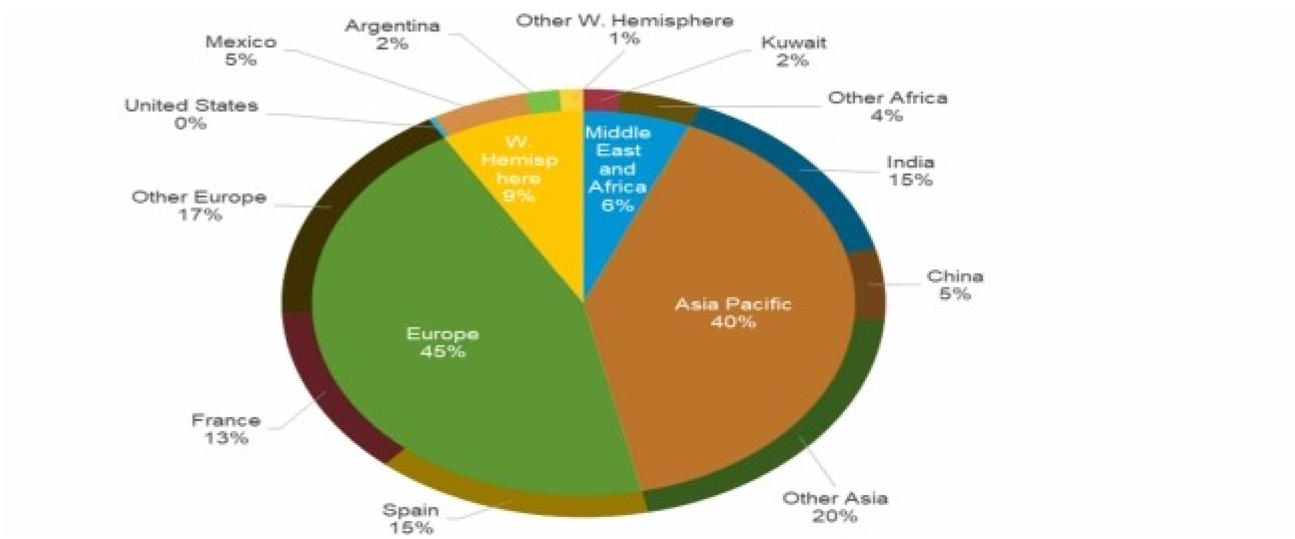


Figure 3: Total liquefied Natural Gas exports in the world from Nigeria (Source: EIA 2020).

The largest natural gas reserve as reported by IEA in 2018 is found in Nigeria. She is reported to be the fifth largest exporter of liquefied natural gas in the world with about 982 BCF LNG exported in 2018 alone. Her economy is centered around natural gas and crude oil. The nation earned about $55billion in 2018 from crude oil and natural gas exports only and this figure is $23 billion dollars over that earned in 2016 (EIA 2020). An estimated 2.0 million b/d of petroleum, and other liquids were produced per day in 2019 and only 1.65 million b/d is crude oil while the remaining is natural gas and other liquids.

The U.S Energy Information Agency (EIA) Report in 2020 stated that as at 2017 the Nigeria had a generating capacity of 12,664 megawatts of which 10,522MW (constituting of 83% of the total generating capacity) was from fossil fuel, 2,110 MW (17%) was from hydroelectricity and 32MW (<1%) was from solar, wind and biomass. It was reported that the net electricity generation was 30.6 billion kilowatt which was far lower than the total capacity to the tune of 28% (EIA 2020).

Furthermore, all three major crude oil refineries in Nigeria with a total distillation capacity of 423,750b/d are presently being rehabilitated and is expected to be completed by 2022 (Robert, 2019), the NNPC has stated in April of 2020 that it will seek private sector company to manage the operations of the newly rehabilitated refineries (Ayodeji, 2020), this will indeed be a step in the right direction and thus brighten the prospect of the industry in Nigeria for Nigerians.

2.3 Hydro-Power Resources

Hydropower remains one of the world's most widely used renewable energy resource, contributing to more than 16% of electricity generation worldwide and about 85% of global renewable electricity and plays an important role in enabling countries and communities around the world meet their power and water needs (Ladokun et al., 2018) as well as fulfilling the sustainable development goals (SDG) of providing affordable and clean energy(Saran & Mitthan, 2020). As at 2017, approximately 1.1 billion of people globally were living without access to energy in its clean, socio-environmentally and directly usable form (Oludamilare et al., 2020). However, in 2018, hydropower has contributed to 4200 TW-hours (TWh) of global electricity generation hereby making it the highest generation contribution by a renewable energy resource (Saran & Mitthan, 2020). Progressively, research reports indicate that the hydropower sector contributed to approximately 15% of global electricity generation in 2019, supplying over 70% of global renewable energy with an annual hydropower production of approximately 4,306 TWh (Paltán et al., 2021). An extensive review by Antwi and Sedegah, (2018) also revealed that Sub-Saharan Africa has a great, less exploited hydropower potential (10%), and climate change will have almost an insignificant (0% change) impact on hydropower generation in the region by 2050.

As at 2011, (Igweonu & Joshua, 2012) revealed that Nigeria generated less than 4000MW of electricity but has the capability of increasing her generation through small hydropower (SHP) considering its unharnessed potentials in the country. This small hydropower had the potential to increase the percentage contribution of hydroelectricity to the total energy mix and to extend electricity to rural and remote areas, considering the economic, social and environmental benefits. Currently, the energy obtained from the three major hydropower stations at Kainji, Jebba, Shiroro and from some smaller schemes presently produces one-fifth of the total energy generated in Nigeria (Ladokun et al., 2018). Saran and Mitthan (2020) reported that sixty-one of global hydropower projects incurred an average of $ 2.5 billion costs and 43 months in time overruns. It is estimated that Nigeria would require about USD 150 billion and USD 600 billion in capital to attain the power density in South Africa and USA respectively (Brimmo et al., 2017).

2.4 Solar Energy

Solar energy refers basically to harnessing the radiant light and heat from the sun via adopting a range of evolving technologies such as Photovoltaic, solar thermal, molten salt, power plants, artificial photosynthesis, and solar heating for meeting man's energy demand. It is an inexhaustible energy resource that offers clean, climate-friendly, and cost-effective energy solutions. Solar energy is indeed an ideal energy source, it is free in nature and limitless (Oghogho et al., 2014). All forms of energy depend largely on solar energy; hydropower with its hydrological cycle manipulated by the intensity of the sun and wind power with air movements dependent on the sun's heating effect (Tyangi et al., 2013). It is, therefore, necessary that these inexhaustible resources be put into adequate and efficient use.

Amongst the many technological trends available, Photovoltaic is notably a remarkable trend, a device developed in 2008 by scientist of the United State' energy department, natural renewable energy laboratory (NERH) capable of converting 40.8% of incident sun rays to electricity (Tyagi, 2013), aside from the fact that it is extremely modular, it is equally easy and fast to install and also accessible to the public. Another notable trend is Solar Thermal Electricity (STE) which allows extension of solar electricity production for long-range hours to Peak or Mid-peak hours via the deployment of thermal storage systems. With the use of fuel-back-up and hybridization with other resources, STE's has become a far cheaper option for including solar energy in the electricity mix.

Solar PV's and STE's notably has the capacity to transform over 1.4 billion lives of people deprived of electricity off-grid in developing countries with Nigeria inclusive. The use of solar cooking and solar water heating can significantly improve the living standards in developing and underdeveloped nations. One of the major advantages of the PV's is the possibility of installing it close to the consumer (e.g., building roofs) while the STE's can serve to complement PV's instead of competing with it, thus solving the problem of storage and transportation of the generated energy.

Table 4 Nigeria Solar Energy Electricity Target Summary

Activity/Item	**Year**		
Activity	**2015**	**2020**	**2030**
Solar PV home systems (SHS)	5	10	15
Solar PV water pumping	50	1000	5000
Solar PV community services	45	500	3000
Solar PV refrigerator	20	500	2000
Solar PV Street and traffic lighting	100	1000	10000
Solar PV large-scale PV plants (1 MW capacity)	80	990	9990
Solar thermal electricity (1 MW capacity)	300	2136	18127

Source: Olusola et al., (2017).

3. PROSPECTS OF NIGERIA ENERGY RESOURCES

Coal power generation could be sufficient to supply at least one-third of the remaining megawatts needed in Nigeria and there are still large deposits of coal in Nigeria which will sustain the high energy demand of the populace(Odesola et al., 2013). With its abundant reserves estimated at about 1-2.175 billion tonnes (Sambo et al., 2010; Ugwoke et al., 2020), Coal power can supply the country's energy demand if the infrastructures are effectively managed. Research reports have also revealed that coal could generate 9.9%, 13.8%, 15.3%, and 15.6% of Nigeria's electricity in 2015, 2020, 2025 and 2030, respectively. This is tantamount to generating 1,200MW, 4,400MW, 15,400MW and 53,900MW of electricity by 2015, 2020, 2025, and 2030, respectively(IEA, 2020). It is also worthy of note that coal power is not subjected to climate changes like biomass or seasonal water level changes like hydropower, neither

can it be easily/illegally bunkered like petroleum. Besides, coal reserves are more evenly spread geographically than petroleum across Nigeria's territory thus is less affected by local, regional, national or global politics (Ohimain, 2014).

If properly exploited, coal production for electricity and coal briquettes for domestic/ industrial heating could bring a number of other benefits including increased and more reliable electricity supply, lower-cost electrical energy, increased employment, expanded industrialization of the economy as well as an increased national income (IEA, 2020).

The main source of energy consumption in Nigeria is derived from natural gas and petroleum and other liquids which constitute about 97%, while traditional biomass and waste (consisting of wood, charcoal, manure and crop residue used do power generation) and other renewable accounts for only 3% (IEA 2020). Following a report from the oil & gas journal (2019), Nigeria had an estimated 200.4 trillion cubic feet (TCF) of proved natural gas reserves as at the end of 2019. In 2008, according to Akachidike (2008), the nation had an estimated 182 TCF of natural gas with a projection of over 70%

by 2025. The Nigerian LNG (NLNG) in December 2019 commenced an expansion project proposed in 2005, the addition of a seventh train to the currently existing facility with the aim to add about 365 BCF of natural gas and thus, increasing the total capacity to 1.4TCF. If properly harnessed, this energy source still has great prospects in advancing Nigeria's energy sector.

Conversely, it is evident that hydropower electricity has great prospects in Nigeria's energy sector because of the availability of abundant water resources scattered across its borders which can meet the requirement for dam and hydro power installation. More so, as Africa's richest economy and most populous nation, the huge gap between the country's energy demand and current production capacity suggests that a huge market is available for this power industry (Brimmo et al., 2017). Similarly, hydropower has a great prospect to increase energy generation capacity by 160% in Africa to reach populations living without electricity and increase electrical energy consumption in the region if public-private partnership is fully harnessed. (Antwi & Sedegah, 2018). Its major advantage is elimination of fuel cost. The cost of operating a hydroelectric plant is nearly immune to increases in the cost of fossil fuels such as oil, natural gas or coal, and no imports are needed, hence it is rarely affected by global economic and political changes. It is also worthy of note that hydroelectric plants have long lifetimes, often 100 years or more (Breeze, 2018). Operating and labour costs are also usually low as automation of the plant is the state of the art. In addition to its prospect, a small hydro development may be installed along with a project for flood control, irrigation or other purposes, hence providing/supplementing extra revenue for project costs (Igweonu and Joshua, 2012).

Likewise, Nigeria with land area of 924×10^3 Km^2, with an average of 6.5 hours per day of sunshine and over 2600 hours of sunlight per year, has an average of over 1.84×10^{15} KWh of incident solar energy annually and an average of 5.535 KW/M^2/day. The energy demand of the entire nation of Nigeria can be met if only 0.1% of the total solar energy radiant on her land area is harnessed with an efficiency of 1% (Bugaje, 2006), this has the potential to supply over

115,000 times the electrical power currently produced (Augustine et al., 2009), and only about 3.7% of Nigeria's land area can collectively gather an amount of solar energy that is equal to her total conventional energy reserves (Mohamed et al., 2013). The monthly average global solar radiation in Nigeria is shown in figure 5.0. It is therefore worthy of note that Nigeria has good radiation sites that can boost the development of solar energy. Following a government report which indicates that around 55% of the country's 190 million inhabitants have no access to grid-connected electricity and even those with nominal access to centralized power are often affected by power cuts and outages. The country has recently launched a $75 million grant to encourage off-grid solar projects which will take advantage of the country's sufficient sunlight and sidestep the leaky grid Infrastructure that has hindered Energy consumption for so long (Casey, 2020).

Nigeria aims at producing 9.74%, 18%, and 20% of electricity consumed from renewable energy by 2015, 2020, and 2030 respectively, and solar energy is expected to produce 1.26%, 6.92%, and 15.27% of the electricity consumed by 2015, 2020, and 2030 respectively. However, there are currently no commercial solar energy plants available in Nigeria.

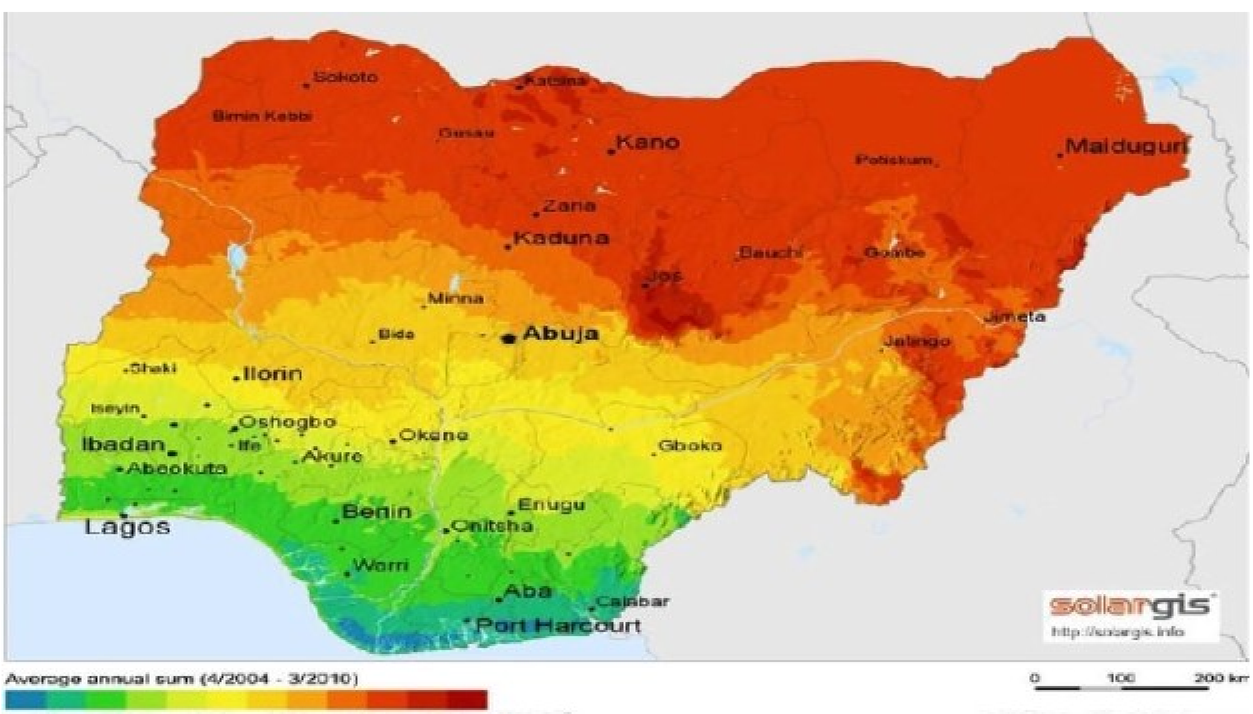


Figure 4: The Monthly Average Global Solar Radiation in Nigeria (Source: Thessa et al., 2016**).**

3.1 Challenges of Nigeria Energy Resources

According to Vivadili et al; (2017) the five cardinal targets of sustainable energy production are; reduced carbon dioxide emission, ecologically friendly process, energy transition security, reduced energy production cost and massive integration of green energy technologies. One of the major challenges of energy in Nigeria is the fossil fuel energy resources like coal, natural gas, crude oil, geothermal, biomass etc. These resources require a certain amount of combustion that will generate greenhouse gases and increase carbon emission into the atmosphere and these are responsible for climate change, increase in global average temperature, ozone layer depletion and overall increase in ultraviolet radiation in the airspace. As the world steers towards greener energy, there are negative global publicity associated with coal power as a result of CO_2 emission. This trend has continued despite technologies such as carbon capture and Storage (CCS), supercritical turbine concept, integrated gasification combine cycle, and coal washing which seeks to considerably ameliorate the effect of these greenhouse gases.

Another challenge which poses an impediment in the use of green technologies is the absence of structural framework and basic physical infrastructure to harness the potential of our energy resource. Our solar energy and hydropower respectively are majorly affected by this problem. This is evident in the absence of solar energy plants and limited number of hydro power stations in the country. For example, the major challenges faced with the installation of solar PV panels for huge electricity generation is the large land requirement. Other adjoining factors like dust and humidity affects the efficiencies of the PV cells (Oghogho, 2014) but with the continuous development on PV cells efficiency and space requirement per KWH of electricity generated, it is believed that these challenges will soon be a thing of the past (Tyagi, 2013).

The policies being formulated to support or encourage the utilization of these energy resources (renewable and renewable) have not received proper implementation and they are not deregulated or regulated to ascertain their general input into the national economy to determine the proportionate growth in gross domestic product (GDP) and National income (NI). This may be as a result of the services of less-knowledgeable individuals or corrupt professionals who have failed to properly interpret the policies as required. This has grossly affected coal power generation in Nigeria. Despite several new policies and construction projects going on since 2011 to revive the coal power project in Nigeria, none is yet fully operational (Ohimain, 2014). Likewise, it is sad to note that Nigeria is ranked amongst the top gas flaring nations in the world, in 2018 the nation flared about 261 billion cubic feet (BCF) of its natural gas (World Bank Group Report, 2018). Re-injection (a method applied in offshore to boost oil recovery) is considered uneconomic and with zero intention to adopt several concept and solution for gas transport and processing, gas flaring seem to be a viable alternative, thus making the nation the leading gas flaring nation and depriving her citizens of constant power supply should the amount of has flared had been directed towards electricity generation.

Another challenge which is also evident in the energy resource sector would be the absence of proper finance/funding to erect the required infrastructure and structural platform required to access and harness the renewable technologies and potentials which are abundant and available for use within the country. This has affected the overhead cost of power generation. For example, meeting the increasingly stringent standards on combustion efficiency and pollutant emissions as well as maintaining fuel flexibility and control technologies makes the generation more cost-intensive (Yan, 2010). Conversely, the economics of any gas reserves depends on several factors like; field cost, development and operation, gas price, sale contracts, and government fiscal regimes. At the moment none of these factors favor the development of remote stranded gas nor even seek to address the challenges in Nigeria. Natural factors such as climatic factors can seriously affect power generation, especially hydropower generation. In Nigeria, seasonal fluctuation of water level can pose a serious challenge to power generation and supply. To date, only about one-quarter of the world's hydropower potential has been utilized, and experts note that it is currently impossible to develop every one of the remaining undeveloped resources because of the social and environmental problems of building large hydroelectric dams (Igweonu and Joshua, 2012).

4. CONCLUSION AND RECOMMENDATION

Upon closer inspection and analysis of the natural resources at our disposal in Nigeria, It can be inferred that Nigeria is a country endowed with both mineral and natural resources which are expected to drive the nation beyond its present economic condition. However, due to poor handling, mismanagement and improper implementation of finances and policies pertaining to energy resources, the gross domestic product (GDP) and general standard of living of the population are still within the poverty range of global calculation. Judging from the position of the energy resource base and capacity of the nation, the following conclusion has been drawn up;

- Introduction of a robust energy mix that will guarantee availability of power to drive the economic situation of the country positively. Such a mix would be a collaboration of hydropower/solar energy as this would ensure a clean environment devoid of carbon emissions that would affect climate change.
- Installation of structural infrastructure that would harness green energy (Solar, hydro, wind etc.) to ensure the use of green technology to drive production, manufacturing and distribution of goods and services.
- Establishment and implementation of energy supportive policies that will ensure availability and proper distribution of energy across all the sectors to ensure a sustainable economy that translates into development and growth.
- Drawing out a master plan for the exploitation and utilization of the energy reserve of the country. Close monitoring of the generation and distribution of these resources to strategic industries for economic development is also pivotal.

With the available energy resources and infrastructure already on ground, the recommended mix which would boost economic growth as well as ensure an efficient power supply utilization in Nigeria would be a blend of solar energy and hydropower alongside the already existing crude/natural gas resources. This is tenable based on the accessibility, even-distribution, sustainability, cost-effectiveness and renewability of these resources.

REFERENCES

Akachidike K. (2008). Remote stranded Gas challenges and opportunities for development, pp. 3 in proceedings on the 38th annual conference of NSCHE 30th

Oct.-1st Nov. 2008 Effurun, Delta state, Nigeria.

Antwi, M., &Sedegah, D. D. (2018). Chapter 5—Climate Change and Societal Change—Impact on Hydropower Energy Generation. In A. Kabo-Bah & C. J. Diji (Eds.), Sustainable Hydropower in West Africa (pp. 63–73). Academic Press. https://doi.org/10.1016/B978-0-12-813016-2.00005-8.

Asghar, Z (2008), Energy – GDP Relationship: A Casual Analysis for the five countries of South Asia.Applied Econometrics and International Development Vol 8-1.

Augustine C., Nnabuchi M. (2009). Relationship between Global Solar Radiation and Sunshine Hours of Calabar, Portharcourt and Enugu, Nigeria. International journals of physical sciences 2009; 4(4): 182-8.

BP, British Petroleum Scenarios (2020), Statistical Review of World Energy 2020.

Breeze, P. (2018). Chapter 10—The Cost of Electricity from Hydropower Plants. In P. Breeze (Ed.), Hydropower (pp. 89–93). Academic Press. https://doi.org/10.1016/B978-0-12-812906-7.00010-7.

Brimmo, A. T., Sodiq, A., Sofela, S., and Kolo, I. (2017). Sustainable energy development in Nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1). Renewable and Sustainable Energy Reviews, 74, 474–490. https://doi.org/10.1016/j.rser.2016.11.162.

Bugaje I. (2006). Renewable Energy for Sustainable Development in Africa, A Review. Renewable and sustainable energy reviews 2006; 10(6); 603-12.

Charlse Asekhame Odumugbo. (2010). Natural gas utilization in Nigeria: Challenges and opportunity. Journal of natural gas sciences and engineering. 2(2010) 310-316.

Chineke T. C and E. C. Igwiro (2008). Urban and Rural Electrification: Enhancing the energy sector in Nigeria using Photovoltaic Technology, African Journal of Science and Technology, 9 (1):102-108.

Chukwu, M, Folayan, C. O, Pam, G. Y and D. O. Obada (2016), Characteristics of some Nigerian coals for Power Generation, Journal of Combustion, Vol. 16, Article ID. 9728278,http://dx.dio.org/10.1155/2016/9728278.

Deffary C., Raymond J. K. and Portray R. R. (2003) Energy Resources and Global Development. State of the Planet Vol. 302 www.sciencemag.org.

Dosunmu, A and Omayore, B (2003) An overview of Nigeria Energy Profile for Power Generation, Strategic planning for Energy and the Environment 22.4, 32-36, DOI:10.1080/10485230309509623.

EIA (2020), Country Analysis Executive Summary: Nigeria, US Energy Information Administration, last updated June 25, 2020.

Enerdata. (2020). Nigeria Energy Information | Enerdata. https://www.enerdata.net/estore/energy-market/nigeria/

IEA (2019), Nigeria Energy Outlook, IEA, Paris https://www.iea.org/articles/nigeria-energy-outlook.

IEA. (2020). Nigeria: 'Coal reserves can generate 53,900MW by 2030'. IEA Clean Coal Centre. https://www.iea-coal.org/nigeria-coal-reserves-can-generate-53900mw-by-2030/

Igweonu, E. I., and Joshua, R. B. (2012). Small Hydropower (SHP) Development in Nigeria: Issues, Challenges and Prospects. Global Journal of Pure and Applied Sciences, 18(1–2), 53–55.

Ikponmwosa Oghogho. (2014). Solar energy potential and its development for sustainable energy generation in Nigeria: A road map to achieving the feet. International Journal of Engineering and Management Sciences (IJEMS). vol.5 (2), 2014. pp. 61-67, ISSN 2229-600x.

Kober, T., Schiffer, H.-W., Denson, M., and Panos, E. (2020). Global energy perspectives to 2060 – WEC's World Energy Scenarios 2019 | Elsevier Enhanced Reader. Energy Strategy Review, 31(100523). https://doi.org/10.1016/j.esr.2020.100523.

Ladokun, L. L., Sule, B. F., Ajao, K. R., and Adeogun, A. G. (2018) Resource assessment and feasibility study for the generation of hydrokinetic power in the tailwaters of selected hydropower stations in Nigeria. Water Science, 32(2), 338–354. https://doi.org/10.1016/j.wsj.2018.05.003.

Liko, G. (2019). Impacts of Energy Sector on Economy, Social and Political Landscape and Sustainable Development.

Muhamed S., Petirin J.O. (2014). Renewable energy potentials in Nigeria: meeting rural energy needs. Renewable and

Sustainable Energy Reviews 29(2014) 72-84.

Ndaceko U.J., Mukhtar A., Muhammad M.A.,Bashir T.S. and Suleiman F.A. (2014). Solar energy potential in Nigeria. International Journal of Scientific and Engineering Research. Vol.5, Issue 10. October 2010, ESN 2229-5518.

Odesola, I. F., Samuel, E., and Olugasa, T. (2013). Coal Development in Nigeria: Prospects and Challenges: Vol. Vol. 4, No. 1.

Ogunjoi S.T., Obafaye A.A., Rabiu A.B. (2020). Solar energy potentials in different climatic zone of Nigeria. IOP Conf. Series Materials science and engineering 1032(2020) 012040 DOI: 1088/1757-899x/1032/1/012040.

Ohimain, E. I. (2014). Can Nigeria Generate 30% of her Electricity from Coal by 2015? International Journal of Energy and Power Engineering, 3(1), 28. https://doi.org/10.11648/j.ijepe.20140301.15.

Okorafor, O. O, Okereke, N. A. A and C. C Egwuonwu (2013) Evaluation of the hydropower potential of Otamiri River for Electric Power Generation. Research Journal of Applied Sciences, Engineering and Technology 6 (24): 4541 – 4547.

Oluwadamilare, B. A., Mark, K. K., Ayodeji, F. A., Theophilus, A., Oluwatobi, I. A., and Tomonobu, S. (2020). Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences. Energy Reports, 6, 993–1009. https://doi.org/10.1016/j.egyr.2020.04.022.

Olusola B., Mustafa D., Akinola B., Oluwaseun A. (2017). "A review of Renewable energy potentials in Nigeria; Solar power development over the years". Engineering and Applied Science research 44(4)

Oyedepo, S. O. (2012). Energy and Sustainable development in Nigeria: The way forward, Energy, Sustainability and Society 2012, 2:15.

UTILIZATION OF COAL, NATURAL GAS AND WATER FOR SUSTAINABLE POWER GENERATION IN NIGERIA: CHALLENGES, PROSPECTS AND WAY

Oluwadare Joshua Oyebode

Civil and Environmental Engineering Department

Afe Babalola University, Ado-Ekiti

Ekiti State, Nigeria

oyebodedare@yahoo.com

ABSTRACT:

Energy mix development is critical for national economic growth, optimal performance of industries and sustainable development in most nations of the world. This study examines the extent of the utilization of Coal, Natural Gas and Water for sustainable power generation and provision of competitive energy in Nigeria. Secondary data analysis was used in this research to analyze the data collected from the various literatures and documentary archives. Challenges facing this aspect of energy mix include issues linked with climate change, lack of technical knowhow, excessive demand with low supply of energy, lack of proper education, inadequate utilization of renewable energy, lack of equitable energy distribution in geopolitical zones and level of poverty in the country. Prospects of their utilization were highlighted. Findings revealed that there are underutilizations of Coal, Natural Gas and Water for power generation in Nigeria. This scenario is due to lack of adequate attention to energy mix, training deficit, inadequate finance, lack of technical knowhow and many other identified challenges. It has been concluded that prospects and other benefits that can be derived from coal, natural gas and hydropower generation should be harnessed for industrial use. Provisions of competitive energy and improved technology by engineering industries have copious advantages in this regard. Efficient energy management system and optimization of available energy sources at various geopolitical zones of Nigeria will improve the system. Utilization of Coal, Natural Gas and Water for sustainable power generation should be encouraged for national economic growth and provision of competitive energy in Nigeria.

Keywords: Natural Gas, Hydropower, Engineering, Sustainable Development, Competitive Energy

1. INTRODUCTION

Coal, natural gas and water can be utilized for sustainable power generation in Nigeria because of geometric and escalated energy demand compared to inadequate supply over the years. An estimated 1.6 billion people worldwide lack access to electricity.

Providing basic electricity services to these people at an average annual consumption level of 50 kWh per person would increase

the global end-use demand for electricity by roughly 80 billion kWh per year. Massive improvements in the efficiency of technologies and devices have facilitated continuing reductions in the quantity of energy required to produce a unit of goods and services in industrialized economies. Significant discovery of coal in Nigeria occurred in 1909 at Enugu, and then coal played a vital role in Nigeria energy mix as it was used to power trains in the Nigerian Railways transportation system, as well as used in the steel industry and cement industry.

Natural gas is a fossil fuel primarily composed of methane, although also present are other higher alkanes such as propane, butane, isobutane, pentane and heptane. In Nigeria, Gas utilization is a primary goal of Nigeria's petroleum and energy policies. This is because, with a proven reserve of 206.5 trillion cubic feet of natural gas, Nigeria's gas reserve is more than triple the nation's crude oil resources. Hitherto, associated gas encountered during the normal course of oil production has been largely flared. Nigeria was the leading oil producer in Africa as of 2020. Oil production amounted to 86.9 million metric tons in the

Only 40% of population in Nigeria is connected to the grid; and this population faces power problems 60% of the time. Nigeria still depends on petroleum oil reserves up till now. Libya was the richest country in oil in Africa as of 2020, accumulating 48.36 billion barrels of proved reserves. Nigeria followed with reserves of 36.97 billion barrels of crude oil, while Algeria's reserves summed up to 12.2 billion barrels. Oil production improves Gross Domestic Product (GDP) growth in African countries such as Algeria, Angola, Egypt and Libya, except in Nigeria. It is therefore essential for these countries to invest their oil largesse in boosting the productive base of their economies to lower fiscal deficits during periods of crude oil price uncertainties and boost GDP growth. However, current per capita consumption of the gas in Nigeria is about 0.8kg/annum (Eregha and Mesagan, 2020; Aliyu *et al.*, 2013).

Natural gas is the cleanest-burning conventional fuel, environmentally friendly and efficient energy source, producing lower levels of greenhouse gas emissions than heavier hydrocarbon fuels such as coal and oil. Nigeria has a lot of Crude Oil, Natural gas, Tar Sands, Nuclear Element, Coal and renewable energy resources that can be used to augment energy demands in the country. Despite Nigeria's steady access to fossil based and renewable energy sources, its per capita electricity has been among one of the lowest in Africa. As power demand studies have projected a medium and long term electricity demand of 30,000MW and 192,000MW respectively, there will need to be substantial improvement in the energy production and supply sector if this demand is to be met. A sustainable energy system may be regarded as a cost efficient, reliable, and environmentally friendly energy system that effectively utilizes local resources and networks. It is not 'slow and inert' like a conventional energy system, but it is flexible in terms of new techno-economic and political solutions.

2. LITERATURE REVIEW

The World Alliance for Decentralized Energy (WADE) defines decentralized energy (DE) as 'electricity production at, or near, the point of use, irrespective of size, technology or fuel used in both off-grid and on-grid' (Modi et al., 2006). Coal was first discovered in Nigeria in 1909. Coal mining in Nigeria began in 1916 with a recorded output of 24,500 tonnes. Production rose to a peak of 905,000 tonnes in the 1958/59 with a contribution of over 70% to commercial energy consumption in the country.

Economic growth and environmental sustainability are important in every nation for health, wealth, sustainable development and circular economy. Sectors of oil and gas in downstream and upstream need drastic and dramatic revitalization. There is great demand for drastic transformation of oil and gas sector for optimal delivery, environmental safety, and economic growth in Nigeria. The ever-increasing demand and insufficient supply of oil and gas products in Nigeria has been a great challenge to her development (Oyebode, 2021).

According to Ajayi et al (2003) there is also large deposit of coal which is a solid fuel mineral. According to Renewable Energy Master Plan of 2006, the proven reserve of coal in Nigeria is 2.7 trillion tones. However, Nigeria Coal Corporation (NCC) estimates indicates 638 million tonnes of proven reserves by direct drilling and 2.75 billion tones of inferred reserves. Coal deposits are found in the Enugu escarpment running from north to south in Anambra state, Otukpo in

Benue state, Okaba in Kogi state, Obi-Lafia basin in Plateau state and south of Gombe state. There are two types of reserve namely

the sub-bituminous grade and lignite. However, Nigeria coal is mainly the sub-bituminous type, low in sulphur and phosphorus, but with a fairly high volatile comp orient petroleum, gas and coal can be harness to generate electricity and such process is regarded as thermal energy.

Hydropower energy potential of Nigeria is high and it currently accounts for about 29% of the total electricity power supply in Nigeria. The first and large hydropower supply station in Nigeria is located in Kanji on the river Niger, in Niger State where it has an installed capacity of 836 MW and it also had provisions for more expansion to 1,156 MW. The second largest hydropower station is located in Jebba, Niger state with an installed capacity of 540 MW, for rivers Shiroro in Kaduna State, Ikom in Cross River State and Makurdi in Benue state estimated their total capacity to about 4,650 MW. The Mambila Plateau rivers estimate was put at 2,330MW (Aliyu and Elegba, 1990)

Sustainability is a critical goal for Civil Engineers, human activity, construction projects and national development. Energy Sources like biomass (wood), oil and gas are indiscriminately consumed in Nigeria with little consideration for sustainability. Proper development of crude oil through indigenous

technology has become an albatross due to political instability, lack of effective policy, regulatory instability and corruption in the oil sector (Oyebode, 2019).

The technologies for harnessing wind energy have, over the years, been tried in the northern parts of the country, mainly for water pumping from open wells in many secondary schools of old Sokoto and Kano States as well as in Katsina, Bauchi and Plateau States. Other areas of "potential application" of wind energy conversion systems in Nigeria are in Green electricity (which is the type of electricity produced from renewable source that is environmentally friendly and non-polluting) production for the rural community and for integration into the national grid system (Agbetuyi et al., 2012).

Sustainability is a critical goal for Civil Engineers, human activity, construction projects and national development (Oyebode, 2019).

All Engineering Infrastructures are subject to aging, wear and tear in the performance of their functions and deterioration by exposure to outside operating environment (Oyebode, 2018).

The large scale and predominant consumption of fuel-wood has been identified as contributing significantly to the environmental problems of soil erosion and desertification. Other serious hazards include respiratory and visual disorders. There is great potential in alternatives to traditional fuelwood based technologies (Igbinovia, 2014).

Sustainable energy transition is generally understood as a concept of developing robust, effective and efficient energy sectors in a particular country or region without compromising the present and future socio-environmental security. The United Nations General Assembly in September 2015 adopted the 2030 agenda for Sustainable Development which includes a total of 17 Sustainable Development Goals (SDGs). In a sustainable environment, clean water and sanitation (goal 6) is non-negotiable, and this directly affects the aquatic life (Goal 14) and life on the land (Goal 15). Quality of life in the water and on the land is a direct indicator of a healthy environment and active climate change actions (Goal 13). The coupling between sustainable energy and quality education (Goal 4) may appear evasive, but it is significant (Adewuyi et al., 2020).

The economic, social and solidarity implications of energy poverty are becoming massive, especially in regions where the income level is low and the average cost of modern energy technology is relatively high such as the sub-Saharan Africa (Meyer et al., 2018).

Energy justice deals with the agreements and decisions on who bears the costs and the inevitable burdens of energy transition or integration of new energy facilities. The issue of energy justice should be more of an intrinsic concern in Africa compared to other industrialized and developing economy such as Indian, China, Japan, Taiwan and so on (Sovacool et al., 2019).

The five cardinal targets from sustainable energy production point of view are identified to be: reduced carbon dioxide emissions, ecologically friendly process, energy transition security, reduced energy production cost and massive integration of green energy technologies. All the listed five targets are directly promoting a better environment while improving economic security. Sustainable energy transition is generally understood as a concept of developing robust, effective and efficient energy sectors in a particular country or region without compromising the present and future socio-environmental security. (Adewuyi et al., 2020).

The National energy supply is at present almost entirely dependent on fossil fuels and firewood (conventional energy sources) which are depleting fast. Despite the abundance of energy resources in Nigeria, the country is in short supply of electrical power. Access to reliable and stable supply of electricity is a major challenge for both the urban and rural dwellers. Only about 40% of the nation's over 200 million people have access to grid electricity and at the rural level, where over 70% of the population live, the availability of electricity drops to 15%. An analysis of Nigeria's electricity supply problems and prospects found that the electricity demand in Nigeria far outstrips the supply, which is epileptic in nature.

According to the World Bank's 2020 Global Gas Flaring Tracker, a leading global and independent indicator of gas flaring, Nigeria is the seventh-largest gas-flaring country globally. The country is surpassed only by Russia, Iraq, Iran, the United States, Algeria and Venezuela. All seven countries have continued to light up the global map for nine years running. In 2020 alone, natural gas valued at $1.24 billion was burned by oil companies, one which could generate the annual electricity use of

804 million Nigerian citizens (Romsom and McPhail, 2021; Yusuf, 2021).

The Nigerian government can curtail the huge financial loss and environmental degradation that accompanies the process of gas flaring with sufficient regulation of the gas industry (Adekomaya et al., 2016). Sufficient amount of useful energy can be harvested from the flared gases by making proper investments on modern and highly efficient natural gas-fired electricity production technologies. The existing Nigerian power system is highly unreliable both in content and in essence; the generation and transmission capacities are grossly insufficient, and the distribution network is outdated and inefficient. As a result of this, energy losses, planned outages (load shedding) and forced outages (voltage collapses) are everyday experiences (Oyedepo, 2012).

3. METHODOLOGY

Secondary data analysis was used in this research to analyze the data collected from the various literatures and documentary archives. The other documentary sources from the International Energy Agency (IEA), Energy Information Administration (EIA), and the World Energy Council (WEC) only have useful evidence and records for the situation Nigeria.

With an estimated population of close to 200 million people, as of late 2018, Nigeria remains the most populated African country. Located in West Africa sub-region along Latitudes 4^0N and 14^0N, and Longitudes spanning from 3^0E to 8^0E and Nigeria covers about 923,768 km^2 of the world area. Figure 1 indicated existing transmission line system in Nigeria. The quantification and very poor utilization levels of some of the energy resources within Nigeria's border are very important. Table 1 presented electricity distribution companies and the state of their network in Nigeria**.**

Figure 1. Map of Nigeria showing existing transmission line system. Source: (Oladipo et al., 2018)

Table 1: Electricity Distribution Companies and the state of their network in Nigeria

Name of company	Owner*	Purchase Value ($ Million)	Coverage	Length of lines							Distribution losses (%)	Capacity (MW)	Peak Load Demand (MW)
				Overhead			Cables			Total			
				33KV	11KV	LV	33KV	11KV	LV				
Abuja	Kann Consortium Utility Company Plc	164	FCT, Niger, Kogi and Nasarawa	3,312	3,804	3,520	0	355	262	11,253	35	515	835
Benin	Vigeo Power Consortium	129	Edo, Delta, Ondo and Ekiti	4,133	5,168	12,576	11,146	132	150	33,305	21	392	100
Eko	West Power & Gas	135	Lagos South	545	2,347	3,980	317	462	262	7,913	18	796	1105
Enugu	Interstate Electrics Limited	126	Enugu, Abia, Imo, Anambra and Ebonyi	4,092	3,210	20,558	4	178	213	28,255	6	612	1017
Ibadan	Integrated Energy Distribution and Marketing Company	169	Oyo, Ogun, Osun and Kwara	8,088	4,594	11,401	0	462	407	24,952	8	878	1193
Ikeja	NEDC/KEPCO	131	Lagos North	7,711	2,730	25,742	12	110	262	36,567	18	854	1335
Jos	Aura Energy Ltd	82	Plateau, Bauchi, Benue and Gombe	3,930	1,395	12,152	0	20	56	17,553	22	378	507
Kaduna	Sahelian Power SPV Ltd (Not fully privatized yet)	58	Kebbi, Doka, Gusau, Mak	1,533	1,614	6,535	5	145	93	9,743	25	344	520
Kano	Sahelian Power SPV Ltd	137	Kano, Jigawa and Katsina	3,583	1,253	2,351	4	156	17	7,364	40	365	596
Port Harcourt	4 Power Consortium	124	Rivers, Cross River, Bayelsa and Akwa Ibom	6,109	9,747	n.a.	n.a.	n.a.	n.a.	15,856	n.a.	486	773
Yola	Integrated Energy Distribution and Marketing Company	59	Yola, Adamawa, Borno, Taraba and Yobe	8,761	1,407	21,485	0	2	25	31,680	22	138	176

*State governments are shareholders in the DISCO that operates in their territory. Ikeja also counts with a private stakeholder: Sahara Energy
**Table created only for indicative purposes. The information included might not be complete or up to date

Countries all over the world are devising efficient technologies and formulating enabling policies towards encouraging significant levels of penetration of clean and cheap alternative energy sources into their energy mix. Significantly, issues that surround energy poverty analysis are broad as they also include the level of mass illiteracy and the socio-economic status of citizens. However, there is not yet an adequate and reliable approach for meeting the huge energy deficit of Nigeria and the entire SSA region. The average power per capita in SSA is about 32.6 Watts per hour per head; this reflects a gross case of energy poverty compared to other parts of the world as shown on Table 2.

Table 2: Average power per capital for some countries

Countries	W/h/head	Countries	W/h/head
USA	1377	NIGERIA*	14
CANADA	1704	TOGO	16
CHINA	492	BENIN	10
AUSTRALIA	1112	GHANA	39
JAPAN	841	IVORY COAST	27
FRANCE	736	EQU. GUINEA	13
MALAYSIA	483	CONGO DR	21
ISRAEL	835	S. LEONE	3
SWITZERLAND	809	CAMEROON	28
INDIA	128	CHAD	1

Source: (Adewuyi et al., 2020; CAs, 2018)

4. CHALLENGES ENCOUNTERED IN THE UTILIZATION OF VARIOUS SOURCES FOR EFFECTIVE ENERGY MIX

Global consumption of commercial forms of energy has increased steadily over the last four decades and has been recently marked by especially dramatic growth rates in many developing countries. Challenges facing this aspect of energy mix include issues linked with climate change, lack of technical knowhow, excessive demand with low supply of energy, lack of proper education, inadequate utilization of renewable energy, lack of equitable energy distribution in geopolitical zones and level of poverty in the country. Some of the factors attributed to the current shortfall in effective policy implementation are poor tariff system which has led to huge cash deficits in the market, outdated metering and market monitoring structure which has contributed heavily to financial loss through illegal energy drain. Economic and financial barriers might be another major issue to contend with the development of renewable energy systems in Nigeria.

A major constraint to the development of the renewable energy market in Nigeria is the poorly established standard and quality control of locally manufactured and imported technologies.

One of the challenges of this effort is the absence of a legal framework to regulate the industry. National government policies formulated for the development of renewable energy sources need to be strengthened. Many of the Government of Nigeria energy initiatives are merely green paper policies that lack the resolve to be taken into the implementation realm. Other challenges are:

i. Inadequate energy infrastructure on ground and its low local contents.

ii. Inadequate indigenous human and manufacturing capacities.

iii. Shortage of funds for the investments in energy development.

iv. Inadequacy of appropriate national energy policies, plans and laws as well as regulatory mechanisms.

v. Lack of good governance and mutual confidence amongst African States.

5. PROSPECTS OF UTILIZATION OF RENEWABLE ENERGY IN NIGERIA

Some of the prospects include the following:

i. Opportunities exist for national and regional cooperation.

ii. Renewable energy resources have the potentials to change the status quo of power generation and consumption in the country.

iii. Multinationals, Private sector and individuals will be given the right environment and encouragement in the form of incentives and subsidized investments by the Government of Nigeria to embark on energy efficient projects through the utilization of renewable energy solutions.

iv. Natural gas is more environmentally friendly. The use of such traditional fuels as wood and dung for cooking is inefficient and generates extremely high levels of indoor pollution. Accelerating the transition to more expensive, but far cleaner kerosene, liquefied petroleum gas (LPG), or electric stoves, would dramatically reduce the exposure to unhealthy levels of particulate pollution in many developing countries

v. Human resource development, critical knowledge and know-how transfer should always be in focus for renewable energy projects development, project management, monitoring, evaluation, implementation and actualization.

vi. Research and Development centers and technology development institutions, like the Universities, Polytechnics and colleges of education will be adequately strengthened to support the shift towards increased renewable energy utilization.

6. CONCLUSIONS

The most significant impediment to the maximization of Nigeria's potentials for adequate socio-economic growth is the poor condition of the power sector. A lot of prospects and other benefits that can be derived from coal, natural gas and hydropower generation should be harnessed for industrial use. Africa is endowed with energy resources of oil, natural gas, coal, hydropower, solar, wind, geothermal, biomass, tidal and wave energy in its territorial waters, which are unevenly distributed. All professionals and stakeholders have to contribute their strategic insights towards achieving sustainable industrialization and demonstrating new approaches for up-skilling and re-skilling key professionals for effective energy mix in Nigeria. Provisions of competitive energy and improved technology by engineering industries have copious advantages in this regard. Energy management system and optimization of available energy sources at various geopolitical zones of Nigeria will improve the system. Lack of technical competence remained and may continue to be a major challenge towards the development of renewable energy systems in Nigeria.

7. RECOMMENDATIONS AND WAY FORWARD

Utilization of Coal, Natural Gas and Water for sustainable power generation should be encouraged for national economic growth and provision of competitive energy in Nigeria. There should be periodic review of energy policies by relevant professional bodies such as Nigerian Society of Engineers and other stakeholders in energy sector for better government regulation, reformation, partnership and effective energy mix utilization. Energy management system and optimization of available energy sources at various geopolitical zones of Nigeria will improve the system. Utilization of Coal, Natural Gas and Water for sustainable power generation should be encouraged for national economic growth and provision of competitive energy in Nigeria. Reliable system, effective funding and better Environment for crowding-in private sector investments in electricity sector should be provided in Nigeria. Natural gas as a transitionary fuel should be pursued to replace coal and facilitate full deployment of renewable energy in Nigeria. Government of Nigeria should provide incentives and mechanisms e.g., feed-in-tariffs, auctions, bidding, self-generation, debt, equity and energy targets, to increase the share of renewable sources in the country's energy mix. Capacity building both at institutional and personnel level for acquiring technical, organizational, and managerial skills required for increased development of renewable energy should be encouraged by the Government.

6. ACKNOWLEDGEMENTS

I thank and acknowledge the President, members of executives, technical committee, reviewers and members of Nigerian Society of Engineers (NSE) for the opportunity given to me to contribute my paper to this conference. Special appreciation to all participants of 2021 National Engineering Conference, Council for the Regulation of Engineering in Nigeria (COREN) and all professional bodies that I belong to such as World Safety Organization (WSO), Nigerian Institution of Civil Engineers (NICE), American Society of Civil Engineers (ASCE), Nigerian Institution of Water Engineers (NIWE), Society of Petroleum Engineers (SPE), Institute of Professional Managers and Administrators of Nigeria (IPMA) and Institute of Policy Management Development (FIPMD).

REFERENCES

Adedokun, A. (2016). Nigeria electricity forecast and vision 20: 2020: Evidence from ARIMA model. *Energy Sources, Part B: Economics, Planning, and Policy*, *11*(11), 1027-1034.

Adewuyi, O. B., Kiptoo, M. K., Afolayan, A. F., Amara, T., Alawode, O. I., and Senjyu, T. (2020). Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences. *Energy Reports*, *6*, 993-1009.

Agbetuyi, A. F, Akinbulire, T.O, Abdulkareem, A., Awosope C.O.A, (2012) Wind Energy Potential in Nigeria, International Electrical Engineering Journal (IEEJ) Vol. 3 (2012) No. 1, pp. 595-601

Ajayi, M., Okafor, C. M., Adebusuyi, B. S., Kukah, S. T. Y. and Enedu, C. I. (2003). Energy in Nigeria demand and supply. In O. J. Nnanna, S. O. Alade and F. O. Odoko (eds) Contempoorary Economic policy Issues In Nigeria (Pp.103-127) Nigeria. Central Bank of Nigeria.

Akinloye, B. O., Oshevire, P. O., and Epemu, A. M. (2016). Evaluation of system collapse incidences on the Nigeria power system. *Journal of Multidisciplinary Engineering Science and Technology*, *3*(1).

Aliyu, A. S., Ramli, A. T., and Saleh, M. A. (2013). Nigeria electricity crisis: Power generation capacity expansion and environmental ramifications. *Energy*, *61*, 354-367.

Aliyu, U.O and Elegba, S. B. (1990). Prospect for Small Hydropower Development for Rural Applications in Nigeria. Journal of Renewable Energy Vol. 1, pp. 74-86.

CAs M.J. Country comparison : electricity-consumption (2018). https://www.cia.gov/library/publications /the-world-factbook/rankorder/2233rank.html Google Scholar.

Emodi, N. V., and Ebele, N. E. (2016). Policies enhancing renewable energy development and implications for Nigeria. *Sustain Energy*, *4*(1), 7-16.

Eregha, P. B., and Mesagan, E. P. (2020). Oil resources, deficit financing and per capita GDP growth in selected oil-rich African nations: a dynamic heterogeneous panel approach. *Resources Policy*, *66*, 101615.

Federal Ministry of Power and Steel, Federal Republic of Nigeria, Renewable Electricity Action Program (REAP), International centre for Energy, Environment and Development, December 2006. www.iceednigeria.org.

Igbinovia, F. O. (2014). An Overview of renewable energy potentials in nigeria: prospects challenges and the way forward. *Energetika Journal*, *46*, 570-579.

Leonard, O. N. (2012). Entrepreneurship opportunities in the power sector of nigeria economy. *Journal of science, technology, mathematics and education (JOSTMED)*, Volume 8(2) by the Department of Science Education, School of Science and Science Education, Federal University of Technology, Minna.

Meyer, S., Laurence, H., Bart, D., Middlemiss, L., and Maréchal, K. (2018). Capturing the multifaceted nature of energy poverty: Lessons from Belgium. *Energy research and social science*, *40*, 273-283.

Modi, P. K., Singh, S. P., Sharma, J. D., and Pradhan, P. K. (2006). Stability improvement of power system by decentralized energy. *Advances in Energy Research*, 65-70.

Oladipo, K., Felix, A. A., Bango, O., Chukwuemeka, O., and Olawale, F. (2018, September). Power sector reform in Nigeria: Challenges and solutions. In *IOP Conference Series: Materials Science and Engineering* (Vol. 413, No. 1, p. 012037). IOP Publishing.

Oyebode, O. J. (2018). Evaluation of Civil Engineering Infrastructures for Economy and Sustainable Construction in Nigeria. In Proceedings of the 16th International Conference and Annual General Meeting held in Calabar International convention center, Calabar.

Oyebode, O. J. (2019). Impacts of Civil Engineering Infrastructures In the Sustainability of the Environment. In paper published in the conference proceedings of 17th International Conference and AGM held in Maiduguri tagged "PEACE 2019" of Nigerian Institution of Civil Engineers (NICE).

Oyebode, O. J. (2021). Strategies for Transforming Oil and Gas Sector for Economic Growth and Environmental Sustainability in Nigeria. Journal of Alternate Energy Sources and Technologies, 12(2), 40-45p.

Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. Energy, Sustainability and Society, 2(1), 1-17.

Romsom, E., and McPhail, K. (2021). Capturing economic and social value from hydrocarbon gas flaring and venting: solutions and actions (No. 2021/6). WIDER Working Paper.

Sovacool, B. K., Lipson, M. M., and Chard, R. (2019). Temporality, vulnerability, and energy justice in household low carbon innovations. *Energy Policy*, *128*, 495-504.

Team, A. P. (2015). Office of the Vice President, Federal Government of Nigeria in conjunction with Power Africa. *Nigeria Power Baseline Report*, 1-36.

Yusuf. A. (2021). World Bank's 2020 Global Gas Flaring Tracker**.** Premium Times Nigeria paper of April 30, 2021.

Prospects and Challenges of Utilization of Coal, Natural Gas and Hydro (Water) for Sustainable Power Generation and Provision of Competitive Energy in Nigeria

Adenubi, Solomon Adetola, MNSE, MSPEI, JP
Department of Petroleum and Gas Engineering, University of Port Harcourt, Nigeria.

ABSTRACT:

Nigeria is abundant in coal, natural gas and water resources. 2.7 billion tons of coal is laid underneath Anambra Basin as sub-bituminous grade spanning across thirteen states, especially Enugu, Kogi and Benue Districts with 3,500MW potentials. 200.79tcf gas reserves in Niger Delta, with expected life-span of 88years (1850 bscf/yr production), portends excellent prospective for gas-fired IPPs with 30,000MW potentials. This is achievable through conversion of PHCN plants (Geregu, Alaoji, Omotosho and Papalanto) and NIPP plants (Calabar, Egbema, Ihovhor, Gbarian, Sapele and Omoku) to combined cycles while developing more privately-sponsored IPPs. Rivers Niger and Benue, their numerous tributaries and several scores of small rivers/streams have possibilities of 11,250MW large-hydro and 3,500MW small-hydro potentials. Nigeria's electricity prosperity can thus blossom if these resources are efficiently harnessed to meet her demands of about 40,000MW for her technological advancement. Challenges in power sector include low reliability of existing power stations, high-energy loss from technical losses, overloaded transmission/distribution infrastructure, unpredictable rainfall/drought and negative public perception.

1. INTRODUCTION

Nigeria is endowed with sufficient energy resources to meet its current and future development requirements: it is gas province with proven reserves of nearly 200.79tcf. Her coal reserves are estimated to be 2.7b tons while identified hydro-electricity sites have an estimated capacity of about 14,750MW. Nigeria also has other very significant resources to meet both traditional and modern electricity generation. Of the current installed generating capacity of 12,067MW, only 6,840MW is available for distribution and is derived at an energy mix of 84% from thermal and balance 16% from hydro-based electricity. Over the last two decades, the Federal Government has established quite a number of power plants and also licensed private companies to establish independent power plants (IPPs) powered by natural gas. The Federal Government also undertook comprehensive reforms to address the electricity situation in the country. The enactment of the Electricity Power Sector Reform Act (2005), establishment of the Nigerian Electricity Regulatory Commission and the unbundling of PHCN are concrete legal, regulatory and institutional steps that have started to address the challenges of the sector. PHCN has been unbundled into eighteen different companies responsible for power generation, transmission, distribution and marketing.

1.1 History of Power Generation in Nigeria

Electricity generation in Nigeria commenced in 1896 while the then Nigerian Electricity Supply Company (NESCO) began as an electric utility company in 1929 with the construction of a hydroelectric power station at Kurra far near Jos (a small hydropower project). The Electricity Corporation of Nigeria (ECN) was established in 1951, while the first 132KV line was constructed in 1962, linking Ijora Power Station to Ibadan Power Station. The Niger Dams Authority (NDA) was established in 1962 with a mandate to develop the hydropower potentials of the country. ECN and NDA carry out their various aspects of electricity business from generation to distribution as different entities until they were merged in 1972 by Decree 24 to form the National Electric Power Authority (NEPA) under one monopolistic corporation. In 1998, NEPA ceased to have an exclusive monopoly over electricity generation, transmission, distribution and sales and operates as a government parastatal under the supervision of the Federal Ministry of Power and Steel. The Reform Act of 2005 unbundled NEPA into 18 successor companies (under the flagship of Power Holding Company of Nigeria, PHCN) comprising of six Generation companies, one Transmission company and 11 Distribution companies.

1.2 Present Generating Capacity

Presently, Nigeria has an installed generating capacity of 12,067 MW, out of which only 6,840 MW is available for use by the citizens. The make-up of this include 40% derived from NIPP thermal power plants, 34% derived from former PHCN thermal power plants, 15% derived from concessioned hydro power plants and 11% derived from other independent power producers. Existing generating power plants consist of the following:

- Old gas-fired power plants at Egbin, Afam, Sapele, Ughelli, Ijora and the hydro power plants at Kainji, Jebba and Shiroro with a total capacity of 5,200MW.
- Niger Delta Power Holding Company new thermal power plants at Geregu, Omotosho,

Papalanto & Alaoji, with a total capacity of 1,588MW.

- NDPHC power projects at Gbaran/Ubie, Egbema, Ihoubor, Sapele, Omoku, Ikot Abasi-Ibom and Calabar, with a total capacity of 2,500MW.
- Other IPPS managed by private sector including Shell Afam, Agip Okpai, Ibom Power, NESCO and AES Barges.

Table 1: Existing generating power plants in Nigeria

S/N	Name	Year of Completion	Type of Fuel	Installed Generation Capacity (MW)	Available Capacity
1	Egbin	1985	Gas	1,320	931
2	Delta	1990	Gas	740	453
3	Odukpani	2013	Gas	561	70
4	Kainji	1968	Hydro	760	180
5	Afam VI	2009	Gas	980	559
6	Jebba	1985	Hydro	576	427
7	Geregu	2007	Gas	414	282
8	Shiroro	1989	Hydro	600	480
9	Okpai	2005	Gas	480	424
10	Olorunsogo	2007	Gas	335	244
11	Omotosho	2005	Gas	335	242
12	Omoku	2005	Gas	150	0
13	Geregu NIPP	2012	Gas	434	424

14	Omotosho NIPP	2012	Gas	450	318
15	Alaoji NIPP	2015	Gas	335	127
16	Rivers IPP	2009	Gas	136	166
17	Ibom Power	2009	Gas	142	115
18	Afam IV-V	1982	Gas	580	98
19	Sapele	1978	Gas	900	145
20	Olorunsogo NIPP	2012	Gas	675	356
21	Ihovbor NIPP	2012	Gas	450	327
22	Sapele NIPP	2012	Gas	450	205
23	AES Barge	2001	Gas	270	267
	Total			**12,067MW**	**6,840MW**

1.3 Nigeria's Electricity Demands

Nigeria should have a theoretical level of demand of 200,000MW using developed countries' standards of end-point aspiration of 1KW demand per person. The Vision 20-2020 put Nigeria's electricity demand as 35,000MW while the Renewable Energy Master Plan suggested a most detailed demand projections estimated peak current electricity demand of 45,490MW. The ideal electricity demand for Nigeria is about 40,000MW which must be sourced from her abundant coal, natural gas and water resources.

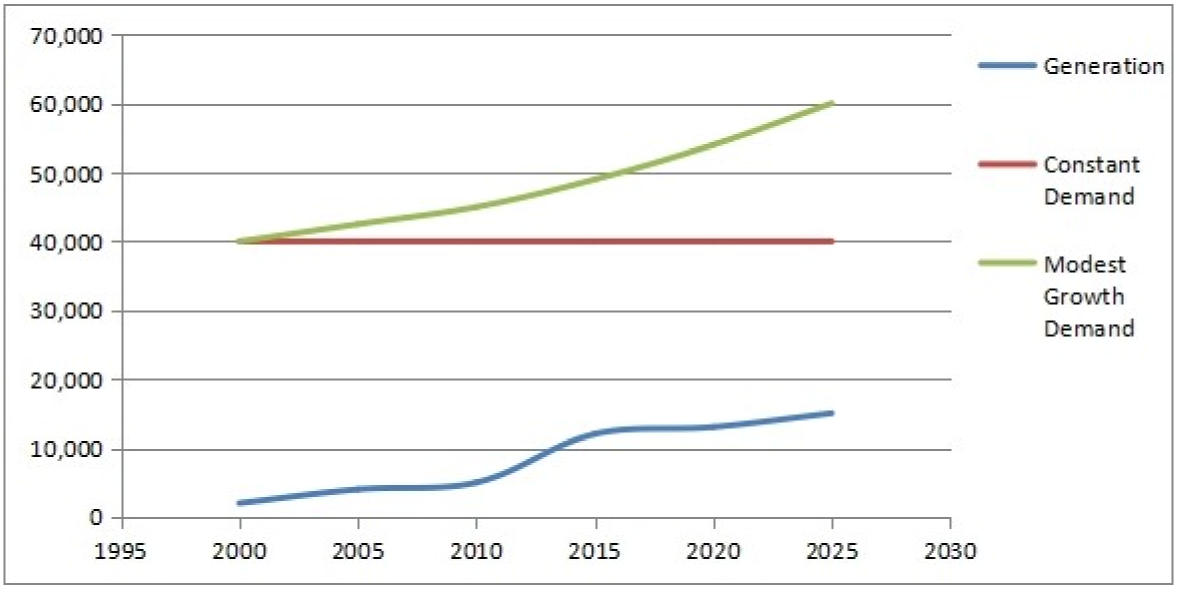


Figure 1: Estimated Electricity Demand in Nigeria

2. PROSPECTS OF UTILIZATION OF COAL, NATURAL GAS & HYDRO FOR POWER GENERATION

The Federal Government is constructing the 3,050MW Mambilla hydroelectric station while the Zungeru 950MW hydroelectric project is currently being worked out. The PHCN owned Geregu, Alaoji, Omotosho and Papalanto are to be converted to combined cycle with funding from NIPP while the NIPP plants at Calabar, Egbema, Ihovhor, Gbarian, Sapele and Omoku will also be converted to combined cycle at a later stage. The Gurara 30MW hydropower plant in Kaduna State and the Kashimbilla 40MW in Taraba State are being prioritized by the FGN while the second phase of NIPPs, focused on building hydro power generation plants, is planned to add 4,000MW of generation.

It was also reported recently that the Federal Government plans to add fifteen power plants by 2037, leaping the power generation by 11,163MW. This will comprise of six coal plants at Ashaka (64MW), Ramos (1000MW), Ashaka/TPGL (500MW), Nasarawa (500MW), Benue (1200MW) and Enugu (2000MW) and nine gas plants at Totalfinaelf/Obitex (420MW), Anambra State IPP (528MW), Knox (501MW), Delta State IPP (500MW), Benco (700MW), Kaduna (900MW), Fortune Electric two plants (1000MW) and Gwagwalada (1350MW). In the nearest future, the country's coal capacity for electricity generation is expected to move from its present zero value to 3,500MW; the natural gas (thermal) plant's capacity is expected to increase to almost 30,000MW while the hydropower capacity is expected to increase from 1,900MW to about 7,200MW. Other sources like nuclear energy and solar capacity is expected to add to this capacity, hopefully by 2030.

2.1 Use of Coal as a Competitive Energy for Sustainable Power Generation

Nigeria's proven coal reserves is about 639 million tonnes while the inferred reserves are about 2.75 billion tonnes, these are scattered as sub-bituminous grade in about 22 coal fields spread within at least 13 states of the federation, capable of adding 3,500MW. Nigeria's coal mining began around 1906 with a recorded output of 24,500 tons in 1916 which rose to a peak of 905,000 tonnes in 1958/59, and contributed 70% to commercial energy consumption in the country. Production was about 14,390 tonnes in year 2000 and coal only contributed about 0.02% to commercial energy consumption in the country in 2001, as compared to 31.9% for oil, 61.9% for natural gas and 6.2% for hydropower.

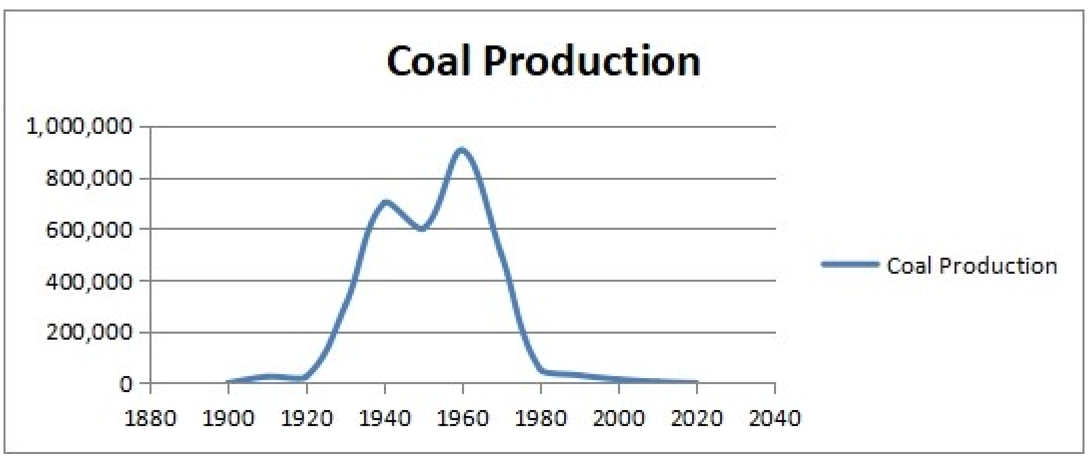


Figure 2: History of Coal Production in Nigeria

The coal deposits of the Anambra Basin contain the largest and most economically viable coal resources. The Kogi Coal District covering 225,000 hectares in the northeastern side of the Anambra Coal Basin is delineated at a total of 123 million metric tonnes of coal (Demonstrated) underlying an estimated 8,900 hectares. An additional 165 million tonnes of coal classed as non-reportable resource is projected to lie in the Ogboyoga area, with a coal thickness of approximately 2.0 meters. The Benue Coal District, covering 175,000 hectares of the coal basin and south of the Kogi District is delineated at a total of 81 million tonnes with another 117 million tonnes of non-reportable coal projected to exist at the west of the existing drilling and an average coal thickness is 3.1meters. The Enugu Coal District, covering 270,000 hectares of the coal basin, south of the Benue District supports the largest amount of commercial mining in the past, with a demonstrated coal resource of 49 million tones averaging 2.2 meters thick and an additional 111 million non-reportable tonnes of in-place coal.

Table 2: Coal Deposits in Nigeria

S/N	**Basin**	**District**	**Area covered**	**Area of Interest**	**Coal thickness**	**Coal Estimates**	
						Demonstrated	**Non-reportable**
1	Anambra Basin	Kogi Coal District	225,000 hectares	Ogboyoga	2.0meters	123million metric tonnes	165million tonnes
		Benue Coal District	175,000 hectares	Orukpa	3.1meters	81million tonnes	117million tonnes
		Enugu Coal District	270,000 hectares	Enugu	2.2meters	49million tonnes	111million tonnes
		Total				**253million**	**393million**

From the foregoing, it appears that the Kogi District and the Benue (Orupka- Ezimo) District can each support a coal-fired power plant with ultimate capacity of approximately 3,500MW. These plants would be built in phases to match the production buildup of the associated coal mining operations, with several units in the size range of 500-700 MW. Based on the economics and logistics of coal transportation, power plants are best sited near the portals of the underground mine where coal can be conveyed directly to the generating facility. Nigeria's coal capacity potentials need to be effectively harnessed into the country's energy delivery system and export commodity mix through the development of a vibrant coal industry. This can also be reinvigorated through private sector participation, especially the indigenous population.

2.2 Use of Natural Gas as Competitive Energy for Sustainable Power Generation

Nigeria's proven natural gas reserves are estimated at about 200.79 trillion standard cubic feet, a figure substantially larger than its oil resources in energy terms. The current reserves and present rate of exploitation gives an expected life-span of Nigerian crude oil at about 44 years (at 2Mb/d production), while that for natural gas is about 88 years (1850 bscf/yr production). Thus, gas is a better substitute for oil both for domestic needs and foreign exchange earnings.

The following companies have responded to the Federal Government's persuasion to establish power plants: Negris Ikorodu thermal (30MW), Chevron Agura thermal (180MW), Rivers State Trans-Amadi (136MW), ExxonMobil Bonny (388MW), Agip Okpai thermal (450MW), Total Obite thermal (450MW), Shell Afam (960MW), Chevron Ijede thermal (780MW), Bayelsa Koko Creek (40MWE), Rivers State Omoku thermal (150MW) and Lagos State Lagos Barge (270MW).

The Nigerian Electricity Regulatory Commission (NERC) has also issued outstanding licenses to prospective IPPs, including Farm Electric Supply Ltd, Ota (150MW), Ethiope Energy Ltd, Ogorode (2,800MW), ICS Power, Alaoji (624MW), Supertek Nig Ltd, Akwete (1,000MW), Mabon Ltd, Dakinkowa (39MW), Geometric Power Aba Ltd, Aba (1,000MW), Anita Energy Services, Agbara (90MW) and Westcom Tech, Sagamu (1,000MW). Others are Bresson Nig Ltd, Magboro (60MW), First Independent, Omoku (150MW), First Independent, Trans-Amadi (136MW), First Independent, Eleme (95MW), Ibafo Power Plant, Ibafo (200MW), Hudson Power Ltd, Warawa (150MW), Shell Afam VI (642MW), Ewekoro Power Ltd (13MW), Ikorodu Industrial Power (39MW) and Westcom Tech, Lekki (50MW). If constructed, all of these plants are expected to feed into the national grid.

2.3 Use of Hydro as a Competitive Energy for Sustainable Power Generation

Hydropower is derived from the potential energy available from water due to a difference in height between its storage level and the tail water end to which it is discharged. Despite its high initial capital cost, hydropower provides one of the cheapest and cleanest sources of electricity. The Rivers Niger and Benue and their numerous tributaries constitute the core of the Nigerian river system, which offers a renewable source of energy for large schemes. In addition, several scores of small rivers and streams do exist and can be harnessed for small schemes.

The ECN estimates the large hydro potential even at 11,250MW and the small hydro potential at 3,500MW, totaling 14,750MW. The major national projects are the Mambilla (3,050MW) and Zungeru (700MW) plants, with others been Gurara I (30MW), Gurara II (360MW), Iti (40MW) and Kashimbilla (40MW). Likewise, the Ministry of Water Resources has identified and carried out studies on some of the completed and on-going dam projects for hydropower. Nineteen of these have the potentials for hydropower generation with a total capacity of 3,557 MW. These dams include: Gurara, Oyan, Ikere Gorge, Bakolori, Dadin Kowa, Tiga, Kiri, Jibiya, Challawa Gorge, Owena, Doma, Waya, Mgowo, Zobe, Kampe, Kashimbilla, Ogwashiku, Zungeru and Mambilla. Only about 13.50% the nation's large hydropower potential has been developed and only 60.58MW which represents about 1.70% of the small hydropower potential has been developed.

Table 3: Existing Small Hydro Power in Nigeria

S/N	State	River	Installed Capacity(MW)
1	Oyo	Ikere	6
2	Kano	Tiga	6
3	Plateau	Lere I & II	8
4	Sokoto	Bakalori	3
5	Plateau	Bagel I & II	3
6	Plateau	Ouree	2
7	Plateau	Kurra	8
	Total		**36**

Small-scale hydro projects have the least social and environmental effect, its production is stable enough to supply an industrial activity for the benefit of surrounding communities (especially for irrigation and electrification), it has the lowest electricity generation price and it is probably the easiest to design, operate and maintain. But Nigeria has failed to utilize the various rivers in the country as SHP potentials to increase the percentage contribution of hydroelectricity to the total energy mix (Igwuonu & Joshua, 2011). However, numerous small installations can bring major hydro-morphologic alterations to river courses as well as changes to habitats and land use, making production unsuitable to protected and biodiversity-rich areas.

Table 4: Small hydro Potential in Surveyed States of Nigeria

S/N	State	Potential Sites	Total Estimate Generation (MW)
1	Adamawa	3	28.6
2	Akwa Ibom	13	
3	Bauchi	1	0.15
4	Benue	10	13.06
5	Cross River	3	3
6	Delta	1	1
7	Ebonyi	5	3
8	Edo	5	3.83
9	Ekiti	6	1.25
10	Enugu	1	
11	FCT	6	
12	Gombe	2	35.099
13	Imo	71	
14	Kaduna	15	25
15	Kano	2	14
16	Katsina	11	234.34
17	Kebbi	1	
18	Kogi	2	1.05
19	Kwara	4	5.2
20	Nassarawa	3	0.45
21	Niger	11	110.58
22	Ogun	13	15.61
23	Ondo	1	1.3

24	Osun	8	2.62
25	Oyo	3	1.06
26	Plateau	14	89.1
27	Sokoyo	1	
28	Taraba	9	134.72
29	Yobe	5	
30	Zamfara	16	
	Total	**240**	**724.019**

3. Challenges of Utilization of Coal, Natural Gas and Hydro for Power

Nigeria has an installed capacity of 12,067MW, but only 6,840MW is available yet the huge discrepancy is blamed on some many reasons. Ijora and Oji River thermal plants based on coal have completely closed down for lack of coal production and early gas thermal units at Afam and Delta are obsolete and needed replacement. Also, the hydro power plants of Kanji, Jebba and Shiroro that generate the highest volume of electricity for the country probably due to good reservoir management but suffered seriously from silting and/or inadequate flow of water into the dam and poor maintenance. Egbin thermal unit suffered from disruption of gas supply through vandalism and poor management and maintenance by PHCN staff. The poor performance of the power plants has led to acute shortage of power across the country, with up to 2,700MW lost due to gas constraints while about 500MW are lost due to water management and several hundred megawatts are regularly lost due to line constraints.

The Nigerian electricity system is characterized by non-availability of spinning reserves; High-energy loss as a result of technical losses; High initial capital cost of installing hydro or thermal; Overloaded transmission and distribution infrastructure; Unpredictable rainfall/drought which affect water supply to dams; High incidence of asset vandalisation/theft; Substantial part of revenue used to service overheads and Over reliance on government subsidies. Others include tariff regime that does not fully recover cost; Unreliable billing and inefficient collection; Inadequate metering of the energy chain; Unwholesome contracting practices; Inadequate financial/business controls; Financial indiscipline and Negative public perception of the organization.

3.1 Challenges of Utilization of Coal for Sustainable Power Generation

Specific challenges for the utilization of coal for sustainable power generation include Uncertainties in the actual coal reserves of coal in the country; Low productivity of the coal mines; Low level of mechanization of production facilities and Absence of cost-effective transportation system such as rail system and port facilities for its export.

3.2 Challenges of Utilization of Natural Gas for Sustainable Power Generation

Specific challenges for utilization of natural gas for sustainable power generation include generation by thermal plants was less optimum due to equipment failure; Lack of adequate maintenance; Incessant disruption in the supply of fuel and Pipeline vandalisation and theft.

3.3 Challenges of Utilization of Hydro for Sustainable Power Generation

Specific challenges for the utilization of water for sustainable power generation include Construction of dam been time consuming and expensive; Hydropower dam constructions disrupting natural ecology as set by nature; Large volume of flowing water required for efficient and effective operation; Increasing public opposition due to environmental and social impact of dams; Adverse impact of climate change and rainfall variability which causes severe power disruption as a result of low water levels; Issue of funding, as domestic markets may be too small to justify investments and

Poor regional interconnections as major impediment to export possibility.

4. CONCLUSION AND RECOMMENDATION

Nigeria is well abundant with enough coal, natural gas and water resources, which if harnessed efficiently and developed promptly, Nigeria's electricity prosperity can blossom to meet and even surpass her current demands of 40,000MW for her technological advancement, despite some challenges been faced. Possible ways to effectively utilize coal, natural gas and water resources for competitive power generation have been discussed.

Some recommendations include:

1. Federal government to reinvigorate current initiatives by developing both an integrated renewable-energy plan and a systematic major increase in investment in research, market development and regulation of renewable energy.
2. Government should reinforce and lead the utilization of coal for power generation and also encourage private sector participation, especially indigenous population.
3. Government should provide incentives, probably through a feed-in tariff, for major pilots of small hydro power generation in each local government area.
4. Government should provide sufficient and affordable low-interest capital financing, with increases in available capital matching growth in the industry.
5. Government and stakeholders should undertake extensive public awareness to improve consumer and policy choices and overcome existing prejudices.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support provided by the Petroleum Technology Development Fund (PTDF), Abuja, Nigeria for this work. Special thanks to Prof. Dulu Appah for his fatherly guidance and assistance.

REFERENCES

Adenubi, S.A. (2011). Natural Gas Utilization in Nigeria: Prospects and Problems. An MBA Research Project submitted to Department of Production and Operations Management, Lagos State University Ojo (Masters of Business Administration)

Adenubi, S.A., Olotu, B. and Ilenreh, G. (2008).Nigerian Gas Utilization for Lundin Petroleum AB by Owel-Linkso Group (Unpublished)

Adenubi, S.A. and Bhagav, R (2010). IPP and LPG Feasibility Studies for OPL 277 and OPL 280 operated Sterling Oil Group (Unpublished)

Deutsche Gesellschaft für Internationale Zusammenarbeit GIZ GmbH (2015). The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. 2nd Edition, June 2015.

Draft National Renewable Energy and Energy Efficiency Policy NREEEP (2014). Energy Commission of

Nigeria, Abuja. Ministry of Science and Technology. March 2014

Eke, K. (2017). Power Infrastructure Development: A Tool for the Diversification of Nigeria's Economy. A paper presented at the 2017 Nigerian Society of Engineers Annual General Meeting and Conference, Abuja 2017.

Hafner, M., Tagliapietra, S. and Strasser, L. (2018). Energy in Africa: Challenges and Opportunities. Springer Briefs in Energy. https://doi.org/10.1007/978-3-319-92219-5.

Igweonu, E.I. and Joshua, R.B. (2011). Small Hydropower (SHP) Development in Nigeria: Issues, Challenges and Prospects. Global Journal of Pure and Applied Sciences. Vol. 18, No. 1&2, 2012: 53-58. ISSN 1118-0579. www.globaljournalseries.com

National Energy Master Plan (2007). National Committee on Energy Masterplan. Energy Commission of Nigeria Garki Abuja, Nigeria. June 2007

National Energy Policy (2003). Energy Commission of Nigeria, Abuja. April 2003

Power Generation in Nigeria. Sourced from www.nerc.gov.ng

Uchegbulam, O, Opeh, R.N and Atenaga, M.O. (2014). Assessment of Power Generation Resources in Nigeria. IOSR Journal of Applied Physics (IOSR-JAP) e-ISSN: 2278-4861.Volume 6, Issue 2 Ver. II (Mar-Apr. 2014), PP 44-50 www.iosrjournals.org

THEME FOCUS:

APPROPRIATE ENERGY MIX TO FACILITATE RURAL DEVELOPMENT AND POVERTY ALLEVIATION

ISLANDING HYBRID MICR-GRID FOR SUSTAINABLE ELECTRICITY

Engr. Rasaki Abiola OLAWOYIN, MNSE, MNIEEE, MIAENG

engr.olawoyin@gmail.com

ABSTRACT:

The myriad of problems in the country Electric Power Sector has resulted in socio-economic problems – negative impact on businesses, health and environment. Many medium manufacturing companies have either relocated from the country or folded up resulting in huge unemployment. The few ones that manage to exist rely on fossil fuel generators; which impacts negatively on the health and environment. Nigeria ranks 171 out of 190 countries of getting sustainable electricity with annual economic losses estimated at $26.2 billion – World Bank data. It is estimated that Nigeria requires 45,000MW of electricity in the year 2030 as against installed generation capacity of 12,522 M. This paper looks at the use of Islanding (also known as off-grid or standalone) hybrid MicroGrid system to provide sustainable and resilient electricity to typical off grid or rural dwellers without access to reliable electricity by harnessing the energy potential of two natural resources (solar and wind) through effective data collection and system design.

Keywords: Islanding, Microgrid, Hybrid, Sustainable, Harnessing.

1. INTRODUCTION

Hybrid system is the integration of two or more renewable energy sources to provide sustainable and reliable electricity. This can be integration of conventional energy (fossil fuel based) and renewable energy (Photovoltaic, wind, biomass, geothermal, hydro etc). Traditionally, Nigeria energy generation is majorly a mix of conventional (thermal) and renewable (hydro). This paper focuses on optimizing the potentials of two renewable energy sources (Solar/Photovoltaic and Wind) to provide sustainable and reliable electricity to rural dwellers as well as locations without access to reliable electricity.

Due to dry and raining seasons weather variations, the two renewable energy sources (Solar and Wind) have different peak operating times. Solar has its highest irradiation in dry season -its peak operating time and wind energy has its highest wind speed in raining season –its peak operating time. The two need to complement each other for seasonal variation. The integration of Photovoltaic and wind energy will ensure harnessing of full potentials thereby reducing over sizing of energy storage medium (such as string of batteries) that normally occurs with the use of single renewable source.

The renewable energy potentials in Nigeria by Akorede et al [1]; gives credence to the need for the use of hybrid renewable system in Nigeria to maximize their full potential. Though a lot of renewable energy source projects have been executed by Rural Electrification Agency (REA); the renewable hybrid potential has not been explored. Independent studies by W.O Idris et al [2] and S.O. Oyedepo [3] reveal that implementation of hybrid renewable energy source in certain part of the country especially in the North where wind speed and solar irradiation are more favourable will lead to reduce Net Present Cost (NPC) and lower Cost of Energy (COE) and ensure power stability and reliability.

2. RESEARCH DESIGN AND METHODOLOGY

The procedure for successful microgrid system design and implementation are the data collection of renewable energy potentials using software such as Weather Spark, HOMER and effective sizing of system components/equipments:photovoltaic panels, Battery charger / charge controller, Battery bank or string of batteries, inverter (DC/AC), cables, Wind Turbine capacity. The basic requirements for the system components are the energy usage required by the users per day and installation environment etc. This process of effective data collection and system design will ensure hazard free installation, operation and maintenance implementation. HOMER software is reliable software for the effective design calculation of major renewable energy system. We shall consider MS Excel in this paper because of its economic benefit for the design calculation of a small system. Small system is defined as any system within the range of 15 KVA – 20KVA or 12 KW – 16KW single phase.

2.1 Data Collection: Renewable Energy Potentials

Data collection of hybrid Solar-Wind renewable sources is essential to the successful and economic implementation of off-grid hybrid microgrid system.

2.1.1 Wind Potential

A study on the wind energy potentials for a number of Nigerian cities shows that the annual average speeds of about 2.2 m/s at the coastal region and 4.5 m/s at the far northern region of the count with an air density of 1.1 kg/m3. The wind energy intensity perpendicular to the wind direction ranges between 4.4 W/ m^2 at the coastal areas and 35.2 W/m^2 at the far northern region [4,5]

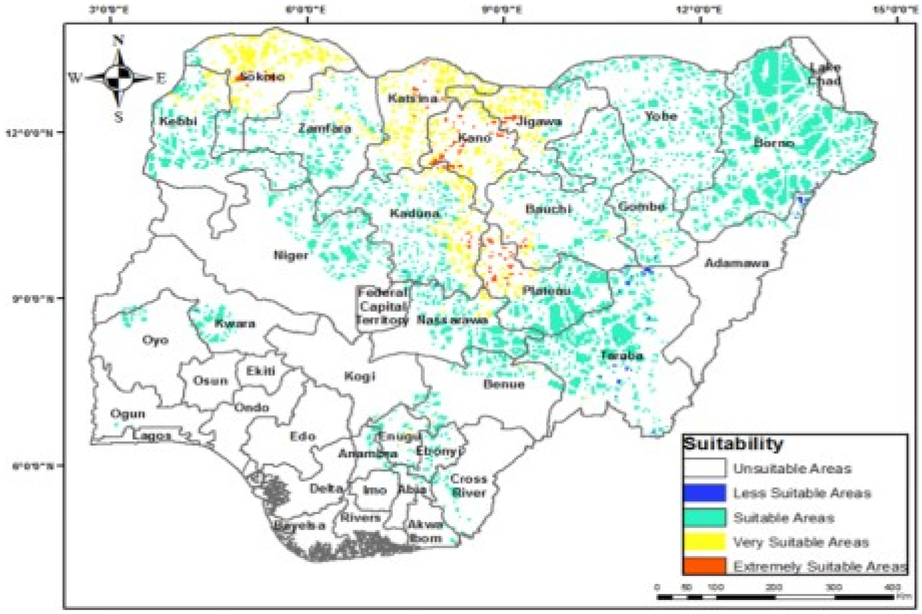


Fig.1 Nigeria Wind Potential: Source: Europe PMC.org

2.1.2 Solar Potential

There is sufficient sun intensity everywhere in Nigeria for electricity generation. Nigeria has an annual average daily sunshine of 6.5 hours with an average solar radiation of 3.5 kWh/m^2 a day at coastal latitude and 7 kWh/m^2 a day at the far north

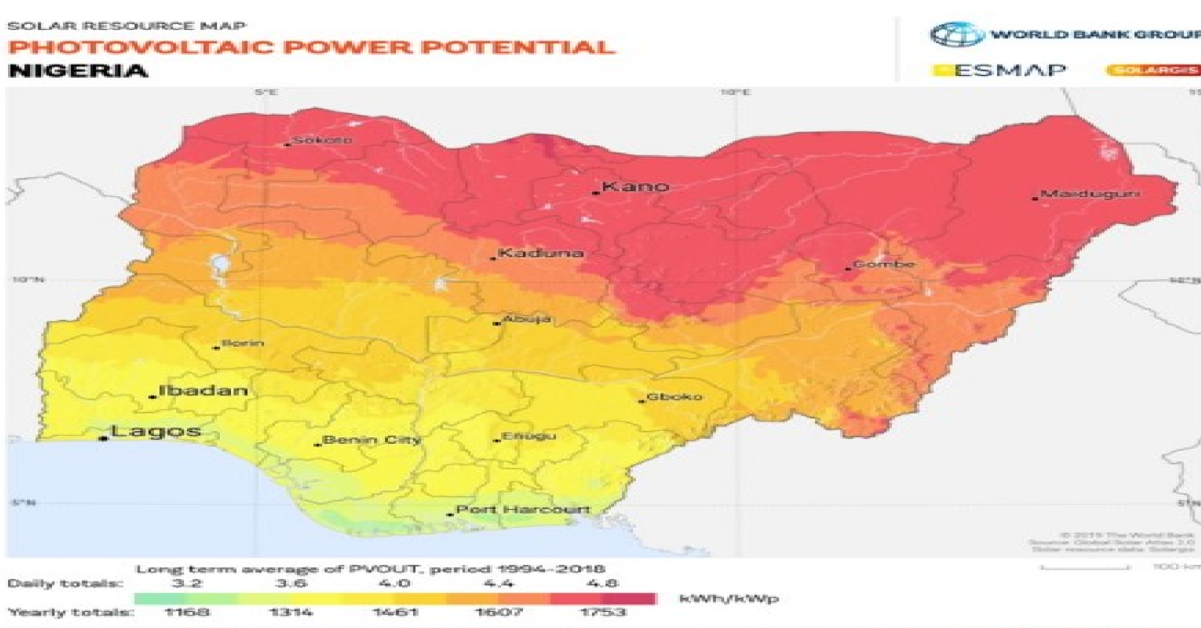


Fig 2: Solar Potential: ***Source:*** Global Solar Atlas 2.0, Solar resource data: Solargis.

2.2 System Components Sizing

Energy Calculations: It is mandatory to determine or calculate the total energy or watt-hours required by a typical user per day before the sizing of system components. The table 1 shows a typical rural dweller or off-grid user household electrical appliances and average daily running hours

Table 1: A typical rural dweller or off-grid user household electrical appliances and average daily running hours

S/N	Appliance	Rating (W)	Qty	Total Rating	Running Hours/Day	AEUD
1	Light (Bulb)	60	8	480	4	1920
2	Light (CFL)	15	8	120	4	480
3	Ceiling Fan	60	5	300	3	900
4	Air conditioner	745	2	1490	3	4470
5	Phone	7	4	28	3	84
6	Electric Iron	1000	1	1000	1	1000
		Total Power		**3,418 or 3.148 KW**	**Total AEUD**	**8854 WH or 8.854 KWH**

Table 1 (Note: AEUD means Average Energy Usage per Day)

The calculation in table 1 above does not include load margin (within 10-25% range) and future load increase (within 10-25% range).

2.2.1 Photovoltaic Panels

The number of photovoltaic panels required is derived from AEUD (Average Energy Usage per Day). The table 2 shows number of Solar panels for the AEUD calculated in Table 1. There are different sizes of solar panels (110, 250, 300 peak wattage W_p). This paper used 250 W_P solar panel in the calculation.

Table 2: Number of Solar panels for the AEUD

S/N	AEUD(WH)	Sun Hours/Day	Power from solar panels (W)	Power Loss in panels etc	Actual Power from all panels (W)	Total of 250Wp Panels
1	8854	6	8854/6 = **1476**	30 %	1476 x 1.3 = **1919**	1919/250 = **8**

Total number of Solar Panels required = **17**

AEUD = 8854 WH

AEUD/ Sun hours = 1476 W

Average sun hours / day = 6

Power to be supplied by Solar Panels =

1476 W x 1.3 = **1919 W**

Power loss in panels, cables and accessories is taken to be 30%

Actual power demand from all solar panels including all losses =

1919/250 = 7.676

Number of 250 Wp panels =

There are basically three Photovoltaic panels: Monocrystalline, Polycrystalline, and Thin-film amorphous silicon. Monocrystalline is most efficient among the three and it is therefore selected for the design

2.2.2 Battery Capacity

The capacity (AH) of the battery required is essential to the reliable supply of electricity. The sizing of the battery should include de-rating factors such as depth of discharge (DOD), cable efficiency or power loss in the cable, inverter efficiency. The table 3 below shows the battery sizing.

Table 3: The battery sizing.

S/N	AEUD	Autonomy	Bus Voltage	Battery Capacity(AH)	De-rating Factors	Actual Battery AH
1	8854	5	12	(8854x5)/12= 3689.2	0.85x 0.70 = **0.6**	3689.2/.6= 6149
				Battery capacity required for the system		**6149 AH**

DOD (0.3-0.9) based on manufacturer data sheet. 0.85 was used for the calculation with 70% efficiency (30% loss in the cables, inverter, tilting angles,shading and accessories

Total de-rating factor = DOD x Efficiency

Autonomy Days = Number of days the battery storage system can effectively

$$\frac{\text{AEUD X Autonomy}}{0.85 \times 0.70 \times 12}$$

Actual Battery Storage Capacity required =

$$\frac{\text{6149AH}}{\text{200AH}}$$

Number of 200AH batteries required =

2.2.3 Inverter Sizing

The size of inverter is calculated thus:

System bus voltage chosen for the paper = 12V

Total power requirement from Table 1 = 3148 W

Required Inverter Power rating = 3148 x 1.1 = 3462.8 W

The inverter size required is 12V/ 3462.8 W

2.2.4 Charge / Discharge Controller

The charge controller is connected to the solar panels. Its function is to prevent overcharging of the batteries bank and reverse current flow. The two basic types of charge controllers are Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). The latter is more efficient than the former; therefore, 12V MPPT charge controller is chosen for this work.

2.2.5 Cable Sizing

There are voltage drops in cables due to length of runs, ampacity or current flowing in the cable, and size of cable in mm^2. The permissive maximum voltage drop in cable is limited to 4%; based on this, the maximum permissible voltage drop in 24 V system is 1V (0.04 x 24V = 0.96V).

To achieve maximum cable efficient and limit the voltage drop, the selection of cable size (mm^2) is given thus:

cable size (mm^2) = 0.08 x length of runs x ampacity.

2.2.6 Wind Turbine Sizing

The theoretical power output (P_T) of a wind turbine is given by the equation:

$P_T = \rho \times A_T \times V^3$ OR $0.5 \times \rho \times A_T \times V^3$

Where:

ρ = density of air (kg/m^3)

A_T = Swept area of the wind turbine which is a function of the blade length

V^3 = cubic of the wind speed

$P_{avail} = 0.5\rho A_T V^3 C_p$ Available power of the Wind Turbine is govern by Betz limit as expressed by power coefficient (C_p) is given by:

16 or 59%

Power coefficient (C_p) is actually the turbine efficient; which by Betz limit is

$$r = \left[\frac{2 P_{avail}}{\rho \times 3.142 \times V^3 \times Cp}\right]^{1/2}$$

$$r = \left[\frac{2 \times 3148}{1.1 \times 3.142 \times 4.5^3 \times 0.40}\right]^{1/2}$$

m

m

r = 7.01m i.e wind turbine blade length should not be less than 7 metres

The two basic types of wind turbine are HAWT (Horizontal Axis Wind Turbine) and VART (Vertical Axis Wind Turbine). The turbine selected in this paper is VART: 4KW

The power coefficient (C_p) of wind turbine manufacturer data sheet is the range 0.30 – 0.45; C_p of 0.40 is chosen in this paper for the sizing of turbine blade.

The wind turbine blade sizing is done with the data below:

Power required from wind turbine = 3148 W from Table 1

Power coefficient (C_p) = 0.40

ρ [density of air (kg/m^3)] = 1.1 kg/m^3

Average wind speed in Northern Nigeria = 4.5 m/s at 10m tower hub height

$A_T = \pi r^2$ -------- swept area of the turbine

Where:

r = radius of the wind turbine swept area; r is also the wind turbine blade length

with 7m blade length). The VART type is selected because it has a low cut-in speed (typically 2.1m/s), it can receive wind from any direction, and it has a very simple design.

3. RESULTS

In this paper, design methodology and procedure for the sizing and selection of system components of Off-grid/Islanding solar-wind hybrid system are considered. The effectiveness of the renewable energy is achieved by using more than one renewable energy source. This will ensure that one augment the other due to seasonal variation or weather condition and reduce the number of batteries and the size of storage system calculated in section 2.2.2.

The paper does not include the sizing and selection of standby fossil fuel (e.g diesel generator) which may be required for emergency in critical areas like Intensive Care Unit of hospital.

4. CONCLUSION AND RECOMMENDATION

The application of solar-wind hybrid system for provision of reliable and sustainable electricity to rural dwellers with no connection to national grid has been employed in this paper. This will ensure sustainable development and improve the living standard of rural dwellers – employment opportunities due to increase in the number of small scale businesses, increase in health and recreational facilities. It is more economical for government to provide incentives to the users and importers of renewable equipment than investing in costly power infrastructure for remote locations. Also renewable energy is environmentally friendly because of its reduction of carbon footprint.

This paper recommends that individuals and Nigerian government should adopt hybrid of renewable energy source to reduce number of storage batteries. It will be cost effective and prevents environmental challenges associated with the proper decommissioning of batteries due to aging or attainment of their lifespan.

REFERENCES:

M.F. Akorede, O. Ibrahim, S.A. Amuda, A.O.Otuoze, B.F.Olufeagba “Current Status and Outlook of Renewable Energy Development in Nigeria”

W.O. Idris, M.Z. Ibrahim and A. Albani “The Status of the Development of Wind Energy in Nigeria”

S.O.Oyedepo, T. Uwoghiren, P.O.Babalola, et al “Assessment of Decentralized Electricity Production from Hybrid Renewable Energy Sources for Sustainable Energy Development in Nigeria”

S.A.Sambo “Strategic Developments in Renewable Energy in Nigeria”

I.Oghogho, O. Sulaimon, B.A. Adedayo, et al “Solar Energy Potential and its Development for Sustainable Energy Generation in Nigeria”

W.Zhon, C.Lou, Z. Li, et al “Current Status of Research on Optimum Sizing of Stand-alone Hybrid Solar-Wind Power Generation Systems”

G. Ofualagba "Technical Trainings on Solar-Wind Power"

Z.Girma "Hybrid Renewable Energy Design for Rural Electrification in Ethiopia"

G. Halasa"wind-Solar Hybrid Electrical Power Generation in Jordan"

N.A. Idris,H.S. Lamin,M.J. Laden et al "Nigeria's wind energy potentials: the path to a diversified electricity generation-mix"

PROPER ENERGY MIX FOR RAPID RURAL DEVELOPMENT AND POVERTY ALLEVIATION IN NIGERIA

Engr. Dr. Hachimenum Nyebuchi Amadi, *MNSE, FNIPE, FNIEEE, SMIEEE*
Department of Electrical and Electronic Engineering,
Rivers State University, Port Harcourt.
hachimenum.amadi@ust.edu.ng, +2349030209994

ABSTRACT

Energy access is vital to the development and improvement of rural living standards. The need for increased energy access to enhance sustainable development and poverty alleviation in the rural areas of Nigeria cannot be overstressed. Energy access facilitates economic development and subsequent improvement of human living conditions. Increased energy access reduces the time spent by rural women and children especially in collecting biomass for cooking thereby creating more time for women to become better empowered to discharge their social roles and children to read their books. One key strategy to achieve a sustainable increase in energy supply is the adoption of a proper energy mix. This paper reviews Nigeria's energy potentials and the impact of energy access on the development and living conditions of the rural populace in the country. The paper concludes by proposing an appropriate energy mix that would enhance rapid development and poverty alleviation in the rural areas of Nigeria.

Keywords. Energy Access, Energy Mix, Rural Development, Rural Electrification, Rural Poverty Alleviation, Sustainable Development.

1. INTRODUCTION

Globally, rural areas are faced with challenges of shortages in energy supply. Lack of access to energy makes it difficult for small-scale enterprises in rural areas to adopt new technology that connects them to modern markets and value chains necessary for the growth of their businesses and subsequent improvement in their welfare (IFAD, 2018).

The absence of electricity in most rural areas in Nigeria has impeded socio-economic development and resulted in increased rural-urban migration in the country. The country has an estimated total population of about 200 million, 48.04% of which are in rural areas without access to electricity (Trading Economics, 2021). The government had the plan to increase electricity access from 75% in 2020 to 90% in 2030 (FMPWH, 2015; Okoye et al.,2017) this dream is not being

realized as a significant percentage of the rural populace is still without access to electricity and this has contributed greatly to the reduction in the level of meaningful development and raised the poverty level among the people in the country's rural areas (Iyabo, 2020).

Energy access is necessary to achieve sustainable development and reduction of poverty worldwide. Energy availability stimulates job creation, industrial activities, enhances transportation and reduces poverty (Hussein & Filho, 2012). In Nigeria, poverty has become a major national challenge that must be addressed through rapid development. Increased energy access in the country is necessary to achieve sustainable rapid rural development and reduction of rural poverty nationwide. This study is aimed at reviewing the energy potentials of Nigeria and the impact of increased energy access on the development and living conditions of her rural populace.

Adequate electricity supply enhances output for small-scale businesses engaged in activities such as sewing knitting, welding etc. Electricity helps power machinery for activities that take the place of manual ones. Electrically-powered machines have been proven to be more efficient and yield higher revenue and profits than manually operated ones. Businesses in areas with access to the grid are known to be 16.2% more profitable than those in areas not hooked up to the grid (Akpan et al, 2013; Iyabo, 2020).

2. NIGERIA’S ENERGY POTENTIALS

Nigeria has an abundance of fossil and renewable energy resources. Tables 1 and 2 show Nigeria’s fossil energy potentials and renewable energy potentials respectively. It is estimated that Nigeria’s oil reserve will deplete in the next 42 years while the gas reserve will last 120 years (SEFORALL, 2016). The country also has plans to harness its nuclear energy resource.

3. THE IMPACT OF ENERGY ACCESS ON RURAL DEVELOPMENT

The International Energy Agency (IEA) defines “energy access” as "a household having reliable and affordable access to both clean cooking facilities and to electricity, which is enough to supply a basic bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average" (IEA, 2021).

Energy access is necessary for the growth of the economy of any nation. The standard of living of a country is directly proportional to its per capita energy usage. The latter is a metric for a country's per capita income as well as its overall prosperity (Rai, 2004).

In Nigeria, successive governments have developed several policies to support their efforts at improving the energy situation by using renewable energy resources in rural areas. Some of these policies are the National Energy Policy (NEP) 2003, the Renewable Energy Master Plan (REMP) 2005 and 2012 (Update), Draft Rural Electrification Strategy and Plan (RESP) 2015 and National Renewable Energy and Energy Efficiency Policy (NREEEP) 2015.

Yet not much achievement has been recorded in electricity supply to these areas.

Table 1. Fossil energy potentials (Uzoma & Amadi, 2019)

Energy Type	
Coal	600 million metric tons (Proven reserve)
	3 billion metric tons (Inferred reserve)
Crude Oil	37.2 billion barrels (Proven reserve)
	2.2 million barrels/day as at 2009 (Production)
Natural Gas	5.2 billion cubic metres (Proven reserve)
	25% (Production)

Table 2. Renewable energy potentials (Uzoma & Amadi, 2019)

Energy Type	
Hydropower	10,000 MW (Large-scale power estimate)
	734 MW (Small-scale power estimate)
Solar	25.2 MJ/m^2-day to 12.6 MJ/m^2-day, North-South (Annual average total solar radiation)
	Average 6 hours daily sunshine has an energy capacity of around 5.08*1012 KWH
Biomass	9,041,000 ha (9.9% of Nigeria's landmass)
Wind	3.0 m/s to 5.12 m/s: South to North at 10m height (Average wind speed)
	4.51 to 21.97 watts per square metre apiece (Maximum extractable power per unit area)

4. THE IMPACT OF ENERGY ACCESS ON RURAL POVERTY ALLEVIATION

The relationship between energy and poverty is established in the literature (USAID, 2002) including World Bank reports (World Bank, 1996). World Bank report on economic growth in countries like Colombia and Mexico, for instance, shows that a 10 per cent improvement in infrastructure can result in a reduction in poverty level by three-quarters of a percentage point (World Bank, 2001). Access to affordable, reliable, and sustainable energy for all is the seventh United Nations Sustainable Development Goal. Access to modern energy stimulates economic growth and human development (United Nations, 2018). A look at Table 3 shows that energy access achieves much of the Millennium Development Goals (MDGs).

Table 3. Energy linkages to the Millennium Development Goals (UNDP, 2015)

MDG	Energy linkages
1. Eradicate extreme poverty and hunger	Employment generation, increased industrial development, agricultural processing, refrigeration and transport of crops.
2. Achieve universal primary education	Lighting, television and communication can help improve the delivery of education services and attract teachers to isolated rural areas. Relieve physical labour so young girls have time to attend school.
3. Promote gender equality and empower women	Women are responsible for most household cooking and water-boiling activities. This takes time away from other productive activities as well as from educational and social participation.
4. Reduce child mortality	Diseases and illnesses resulting from unboiled water and indoor air pollution from traditional fuels and stoves directly contribute to infant and child disease and mortality.
5. Improve maternal health	Women are disproportionately affected by indoor air pollution and water and food-borne illnesses. Daily drudgery and the physical burden of fuel collection and transport contribute to poor maternal health conditions, especially in rural areas.
6. Combat HIV/AIDS, malaria and other diseases	Electricity for communication can spread important public health information. Health care facilities require illumination, refrigeration, sterilization to deliver health services.
7.Energy environmental sustainability	Cleaner energy systems and improved energy efficiency are needed to address all detrimental effects of energy production, distribution and consumption. National and

	local policies are needed to ensure the mitigation of environmental impacts associated with the use of fossil and non-sustainable fuel supplies.
8. Develop a global partnership for the development	Partnerships are essential for increasing energy access and supply to help meet the MDGs.

Ravago et al (2018) focus on the limited access to electricity as a hindrance to improving the well-being of poor families in the Philippines. It provides a strong association between electricity use and poverty in the country using data evidence from some select families.

The presence of electricity can stimulate economic growth at the different levels of the nation's economy. Poverty (whether income or non-income) can be improved upon through improvement in education and domestic tasks brought about by the provision of a reliable electricity supply (Ravago et al, 2018).

5. POVERTY LEVEL IN NIGERIA'S RURAL COMMUNITIES

Despite Nigeria's abundant natural resources, the poverty level remains high. According to available data, approximately 69 million Nigerians lived in poverty in 2004, an increase of more than 24 per cent since 1980 (Omonona, 2009). Nigeria's national poverty profile for 1980-2004 is shown in Figure 1. The poverty level has consistently risen since 1980, though the value declined during the period 1985-1992 and 1996-2004. The national poverty rate was 65.6 % in 1996 and 54.4 % in 2004, according to national poverty surveys conducted in 1996 and 2004. In 1996, the poverty depth (P1) and severity (P2) were 0.358 and 0.207, respectively, while they were 0.225 and 0.122, respectively, in 2004. (Figure 2) (Omonona, 2009). Rural poverty, however, was repeatedly much higher than urban poverty

during the period, 1996- 2004. In 1996, over 70% of rural households were poor, compared to only 58 % of urban households.

In 2004, urban poverty decreased at a quicker rate than rural poverty, with 64 % of rural families (a 6% decrease) and 15% of urban households being poor (a 43 % decrease). The other poverty indicators follow a similar pattern (depth and severity). It's worth noting that, as shown in Figure 2, rural households have a larger incidence, depth, and severity of poverty than national poverty estimates, whereas urban households have a lower incidence, depth, and severity of poverty. In 1980, the percentage of poor people in rural areas increased from 28.3 % to 63.8 %. (See Figure 1) (Omonona, 2009). Within rural communities in 2004, nearly 45 per cent of families were unable to afford food while nearly 20 per cent that could afford it lacked other basic needs (Omonona, 2009).

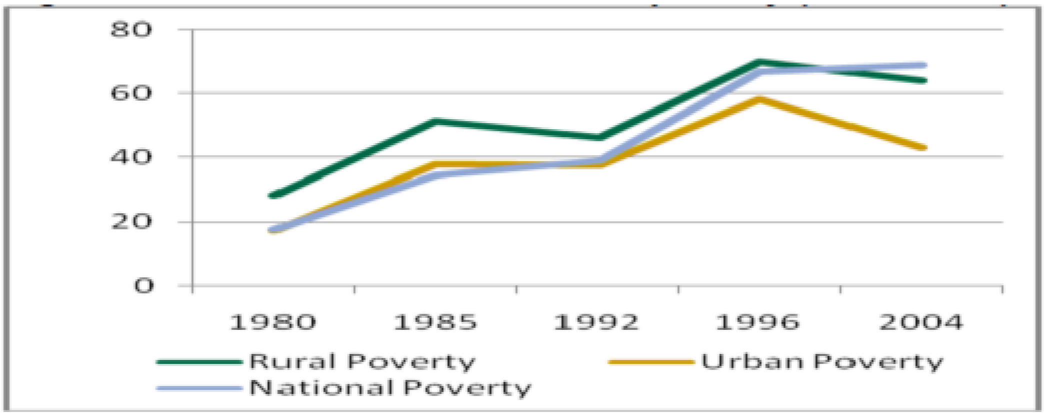


Figure 1. Trends in rural and urban poverty (1980- 2004) (Omonona, 2009)

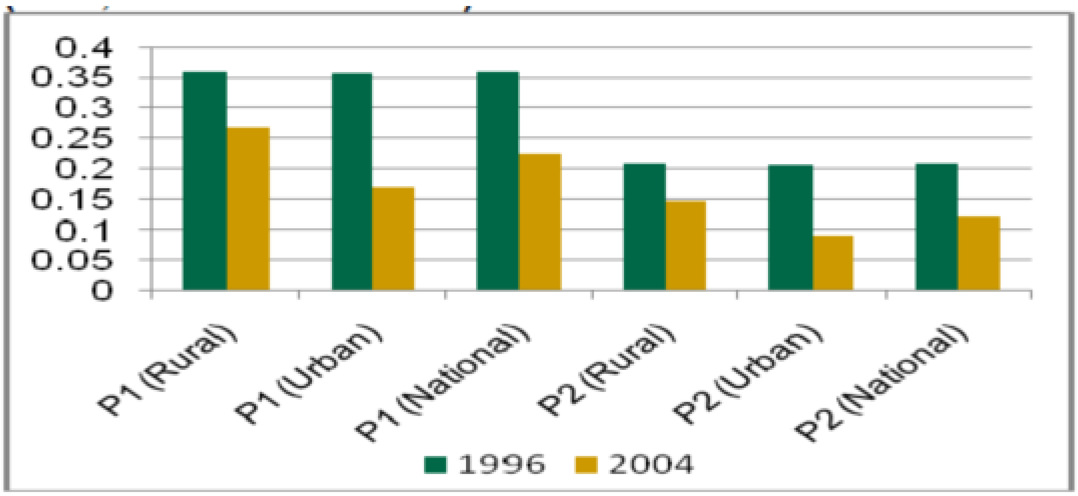


Figure 2. Poverty depth (P1) and Severity (P2) (Omonona, 2009).

6. ENERGY MIX LEADS TO SUSTAINABLE INCREASE IN ENERGY ACCESS

The energy mix refers to the classes of primary energy sources from which the different types of energy consumed in the country were derived (Paris Innovation Review, 2014). It describes the different energy sources that were combined to meet a country's energy needs (Wikipedia, 2021). The energy mix is determined by the energy resources that are freely available in a country (TUTOR2U, n.d.). The choice mix is dependent also on the country's level of development. Among developed and developing countries, oil and other petroleum products are commonly used in transportation (Brazil uses more biofuels derived from cane sugar). To ensure the

availability of electricity, each country chooses a specific mix based on what resource is naturally available and to counterbalance the cost of importing that same resource. Many countries like Japan, China and India, however, prefer to import and burn coal due to its relatively low cost (Paris Innovation Review, 2014).

Energy access depends on the level of energy security, which is in turn determined by the diversity in the energy mix. Diversifying the energy mix through investments in renewable energies enhances energy security and therefore increased energy access. About 40 per cent of the electricity used in the world today is derived from coal. Coal is the main energy in use in Poland, the USA and Australia. Norway, Brazil or Canada rely mostly on hydroelectric power while France, Sweden and Belgium depend majorly on electricity generated from nuclear power. Most countries adopt a mix that is highly diversified being comprised of coal, hydro, gas and nuclear. Most rural communities in the less developed countries rely mainly on wood to cook food, boil water and heat their homes. Unfortunately, this practice contributes to deforestation and is harmful to the climate. India has about 500 million people in its rural areas without access to energy services. The use of locally sourced biomass and the increasing reliance on fossil fuels there are contributing to environmental challenges and climate change (GIZ, n.d.).

The Economic Research Institute for ASEAN and East Asia (ERIA) defined the term “Best Energy Mix” as “the combination of energy resources available to a target community that achieves the maximum positive impacts for the three pillars of sustainability, namely, environmental, economic, and social[aspects].” (ERIA, 2015, P.3). There is no ideal energy mix because no country can be said to have completely tackled the climate change challenge. Every country depends significantly on fossil fuels despite its emission of large quantities of CO2 when burnt thus being a major cause of global warming. Besides, fossil fuels are not infinitely available (Paris Innovation Review, 2014). Countries like France and Sweden depend less on fossil fuels because they generate electricity from hydro and nuclear power plants.

7. NIGERIA’S ENERGY MIX

The government has since settled for renewable sources such as biomass and solar to produce electricity mostly for rural areas that cannot be reached by distribution companies. The government, through the Rural Electrification Agency (REA), has in the recent past commissioned some solar electrification projects in some of these rural areas (ITA, 2021). Nigeria's energy profile shows the following energy mix:

biomass (81.25%), natural gas (8.2%), petroleum products (5.3%), crude oil (4.8%), hydropower (0.4%) and others (< 1%). It is expected that nuclear energy will constitute 2.5% of the electricity mix by 2025 and 4.5% by 2030 (Uzoma & Amadi, 2019). Reports show that increased adoption of renewables in the Senegalese rural areas resulted in decreased biomass consumption, reduction in both respiratory problems and infant mortality equity as well as increased time for women due to a decrease in time spent in gathering biomass for domestic use etc. (Thiam, 2011). Nigeria's rural populace can experience the same. Interestingly, the country has biomass, hydropower, solar, wind etc. energy resources. In terms of sustainability, reports on Europe and other parts of the world indicate that renewable energy can produce electricity to feed big industries. Given the obvious low development and high poverty level in Nigeria's rural communities, strengthening the energy sector and increasing electricity access in these areas through increased investment in the development and adoption of renewables is the most viable way to stimulate rapid rural development and facilitate the alleviation of rural poverty. The increased adoption of renewables in the nation's energy mix is the best and the easiest way to solving the country's perennial energy crisis.

8. CHALLENGES OF RENEWABLE ENERGY INTEGRATION IN NIGERIA

Renewable energy adoption, development and integration in Nigeria is faced with many challenges including the following:

- The high startup cost is among the major reasons for the low-level adoption of renewable energy technologies in Nigeria. The high initial investment cost is affecting greatly the inclusion of more renewables in the nation's energy mix (Oluwatoni, 2017).
- In addition to high initial investment cost, shortage of funds is another major factor affecting renewable energy integration in Nigeria. For instance, the Government had to cut the 2017 budget allocations for power projects due to inadequate funds. The Mambilla Project was sliced from N950 m to N500 m, the 215 MW dual plant was reduced from N5 billion to N4 billion, the Zungeru power project from N1.3 billion to N1 billion and the Katsina wind farm from N904 m to N804 (Oluwatoni, 2017).
- Despite lack of funds for integration of renewable in Nigeria, most Nigerians are unaware of the benefits of the use of renewable energy to their social and economic well-being. Many believe that the country is not mature for the adoption of renewable energy technology and that the technology does not work (Oluwatoni, 2017).

- Worse still, Nigeria is good at reviewing policies severally without passing these policies into law. An example is the biofuel policy which though severally reviewed is yet to be passed into law. Most Government policies even after being passed into law are hardly implemented and this creates doubts in investors and discourages them from making investments (Oluwatoni, 2017).
- Notably, there is currently inadequate incentives that could encourage private investors to go into renewable energy development in Nigeria. The existing incentives are not as encouraging as those for conventional energy sources, the latter having been much incentivized over the years. Besides, there is too much bureaucracy in securing these incentives especially the waiver on import duty and this often leads to importers paying unnecessary demurrages (Oluwatoni, 2017).
- The Nigerian government is not good at starting and completing projects including renewable energy projects. The country suffers also from massive corruption characterized by mismanagement and embezzlement of funds and these hinder the successful adoption of renewable energy technology. Sometimes funds allocated to projects are not accounted for. An example is the N9.2 billion said to have been budgeted for the clean cooking stoves project but which is neither here nor there (Oluwatoni, 2017).
- The abundance of renewable energy resources in Nigeria notwithstanding, there is an acute shortage of indigenous technologies for renewable energy utilization and this makes adoption of the technology more expensive as the country has to depend on the importation of these technologies. This is coupled with a shortage of manpower with cognate technical expertise in the technologies (Oluwatoni, 2017).
- Most of the renewable energy technologies in Nigeria are imported without a trademark certificate or logo. This is possible because Nigeria lacks national standards. Besides, the renewable energy technologies market is currently unregulated, thus the quality of the imported renewable energy technologies cannot be ascertained; not even the Customs Officers know the required codes that should be adhered to by manufacturers (Oluwatoni, 2017).
- Most times when there is a change of government in Nigeria, many already existing or planned projects are abandoned by the succeeding

government. This is another reason for the slow adoption of renewable energy in the country. For example, the Katsina wind farm project was initiated by the Musa Yar'Adua government in 2010 only to be abandoned by Goodluck Ebele Jonathan and resuscitated later when the Mohammadu Buhari administration came to power in 2015 (Oluwatoni, 2017).

9. CONCLUSION AND RECOMMENDATIONS

The proper energy mix is a key strategy for enhancing energy availability and promoting sustainable development and poverty alleviation in rural areas in Nigeria. An appropriate energy mix will help provide adequate clean fuels to enhance basic household activities. Integration of more renewable energy resources will also lead to increased mechanized agricultural activities due to the availability of liquid fuels and electricity to the rural dwellers. This also will facilitate the provision of clean and cheap electricity to attract and encourage industrial activities thus combating rural-urban migrations by creating well-paying jobs (Goldemberg, n.d.) while at the same time reducing poverty levels among the rural dwellers.

Nigeria is rich in both solar and biomass energy resources. Solar energy can be deployed to power water pumping machines, water heaters, sewing and knitting machines, refrigerators/cooling systems as well as crop drying machines in the country's rural areas. Biomass, like solar photovoltaic (PV) cells, can easily be used off the grid in rural areas. Biomass though harmful to the environment but Federal Government can toe the line of the Lagos State Government which in 2012 adopted biomass by converting municipal waste to clean energy.

Government should develop and vigorously implement a strategic policy framework for the adoption of renewable energy so that the country can take better advantage of the much available renewable energy resources. This will enhance energy access for education, portable water provision, improved health centre services thereby facilitating socio-economic development and poverty alleviation by creating job opportunities among the nation's rural dwellers. It is imperative hence to harness the non-fuel wood biomass energy sources such as municipal wastes as this will help reduce desertification arising from the continued use of fuelwood in the country.

This paper recommends that Nigeria adopts an energy mix comprised of biomass (75%), solar (9%), natural gas (8%), petroleum products (4%), crude oil (3%), hydropower (0.6%) and others (< 1%). This will reduce deforestation and promote the use of cleaner energy in isolated, remote and rural areas of the country.

The Nigerian government should encourage and vigorously promote investment in clean energy sources and make appropriate institutional changes for transitioning Nigeria energy mix towards renewables. Increased investment in small solar PV installations, decentralized biogas projects and mini or small hydropower plants will contribute significantly to making electricity available to the country's rural areas. South-East Mali adopted decentralized power plants to supply mini-grids and the strategy resulted in to increase in rural electrification rate 'from 1% in 2006 to 11.9% in 2012 and 18% in 2014' (Béguerie & Pallière, 2016, Para. 1).

The Federal Government should also encourage the Local Governments and business developers to get more involved in rural electrification as a vehicle for the development of local industries and enhancement of living standards of citizens in the rural areas.

There should be a massive public enlightenment campaign about the benefits of renewable energy in other to correct the existing wrong impressions about its use in the country. The government should intensity effort also in educating the citizens on energy use and efficiency.

Nigerian Government should create better incentives to attract financial institutions, prospective investors and importers to support the increased adoption of renewables. Such incentives should include favourable exchange rates and duty waivers/concessions on renewable energy equipment.

REFERENCES

IFAD (2018). Empowering rural people by promoting renewable energy. Retrieved from https://www.ifad.org/en/web/latest/-/blog/empowering-rural-people-by-promoting-renewable-energy

Akpan, U., Essien, M., & Isihak, S. (2013). Impact of Rural Electrification on Rural Micro-enterprises in Niger Delta, Nigeria. *Energy for Sustainable Development* 17(5), 504–09.

Iyabo, A. O. (2020). Assessing the Effects of Rural Electrification on Household Welfare in Nigeria. *Journal of Infrastructure Development*, 12(1), 7–24.

FMPWH (2015). Federal Republic of Nigeria final draft rural electrification strategy & implementation plan (RESIP) for implementation by Rural Electrification Agency (REA). Retrieved from http://rea.gov.ng/wp-content/uploads/2017/09/RESIP.pdf

Okoye, P.U., Ezeokonkwo, J. U., & Nworji, G. C. (2017). Sustainability of Renewable Sources of Energy for Rural Communities in Anambra State. *Advances in Energy and Power* 5(4), 37-47. http://www.hrpub.org

Hussein, M.A. & Filho, W.L. (2012). Analysis of energy as a precondition for improvement of living conditions and poverty reduction in sub-Saharan Africa. *Scientific Research and Essays*. 7(30), 2656-2666. http://www.academicjournals.org/SRE

Trading Economics (2021). Nigeria - Rural Population. Retrieved from https://tradingeconomics.com/nigeria/rural- population-percent-of-total-population-wb-data.html

SEFORALL (2016). Federal Republic of Nigeria. Retrieved from https://www.seforall.org/sites/default/files/NIGERIA_SE

Uzoma, C. C & Amadi, K.C (2019). Energy Access: A Key to Rural Development in Nigeria. *Research & Reviews: Journal of Social Science*. 5(1). https://www.rroij.com/open-access/energy-access-a-key-to-rural-development-in-nigeria.php?aid=87509

IEA (2021). Defining energy access. Retrieved from https://www.iea.org/articles/defining-energy-access-2020-methodology

Rai, G.D. (2004). *Non-Conventional Energy Sources*. Delhi: Khanna Publishers.

USAID (2002). Evaluation and social impact evaluation study of the rural electrification program in Bangladesh. Retrieved from https://pdf.usaid.gov/pdf_docs/pdabz138.pdf

World Bank (1996). Rural energy and development - improving energy supplies for two billion people. Retrieved from https://digitallibrary.un.org/record/195551?ln=en

World Bank (2001). Making Infrastructure Reform Work for the Poor: Policy Options based on Latin American Experience. Retrieved from https://documents.worldbank.org/en/publication/documents-reports/documentdetail/169571468266160301/making-infrastructure-reform-work-for-the-poor-policy-options-based on-latin-american-experience

United Nations (2018). Transforming Our World: The 2030 Agenda for Sustainable Development. In A New Era in Global Health. Retrieved from https://connect.springerpub.com/content/book/978-0-8261-9012-3/back-matter/bmatter2

UNDP (2015). Energizing the Millenium Development Goals: A Guide to

Energy's Role in Reducing Poverty. Retrieved from https://www.undp.org/publications/energizing-mdgs-guide-energys-role-reducing-poverty

Ravago, M., Roumasset, J.A & Danao, R. (2018). *Powering the Philippine Economy: Electricity Economics and Policy* Quezon City: University of the Philippines Press.

Omonona, B. T. (2009). Quantitative analysis of rural poverty in Nigeria. NSSP Working Paper 9. Abuja, Nigeria. *International Food Policy Research Institute (IFPRI)*. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/27367

Paris Innovation Review (2014). A new Grail: the quest for an ideal energy mix. Retrieved from http://parisinnovationreview.com/articles-en/a-new-grail-the-quest-for-an-ideal-energy-mix

Wikipedia (2021). Energy Mix. Retrieved from https://en.wikipedia.org/wiki/Energy_mix

TUTOR2U (n.d.). Energy Mix. Retrieved fromhttps://www.tutor2u.net/geography/reference/energy-mix

GIZ (n.d.). India Renewable Energy Supply for Rural Areas 2008 to 2014. Retrieved from https://www.giz.de/en/worldwide/15847.html

ERIA (2015). Selecting the Best Mix of Renewable and Conventional Energy Sources for Asian Communities. Retrieved from https://www.eria.org/publications/selecting-the-best-mix-of-renewable-and-conventional-energy-sources-for- asian-communities/

ITA (2021). Nigeria - Country Commercial Guide. Retrieved from https://www.trade.gov/country-commercial-guides/nigeria-electricity-and-power-systems

Thiam, D.R. (2011). Renewable energy, poverty alleviation and developing nations: Evidence from Senegal. *Journal of Energy in Southern Africa*, *22*(3), 23–34. https://doi.org/10.17159/2413-3051/2011/v22i3a3219

Oluwatoni, O. O. (2017). Integrating Renewable Energy into Nigeria's Energy Mix: Implications for Nigeria's Energy Security. *Master's Thesis*. Norwegian University of Life Sciences, Norway. Retrieved from https://www.nmbu.no/fakultet/landsam/instituttt/noragric

Goldemberg, J (n.d.). Rural energy in developing countries. World Energy Assessment: Energy and the Challenge of Sustainability. Retrieved from https://www.undp.org

Béguerie, V. & Pallière, B. (2016). Can rural electrification stimulate the local economy? Constraints and prospects in south- east Mali. *OpenEdition Journals*. Special Issue 15, 20-25. Retrieved from https://journals.openedition.org/factsreports/4132

Proceedings of the 2021 National Engineering Conference
of the Nigeria Society of Engineers [NSE] .
Printed in Nigeria

RURAL ENERGY DEVELOPMENT: A PANACEA FOR POVERTY ALLEVIATION.

[1]Achekuogene, S. N., [2]Omoakhalen A. I, [3]Shuaibu-Sadiq M., Oyathelemi E. O.

[1]Works & Maintenance Dept, Auchi Polytechnic Auchi.

billans4u@yahoo.com, 08038970595

[2]Mechanical engineering dept, Auchi Polytechnic Auchi.

abdul_ismail2008@yahoo.ca, 08061649563

[3]Electrical & Electronic Dept, Auchi Polytechnic Auchi.

munerata@yahoo.com, 08038486751

[4]Minerals & Petroleum Recourse Eng. Auchi Polytechnic Auchi

eddielemi99@gmail.com, 08034258394

ABSTRACT

Poverty has been described as a global challenge and its alleviation is among the international institutions overarching goals. The UN general assembly of 2015 established sustainable development goal 7 (SDG7) to ensure access to affordable, reliable, sustainable and modern energy for all. Access to energy is a very important pillar for the wellbeing of the people as well as economic development and poverty alleviation. But, lack of access to energy is considered a core dimension of poverty. Although, Energy is not a basic human need, but it is required as a crucial input for providing other essential human needs. The satisfaction of these basic human needs and poverty alleviation efforts cannot be achieved without improving access to better energy services. This study therefore evaluates how energy development improves household welfare and socioeconomic status of rural dwellers. It further deals with the sustainability of rural livelihood through the use of traditional energy source and energy policies to alleviate rural poverty were also examined. The study findings established that the essential aspects of human welfare may improve only if energy becomes available within the rural community.

Keywords. Energy, poverty alleviation, rural development, rural communities

1. INTRODUCTION

Poverty creates terrible human suffering and wasted human potential, and it's urgent that we find solutions. Some solutions are obvious and widely popular, such as vaccines, free primary schooling and better nutrition. But we have also come to understand that energy is among the most important anti-poverty tools, an underpinning for other development goals. Yet energy access as a way to fight poverty is often greatly misunderstood. Energy is crucial, but in the search for solutions it is important to understand that energy supply is not a goal in itself, but only a means through which peoples' needs can be met (Hussein et al 2012).

According to Tisha Schuller and Seth Levey (2018), No one would argue that a single light bulb and cell phone charger are adequate to eliminate poverty. As a first step, however, they are critical. Light expands the hours available for both working and education and eliminates the burning of inefficient fuels that create health problems. Chargers increase connectivity and access to information. Economic development truly begins when energy expands to transform hard manual labor to other more productive pursuits. True economic development begins when energy can support farming, commercial development and, ultimately industrialization. Rural development is here refers to the physical, economic, social, human, and institutional changes that expand a communities capability to provide a good quality of life to its people while sustaining its natural resource base. Elimination of hunger and poverty is certainly one of the most fundamental objectives of rural development. The system of traditional energy supply always was and remains very much an integral part of village life. Any change in energy use (e.g. increased consumption) has far reaching consequences on other aspects of life and the rural environment.

Energy consumption levels of the majority of the rural population in developing countries are sufficient only to satisfy subsistence requirements according to a study commissioned by United States Agency for International Development (USAID). Modern sources of energy are required for the improvement of living standards of the rural community either by helping to create jobs or by boosting productivity. The principle of integrated rural energy strategy is defined as developing all possible local alternative resources of energy while rationally utilizing the current sources. Agriculture can have a major role in supporting rural livelihoods and community development through provision of locally sourced biomass energy. Wolfgang Lutz (2004), reveal that, in rural areas where almost 75% of the population lives, biomass (primarily firewood) accounts for more than 90% of energy needs. It may not be possible to replace this entirely with more modern energy forms but developing modern biomass technologies will be a key element for addressing the needs of rural areas. One of the important constraints is the inability to use modern technologies and renewable energy for decentralized power supply due to inefficient policies. According to Stephan Baas (1997), rural areas are facing two crucial and related problems in the energy sector. The first is the widespread inefficient production and use of traditional energy sources, such as fuelwood and agricultural residues, which pose economic, environmental, and health threats. The second is the highly uneven distribution and use of modern energy sources, such as electricity, petroleum products, and liquefied or compressed natural gas, which pose important issues of economics, equity, and quality of life. Expanding Access to reliable and abundant energy helps to create safe and prosperous communities. To support the creation of an increasingly prosperous society, a modern energy system must be affordable, sustainable, dispatchable, reliable and scalable. For poor rural people to escape from poverty, they must be able to improve their livelihoods in ways that they can cope with, and recover from stresses and shocks, while maintaining and enhancing their material and social assets and opportunities, both now and in the future, without undermining the natural resource base. Energy impoverished populations lack access to modern energy services to meet their basic human needs. Exploring the characteristics of this population requires discussions of basic human needs, modern energy services, and access.

2. SUSTAINING RURAL LIVELIHOOD THROUGH ENERGY SOURCES

Many rural communities do not have access to electricity or other forms of energy despite the available potentials of energy sources within the communities. The bulk of the energy consumed at the household level in rural areas is supplied basically from traditional sources of forest wood, dung and agro-residues. The role of agriculture as a source of energy producer with a view to strengthen and sustain effective energy supply in rural area must not be ignored since rural livelihood revolves around it. Consequently, for energy to be sustainable and improves the livelihood of rural dwellers, the energy mix must integrate all available sources of energy that will place emphasis on the readily sourced renewable energies of biomass, solar, wind and mini-hydro energy. This forms of energy will provide remote rural regions with the opportunity to produce their own energy (electricity and heat in particular), rather than importing conventional energy from outside. Being able to generate reliable and cheap energy can trigger economic development; contribute indirectly to poverty alleviation by improving productivity and enabling income. According to Douglas and Willem (1996), Agriculture can have a major role in supporting rural livelihoods and community development through provision of locally sourced biomass energy. Modern biomass systems such as briquettes offer an economically promising and environmentally sustainable means of increasing access to improved rural energy services. Biomass can produce all forms of energy, electricity, gas, liquid fuels and heat, and its exploitation can provide rural employment, encourage people to remain within their communities, increase profitability in the agriculture sector and help to restore degraded lands. A transition to modern energy systems, some of which may continue to use traditional energy sources but in new ways, needs to be achieved if sustainable economic activity is to be realized in rural areas. This is a slow process in which traditional energy technologies will co-exist with a gradual improvement and introduction of new technologies accompanying the rural development process. This often involves grid extension and off-grid such as solar home systems into rural areas. Grid extension is not economic for low density energy demands. Low density demand arises from a combination of the dispersed nature of the rural population and the low initial electricity consumption in low income households. Simply expanding supplies of modern energy will not solve the problems in practice, because even under the most optimistic growth scenarios, many rural people in the developing world are likely to still depend on traditional fuels produced in rural areas. Hence, an energy strategy for the rural community should be designed to make production and use of traditional energy more sustainable and efficient while expanding and accelerating a broader social transition to clean and efficient use of modern fuels. High connection and wiring costs can militate against households hooking-up to grid supplies even where the supply has reached their village (World Bank, 2000b). However, to attain sustainable energy in rural areas, all energy technology options are relevant: renewable energy, energy efficiency, grid extension, wind energy, hydro energy, diesel, kerosene, LPG, modern biomass, municipal solid waste, batteries, hybrids and inter-fuel substitution etc. Rural energy development works best when it develops functional linkages with core rural businesses, in particular agriculture, forestry, traditional manufacturing and green tourism. Rural energy development has to be well integrated within rural economies. This means that the choice and scale of projects reflects local opportunities. This golden rule should be respected regardless of whether energy is deployed for household use, environmental or to create new employment opportunities.

3. EFFECT OF ENERGY DEVELOPMENT ON HOUSEHOLD WELFARE AND SOCIOECONOMIC STATUS OF RURAL DWELLERS

According to Singh (1999) Energy access within agricultural activities has an important impact on agricultural yield's improvement, because energy access in this sector facilitates irrigation, harvesting, and post-harvesting activities which lead to more mechanization of agricultural process thereby resulting to increase food yields. Although priority might be placed on electricity for productive activities, such as food production, agro-industries and small scale rural industries, but the reality is that the household and community needs for lighting, space and water heating and small appliance power, need to receive rather more attention. Poverty as adopted by the 1995 Social Summit is viewed as a condition characterized by severe deprivation of basic human needs, including food, safe drinking water, sanitation facilities, health, shelter, education and information (UN, 2009). The benefits of energy to basic human needs of lighting, health, education and communication at the household level starts immediately through lighting, which is the primary use of electricity in most households, extended study hours for school-going children, knowledge and information access through electronic media (TV and radio), extended hours of operation for income generating activities, and increased productivity from electrically operated tools and machinery. This can be achieved through easy to access energy sources such as biomass, solar power, off-grid electrification etc. There is a variety of technologies that can convert biomass into more convenient energy carriers, such as gaseous and liquid fuels, process heat, mechanical power or electricity, which can be used in energy-efficient conversion devices (cook stoves, electric lamps, motors, refrigerators, etc.) to provide energy services. A multi- functionally energized engine which can drives several end-use devices such as cereal grinding mill, dehusker, oil press, carpentry and joinery tools, water pumping and mini-grid electricity can be driven or powered by diesel or bio- fuels produced from plants such as the Jatropha Curcas plant. Rural areas produce abundant wood supplies, crop residues, animal and human waste, and agro-processing residues such sugar cane bagasse, rice husks, cotton husks and groundnut shells etc. can all be used particularly for process heat or co-generation of energy. A decentralized energy-generation mechanism based on solar home system (SHS) through solar photovoltaics (PV) is another good means of promoting solar power as part of achieving rural energy development. SHS used for lighting, powering fans and television sets, and charging mobile devices and other electrical equipment etc. provides immediate benefit on study behavior of school going children, extending the working hours and the health of all household members. With solar-powered television, family members, including women, gain access to knowledge and information, which empowers them and helps them acquire capabilities and social interaction they did not have earlier. Families can earn income through small scale businesses such as hair saloon, renting out mobile phone–charging services etc. will enhance a robust market for socioeconomic development. Ultimately, solar-powered electricity facilitates a virtuous cycle of growth in household consumption and income. Improved household incomes and better access to social services by rural dwellers has a direct and positive impact on poverty reduction.

4. ENERGY POLICIES TO ALLEVIATE RURAL POVERTY

Energy development can contribute to providing improved livelihood for the rural dwellers and alleviate poverty as well. However, widespread diffusion of different energy-based systems faces strong institutional, technical and financial barriers that need to be overcome in order to improve their contribution to poverty alleviation. For successful rural development and poverty alleviation, partnerships and close interaction between Governments, Civil Society, the private sector and the poor themselves are needed. A national energy policies need to be focused on beneficiaries priorities and on affordability rather than only on technology. This is also most relevant for donor supported interventions which must recognise the importance of community involvement in project design and implementation. In this regard, government policies have a great role to play to effectively channel energy development programs in rural area. A multi-sectoral approach to policy formulation, project design and implementation will have the greatest positive impact on poverty reduction. In some cases central "top-down" energy programmes have been imposed without local community consultation, involvement or support, and insufficient institutional structures have led to disappointing results. Even in deregulated markets, few financial incentives exist for utilities to invest in rural energy schemes, and central policy direction from the government can hinder rural energy development. For example, independent power generation is often not permitted, or is controlled very tightly by government. Legislative and institutional weaknesses can create barriers to the development of local resources, and act as a disincentive for private investors or entrepreneurs to invest in rural energy markets. Making a positive connection between rural energy development and local economic growth will require more coherent strategies, the right set of local conditions, and a place-based approach to deployment. Government policy should avoid the problems of promoting particular technologies implementation across all rural areas because each community has area of cooperative advantage in energy generation. They should shift to providing technical assistance; establishing regulations and ensuring policies that encourage competition, development, safety; and providing loans for energy products that are in significant demand in rural areas. Governments should ensure a liberal trade policy for imported fuels, grid electricity and equipment to be used by rural communities, including liquid fuels and renewable energy products and components. Energy technologies such as improved methods for biomass production and use, solar-based agro-processing technologies, batteries, micro and small hydro, biogas, wind and ramp pumps should be encourage and subsidized for by the government. The goal is to provide a regulatory environment that ensures equal opportunity for different types of energy services.

5. CONCLUSION

No doubt, the mechanisms for the delivery of energy to rural communities are full of constraints. But they are also full of options. Energy's most efficient contribution to poverty alleviation may be as input to other activities and as an enabling factor. Access to modern energy services can contribute directly to poverty alleviation by improving the quality of life and effective social services delivery through better lighting (for home, school, event and social centers) reliable heating, access to cleaner cooking fuels and safe drinking water, refrigeration of vaccines and other medicines, sterilization of equipment in health centers, and improving their employment prospects. The provision of energy to rural communities must be examine in the context of the needs of beneficiaries to generate income, improve their access to quality life, education, health and clean water supply. The public sector, the private sector and financing institutions must join hands in exploring and exploiting all options for the delivery of modern energy services for the benefit of the rural communities. Appropriate energy policies framework and a long-term strategy combined with enlightened enabling conditions is required to stimulate economic growth and poverty alleviation in rural communities

REFERENCES

Baas, S., Rouse J., 1997. Poverty Alleviation: The role of rural institutions and participation: Land Reform Bulletin Vol .1 1997, FAO, Rome.

Douglas F. Barnes and Willem M. Floor (1996), Rural Energy in Developing Countries: A Challenge for Economic Development. Annual Review of Energy and the Environment. Vol. 21:497-530.

Muawya Ahmed Hussein and Walter Leal Filho (2012) Analysis of energy as a precondition for improvement of living conditions and poverty reduction in sub-Saharan Africa. Scientific Research and Essays Vol. 7(30), pp. 2656-2666.

Singh, I. et al. (1999). A Survey of Agricultural Household Models: Recent Findings and Policy Implications. The World Bank Economic Review 1(1): 149-79.

Tisha Schuller and Seth Levey (2018), To End Poverty, Increase Access to Energy - Scientific American Blogs blogs.scientificamerican.com › observations › to-end-poverty-increase-acce...

United Nations (2009). The millennium development goals report (2009). United Nations Department of Economic and Social Affairs (DESA) — July 2009, I S B N 978-9 2 - 1 - 1 0 1 1 9 6 – 8.

Wolfgang Lutz (2004), Potential for Energy Efficiency: Developing Nations Randall Spalding-Fecher, in Encyclopedia of Energy.

World Bank (2006). Energy Poverty Issues and G8 actions, World Bank Moscow-Washington

Three-Dimensional Buckling Analysis of Thick Plate Using an Improved Plate Theory

Onyeka, F. C.[1], Okeke, T. E.[2], Mama, B. O.[2]
[1]*Department of Civil Engineering, Edo State University, Uzairue, Edo State, Nigeria*

[2]*Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria*

Phone No: +2348068285789

Abstract: *An improved plate theory is applied for the buckling analysis of three-dimensional isotropic rectangular thick plate with all edges simply supported (SSSS) subjected to a uniaxial compressive load. In the analysis, both trigonometric and polynomial displacement functions were used. Total potential energy equation of a thick plate was formulated from the three-dimensional constitutive relations. Thereafter, the compatibility equations for the determination of the relations between the rotations and deflection were obtained. In the same way, governing equation was obtained through minimization of the total potential energy functional with respect to deflection. The solution of the governing equation is the function for deflection. Functions for rotations were obtained from deflection function using the solution of compatibility equations. These functions, deflection and rotations were substituted back into the energy functional, from where, through minimizations with respect to displacement coefficients, formulas for analysis were obtained. The proposed method obviates the need of shear correction factors which is associated with Mindlin's theory for the solution to the problem. From the previous studies in the literature. it is found that incomplete 3D or 2-D theory (refined plate theories) was used for the analysis, but for a typical thick plate analysis, a typical 3-D plate theory is required. The proposed method applied 3-D theory in the analysis to obtain the exact displacement function derived from the compatibility equation obtained from the elastic principle, unlike previous studies that used an assumed displacement function, and thereby over-predict the buckling load in the plate. The values of critical buckling loads obtained from the present study are in agreement with those obtained in the past studies using 3-D theory but varied with those of refined plate theories (RPT) by 7.70% signifying the coarseness of the RPT. Thus, confirming the accuracy and reliability of the derived relationships.*

Keywords. *3-D plate theory, compatibility governing equation, critical buckling load, trigonometric and polynomial displacement functions*

1. INTRODUCTION

The use of thick plate materials in engineering is on the increase over the years due to its attractive properties such as light weight, economy, its ability to withstand heavy loads and ability to tailor the structural properties.

The plates are mostly subjected to transverse and compressive loads acting in the middle plane of the plate. When a plate is subjected to axial load applied at the boundary parallel to the mid-plane of the plate and distributed uniformly over the plate's thickness, the state of loading is called an in-plane compressive loading [1]. In-plane loading causes a plate to buckle or become elastically unstable. The commencement of instability is called buckling [2]. Critical buckling load is the greatest load which causes an axially loaded plate to lose its stability. If the in-plane compressive load applied to the plate are further increased beyond their critical values, very large deflections and bending stresses will occur which will eventually lead to complete failure of the plate. To avoid failure of the plate, relatively more accurate and practical studies on stability analysis of plate are required.

The classical plate theory (CPT) based on Kirchhoff assumptions [3] is normally used to plate analysis. It was discovered the solutions based on the classical theory agree well with the full elasticity solutions (away from the edges of the plate), provided the plate thickness is small relative to its other linear dimensions. The classical plate theory is inconsistent in the sense that elements are assumed to remain perpendicular to the mid-plane, yet the equilibrium requires that stress component τ_{xz} and τ_{yz} which would cause these elements to deform still arise. In other words, the thin plate model still makes the assumption that normal stress and strain along the z axis (ε_z and σ_z) are zero. It was also assumed that the transverse shear stress (τ_{xz} and τ_{yz}) are zero. This assumption has discovered to have introduced errors, hence does not offer a very accurate analysis of plates in which the thickness-to length proportion is relatively large [4-6].

When the plate is relatively thick, one is advised to use a 3-D theory, for example one of the shear deformation theories. In the mid-1900s, the Mindlin shear deformation plate theory (or moderately thick plate theory theory) was developed to allow for possible transverse shear strains. In this theory, there is the added complication that vertical line elements before deformation do not have to remain perpendicular to the mid-surface after deformation, although they do remain straight [7-10]. This moderately thick theory plates are discovered to be more consistent compared with CPT, but it still makes the assumption that the normal stress along the z axis (σ_z) is zero. The theory also assumed transverse shear stress to be constant through the thickness of the plate, which violates the shear stress free surface conditions on the top and bottom surfaces of the plate [9 and 10]. Mindlin plate theory is a first order shear deformation theory (FSDT), thereby require a shear correction factor in the kinematics formulation to satisfy constitutive relations and achieve accepted transverse shear stress to the thickness of plate variation.

In [10], the authors applied assumed the hyperbolic shape function in their work on, the bending and vibration equations of thick rectangular plates while authors in [11], studied the buckling and vibration analysis of thick rectangular plate. Both authors in [10 and 11] used FSDT in their analysis. The FSDT has a limitation of inclusion of a shear correction factor. In avoiding shear correction factor and to get the realistic variation of the transverse shear strains and stresses through the thickness of the plate for improved reliability in the thick plate analysis, a higher order shear deformation theory (HSDT) were implored [12-15]. This HSDT, is an incomplete three-dimensional analytical approach because it does not include all the stress and strain in the plate, rather it neglect the strain and stress along the thickness direction (ε_z and σ_z). Authors in [17] used both first order shear deformation theory (FSDT) and higher order shear deformation theory (HSDT) in their analysis.

Previous scholars have studied the thick plate analysis using the incomplete three-dimensional theory for buckling [16-21]. This thick theory plates is discovered to be more consistent than Mindlin's theory (FSDT) but it still poses a limitation of zero vertical stress (σ_z) and strain (ε_z). In [16], the authors studied, stability and vibration of isotropic, orthotropic and laminated plates. They applied the higher-order shear deformation theory to obtain the governing equation for the buckling analysis of thick rectangular plate. They also performed the vibration analysis for both isotropic and orthotropic plates, while the authors in [17] studied the buckling and vibration of plates using hyperbolic shear deformation theory (HSDT).

In [18], the authors studied, buckling analysis of thick isotropic plates subjected to uniaxial and biaxial in-plane loads using exponential shear deformation theory (ESDT) and assumed exponential functions as their displacement functions. Another study was carried out by the authors in [19] using refined trigonometric shear deformation theory (TSDT) to obtain the buckling load of thick isotropic rectangular plates.

Authors in [20], used orthogonal polynomial displacement functions (OPDF) and a polynomial shear deformation function f (z) in the buckling analysis of isotropic thick rectangular plate subjected to uniaxial in-plane compressive loading, Nx. The same type of function (polynomial displacement shape function) was also applied by the authors in [21], in their work, the free vibration and stability analysis of thick isotropic and orthotropic plates with SSSS and SSFS support conditions were performed by applying the alternative II theory. Alternate II theory is perceived a shear deformation theory whose kinematics formulation involves the addition of the classical and shear deformation parts of the in-plane displacements to give the total in-plane displacements. This theory is an improvement on HSDT and FSDT as it obviates the need of a shear correction factor. Meanwhile, literature [22] proves that the formulated Alternative II relationship introduces some error in the result of the analysis. The Alternate I theory formulation circumvents the inclusion of classical plate theory part of the in-plane displacement in the formulation of the total in-plane displacement kinematics. This Alternative I theory is an improved FSDT (without shear correction factor) which is proved to be an improvement of the Alternative II theory [22] in the thick plate analysis.

From the previous studies in the literature, it is found that incomplete 3D or 2-D theory was used for the analysis, but for a typical thick plate analysis, a typical 3-D plate theory is required. A typical 3-D plate theory involves all the six strains $\left(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{xz}\ and\ \gamma_{yz}\right)$ and stress $\left(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}\ and\ \tau_{yz}\right)$ components, unlike the FSDT and HSDT plate theory which assumed that the strain normal to the x-y plane (σ_z) is so small that it can be neglected. $ie. (\sigma_z = 0)$. Furthermore, it is recorded that both Mindlin's theories (FSDT) and other higher shear deformation incomplete three-dimensional analysis are approximations of the elasticity three-dimensional equilibrium equations and cannot be reliable for thick plate analysis. This gap in the literature is worth filling.

In this research, an improved shear deformation theory (without shear correction factor) was applied in the three-dimensional (3-D) plate analysis under uniaxial compressive uniformly distributed load. The aim of this work is to study the exact three-dimensional stability analysis of thick rectangular plates with all edges under SSSS boundary conditions to determine the critical buckling load using the direct variational energy method.

The symbol w denotes deflection, the symbol u denotes in-plane displacement along x-axis, the symbol v denotes in-plane displacement along y-axis, the symbol θ_x denotes shear deformation rotation along x axis, the symbol θ_y denotes shear deformation rotation along the y axis, the symbol ε_x denotes normal strain along x axis, the symbol ε_y denotes normal strain along y axis, the symbol ε_z denotes normal strain along z axis, the symbol γ_{xy} denotes shear strain in the plane parallel to the x-y plane, the symbol γ_{xz} denotes shear strain in the plane parallel to the x-z plane, the symbol γ_{yz} denotes shear strain in the plane parallel to the y-z plane.

2. METHODOLOGY

Considering a section of plate in figure 1 under axial loading, the stress-strain relationship are analyzed by applying the established displacement and strain-displacement relation, to determine the value of stresses in the plate using generalized Hooke's law.

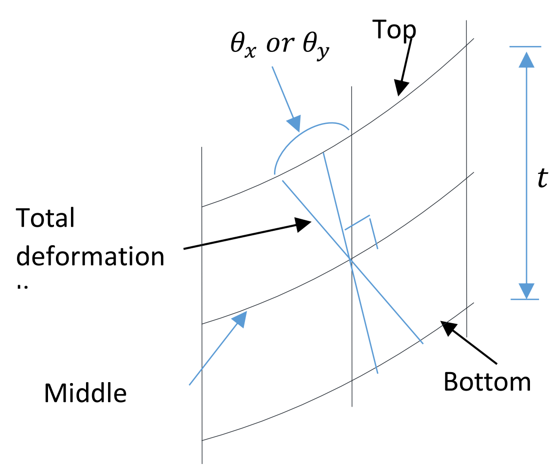


Fig. 1: Rotation of x-z (or y-z) section after bending

Using trigonometry, the relationship between the rotation along x-axis and y-axis (θ_x and θ_y), and displacement at x-axis and y-axis (u and v) are expressed as:

$$\theta_x = \frac{\partial u}{\partial z} \quad (1)$$

$$\theta_y = \frac{\partial v}{\partial z} \quad (2)$$

Assuming that the spatial dimensions of the plate along x, y and z-axes are a, b and t respectively. More so, the non-dimensional form of coordinates are R = x/a, Q = y/b and S = z/t corresponding to x, y and z-axes respectively.

$$\theta_x = \gamma_{xz} - \frac{1}{a}.\frac{\partial w}{\partial R} = \frac{c}{a}\frac{\partial w}{\partial R} \quad (3)$$

$$\theta_y = \gamma_{yz} - \frac{1}{a\beta}.\frac{\partial w}{\partial Q} = \frac{c}{a\beta}.\frac{\partial w}{\partial Q} \quad (4)$$

Where; the ratio of the length to breadth (b/a) is denoted as β while the ratio of the span to breadth (a/t) is denoted as α. The six stress elements are given in Equation 5 to 10:

$$\sigma_x = \frac{EtS}{(1+\mu)(1-2\mu)a}\left[(1-\mu).\frac{\partial\theta_x}{\partial R} + \frac{\mu}{\beta}.\frac{\partial\theta_y}{\partial Q} + \frac{\mu a}{St^2}.\frac{\partial w}{\partial S}\right] \quad (5)$$

$$\sigma_y = \frac{EtS}{(1+\mu)(1-2\mu)a}\left[\mu.\frac{\partial\theta_x}{\partial R} + \frac{(1-\mu)}{\beta}.\frac{\partial\theta_y}{\partial Q} + \frac{\mu a}{St^2}.\frac{\partial w}{\partial S}\right] \quad (6)$$

$$\sigma_z = \frac{EtS}{(1+\mu)(1-2\mu)a}\left[\mu.\frac{\partial\theta_x}{\partial R} + \frac{\mu}{\beta}.\frac{\partial\theta_y}{\partial Q} + \frac{(1-\mu)a}{St^2}.\frac{\partial w}{\partial S}\right] \quad (7)$$

$$\tau_{xy} = \frac{E(1-2\mu)tS}{2(1+\mu)(1-2\mu)a}.\left[\frac{1}{\beta}\frac{\partial\theta_x}{\partial Q} + \frac{\partial\theta_y}{\partial R}\right] \quad (8)$$

$$\tau_{xz} = \frac{E(1-2\mu)tS}{2(1+\mu)(1-2\mu)a}.\left[\frac{a}{tS}\theta_x + \frac{1}{tS}\frac{\partial w}{\partial R}\right]$$

$$\tau_{yz} = \frac{E(1-2\mu)tS}{2(1+\mu)(1-2\mu)a}.\left[\frac{a}{tS}\theta_y + \frac{1}{\beta tS}\frac{\partial w}{\partial Q}\right]$$

Where:
the symbol μ denotes poisons ratio, the symbol E denotes modulus of elasticity of the plate, the symbol σ_x denotes stress normal along x axis, the symbol σ_y denotes stress normal along the y axis, σ_z denotes stress normal along the z axis, the symbol τ_{xy} denotes shear stress along the x-y axis, the symbol τ_{xz} denotes shear stress along the x-z axis, the symbol τ_{yz} denotes shear stress along the y-z axis.

2.1. Equation of Energy Functional

The total potential energy function (Π) is the algebraic summation of strain energy (U) and external work (V). That is:

$$\Pi = U - V$$

That is:

$$\Pi = \frac{D^*ab}{2a^2}\int_0^1\int_0^1\left[(1-\mu)\left(\frac{\partial\theta_x}{\partial R}\right)^2 + \frac{1}{\beta}\frac{\partial\theta_x}{\partial R}\cdot\frac{\partial\theta_y}{\partial Q} + \frac{(1-\mu)}{\beta^2}\left(\frac{\partial\theta_y}{\partial Q}\right)^2 + \frac{(1-2\mu)}{2\beta^2}\left(\frac{\partial\theta_x}{\partial Q}\right)^2 + \frac{(1-2\mu)}{2}\left(\frac{\partial\theta_y}{\partial R}\right)^2 + \frac{6(1-2\mu)}{t^2}\left(a^2{\theta_x}^2 + a^2{\theta_y}^2 + \left(\frac{\partial w}{\partial R}\right)^2 + \frac{1}{\beta^2}\left(\frac{\partial w}{\partial Q}\right)^2 + 2a.\,\theta_x\frac{\partial w}{\partial R} + \frac{2a.\,\theta_y}{\beta}\frac{\partial w}{\partial Q}\right) + \frac{(1-\mu)a^2}{t^4}\left(\frac{\partial w}{\partial S}\right)^2 - \frac{N_x}{D^*}\cdot\left(\frac{\partial w}{\partial R}\right)^2\right]dR\,dQ \quad (12)$$

Where:

$$U = \frac{D^*ab}{2a^2}\int_0^1\int_0^1\left[(1-\mu)\left(\frac{\partial\theta_x}{\partial R}\right)^2 + \frac{1}{\beta}\frac{\partial\theta_x}{\partial R}\cdot\frac{\partial\theta_y}{\partial Q} + \frac{(1-\mu)}{\beta^2}\left(\frac{\partial\theta_y}{\partial Q}\right)^2 + \frac{(1-2\mu)}{2\beta^2}\left(\frac{\partial\theta_x}{\partial Q}\right)^2 + \frac{(1-2\mu)}{2}\left(\frac{\partial\theta_y}{\partial R}\right)^2 + \frac{6(1-2\mu)}{t^2}\left(a^2{\theta_x}^2 + a^2{\theta_y}^2 + \left(\frac{\partial w}{\partial R}\right)^2 + \frac{1}{\beta^2}\left(\frac{\partial w}{\partial Q}\right)^2 + 2a.\,\theta_x\frac{\partial w}{\partial R} + \frac{2a.\,\theta_y}{\beta}\frac{\partial w}{\partial Q}\right) + \frac{(1-\mu)a^2}{t^4}\left(\frac{\partial w}{\partial S}\right)^2\right]dR\,dQ \quad (13)$$

given that D^* is the Rigidity for three-dimensional thick plate, let

$$D^* = \frac{Et^3}{12(1+\mu)(1-2\mu)} = D\,\frac{(1-\mu)}{(1-2\mu)} \quad (14)$$

However, the external work for buckling load is given as:

$$V = \frac{abN_x}{2a^2}\int_0^a\int_0^b\left(\frac{\partial w}{\partial R}\right)^2 dR\,dQ$$

Where; N_x is the uniform applied uniaxial compressive load of the plate.

2.2. Equilibrium Equation

The minimization of the total potential energy functional with respect to θ_x and θ_y gives the two equilibrium equation in the form of compatibility equation as:

$$\frac{\partial\Pi}{\partial\theta_x} = \frac{D^*ab}{2a^2}\int_0^1\int_0^1\left[(1-\mu)\frac{\partial^2\theta_x}{\partial R^2} + \frac{1}{2\beta}\cdot\frac{\partial^2\theta_y}{\partial R\partial Q} + \frac{(1-2\mu)}{2\beta^2}\frac{\partial^2\theta_x}{\partial Q^2} + \frac{6(1-2\mu)}{t^2}\left(a^2\theta_x + a.\frac{\partial w}{\partial R}\right)\right]dR\,dQ = 0 \quad (16)$$

$$\frac{\partial\Pi}{\partial\theta_y} = \frac{D^*ab}{2a^2}\int_0^1\int_0^1\left[\frac{1}{2\beta}\cdot\frac{\partial^2\theta_x}{\partial R\partial Q} + \frac{(1-\mu)}{\beta^2}\frac{\partial^2\theta_y}{\partial Q^2} + \frac{(1-2\mu)}{2}\frac{\partial^2\theta_y}{\partial R^2} + \frac{6(1-2\mu)}{t^2}\left(a^2\theta_y + \frac{a.}{\beta}\frac{\partial w}{\partial Q}\right)\right]dR\,dQ = 0 \quad (17)$$

The solution to compatibility equations is:

$$\frac{6(1-2\mu)(1+c)}{t^2} = -\frac{c(1-\mu)}{a^2}\left(\frac{\partial^2 w}{\partial R^2} + \frac{1}{\beta^2}\frac{\partial^2 w}{\partial Q^2}\right) \quad (18)$$

2.3. General Governing Equation

The minimization of the total potential energy functional with respect to deflection (w) gives the equilibrium equation (Governing Equation) along the z-axis as presented in Equation 19. That is:

$$\frac{\partial \Pi}{\partial w} = \frac{D^*}{2a^2}\int_0^1\int_0^1 \left[\frac{12(1-2\mu)}{t^2}\left(\frac{\partial^2 w}{\partial R^2} + \frac{1}{\beta^2}.\frac{\partial^2 w}{\partial Q^2} + a.\frac{\partial \theta_x}{\partial R} + \frac{a}{\beta}\frac{\partial \theta_y}{\partial Q}\right) + 2\frac{(1-\mu)a^2}{t^4}.\frac{\partial^2 w}{\partial S^2} - 2\frac{N_x}{D^*}.\frac{\partial^2 w}{\partial R^2}\right] dR\, dQ = 0 \quad (19)$$

Substituting Equations 2, 3 and 18 into Equation 19 and simplifying the outcome gives:

$$\frac{D^*}{2a^4}\int_0^1\int_0^1 \left[\left(\frac{\partial^4 w}{\partial R^4} + \frac{2}{\beta^2}.\frac{\partial^4 w}{\partial R^2 \partial Q^2} + \frac{1}{\beta^4}.\frac{\partial^4 w}{\partial Q^4}\right) + \frac{(1-\mu)a^4}{gt^4}.\frac{\partial^2 w}{\partial S^2} - \frac{N_x a^4}{gD^*}.\frac{\partial^2 w}{\partial R^2}\right] dR\, dQ = 0 \quad (20)$$

Assuming the solution to be separable, it can be written that: Hence, the two possibilities of Equation 20 to be true is:

$$\frac{\partial^4 w_1}{\partial R^4} + \frac{2}{\beta^2}.\frac{\partial^4 w_1}{\partial R^2 \partial Q^2} + \frac{1}{\beta^4}.\frac{\partial^4 w_1}{\partial Q^4} - \frac{N_{x1} a^4}{gD^*}.\frac{\partial^2 w_1}{\partial R^2} = 0 \quad (22)$$

$$\frac{(1-\mu)a^4}{t^4}.\frac{\partial^2 w_S}{\partial S^2} = 0$$

Given that; $w = w_R.w_Q.w_S$ and $w_1 = w_R.w_Q$, thus; Equations 22 and 23 are the two governing equations of a 3-dimensional rectangular plate subject to pure buckling assuming that the at the extreme fibers (where S = ±0.5) the straining of the plate along z axis is allowed.

The solution to the governing differential equation of 22 gives the exact deflection (w) and rotation (θ_x and θ_y) functions in trigonometric and polynomial form as:

$$w = \Delta_0[1 \;\; R \;\; Cos\,(c_1R) \;\; Sin\,(c_1R)]\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix}.[1 \;\; Q \;\; Cos\,(c_1Q) \;\; Sin\,($$

$$w = \Delta_0\,[1 \;\; R \;\; R^2 R^3 R^4]\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \end{bmatrix}.[1 \;\; Q \;\; Q^2 Q^3 Q^4]\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix}$$

$$\theta_x = \frac{A_{2R}}{a}.\frac{\partial h}{\partial R}$$

$$\theta_y = \frac{A_{2Q}}{a\beta}.\frac{\partial h}{\partial Q}$$

Where:

$$A_{2R} = c.\Delta_0.\frac{\partial h}{\partial R}.A_Q$$

$$A_{2Q} = c.\Delta_0\frac{\partial h}{\partial Q}.A_R$$

The constants c, Δ_0, A_R and A_Q whose values are unknown, will aid the solution of direct governing equation.

2.4. Direct Governing Equation

The minimization of the total potential energy functional with respect to rotation coefficients (A_{2R} and A_{2Q}) gives the direct governing equation as presented in Equation 30 and 31:

$$\left[(1-\mu)k_{RR} + \frac{1}{2\beta^2}(23)(1-2\mu)k_{RQ} + 6(1-2\mu)\left(\frac{a}{t}\right)^2 k_R\right]A_{2R} + \left[\frac{1}{2\beta^2}k_{RQ}\right]A_{2Q} = \left[-6(1-2\mu)\left(\frac{a}{t}\right)^2 k_R\right]A_1$$

$$\left[\frac{1}{2\beta^2}k_{RQ}\right]A_{2R} + \left[\frac{(1-\mu)}{\beta^4}k_{QQ} + \frac{1}{2\beta^2}(1-2\mu)k_{RQ} + \frac{6}{\beta^2}(1-2\mu)\left(\frac{a}{t}\right)^2 k_Q\right]A_{2Q} = \left[-\frac{6}{\beta^2}(1-2\mu)\left(\frac{a}{t}\right)^2 k_Q\right]A_1 \quad (31)$$

Where:

$$k_{RR} = \int_0^1\int_0^1 \left(\frac{\partial^2 h}{\partial R^2}\right)^2 dRdQ\text{: } k_{RQ} = \int_0^1\int_0^1 \left(\frac{\partial^2 h}{\partial R\partial Q}\right)^2 dRdQ;\ k_{QQ} = \int_0^1\int_0^1 \left(\frac{\partial^2 h}{\partial Q^2}\right)^2 dRdQ;$$

$$k_R = \int_0^1\int_0^1 \left(\frac{\partial h}{\partial R}\right)^2 dRdQ;\ k_Q = \int_0^1\int_0^1 \left(\frac{\partial h}{\partial Q}\right)^2 dRdQ \text{ and } A_1$$ is the deflection coefficient.

Equations 32 and 33 are the solution to the Equation 32 and 33:

$$A_{2R} = G_2 A_1 \quad (32)$$

$$A_{2Q} = G_3 A_1 \quad (33)$$

Let:

$$G_2 = \frac{(c_{12}c_{23} - c_{13}c_{22})}{(c_{12}c_{12} - c_{11}c_{22})} \quad (34)$$

$$G_3 = \frac{(c_{12}c_{13} - c_{11}c_{23})}{(c_{12}c_{12} - c_{11}c_{22})} \quad (35)$$

$$c_{11} = (1-\mu)k_{RR} + \frac{1}{2\beta^2}(1-2\mu)k_{RQ} + 6(1-2\mu)\left(\frac{a}{t}\right)^2 k_R \quad (36)$$

$$c_{22} = \frac{(1-\mu)}{\beta^4}k_{QQ} + \frac{1}{2\beta^2}(1-2\mu)k_{RQ} + \frac{6}{\beta^2}(1-2\mu)\left(\frac{a}{t}\right)^2 k_Q \quad (37)$$

$$c_{12} = c_{21} = \frac{1}{2\beta^2}k_{RQ};\ c_{13} = -6(1-2\mu)\left(\frac{a}{t}\right)^2 k_R;\ c_{23} = c_{32} = -\frac{6}{\beta^2}(1-2\mu)\left(\frac{a}{t}\right)^2 k_Q \quad (38)$$

2.5. Direct Governing Equation

The solution of the direct governing equation is obtained by minimizing the total potential energy equation with respect to the deflection coefficient (A_1) to determine the formulae for calculating the buckling load of the plate:

Rearranging Equation 89 and using Equation 23, yields:

$$\frac{N_x a^2}{Et^3} = \frac{(1+\mu)}{2}\left(\frac{a}{t}\right)^2\left([1+G_2] + \frac{1}{\beta^2}.[1+G_3].\frac{k_Q}{k_R}\right) \quad (39)$$

Where:

N_x is the critical buckling Load of the plate

3. NUMERICAL PROBLEM

Determine the critical buckling Load of the rectangular ssss plate shown on Figure 3 for various aspect ratios and span-depth ratio. The Poisson's ratio of the plate is 0.25.

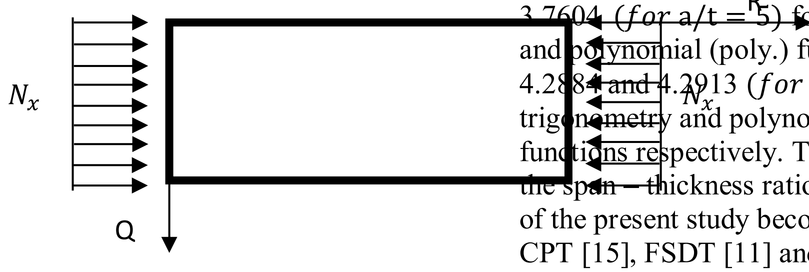


Fig. 2: SSSS rectangular thick plate

The deflection functions in Equation (24 and 25) after satisfying the boundary conditions in trigonometric and polynomial forms are presented in Equation (40) and (41) respectively as:

$$w = ASin\,(\pi * R)Sin\,(\pi * Q) \quad (40)$$

$$w = A(R - 2R^3 + R^4)(Q - 2Q^3 + Q^4) \quad (41)$$

The stiffness coefficients for the trigonometric and polynomial deflection functions are presented on Table 1.

Table 1: Stiffness coefficients of SSSS plate for trigonometric and polynomial forms of deflection function

Deflection form	k_{RR}	k_{RQ}	k_{QQ}	k_R	k_Q
Trigonometry	$\frac{\pi^4}{4}$	$\frac{\pi^4}{4}$	$\frac{\pi^4}{4}$	$\frac{\pi^2}{4}$	$\frac{\pi^2}{4}$
Polynomial	0.23619	0.235919	0.23619	0.0239	0.0239

4. RESULTS AND DISCUSSIONS

The present theory predicts 3.7582 and 3.7604 $(for\ \mathrm{a/t} = 5)$ for trigonometry (Trig.) and polynomial (poly.) functions respectively; 4.2884 and 4.2913 $(for\ \mathrm{a/t} = 10)$ for the trigonometry and polynomial displacement functions respectively. The results shows that as the span – thickness ratio increases, the results of the present study becomes closer to that of CPT [15], FSDT [11] and other shear deformation theory with incomplete 3-D [16, 17, 18, 19, 20] and 3-D plate theory [23]. Then, it can be said that the values obtained are in agreement with those obtained in the literature. Hence, confirming the accuracy and reliability of the derived relationships. For the non-dimensional values obtained, it reveals that the values of critical buckling load N_x increase as the span- thickness ratio increases.

The maximum percentage difference between the values from the present study and those of [11, 16, 17 and 21] is about 12.4% and 12.5% $(for\ \mathrm{a/t} = 5)$ for the trigonometry and polynomial displacement functions respectively. This means that at the 87% confidence level, the values from the present study are the same with those from of previous studies. Also, the maximum percentage difference between the values from the present study and those of [11, 16, 17 and 21] is about 11.5% and 11.6% $(for\ \mathrm{a/t} = 10)$ for the trigonometry and polynomial displacement functions respectively. This means that at the 88 % confidence level, the values from the present study are the same with those from of previous studies. It is observed that all the recorded percentage differences are higher than 7.70%. Then, it can be said that the values obtained are in agreement with those obtained in the literature. Thus, confirming the accuracy and reliability of the derived relationships.

The results of the critical buckling load for a rectangular thick plate with simply support at the four edges (SSSS). It reveals that the increase in the value of the length-breadth ratio $(\beta = 1.0, 1.5 \text{ and } 2.0)$ decreases the value of the critical buckling load N_x.

The average total percentage difference between the values from the present study [trig.] with 3-D theory [poly.], [23] and those of incomplete 3-D theory [18, 19 and 20] is about 0.89% and 8.79%, respectively $(for\ a/t = 5, 10, 20\ and\ 100$. Similarly, from Table 4, the average total percentage difference between the values from the present study [poly.] with 3-D theory [poly.], [23] and those of incomplete 3-D theory [18, 19 and 20] is about 0.91% and 8.85% respectively $(for\ a/t = 5, 10, 20\ and\ 100$.

Finally it is shown that, all the recorded the average percentage differences between trigonometric and polynomial approaches used in this work is lower than 1.0%. Also, the average percentage differences between the present work (trig. and poly.) and those of 3-D elasticity theory [23] is lower than 1.0%. These differences being insignificant, confirmed that the present theory provides a good solution for the 3-D buckling analysis of isotropic thick rectangular SSSS plate. Meanwhile, the average percentage differences between the present work (trig. and poly.) and those of incomplete 3-D theory [18, 19 and 20] is higher than 8%. These differences being far higher than 5% are quite unacceptable in statistics and cannot be overlooked. Thus, confirming that the incomplete 3-D shear deformation theory is unreliable for the buckling analysis of isotropic thick rectangular SSSS plate.

From Figure 3 to 12, comparison made from the present study and those from past scholars (from CPT and incomplete three-dimensional analysis) proves that, the incomplete three-dimensional shear deformation theory is only an approximate relation for buckling analysis of thick plate and cannot guarantee safety in a typical thick plate analysis. Furthermore, the trigonometric displacement functions developed to give a close form solution, thereby considered more accurate and safer for complete exact three-dimensional plate analysis than the polynomial displacement function. Its use in the analysis of thick plates will yield almost an exact result. On the other hand, the polynomial displacement function which predicts a slightly higher value of average percentage difference gives an approximate solution whose exact value is tends to infinity.

5. CONCLUSION AND RECOMMENDATION

The 3-D exact theory is a plate theory that involves all the six strains $(\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{xz}\ and\ \gamma_{yz})$ and stress $(\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{xz}\ and\ \tau_{yz})$ components in the analysis. Hence, they include more modulus of elasticity (E) and other mechanical properties of the plate. As a consequence, the proposed 3-D approach always predicts buckling load greater than those predicted by CPT, FSDT and polynomial and non-polynomial higher-order plate theories because of these additional load (stresses), modulus of elasticity (E) and other mechanical properties of the plate.

From the result of percentage difference recorded, it can be concluded that the classical theory is good for thin plates, but over-predicts buckling loads in relatively thick plates. Hence, the incomplete three-dimensional shear deformation theory is only an approximate relation for buckling analysis of thick plate (although it turns out to be exact in the case of pure bending). Furthermore, the trigonometric displacement shear deformation theory developed to give a close form solution, thereby considered more accurate and safe for complete exact three-dimensional thick plate analysis than the polynomial. Its use in the analysis of thick plates will yield almost an exact result. On the other hand, the polynomial displacement function which predicts a slightly higher value of average percentage difference gives an approximate solution whose exact value is tends to infinity. Thus, confirming that the improved refined plate shear deformation theory using polynomial and trigonometric displacement function provides a good solution for the buckling analysis of isotropic thick rectangular SSSS.

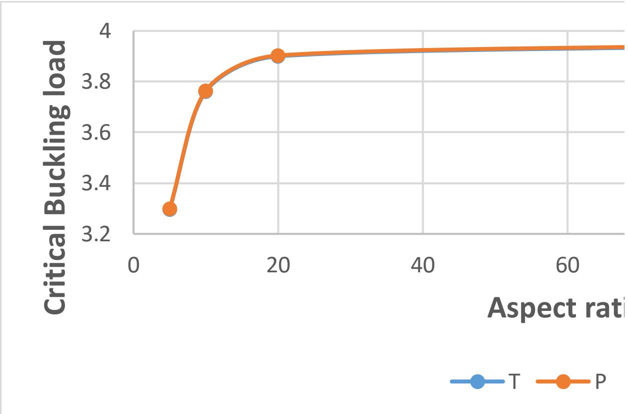


Fig. 3: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate using trigonometric (T) and polynomial (P) of the present study

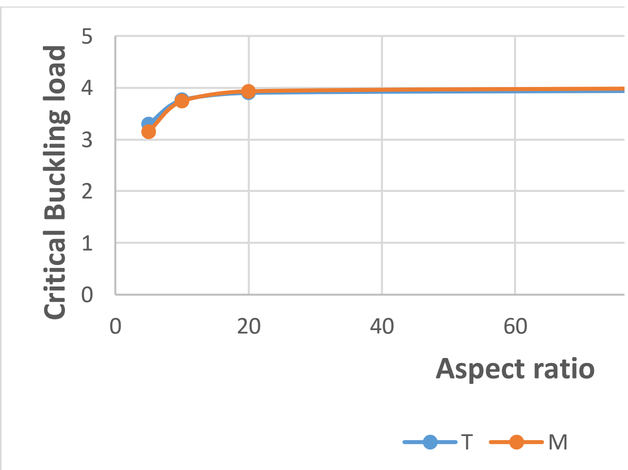


Fig. 4: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study (trigonometric) (T) and Moslemi *et al.* (2016) (M)

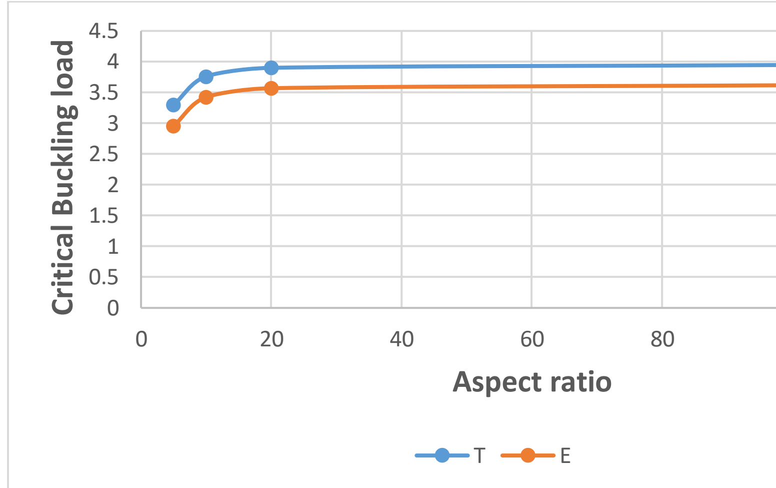


Fig. 5: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study (trigonometric) (T) and Ezeh *et al.* (2018) (E)

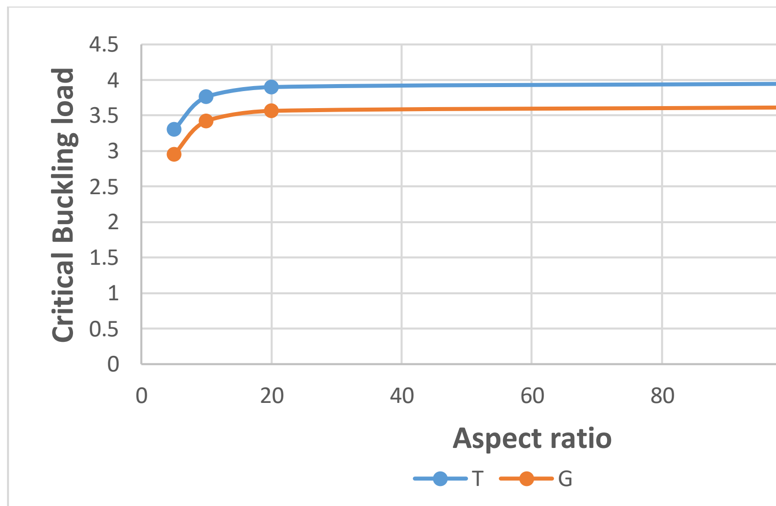


Fig. 6: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study (trigonometric) (T) and Gunjal *et al.* (2015) (G)

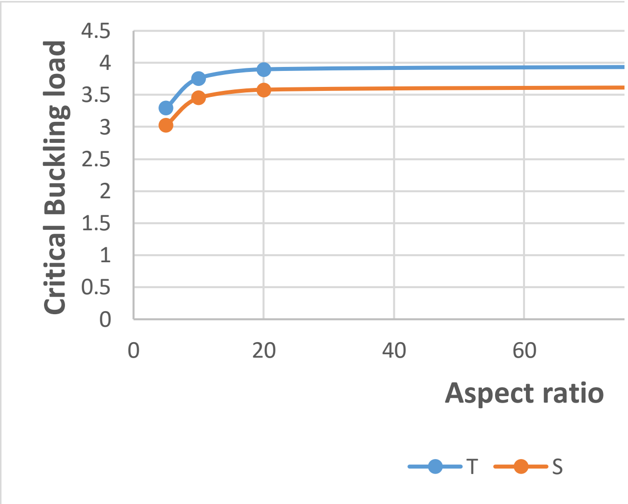


Fig. 7: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study (trigonometric) (T) and Sayaad and Ghugal (2012a) (S)

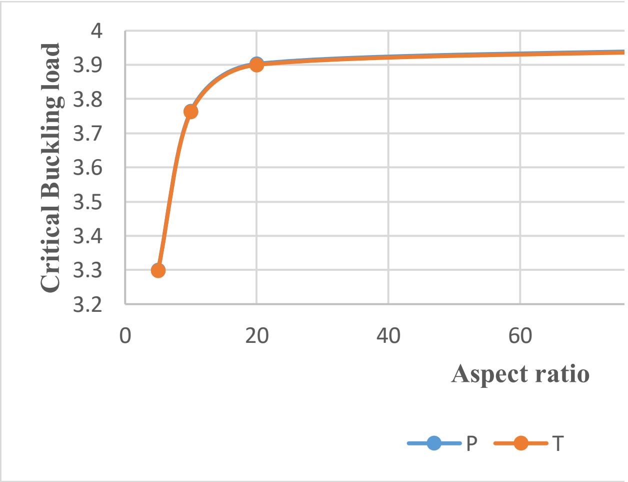


Fig. 8: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate using polynomial (P) and trigonometric (T) of the present study

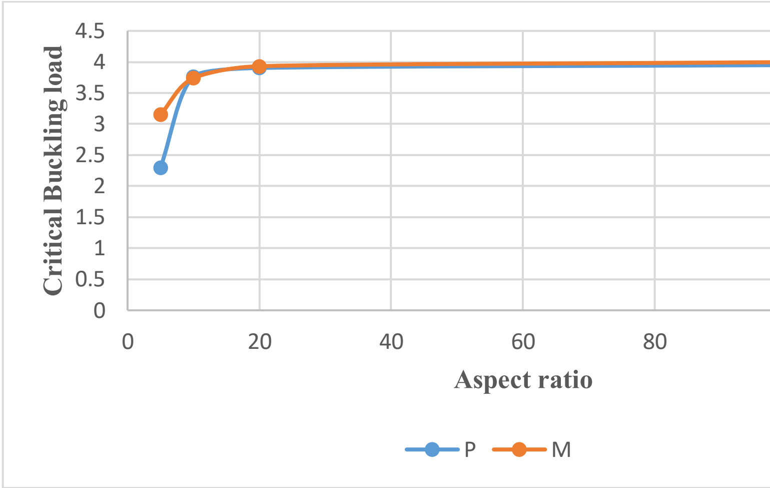


Fig. 9: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study polynomial (P) and Moslemi *et al.* (2016) (M)

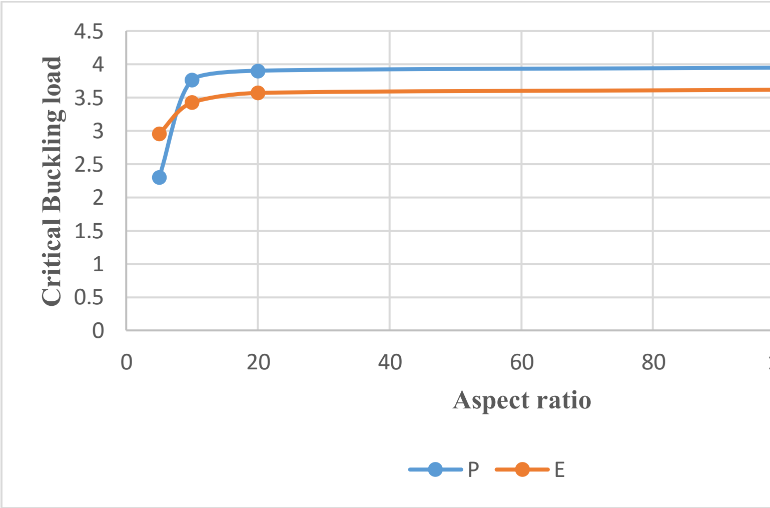


Fig. 10: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study polynomial (P) and Ezeh *et al.* (2018) (E)

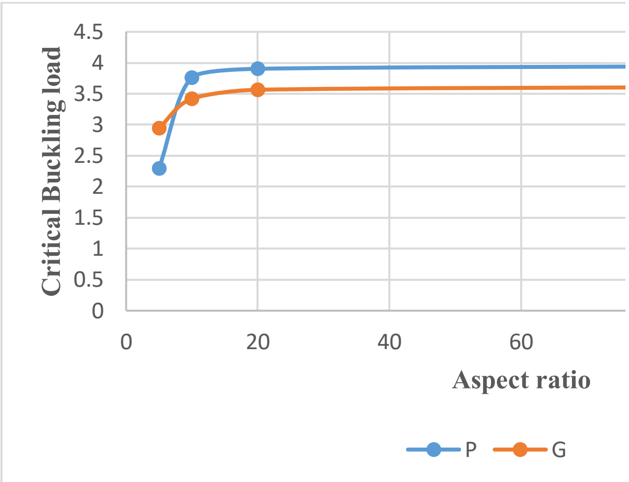


Fig. 11: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study polynomial (P) and Gunjal *et al.* (2015) (G)

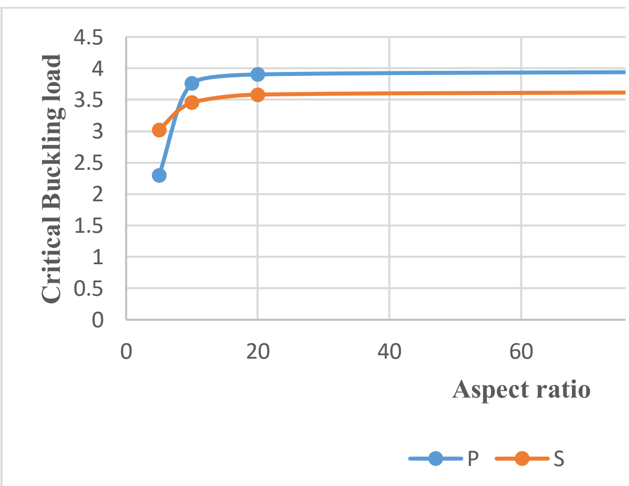


Fig. 12: Graph of critical buckling load versus aspect ratio (a/t) for SSSS plate showing comparison between the present study polynomial (P) and Sayaad and Ghugal (2012a) (S)

REFERENCES

[1] Ibearugbulem, O. M., Opara, H. E. Ibearugbulem, C. N and Nwachukwu, U. C. (2020). Closed form buckling analysis of thin rectangular plates. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 16*(1), 83-90.

[2] Shufrin, M. E. (2005). Stability and vibration of shear deformable plates - First order and higher order analyses. *International Journal of Solids and Structures, 42*(3– 4), 1225–1251.

[3] Kirchhoff, G. R. (1850). U’’ber das Gleichgewicht and die Bewe gung einer elastschen Scheibe. *Journal f’’ ur die reine und angewandte Mathematik,* 40, 51-88 (in German).

[4] Zenkour, A. M. (2003). Exact mixed-classical solutions for the bending analysis of shear deformable rectangular plates. *Applied Mathematical Modelling, 27(7),* 515-534.

[5] Ibearugbulem, O. M., Opara, H. E., Ibearugbulem, C. N., Nwachukwu, U. C. (2020). Closed form buckling analysis of thin rectangular plates. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 16*(1), 83-90.

[6] Timoshenko, S., Gere, J. M. (1963). *Theory of elastic stability 2nd Edition*, New York, McGraw-Hill Books Company.

[7] Reissner, E. (1944). On the theory of bending of elastic plates. *Journal of Mathematics and Physics, 23*, 184–191.

[8] Reissner, E. (1945). The effect of transverse shear deformations on the bending of elastic plates. *ASME Journal of Applied Mechanics, 12,* A69-A77.

[9] Mindlin, R. D. (1951). Influence of rotary inertia and shear on flexural motion of isotropic elastic plates. *ASME Journal of Applied Mechanics, 18*, 31 – 38.

[10] Sadrnejad, S. A., Daryan, A. S., Ziaei, M. (2009). Bending and vibration equations of thick rectangular plates using mindlin plate theory. *Journal of Computer Science, 5*(11), 838-842.

[11] Shufrin, M. E. (2005). Stability and vibration of shear deformable plates - First order and higher order analyses. *International Journal of Solids and Structures, 42*(3– 4), 1225–1251.

[12] Sayyad, A. S., Ghugal, Y. M. (2012a). Bending and free vibration analysis of thick isotropic plates by using exponential shear

deformation theory, Applied and Computational Mechanics 6, 1 (2012a) 65–82.

[13] Murthy, M. V. V. (1981). An improved transverse shear deformation theory for laminated anisotropic plates. *NASA Tech. Paper 1903,* 1–37.

[14] Ibearugbulem, O. M., Onyechere, I. C., Ezeh, J. C., Anya, U. C. (2019). Determination of exact displacement functions for rectangular thick plate analysis. *FUTO Journal Series (FUTOJNLS), 5*(1), 101 – 116.

[15] Ibearugbulem, O. M. Gwarah, L. S. Ibearugbulem, C. N. (2016). Use of polynomial shape function in shear deformation theory for thick plate analysis. *Journal of Engineering (IOSRJEN), 6*(6), 8-20.

[16] Reddy, J. N. Phan, N. D. (1985). Stability and vibration of isotropic, orthotropic and laminated plates according to a higher-order shear deformation theory. *Journal of Sound and Vibration, 98*(2), 157–170.

[17] Ghugal, Y. M., Pawar, M. (2011). Buckling and vibration of plates by hyperbolic shear deformation theory. *Journal of Aerospace Engineering & Technology, 1*(1), 1–12.

[18] Sayyad, A. S., Ghugal, Y. M. (2012b). Buckling analysis of thick isotropic plates by using exponential shear deformation theory. *Journal of Applied and Computational Mechanics, 6*, 185 – 196.

[19] Gunjal, S. M., Hajare, R. B., Sayyad, A. S. (2015). Ghodle, Buckling analysis of thick plates using refined trigonometric shear deformation theory. *Journal of Materials and Engineering Structures, 2*, 159–167.

[20] Ezeh, J. C., Onyechere, I. C., Ibearugbulem, O. M., Anya, U. C., Anyaogu, L. (2018). Buckling analysis of thick rectangular flat SSSS plates using polynomial displacement functions. *International Journal of Scientific & Engineering Research, 9*(9), 387- 392.

[21] Ibearugbulem, O. M., Ebirim, S. I., Anya, U. C., Ettu, L. O. (2020). Application of alternative II theory to vibration and stability analysis of thick rectangular plates (isotropic and orthotropic). *Nigerian Journal of Technology (NIJOTECH) 39*(1), 52-62.

[22] Ibearugbulem, O. M. (2016). *Note on rectangular plate analysis*, Lambert Academic Publishing.

[23] Vareki, A. M., Neya, B. N., Amiri, J. V. (2016). 3-D Elasticity buckling solution for simply supported thick rectangular plates using displacement potential functions. *Applied Mathematical Modelling, 40*, 5717-5730.

Nomenclature

w - Deflection
u - In-plane displacement along x-axis
v - In-plane displacement along y-axis
θ_x- Shear deformation rotation along x axis
θ_y - Shear deformation rotation along the y axis
ε_x- Normal strain along x axis
ε_y - Normal strain along y axis
ε_z - Normal strain along z axis
γ_{xy} - shear strain in the plane parallel to the x-y plane
γ_{xz} - shear strain in the plane parallel to the x-z plane
γ_{yz} - shear strain in the plane parallel to the y-z plane
x – Horizontal co-ordinate
y – Diagonal co-ordinate
z- Vertical co-ordinate
a - spatial dimensions of the plate along x -axes
b - Spatial dimensions of the plate along y-axes
t - Spatial dimensions of the plate along z-axes
R - Non-dimensional form of coordinates x-axes
Q - Non-dimensional form of coordinates x-axes
S - Non-dimensional form of coordinates x-axes
β - Aspect ratio (b/a)
μ - Poisons ratio
E - Modulus of elasticity of the plate
σ_x - Stress normal along x axis
σ_y - Stress normal along the y axis
σ_z - Stress normal along the z axis
τ_{xy} - Shear stress along the x-y axis
τ_{xz} - Shear stress along the x-z axis
τ_{yz} - Shear stress along the y-z axis

D^* - Rigidity for three-dimensional thick plate
D - Rigidity of the CPT or incomplete three-dimensional thick plate
Π - Total potential energy function
U - Algebraic summation of strain energy
V - External work for buckling load
A – Coefficient of deflection
N_x - Uniform applied uniaxial compression load of the plate

N_{cx} – Critical buckling load of the plate

A VIABLE ENERGY MIX OPTION FOR NIGERIA TERTIARY INSTITUTIONS: FEDERAL POLYTECHNIC ILARO AS A CASE STUDY

[1]Ogunyemi, J, [2]Adetona, Z. A., [3]Mbamaluikem, P. O. and [4] Okufuye, O. A.
[1,2,3]Department of Electrical/Electronic Engineering
[4]Works and Services Department
The Federal Polytechnic Ilaro, Ilaro.

ABSTRACT
For dynamic academic and research activities, a steady power supply ranks number one in the list of infrastructural requirements. Most often, standby generators are used to keep the system running with huge resources expended annually on fuel and maintenance. Solar energy is abundantly available in Nigeria with an average of 5.25 kWh irradiation and is proposed for an energy mix utilising mains utility supply, diesel generators and solar PV system for Federal Polytechnic Ilaro. For a total daily energy demand of 10.72 MWh for the institution, when only 90% of the proposed system is implemented, the mix would be: mains 4 % (380.23 kWh), diesel generators 5 % (526.13 kWh), proposed solar PV system 90 % (17.814 MWh), existing solar PV/inverters 165.5 kWh of energy daily, reducing the 2.75 MWh currently supplied from diesel generators daily by 81 % and saving the monthly cost of fuel by N6.48m. The total cost of the proposed PV system is N 2.028 billion.

Keywords: Academic activities, energy mix, Nigeria tertiary institutions, solar PV renewable energy.

1. INTRODUCTION

Nigeria's power sector is facing several challenges, chiefly because of low generation capability that has restricted electricity supply, leading to low access and self-generation through fossil-fuel based power generation. However, fossil fuels are the most expensive means for generating electricity, and this might be exacerbated by high fuel costs. This, no doubt has magnified the price of products and services in the Federal Republic of Nigeria. Electrical energy is required for rapid development in almost every aspect of life. Even so, half of the population in Nigeria is predicted to stay without access to electricity up to 2030, regardless of the fact that the state is endowed with a variety of renewable energy (RE) sources, including wind, solar, hydro, tidal, biomass, and so on. As a result, low academic research output in tertiary institutions, sustained economic growth, and industrial development in Nigeria have been hampered (Asiyai, 2013; Mukhtar et al., 2021; Nwankwo & Njogo, 2013; Ohajianya, Abumere, Owate, & Osarolube, 2014; Olówósejéjé, 2020).

For Nigeria to fare well in the comity of nations in terms of education, there is a need for a steady power supply across the institutions and research centres in the nation. A consistent power supply is the most important infrastructural requirement for dynamic academic and research activities. Typically, standby generators are used to keep the system running, with significant resources spent on fuel and maintenance each year. To improve The Federal Polytechnic Ilaro (FPI) campus' insufficient power supply, and to reduce the huge resources expended annually on fuel and maintenance, RE (solar energy) is proposed as a viable, sustainable energy mix. This is because, at an average of 5.25 kWh irradiation, solar energy is abundant in Nigeria and ranks first among available RE sources in Ogun State. The State has massive solar resource of 3.5 kWh/m2–7.0 kWh/m2 daily (4.2 x 106 MWh/day using 0.1 per cent land area), of which approximately 6 MWh/day is produced, as shown in Table 1 (Khan, Pasupuleti, Al-Fattah, & Tahmasebi, 2018). Reducing greenhouse gas (GHG) emissions and invariably overreliance on fossil fuels necessitated the search for new technologies coupled with advanced technology resulting in lower prices of these materials. Globally, RE has gained a tremendous position in the energy mix. Figure 1 shows the installed solar PV capacity per capital in some of the EU countries with Germany in the lead.

Furthermore, many locations in Nigeria have been assessed and identified as having the potentials to provide sustainable solar energy (Ley, Gaines, & Ghatikar, 2019; Olujobi, 2020). In Nigeria as a whole, solar energy alone is said to be capable of producing 207,000 GWh per year of electricity if 1% of the total landmass were to be used for the installation of the state-of-the-art polycrystalline PV modules with an electricity yield of 1500Wh/Wp per year (NESP, 2015).

Thus, the solar energy PV system is proposed as part of an energy mix that includes mains utility supply and diesel generators for continuous power supply at the minimum possible cost to the FPI. Similar efforts have been made for other tertiary institutions and rural off-grid communities, and these have been reported in the literature (Ali, Ahmar, Jiang, & Alahmad, 2020; Babatunde et al., 2021).

Table 1: Nigeria's RE and non-RE reserves, and potentials (Emodi & Boo, 2015; Ley, Gaines, & Ghatikar, 2019)

Resource	Reserve	Production
Crude Oil	5.24 Btoe (37,453 million bbl)	1.83 x 109 bbl/day
Solar	About 4.2 x 106 MWh/day using 0.1% land (potential of 3.5 kWh/m^2 −7.0 kWh/m^2 daily)	6 MWh/day
Natural Gas	1.93x1014 scf	2.78 x 1012 scf
Small Hydropower	3,500 MW (0.34 Btoe)	30 MW
Large Hydropower	11,250 MW (0.8 Btoe)	1938 MW

Wind	4 m/s at 12% probability, 70 m height, 20 m rotor (2−4 m/s at 10 m height)	-
Coal and Lignite	2.175 x 109 tonne	-
Animal Waste	245 x 106 assorted animals in 2001	7.81 x 105 ton of waste/day
Tar Sand	3.1 x 1010 bbl equivalent	-

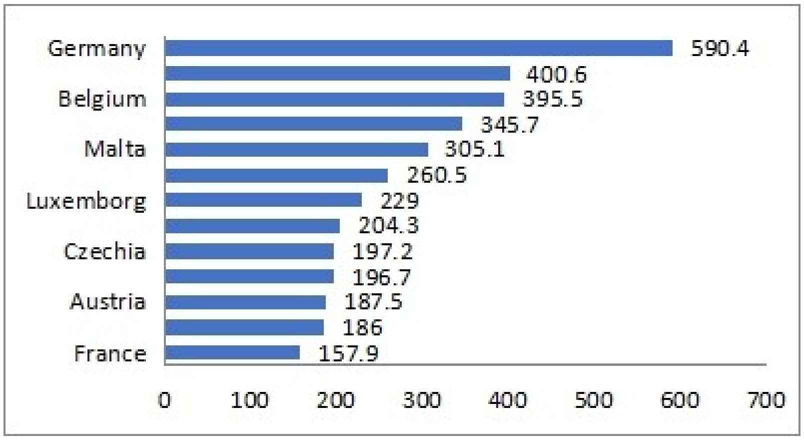


Figure 1: Installed solar PV capacity per capita in EU

RE should be made to account for the lion's share of the energy mix in order to achieve an ecologically sustainable environment, low GHG emissions, and vibrant economic growth (Holtz & Golubski, 2021), (Anomohanran, 2011; Kweku et al., 2018; Mohammed et al., 2012). Exploiting RE sources and liberalizing the energy sector to attract private-sector participation could reduce the cost of producing electricity and increase access to it. Although the short-term cost of generating electricity from RE sources may be prohibitive, in the long run, fixed costs are likely to be offset by the implementation of feed-in tariff schemes and economies of scale. According to IRENA (2020), replacing 500 gigawatts of existing coal plants (with the highest operating costs) with new solar PV and onshore wind could: cut annual system costs by up to USD 23 billion per year; reduce annual CO2 emissions by around 1.8 gigatonnes, or 5% of last year's global total; yield a stimulus worth USD 940 billion, or around 1% of global GDP. The need for RE has been well captured in the Nigeria Energy Policy (NEP) which made provision for effective utilisation of all forms of energy including RE. The Nigerian Energy Policy (NEP 2003) stated thus: the level of energy utilisation in an economy coupled with the efficiency of the conversion of energy resources is vital for the development of the economy.

2. METHODOLOGY

The current energy mix and its component parts were established and proportions determined. The mains utility supply record and fuel consumption data of the generators on the FPI campus were obtained from the Department of Works, FPI. An energy mix of the existing three components is determined with appropriate proportions. The new energy mix is worked out to ensure economic viability and sustainability (Ali, Ahmar, Jiang, & Alahmad, 2020) and adequate power supply to the Polytechnic community. This was done giving considerations to the current utilisation of energy, sources and the periodic electrical load of the institution as a whole.

2.1 FPI Physical Structure and Current Power Supply Setup

The FPI community comprises three sections namely the East Campus, West Campus and Gbokoto staff quarters. The Institution has a robust power supply network with both overhead and underground supply systems. Figure 2 shows the single line diagram of power supply to FPI from Ikeja transmission station. The various sections of the campus are supplied simultaneously from the same electric energy source. Presently, the three main sources of power supply at FPI are Public power supply, Standby generators and Solar PV/inverter supply system. The study looked into the present energy mix and determine the ratio of mains supply vis-a-vis diesel generator supply and existing solar photovoltaic (PV) system that would yield an optimal power supply to the Polytechnic community.

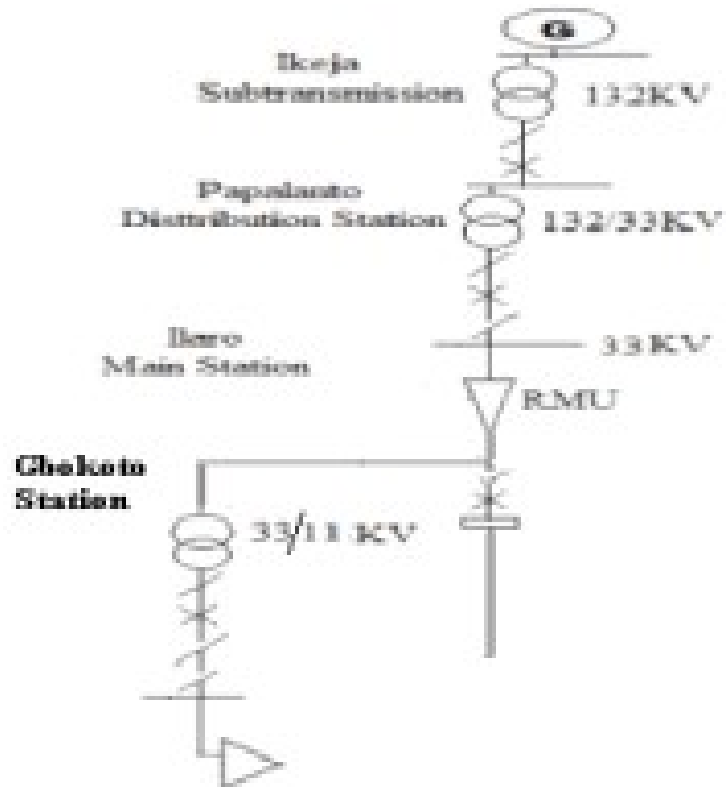


Figure 2: Single line diagram of power supply to FPI

2.2 The Power Supply at FPI

The institution is connected to the national grid on a 33 kV power supply. A 33/11 kV 2.5 MVA transformer on the FPI campus steps down the distribution voltage to 11 kV and this is transmitted and distributed through nine (9) 11/0.415 kVA transformers situated around the campus premises. Figure 3 shows the power distribution network of the campus. About N800,000 is usually spent on utility energy bills depending on availability and consumption for each month with the least monthly cost of N 600,000 only.

There are 14 diesel generator sets serving the entire FPI campus. These generators and their locations, sections served and total ratings are identified in Table 2. Few of these (Gbokoto and East Campus generators) are centralised and connected to two 0.415/11 kV transformers linked to the central distribution network to supply power to the entire Polytechnic. Others produce 415V to be used in various buildings served using a change-over switch at the location. These generators are the main ones operated by the Polytechnic Management to augment the public power supply. There is a litany of other small generators virtually in every Department and section to augment these main ones as well. Generally, in the evening, a dedicated generator is usually turned on by 7 pm and shut down by 11 pm or 12 am, leaving 6-9 hours without power supply on days with a total outage from the mains supply.

The data collected from the FPI Department of Works, showed that the cost of mains utility supply for one year is about N5 million and the cost for diesel for the generators is about N 48 million, servicing cost and other expenses for electricity, engine oil, etc are close to N10 million (about N833,000 per month). The fuel consumption rate of a 500 kVA diesel generator is about 110 litres per hour. Generally, all the generators consume 33,000 litres per month. This quantity of fuel is rationed among the generators within the month to ensure continuity of services in all sections when there is power failure from the mains. With the present cost of diesel being N 242.43 per litre, the total cost of diesel in a month is therefore given as 33000 x N242.43 = N 8,000,190. Thus, in a year this will translate to N96,002,280.

Apart from the mains and diesel generators operated in the FPI campus, there are installed RE systems in form of solar photovoltaic systems and AC inverters. Table 3 gives the number, location, capacity and ownership of these RE installations in FPI. As is indicated in the Table, a total of 165.4 kVA of solar PV/inverter system is available to augment the mains and diesel generating sets on the campus. Note that few of these installations are only inverter-operated without any solar panel installations.

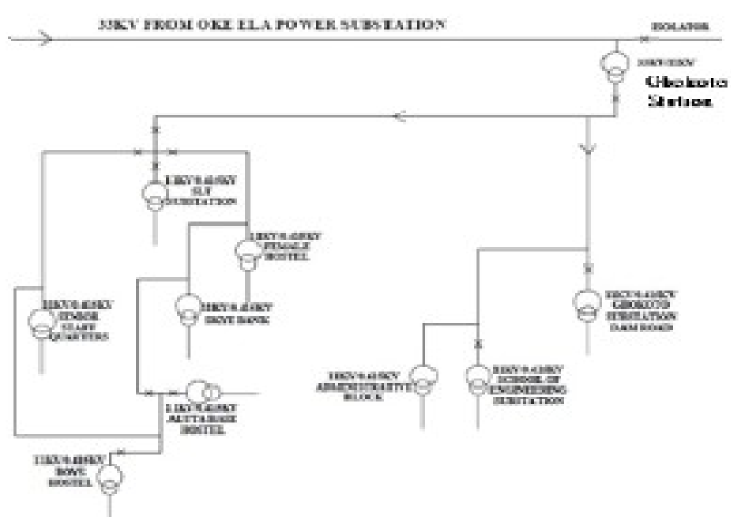


Figure 3: Single line diagram of power distribution at FPI

Table 2: Statistics of Generators at FPI

S/N	Generator Location	Capacity (kVA)	Areas served
1	Gbokoto	500	Entire campus on base-load

2	East Campus	500	Entire campus on base- load
3	School of Engineering	250	Engineering Building, Lecture rooms, and some offices at West Campus
4	Admin Block	250	Central Admin only
5	ICT	60	ICT
6	PTDF	60	PTDF
7	Library	40	Library complex
8	Auditorium 2&3	40	Auditorium 2&3
9	Auditorium 1	150	Auditorium
10	Food Tech	250	Departmental buildings
11	Health Centre	40	Medical Centre and Staff Quarters
12	Rector's house	60	Gbokoto Staff Quarters
13	Mass Communication Department	60	Departmental buildings
14	Agric Farm	500	Agricultural Technology farm buildings
	Total	**2760**	

Table 3: Solar/RE Installation at FPI Ilaro

S/N	Location	Capacity (kVA)	Ownership
1	ICT (West Campus)	30.0	Institution
2	ICT East Campus	3.5	Institution
3	Dept of Elect	4.0	Department
4	Dept of Computer	3.5	Department
5	School of Part-time	2.4	Institution
6	PTDF*	24.0	Institution
7	Library*	30.0	Department
8	Telecomm Lab.	5.25	Department
9	Basic Electricity Lab.	3.75	Department
10	Control Lab.	3.0	Department
11	TIKC	10.0	Institution
12	Mass Communication	23.5	Institution
13	Auditorium 1	15.0	Institution
14	Auditorium 3	5.0	Institution
15	Health Centre*	2.5	Institution
16	**Total**	**165.4**	

* Only inverter-operated

2.3 Current Energy Mix and Electric Power Requirement for FPI

The current energy mix is derived considering the hours of usage of the power supply from the various sources on the polytechnic campus. Average monthly mains energy consumption stands at 1,140.69 MWh per month on the average of 5 hours daily supply. Generating sets total energy supply is determined by using standard fuel consumption generation value of 0.4 litres per kWh. Thus, 33,000 litres of fuel gives 82,500 kWh of energy per month. The solar PV/inverter systems are operated on average for 6 hours daily. The current energy mix is presented in Figure 4. Thus, the total energy supply from the renewable system in the mix stands at:

$$E = 165.5 x\ 4\ x\ 30 \quad (1)$$

= 19,860 kWh per month.

Presented in Table 4 are the present electric power supply requirements for various

locations at the FPI campus. Thus, different hours of use and diversity factor were imposed on different locations to determine the current energy demand. The weekend energy demand is quite low for most locations and has been embedded in the daily estimates. Thus, the total energy required was calculated as in Table 5. The proposed energy mix is to cater for the total energy demand as indicated in the table. The solar PV system requirements in terms of inverter, batteries and solar panels shall now be presented.

2.4 Estimation of Total Solar Requirements for FPI Community

The various locations on the FPI campus utilise electric energy for varying hours each day. The FPI campus comprises residential buildings, office buildings, academic areas, commercial centres and outdoor electric power utilisation. Figure 5 shows an illustration of three sources being proposed in this paper.

Table 4: FPI Energy demand estimate

Location	Total Electrical Load (kW)	Usage (hr)	Energy Demand (kWh)	Diversity Factor	Total Estimated Energy Demand (kWh)
Residential Building	1260	15	18,900	0.3	5670
Health Centre	16	24	384	0.25	96
Religious Building	14	1.67	23.38	0.75	17.535
Library	84	10	840	0.7	588
Poly Staff schools	26	4.5	117	0.6	70.2
Lecture Rooms	56	8.66	484.96	0.3	145.49
Laboratories/Workshops	485	3.5	1697.5	0.35	594.13
Enterprises/Business Ventures	260	10	2600	0.45	1170

Offices	760	5.86	4453.6	0.5	2226.8
General Services	18	12	216	0.65	140.4
Total					**10,718.55**

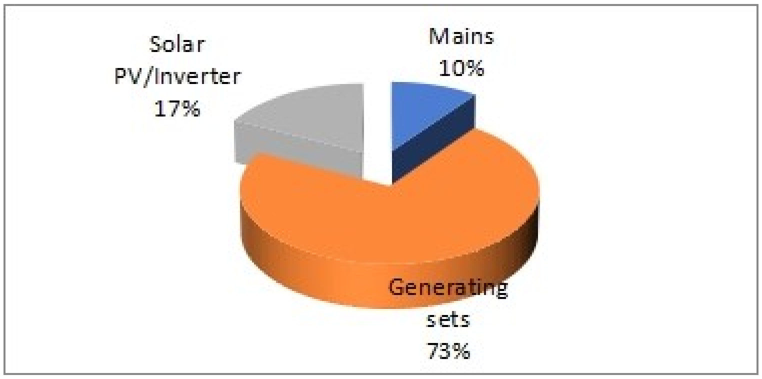


Figure 4: FPI current energy mix

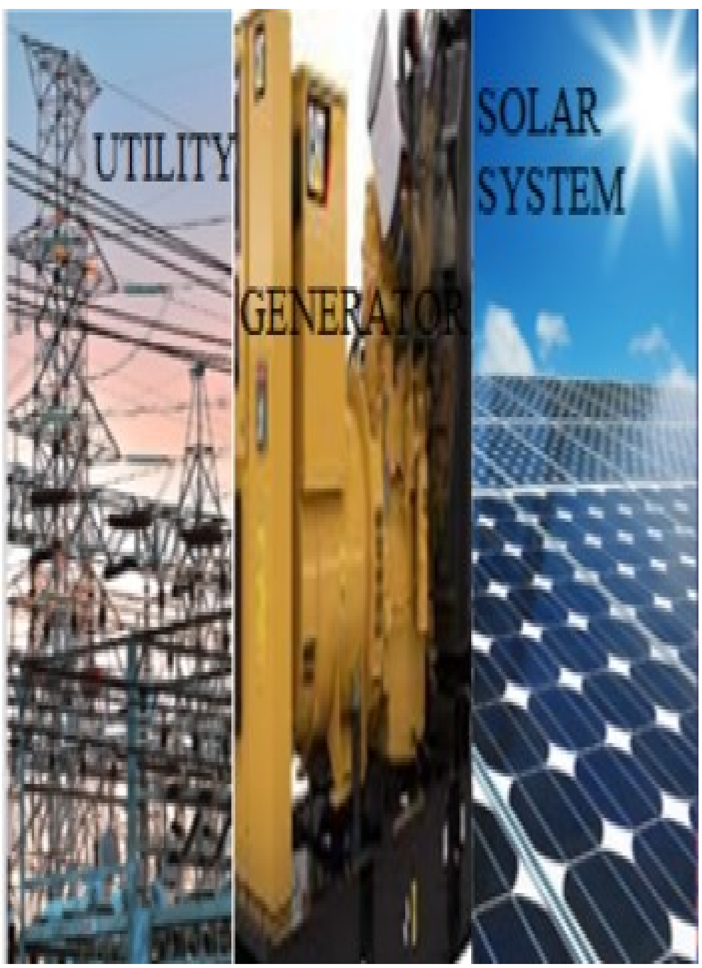


Figure 5 Energy mix power sources under consideration Sizing of the Proposed Solar PV System

2.5.1 Inverter Sizing

In an off-grid solar system, the total wattage of the appliances the inverter is to supply should be lower than the rating of the inverter. Hence, the inverter is rated 25% - 30% higher than the total wattage of the appliances it is meant to supply (Mbamaluikem & Okeke, 2021). For this study,

Inverter rating = total appliance wattage x1.3 = 3,000 x 0.45 x 1.3

= 1,755 kW or ≅2,193.75 kVA

Applying an average diversity factor of 0.45 for all the loads and marking it up, the size of the inverter required is 2,500 kVA.

2.5.

2 PV Module Sizing

Table 5 shows the data of the solar panels used in this study. The kilowatt-hour (kWh) consumption of the Polytechnic using the energy demand estimate from Table 4 is 10,718.55kWh and this is marked up to $\mathbf{11,000\ kWh}$ daily.

The kWh needed from the PV module/day using a diversity factor of 0.6

$$\text{total kWh load x1.3 (system loss factor)} =$$

$$= 11,000 \times 0.6 \times 1.3$$

$$= 8,580\ \text{kWh/day}$$

$$total\ appliance\ Wh * 1.3\ (system\ loss\ factor)$$

Therefore, total Watt-peak (Wp) needed for PV modules = $\dfrac{total\frac{kWh}{day}}{Panel\ generation\ factor}$ (3)

$$= \frac{8,580}{3.41}$$

$$= 2,516.13\ kW$$

Minimum number of PV Panels $= \dfrac{total\ Wp}{Rated\ output\ Wp\ of\ Panel}$ (4)

Using a panel output power of 270 W as given in Table 5:

Minimum number of PV Panels $= \dfrac{2,516.13 x\ 1000}{270}$

$\cong 9,319$ panels.

The proposed solar PV system would require 9,319 panels of 270Wp, 12 V rating or 4,660 panels of 270 Wp, 24 V rating. The design can be modified for higher wattage of PV modules say 300W or 320W to reduce the number required.

Table 5: Solar panel data

Panel Model: 270M-60	
Maximum Power	270 ± 3%
Maximum Power voltage	30 V

Maximum Power current	9:00 AM
Open-Circuit Voltage	36 V
Short-circuit Current	9.81 A
Maximum System Voltage	IEC1000V
Maximum fuse current	15 A
Electrical data at standard test conditions: AM 1.5, irradiance 10000 W/m, cell temperature 25^0C	

2.5.3 Deep Cycle Battery Sizing

A depth of discharge of 60% is used in this design to ensure that the battery is returned to fully charge again every day and the lifespan is maintained. Therefore,

Battery capacity (Ah) $= \frac{Wh * DOA}{BLF * DOD * NBV}$ (5)

$= \frac{8,580,000x1}{0.85x0.6x96} = 175,245\ Ah.$

Where:

DOA = Days of autonomy

BLF = Battery loss factor

DOD = Depth of Discharge

NBV = Nominal Battery Voltage

No of batteries $= \frac{Battery\ Capacity}{Battery\ Nominal\ amperage}$ (6)

$= \frac{175,245}{220} \cong 797\ \text{batteries}.$

The proposed energy mix requires 797 batteries rated 96 V, 220 Ah each. Since deep cycle batteries are not rated 96 V, therefore the design would need:

No. of batteries = 8 x 797

= 6,372 batteries rated 12 V, 220 Ah.

2.5.4 Solar charge controller

Minimum Solar charge controller rating = No. of panels x I_{sc} x 1.3 (7)

= 9,319 x 9.81x1.3

= 118,845 A.

Single Solar charge controller rating = No. of panels parallel paths x I_{sc} x 1.3 (8)

= 8 x 9.81 x 1.3; using eight parallel paths for the panels,

= 102.02 A ≅ 120 A.

No. of charge controllers $= \frac{\text{Minimum Solar charge controller rating}}{\text{Single Solar charge controller rating}}$ (9)

$= \frac{118,845}{120}$.

Hence, 990 numbers of 120 A charge controller would be required.

2.5.5 System Costing

The cost requirement is presented in Table 6. Due to the skyrocketing cost of materials and devalued naira currency, the cost of implementation of the proposed energy mix is quite high. As can be observed in Table 6, the total cost of implementation is over N2.028 billion at the current rate.

Table 6: The Bill of Engineering Measurement and Evaluation for the designed solar system

S/N	Description	Requirement	Quantity	Rate (Nm)	Amount (Nm)
1	Batteries	Tubular 220 Ah, 12 V Deep cycle	6372.00	0.145	923.940
2	Solar PV panels	270 W, 12 V	4660.00	0.066	307.560
3	Charge controller	MPPT 120 A, 48 V	990.00	0.485	480.150
4	Inverter	Central 2,500 kVA, Grid tied.	1.00	81.540	81.540
5	Battery rack	Steel construction	1.00	152.928	152.928
6	Panel rack	Aluminium Frame	1.00	46.600	46.600
7	Automatic change over switch	Assorted	1.00	6.678	6.678
8	Cables and accessories	Assorted; 4 mm^2, 6 mm^2 16mm^2	1.00	9.567	9.567
9	Cost of power house construction and system installation	0.09895 % of total	1.00	19.879	19.879
	Total Cost				**2,028.842**

3. RESULTS AND DISCUSSION

The proposed energy mix value will be adequately equipped to cater for the 10,718.55 kWh daily energy demand for the FPI campus without the need for diesel generators and the epileptic mains supply. That is 321.56 MWh per month and N8,000,000 saved in the cost of fueling the generators monthly. If only 90% of the proposed PV system design is implemented the generators will take care of only 5 % and mains supply only 4 % of the energy demand in the new mix as shown in Figure 6. This will reduce the overall cost by 10%. Thus, a total of about N6,480,000 (0.81 x N8,000,000) monthly reduction in generating sets fueling only is achievable. Also, the cost of maintenance of the generators would drastically reduce. The PV system setup would require some level of maintenance such as highlighted by Adetona, Ogunyemi, & Bitrus, 2020. When such maintenance work is routinely carried out, the system is expected to last its entire design lifetime. This maintenance would also require a minimum cost to achieve.

4. CONCLUSION AND RECOMMENDATION

A RE source that would serve as a viable energy mix for FPI was designed. The design is to ensure a 24-hour power supply to the campus using the new energy mix with the proportions of each power source shown in Figure 6. The implementation can be integrated into the FPI power distribution network. Based on the results of data analysis, solar energy source was considered a viable means because of its availability despite its high initial cost of installation.

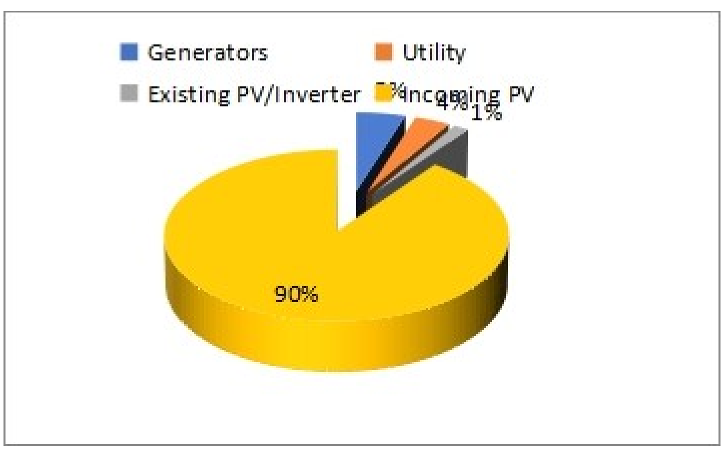


Figure 6: Proportions of energy supply in the proposed energy mix

Depending on the availability of funds, a fraction of the proposed system can be implemented. For instance, one-half of the total energy demand can be implemented and this can reduce the cost of implementation by half. Also, a modular, rather than grid system can be implemented at various locations on the FPI campus. Thus, the implementation can be carried out in phases depending on needs and funds availability. Such a modular approach is suggested to focus on the areas of critical needs for implementation. However, when this system is adopted, the total estimated cost would increase in the course of implementation due to skyrocketing cost of component parts required for the implementation.

REFERENCES

Adetona, Z. A., Ogunyemi, J., & Bitrus, I. (2020). Maintenance Management Regime for Off-Grid Solar PV RE System in Nigeria. *European Journal of Engineering Research and Science*, *5*(11), 1376–1382. https://doi.org/10.24018/ejers.2020.5.11.2233 .

Ali, F., Ahmar, M., Jiang, Y., & Alahmad, M. (2020). A techno-economic assessment of hybrid energy system in rural Pakistan. *Energy*, 1–12. https://doi.org/10.1016/j.energy.2020.119103

Anomohanran, O. (2011). Estimating the greenhouse gas emission from petroleum product combustion in. *Journal of Applied Sciences*, *11*(17), 3209–3214.

Asiyai, R. I. (2013). Challenges of Quality in Higher Education in Nigeria in the 21 st Century. *International Journal of Educational Planning & Administration*, *3*(2), 159–172.

Babatunde, O., Denwigwe, I., Oyebode, O., Ighravwe, D., Ohiaeri, A., & Babatunde, D. (2021). Assessing the use of hybrid RE system with battery storage for power generation in a University in Nigeria. *Environmental Science and Pollution Research*, 2–3. https://doi.org/https://doi.org/10.1007/s11356-021-15151-3

Emodi, K. J., & Boo, N. V. (2015). Sustainable energy development in Nigeria : Current status and policy options. *Renewable Sustainable Energy Review*, *51*, 356–381.

Holtz, L., & Golubski, C. (2021). Figures of the week : Africa ' s RE potential.

IRENA (2020), Renewable Power Generation Costs in 2019, International RE Agency, Abu Dhabi.

Khan, M. R. B., Pasupuleti, J., Al-fattah, J., & Tahmasebi, M. (2018). Optimal Grid-Connected PV System for a Campus Microgrid Optimal Grid-Connected PV System for a Campus Microgrid. *Indonesian Journal of Electrical Engineering and Computer Science*, *12*(3), 899–906. https://doi.org/10.11591/ijeecs.v12.i3.pp899-906

Kweku, D. W., Bismark, O., Maxwell, A., Desmond, K. A., Danso, K. B., Oti-Mensah, E. A., … Adormaa, B. B. (2018). Greenhouse Effect : Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research and Reports*, *17*(6), 1–9. https://doi.org/10.9734/JSRR/2017/39630

Ley, K., Gaines, J., & Ghatikar, A. (2015). The

Nigerian Energy Sector: An Overview with a Special Emphasis on RE. Nigerian Energy Support Programme (NESP).

Mbamaluikem, P. O., & Okeke, H. S. (2021). Cost Implication of using a Petrol Generator and PV System in a Middle-Income Residential Apartment in Nigeria. *International Journal of Scientific & Engineering Research, 12*(6), 1328-1332.

Mohammed, Y. S., Mokhtar, A. S., Bashir, N., Abdullahi, U. U., Kaku, S. J., & Umar, U. (2012). A Synopsis on the Effects of Anthropogenic Greenhouse Gases Emissions from Power Generation and Energy. *International Journal of Scientific and Research Publications*, *2*(10), 1–6.

Mukhtar, M., Obiora, S., Yimen, N., Quixin, Z., Bamisile, O., Jidele, P., & Irivboje, Y. I. (2021). Effect of Inadequate Electrification on Nigeria ' s Economic Development and Environmental Sustainability. *Sustainability*, *2021*(13), 1–24.

NESP, (2015). The Nigerian Energy Sector: An Overview with a Special Emphasis on RE, Energy Efficiency and Rural Electrification

Nwankwo, O. C., & Njogo, B. O. (2013). The Effect of Electricity Supply on Industrial Production Within The Nigerian Economy (1970 – 2010). *Journal of Energy Technologies and Policy*, *3*(4), 34–42.

Ohajianya, A. C., Abumere, O. E., Owate, I. O., & Osarolube, E. (2014). Erratic Power Supply In Nigeria : Causes And Solutions Erratic Power Supply In Nigeria : Causes And Solutions. *International Journal of Engineering Science Invention*, *31*(7), 51–55.

Olówósejéjé, S. A. (2020). What Nigeria's poor power supply really costs and how a hybrid system could work for business.

Olujobi, O. J. (2020). The legal sustainability of energy substitution in Nigeria ' s electric power sector : RE as alternative. *Protection and Control of Modern Power Systems*, *5*(32), 1–12.

Schwerhoff, G., & Sy, M. (2020). Where the Sun Shines. *Finance & Development*, *March*, 54–57.

THEME FOCUS:

DEPLOYMENT OF TECHNOLOGY INNOVATIONS TO PROMOTE RENEWABLE ENERGY SYSTEMS

AN ANALYSIS OF A SOLAR PHOTOVOLTAIC MOBILE PHONES CHARGING PROJECT FOR RURAL USE IN NIGERIA

O. Adeoti
Department of Agricultural and Bio-Environmental Engineering

The Federal Polytechnic, Ado Ekiti, Ekiti State, Nigeria

E-mail: olusegunadeoti@yahoo.co.uk Tel: +234 (0) 80 3456 2476

ABSTRACT

The use of private portable solar cells to charge mobile phones is not common in rural areas. This paper introduces charging mobile phones on a commercial basis in rural areas using solar photovoltaic (pv) system. The purpose is to promote development, mobile phones use, and its penetration in rural areas. The study analysis revealed that the project would require an initial investment cost of US$830.99 and annual operating expenses of US$539.84. The Net Present Value (NPV) of the project was positive at 40, 60, 75, and 100% capacity utilisations, and had a discounted payback period of 2 years at 100% capacity utilisation compared with the project's overall economic life of 10 years. This implies that the project will make a profit and support its own development. The project has a wide applicability especially in developing economies and offers some societal benefits.

Keywords: Solar PV system, Mobile phones charging project, Components design, Micro economic analysis, Sensitivity analysis, Rural use.

1. INTRODUCTION

The use of portable solar cells to charge mobile phones is not new. Available devices in the Nigeria markets, which are common in urban areas, vary from 5 to 20 Watts (W). From available technical details, these devices are designed for individual use and could charge 1 or 2 phones at a time depending on system capacity. Because these devices are less common in rural areas, this paper introduces another concept which entails charging mobile phones on a commercial basis in rural areas using a solar photovoltaic (pv) system. The purpose is to promote sustainable rural development, mobile phones use, and its penetration in poorly served rural areas or in rural areas not connected to the national grid.

One major factor limiting mobile phones use penetration in rural areas is the unavailability of grid electricity. Despite the various pronouncements to improve grid electricity supply to 25,000 megawatts (MW) by the end of 2020 (revised from 40,000 MW) (Table 1), grid transmission wheeling capacity averaged 5,300MW, higher than average operational generation capacity of 3,879 MW (Nigerian Electricity Regulatory Commission (NERC), 2021a). Roughly 26 per cent of rural dwellers had access to grid electricity in Nigeria in 2019

(World Bank, 2021a). By proportion, the rural areas accounted for about 49 per cent of the Nigerian population in 2019 (World Bank, 2021b). While the use of portable solar cells is common in many urban areas, they are less adopted in rural areas due to affordability and unavailability in rural markets. Market information revealed that the prices of available portable solar cells in Nigeria varied from 5,000 to 15,000 Naira. However, documentary evidence suggests that about 43.8 per cent of rural dwellers earned less than 10,000 Naira a month as of 2012 (National Bureau of Statistics (NBS), 2012). The availability of electricity provides opportunities for use and for users to charge their mobile phones. In the case of Nigeria, because of inadequate grid electricity supply or incessant power outages, people who could not afford private gasoline/diesel-fuelled electricity generators (or have the opportunity to charge for free) charge their mobile phones from vendors who have generators. This situation is more prevalent in rural areas where access to, and availability of, grid electricity or private electricity generators is low. Market information revealed that vendors collect 50 Naira per mobile phone, without any major consideration to charging time. While there is a paucity of data on the number of mobile phones-in-use in rural areas of Nigeria, it is reported that as of July 2021 there were 187.47 million active mobiles (GSM) phone lines in Nigeria (Nigerian Communications Commission (NCC), 2021). Roughly speaking, therefore, considering those with dual-SIM mobile phones with 2 SIM cards installed, the number of mobile phones-in-use in Nigeria could be up to 139 million.

Table 1: The various grid electricity generation targets set by the Federal Government of Nigeria

Target (in MW)	Timeline
4,000	1999
6,000	End of May 2007
10,000	End of 2008
11,000	End of 2011
5,000	End of December 2014
6,000	End of 2014
5,000	End of September 2015
6,000	End of 2015
10,000	End of December 2016

Current generation +2,000 (or over 6,000)	End of 2016
12,500	End of December 2017
7,000	End of 2017
10,000	End of 2019
40,000	2020
25,000	End of 2020
30,000	In 2030

(Sources: Adeoti, 2016; NERC, 2021b)

The combined effect of inadequate grid electricity supply, rural poverty and the need to encourage sustainable business development as well as promote mobile phones use penetration in rural areas serve to support the concept of mobile phones charging projects on a commercial basis using a solar pv system. In terms of solar resources which are key input parameters for effective functioning of solar pv systems, the daily solar radiation (or insolation) in Nigeria varies from 3.5 in the coastal areas of the south to 7.0 kilowatt-hour/square metre (kWh/m^2) in the arid regions of the north (Federal Ministry of Science and Technology (FMST), 2014a, 2014b; Shaaban and Petinrin, 2013; Akinyele et al., 2018; Ohunakin et al., 2014). Nigeria's daily sunshine hours have an annual average of 4 to 9 hours (h), increasing from the south to the north (FMST, 2014a). Despite its importance, there is a dearth of documentary evidence suggesting that there are rural solar pv mobile phones charging businesses in Nigeria. Therefore, this paper examines the facility requirements and the financial implications of operating a rural solar pv mobile phones charging project in Nigeria. This paper differs from that of Acquah et al. (2017) in that it provides the calculation procedure as well as the assumptions informing the selection of key solar pv component sizes and used the dynamic approach to assess the project's financial viability. In the case of Acquah et al. (2017), the calculations and the assumptions informing the selection of battery and inverter sizes were not stated. It also evaluated profitability based on the financial records of income and expenditure, possibly because the paper was evaluating the performance of an already installed community solar project. It is important to highlight that the dynamic approach used in this paper offers a more important investment guide from the viewpoint of an entrepreneur than the static approach.

This paper is beneficial to researchers, policymakers, equipment fabricators and prospective entrepreneurs wishing to invest in rural solar pv mobile phones charging projects in Nigeria and elsewhere. Worldwide, some 18 per cent of the rural population were without access to electricity in 2019 (World Bank, 2021c). The rest of this paper is organised as follows: Section 2 takes a brief look at solar pv and its applications. Section 3 provides the procedure followed which includes the load sizing assumptions, design process and project's financial analysis. Results are presented and discussed in Section 4 and the sensitivity analysis in Section 5. Section 6 highlights some other benefits that could be derived from the implementation of the rural solar pv mobile phones charging project at the societal level, which is followed by a conclusion and recommendations in Section 7.

2. THE SOLAR PV AND ITS APPLICATIONS

Becquerel discovered the pv effect in 1839 while studying the effect of light on electrolytic cells (Razykov et al., 2010) and suggested that sunlight could be converted directly into electricity (Joshi et al., 2009). By the end of 2017, global solar pv capacity reached 400 gigawatts (GW) (IEA, 2018b). While Nigeria's solar resource potential is estimated at 4.2 terawatt-hours/day (TWh/day) (from 0.1 per cent land area), roughly 6 megawatt-hours/day (MWh/day) have been harnessed (Emodi and Boo, 2015; Shaaban and Petinrin, 2013). Worldwide, solar pv has been deployed for various applications either as a standalone or as a hybrid system. These include water pumping (Giwa et al., 2016; Joshi et al., 2009; Obeng and Evers, 2010; Rahman, 2011), on/off grid electricity supply (Joshi et al., 2009; Rahman, 2011; Akinyele et al., 2018), street lights/traffic signals (Joshi et al., 2009), highway and pipeline lighting (Chaurey and Kandpal, 2010a), hydrogen production (Hollmuller et al., 2000), space heating (Joshi et al., 2009), ventilated solar greenhouse dryer (Janjai et al., 2009; Barnwal and Tiwari, 2008; Mumba, 1995), charge car batteries/solar vehicles (Arsie et al., 2006; Gaddy, 2003; Rizzo, 2010), telecommunications (Mpagalile et al., 2005; Shaaban and Petinrin, 2013), railway signalling and off-shore oil platforms (Purohit and Michaelowa, 2006), space vehicles (Bhutto et al., 2012), satellites (Razykov et al., 2010; Joshi et al., 2009), vaccine refrigeration (Chaurey and Kandpal, 2010a; Omer, 2002), oil expeller (Mpagalile et al., 2005), remote meteorological stations (Chaurey and Kandpal, 2010b; Purohit and Michaelowa, 2006), battery charging and radio systems in airports (Omer, 2002), calculators and watches (Joshi et al., 2009), and lantern/mobile phones charging (Acquah et al., 2017).

3. METHODOLOGY

3.1 Load sizing assumptions

For the solar pv system components design, the following assumptions were made:

to be economical, the facility will be capable of charging 10 mobile phones at a time because of variations in phone design and state of charge, the maximum charging duration per phone is limited to 2 hours (with phones switched off during charging). Therefore, the facility will be capable of charging 30 mobile phones per day the facility is to operate between 10.00am and 4.00pm, 6 hours per day, Monday through Saturday, 300 days per year (excluding some notable public holidays).

The allowable system autonomy is 3 days (that is, 3 cloudy/raining days in a row without sunlight) the maximum power consumption is 6 W per mobile phone. At present there are mobile phones of 11.4 Wh in Nigeria mobile phones are to be plugged-in directly using their chargers. This will allow each phone to be charged at their recommended ampere-voltage rating the system output voltage is 220 Volts (V) since mobile phones come with in-built over-charging and deep-discharging protections for the batteries, there is no need to consider these in the system design because of variations in the charging current of mobile phones, the sockets (or load bus) are to be connected in parallel. On the average, it is assumed that most phones would require charging at the end of the third day or charged twice per week of 7 days.

Based on the assumptions made above, the expected maximum load is 6 W x 10 x 6 hours = 360 Wh/day. To cater for future improvements which may lead to a higher mobile phones built-in battery capacity, the paper has used 500 Wh/day in the design calculation.

3.2 Solar pv system components sizing

This paper has adopted a very simplified calculation procedure to estimate the sizes of key solar pv system components as follows:

- *solar pv generator*

  A solar pv generator is made up of modules. A module consists of several cells and works on the principle of the photoelectric effect. A combination of several modules arranged either in series or in parallel or both makes an array. The cells in the modules convert the solar light into direct current (dc) electricity. Therefore, the brighter the solar light impinging on a module, the higher the dc electricity produced. From equation 1 (after Chaurey and Kandpal, 2010a; Mpagalile et al., 2005), the solar pv generator size required to power a load of 500 Wh/day is 379 W_p. Considering market availability, the paper has selected 2 x 200 W_p, 12 V solar modules. The service life of solar pv modules varies from 20 to 30 years except film modules.

Size of solar pv generator, PV_{gs} =

$$\frac{q}{S_{h(m)}\, x\, \gamma}\ (W_p) \qquad (1)$$

Where q is the load in Wh/day (= 500 Wh/day), $S_{h(m)}$ the mean minimum daily sunshine hours in Nigeria (= 4 h). In Nigeria, the least total solar radiation intensity occurs in the month of August (Aliyu et al., 2015). γ, the overall derating factor which compensates for efficiency reduction in the solar pv performance (for temperature-related losses and non-temperature related losses) = (η_{INV} x η_B x η_{CC} x η_{PC} x (1 – $L_{mismatch}$) x (1 – L_{dust}) x (1 – L_{temp}) = 0.33); where inverter efficiency, η_{INV} = 0.80, battery efficiency, η_B = 0.85, efficiency of charge controller, η_{CC} = 0.85, the efficiency of mobile phones charger, η_{PC} = 0.80 (Acquah et al., 2017), loss of energy due to the mismatch among solar cells put at 0.15 (Chaurey and Kandpal, 2010a), loss of energy due to dust, shading/shadow, wiring and connections, switches, ammeter, fuse, reflection, etc. put at 0.15, and loss of energy due to increase in ambient temperature estimated at 0.014.

To minimise operational cost, no tracking system is included in the pv design.

The value 0.014 was obtained as follows:

The literature argues that with an increase in cell temperature the efficiency of the cells decreases significantly (Joshi et al., 2009; Chander et al., 2015; Krauter and Ochs, 2003). The cell temperature is primarily affected by the ambient temperature, solar irradiance, and wind speed (Standards Organisation of Nigeria, 2015). It is assumed in this paper that air cooling may likely not be achieved where pv modules are mounted directly on rooftops. Therefore, wind speed may have a little cooling effect. In Nigeria, the mean monthly temperature varies from 14 degrees Celsius (°C) in the mountain zone to 32 °C in the semi-arid zone (Food and Agriculture Organisation of the United Nations (FAO), 2002).

In the market, there are different kinds of pv technologies. These include the mono-crystalline (m-Si), poly-crystalline (p-Si), thin films–amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium selenide (CIGS), organic pv

(Akinyele et al., 2018), nano-pv (Razykov et al., 2010), and ribbon silicon (Park et al., 2013). Although mono-crystalline and multi-crystalline silicon cell based panels account for over 90 per cent of the global market, the commonly used solar pv technology in Nigeria is the crystalline silicon type, that is., m-Si and p-Si (Akinyele et al., 2018). For a mono-crystalline silicon solar cell, Chander et al. (2015) found that the output power decreased by 0.002/°C due to an increase in cell temperature. This value was adopted in this paper. The 0.014 was therefore obtained from the calculation that as the average ambient temperature increases by 7° (that is, from 25 °C, the nominal temperature for pv cells to 32 °C, the average maximum ambient temperature; taken the semi-arid zone and other parts of the country with relatively high mean monthly temperature into consideration), the output power of the solar pv generator is expected to drop by 0.014 on the average.

- *storage battery*

Because of variation in sunlight intensity during the day and the possibility of cloudy as well as raining days without sunlight, these suggest that the system needs a battery. A battery is an electrochemical device. It stores electrical energy in the form of chemical energy and releases it as electrical energy when a load is connected (Ani, 2016). Batteries can be connected in series and/or in parallel to realise the desired voltage and ampere level. The size of the storage battery for the mobile phone charging project required to power a load of 500 Wh/day for 3days without sunshine was obtained from equation 2 (after Chaurey and Kandpal, 2010a) as 230 Ah. This value was derated for low temperature as suggested by Electricalnotes (2015) using the lowest expected average temperature of 15.6°C in Nigeria to obtain 255.1 Ah from equation 3. Considering market availability, this paper has selected: 2 x 150 Ah, 12 V deep cycle battery.

Battery size, B_s = $\left[\frac{q}{O_v \, x \, m_d \, x \, \eta_{INV} \, x \, \eta_B}\right] x \, a \; (Ah)$ 2)

Where q is as defined above, O_v is the operating voltage (= 12 V), m_d is the maximum depth of discharge for deep cycle battery (= 0.80), and a is the system autonomy (= 3 days). η_{INV} and η_B are as defined above.

Battery size$_{(derated)}$, B_{sd} = $B_s \, x \, L_t$ (Ah) (3)

Where B_s is as defined above and L_t is the low-temperature correction factor = 1.11, obtained from the table of temperature correction factors at 15.6°C. From the manufacturers' viewpoint, deep cycle batteries will last between 8 and 20 years (Ani, 2016).

- *charge controller*

The charge controller serves as a protective and monitoring device. It regulates the battery's overcharge and over-discharge as well as monitors the state of charge of the battery. It helps to control the energy inflow and outflow into and from the storage battery (Chaurey and Kandpal, 2010a) and also prevents reverse flow of current (Purohit and Michaelowa, 2006). Overcharging and over-discharging reduce batteries life span. In this paper, the selected solar modules are 2 x 200 W_p. Following standard practice, the size of the charge controller obtained is 14.6 A from equation 4 after Leonics (2018). Considering durability and losses (charge controller efficiency is between 80 and 85 per cent (Chaurey and Kandpal, 2010a)), the preferred ampere rating of the charge controller is 20 A at 12 V.

Charge controller size = number of strings x 1.3 x short circuit current (A) (4)

Where the number of strings (for the pv generator) = 2, the safety factor = 1.3, and for a 200 W_p crystalline pv module, the short circuit current = 5.63 A.

- *inverter*

The built-in battery of mobile phones requires alternating current (ac) electricity to charge, while the solar pv generator and the system storage battery deliver dc electricity. To use the dc electricity from the solar pv system directly would require for each mobile phone to have a dc-to-dc charger, leading to additional investments on the part of the phone users which they may not be willing to make. However, using this configuration will eliminate the need for an inverter. Since mobile phones come with an ac-to-dc charger, this suggests the need for an inverter. The inverter will convert dc electricity to ac electricity, and also perform the following functions: waveshaping, regulate the output voltage, and operate near peak power point (Norton et al., 2009). Rated by its output power and dc input voltage, the design procedure suggests that the power rating of an inverter should not be less than the total power to be consumed by the loads. From equation 5 after Electricalnotes (2015), the inverter size, for all the loads running concurrently, was calculated at 97.7 W. Therefore, considering market availability and the need to supply continuous power, the paper has selected: 1 x 12 V, 0.1 kW inverter (one phase supply).

Inverter size, $I_s = \frac{T_L}{\gamma} \times \sigma$ (W) (5)

Where T_L is the total load (= 62.5 W). It is important to highlight that mobile phones could be categorised as mostly resistive loads. Therefore, no initial load surge associated with inductive devices is expected. γ is the efficiency of inverters (taken as 0.8 in this paper for pure sine wave inverters. Pure sine wave inverters are ideal for running loads with sensitive electronics). The safety factor for unforeseen minor load surge, σ = 1.25.

3.3 System operating procedure

Figure 1 illustrates the solar pv mobile phones charging system layout. During daytime when there is sunlight, the pv generator serves the ac loads. Extra energy produced is stored in the battery. However, when there is no sunlight or when power from the pv generator becomes insufficient, the battery supports and powers the ac loads as well as helps to stabilise supply at 12 V. The extension box serves as the load bus where the mobile phones are plugged in via the sockets. Figure 2 shows a simplified electrical circuit of the solar pv mobile phones charging project.

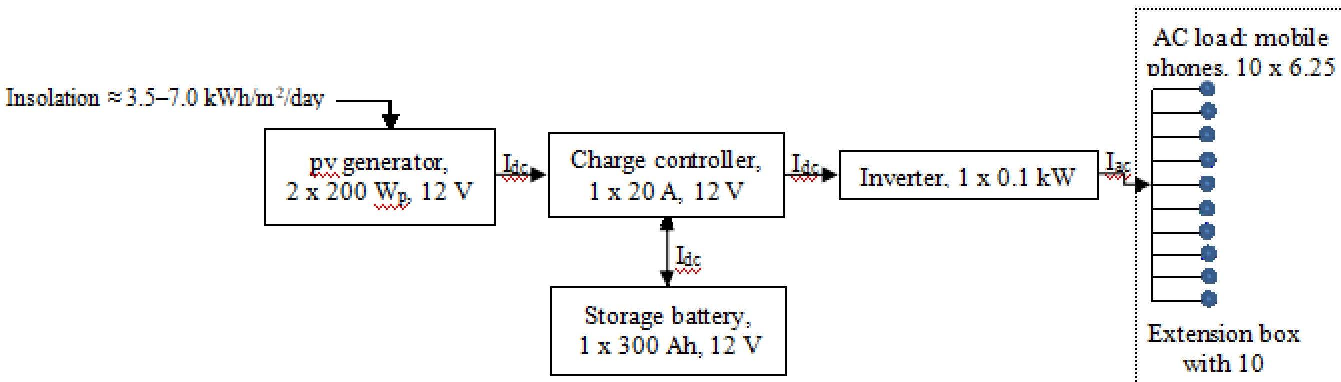


Fig. 1: The solar pv mobile phones charging system layout

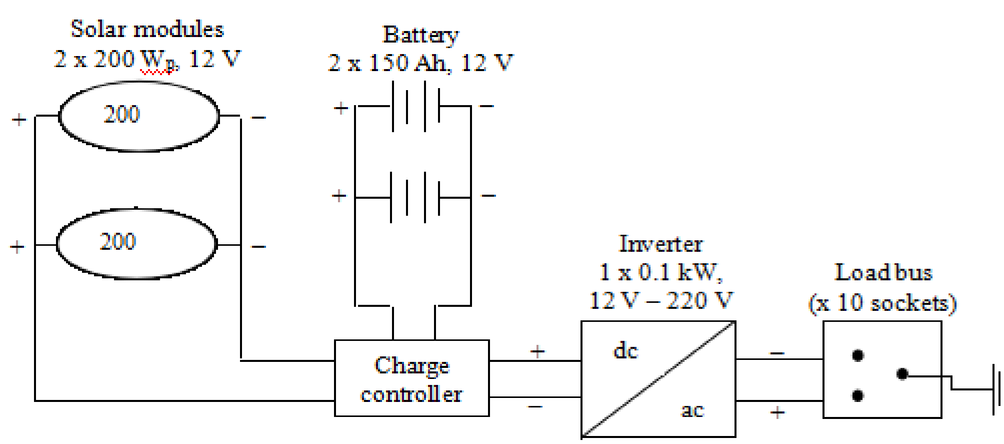


Fig. 2: Electrical circuit of the solar pv mobile phones charging project

3.4 Project's financial analysis

Table 2 provides information on facilities and structure needed for the project and their market cost. Market survey was carried out in August 2021. The project is estimated to have an overall economic life of 10 years.

Table 2: Facilities and structure for the solar pv mobile phones charging project

S/No	Item description	Capacity	Quantity	Unit cost (Naira)	Total cost (Naira)
1.	Solar module (mono)	200 Wp, 12 V	2	**30,315**	**60,630**
2.	Storage battery (Deep cycle)	12 V 150 Ah	2	90,000	**180,400**
3.	Charge controller	20 A 12 V	1	**9,500**	9,500
4.	Inverter	12 V 220 V 0.1 kW	1	11,000[a]	11,000
5.	Charging kiosk[b]		1	15,000[a]	15,000
6.	Cable	2.5 mm^2 (flex)	5 m	200/m[a]	1,000
7.	Extension box, with 10 sockets		1	5,000[a]	5,000
8.	Installation expenses			15,000[a]	15,000
	Sub-total				**297,130**
9.	Transport cost (average) (at 5% of sub-total)				14,856.5
10.	Exigencies (at 10% of sub-total)				29,713
	Total				341,699.5 (US$830.99[c])

[a]Estimated

[b]The installation of pv modules on kiosk rooftop is recommended where possible.

[c]US$1 = 411.196 Naira (Oanda, 2021)

In the financial analysis of the project, the arithmetic gradient series model was used to estimate the annual operating expenses over the overall economic life of the solar pv mobile phones charging project, n (= 10 years). In the model, the annual operating expenses of the project were estimated at A_1 in the first year and G more Naira for each additional year until the end of the tenth year (an increasing gradient series). The Present Worth-cost (PW-c) of annual operating expenses was first calculated (Equation 6) and thereafter was converted to Annual Worth-cost (AW-c) using equation 7 after Ilori et al. (1997).

$$PW\text{-}c = A_1 (P/A, i\%, n) + G (P/G, i\%, n) \quad (6)$$

$$AW\text{-}c = PW\text{-}c (A/P, i\%, n) \quad (7)$$

Where i is the minimum attractive rate of return (MARR), and the factors (P/A, i%, n), the uniform payment present worth factor, (P/G, i%, n), the gradient to present worth conversion factor, and (A/P, i%, n), the capital recovery factor were obtained from the interest table. A_1 and G were estimated at 148,500 and 22,275 Naira, respectively, for the project operating at 100% capacity.

The MARR, i, of 16.3% was obtained from equation 8 after Finck and Oelert (1985):

$$i = \left[\frac{(100+p)}{(100+a)}\right] x\, 100 - 100 \quad (8)$$

Where p is the annual average maximum lending rate in Nigeria for 2018 to 2020 = 30.50% (Central Bank of Nigeria (CBN), 2021a), and a, is the annual average rate of inflation for 2018 to 2020 = 12.25% (CBN, 2021b). A three-year average was used due to market instability in Nigeria. The Net Present Value (NPV) model was used to inspect the ability of the project to make a profit from the perspective of an entrepreneur before tax. The model refers to the equivalent of a single sum of money to be received or disbursed at t = 0, if all future receipts and disbursements over time are discounted to the present. The model is specified by Adeoti et al. (1999) as:

$$NPV = \sum_{t=0}^{n} A_t (P/F, i\%, n) = - I_o + \sum_{t=1}^{n} A_t (1+i)^{-n} \quad (9)$$

Where I_o is the initial investment cost, A_t is the net cash flow [= $(C_b – C_C)_t$] at the end of year (t), C_b is the annual cash benefit of the solar pv mobile phones charging project in Nigeria, C_c is the annual cash cost of the project (obtained from equation 7), n and i are as defined above, and the factor (P/F, i%, n), the single payment present worth factor. If NPV is positive, then the project is worthwhile, otherwise not. The NPV model is usually preferred as an investments decision guide because of its ease of use, robustness, and consistency (Park and Sharp-Bette, 1990). The model has been used in the profitability analysis of various engineering and technical projects (Ilori et al., 1997). The discounted payback period (P_p) was used to inspect the riskiness of the project. The discounted payback period (P_p) is defined by DeGarmo et al. (1979) as the period of time starting from the first day of the project required to fully recover the initial investment and operating expenses. The project is not a risk if the discounted payback period is lesser than the overall economic life of the project, otherwise not. The calculation formula in terms of present value by Adeoti et al. (1999) is:

$$\sum_{t=0}^{P_p} (C_b - C_c)_t \; (1+i)^{-t} = 0 \quad (10)$$

The discounted payback period (P_p) is the smallest t that satisfies equation 10 above. $(C_b – C_c)_t$ and i are as defined above.

4. RESULTS AND DISCUSSION

Table 3 illustrates the cash flow analysis of the solar pv mobile phones charging project at four capacity utilisations: capacity A, 40%; capacity B, 60%; capacity C, 75%; and capacity D, 100%. As shown in Table 3, the initial investment cost is made up of the capital investment cost, 341,699.50 Naira. No pre-production investment expenses are expected. The annual operating expenses were estimated at 148,500 Naira for the first year at 100% capacity utilisation (Table 3). The solar pv mobile phones charging project will require one semi-skilled attendant (optional). Its wages in the first year will amount to 120,000 Naira at 100% capacity utilisation. Other operating expenses at 100% capacity utilisation include the maintenance cost (for example, dusting the surface of the solar modules during the dry periods for effective performance, readjusting the socket pins and the charge controller thresholds, etc.) and exigencies (for example, replacing blown fuse, etc.). It should be noted that the annual operating expenses were readjusted over the economic life of the project considering market instability in Nigeria using equations 6 and 7 to obtain 221,979.34 Naira per year used in the paper. In the estimation of revenue from the charging of mobile phones, the 50 Naira per charge was used. As highlighted in Section 3.1, at 100% capacity utilisation, about 9,000 charging times per year are expected. This translates to 0.45 million Naira per year. At a minimum, about 90 mobile phones will be needed to realise the 9,000 charging times per year. Estimates for other production capacities for annual operating expenses and revenue in the first year are also illustrated in Table 3. The other capacities were considered assuming that (i) there is a significant improvement to grid electricity supply, (ii) grid electricity extension to rural and unconnected rural households, (iii) fall in the prices of fossil fuels/generators, encouraging self-generation, and/or (iv) increasing opportunities to charge for free in rural areas. The cash flow diagram of the project at 100 per cent capacity utilisation is shown in Figure 3.

Table 3: Cash flow (in Naira) of the solar pv mobile phones charging project

Cost factor	Capacity A	Capacity B	Capacity C	Capacity D
Initial investment cost:				
- *Capital investment (from Table 3)*	341,699.5	341,699.5	341,699.5	341,699.5

Annual operating expenses:				
- *Labour*	48,000	72,000	90,000	120,000
- *Maintenance and repair*	6,000	9,000	11,250	15,000
- *Exigencies (at 10% annual operating expenses)*	5,400	8,100	10,125	13,500
sub-total	59,400	89,100	111,375	148,500
Annual revenue:				
- *Revenue from mobile phones charging*	180,000	270,000	337,500	450,000
- *Salvage value*	58,088.92	47,837.93	41,003.94	30,752.96
NPV	107,080.46 (US$260.41)	322,790.13 (US$785.00)	484,761.01 (US$1,178.91)	754,964. 29 (US$1,836.02)
The discounted payback period at 100% capacity utilization				2 years

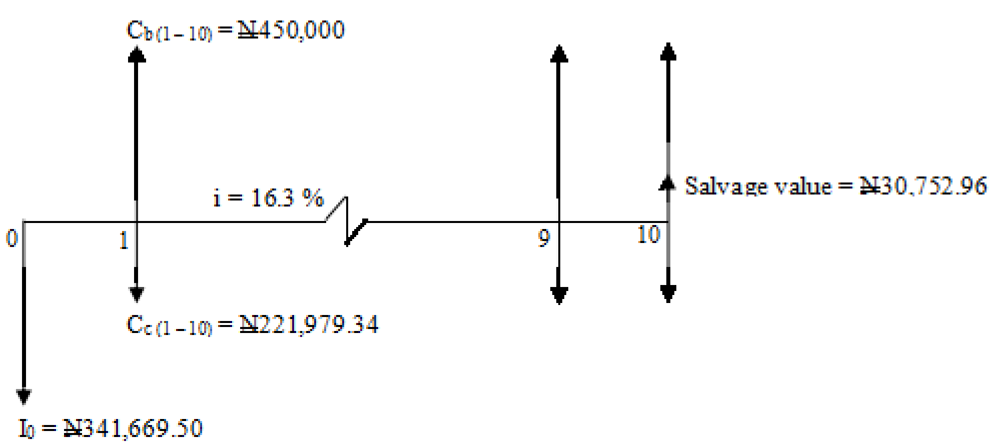


Fig. 3: Cash flow diagram of the mobile phones charging project (before tax)

The profitability analysis (Table 3) shows a positive NPV before tax for the project operating at the four different capacity utilisations considered in this paper. This shows that the project will make some profit from the perspective of an entrepreneur at the four capacity utilisations since their NPVs are greater than zero. In addition to this, the discounted payback period at 100% capacity utilisation is 2 years (see Table 3). This suggests that at 100% capacity utilisation, the project has a good feature of not being a risk as the initial investment cost and the operating expenses of the project can be recovered within a period of 2 years which is less than the overall economic life of the project, 10 years.

5. SENSITIVITY ANALYSIS

Considering market instability, possible improvements to grid electricity supply and other factors as highlighted above which could constitute a risk to the project, the behaviour of the solar pv mobile phones charging project was tested with its effect on profitability from the perspective of an entrepreneur. Three main factors that could affect the project's profitability (or internal rate of return (IRR)) were selected to carry out the sensitivity analysis at 100% capacity utilisation using the NPV model. The selected factors are: initial investment cost, mobile phone charging price, and annual operating expenses. The results of the sensitivity analysis, illustrated in Table 4, reveal that the selected factors have a significant effect on the profitability of the project in the following order: (a) charging price, (b) initial investment cost, and (c) annual operating expenses.

Table 4: Results of sensitivity analysis

Factor	IRR[a] (%) (original state)	Variation	IRR (%) (varied state)
Initial investment cost	66.32[b]	Increase 20%	54.91
		Decrease 10%	73.85
Charging price	66.32	Increase 10%	79.67
		Decrease 20%	38.88
Annual operating expenses	66.32	Increase 20%	52.97
		Decrease 10%	72.92

[a]The Internal Rate of Return (IRR) criterion also reflects the profitability of a project. When the IRR is greater than the MARR in the financial analysis, the project is worthwhile, otherwise not. Its calculation formula (Adeoti et al., 1999) is: $\sum_{t=0}^{n} A_t \, (1+irr)^{-t} = 0$

[b]At IRR of 66.32%, the project will bring sufficient funds to pay for itself in 10 years and also provide the entrepreneur with a return of 66.32% on its invested capital over the overall project life

However, with the IRR of the selected factors in their varied state (see column 4 of Table 4) greater than 16.3% (the MARR), this suggests that the three factors if varied in cost (as suggested in column 3 of Table 4) will not constrain the ability of the project to make a profit. The project will lack the ability to support its own development if the project IRR (see column 2 of Table 4) is less than 16.3%, the MARR. Besides this, at 100% capacity utilisation, using the NPV model, the project becomes unattractive if the charging price falls below 33.00 Naira per mobile phone. Also, the project becomes unattractive at a capacity utilisation below 40 per cent.

6. OTHER BENEFITS OF THE PROJECT

Global greenhouse gas emissions due to human activities have grown since pre-industrial times (Intergovernmental Panel on Climate Change (IPCC), 2007). However, Nigeria ranks as one of the highest producers of greenhouse gases in Africa, estimated at 2 x 10^3 CO_{2eq} per capita in 2015 (The Federal Government of Nigeria, 2015). Due to their advantages in reducing emissions as well as being sustainable, solar pv technologies are attracting increasing attention all over the world (Chen and Bi, 2017). Solar pv technologies do not emit any direct greenhouse gases during operation (Joshi et al., 2009). Therefore, it could be used to realise Nigeria's pledge to unconditionally reduce carbon emissions by 20 per cent under the Paris Agreement. Besides its financial benefits from the viewpoint of an entrepreneur (see Tables 3 and 4), investments in solar pv mobile phones charging projects also have some other important advantages at the societal level. These include load reduction on the national grid, climate and health value. These are further discussed below.

At an average of 3 W per mobile phone and with roughly 10 million mobile phones-in-use in rural areas [it is roughly assumed that rural dwellers account for 8 per cent of the mobile phones-in-use in Nigeria, although a 2015/16 survey revealed that 48.3 per cent of rural dwellers in Nigeria owned a mobile phone (NBS, 2016)], about 30 MW of electricity will be drawn from the national grid. Using an average charging time of 208 hours per year per mobile phone, translates to 6.24 GWh of electricity consumed. Should rural dwellers switch to solar pv, this represents the overall energy that will be saved which could be available for the underserved areas in Nigeria. In terms of impact on climate and health, using private fossil fuel-based generators or power plants (as in the case of grid electricity) to charge mobile phones would result into the emissions of gaseous pollutants (such as – carbon monoxide (CO), carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_X), etc) and black carbon. These gases and black carbon have been implicated in climate change (Akindele, 2016; Ani, 2016; İçöz et al., 2008). In the case of grid electricity supply, based on the life cycle approach (LCA), the CO_2 emissions from hydro and gas-fired plants vary (see – World Nuclear Association, 2016; Time for Change, 2018). Using a conservative average for the case of Nigeria due to a paucity of data, CO_2 emissions from hydro plants are estimated at 0.01 kg/kWh, while from gas fired thermal plants are put at 0.45 kg/kWh – averaged at 0.23 kg/kWh due to the epileptic operation of power plants in Nigeria. For mobile phones in rural areas, assuming fully on grid supply, this would amount to 1.44×10^6 kg CO_2 emitted into the atmosphere per year. On the other hand, assuming mobile phones-in-use in rural areas are powered by private generators, the CO_2 emissions would translate to 11.81×10^6 kg CO_2 per year as calculated below: Using the popular 0.65 kW gasoline generator by vendors in Nigeria to charge, to generate 30 MW of electricity will require about 0.046 million units of 0.65 kW capacity gasoline generators. On average, each generator consumes about 0.5 litres of E10 (90 per cent gasoline, 10 per cent ethanol) per hour. From the literature, the CO_2 emissions value of E10 fuel (oxidation factor of 0.99) translates to 2.27 kg/litre (Serpa, 2008). On the average, a 0.65 kW generator would power about 200 mobile phones (at an average of 3 W per phone). Therefore, the CO_2 emissions per phone per hour of charging would translate to 5.68×10^{-3} kg. Charging for an average of 208 hours per mobile phone per year would emit 1.18 kg CO_2 into the atmosphere. For the assumed 10 million mobile phones-in-use in rural areas, this translates to 11.81×10^6 kg CO_2 being emitted into the atmosphere per year.

Apart from heat, vibration, and noise (Mbamali et al., 2012), the use of private fossil-fuelled electricity generators also poses important health and safety risks especially when these generators are used indoors or in close proximity to humans (Ani, 2016). Fumes from fossil-fuelled electricity generators contain many known or suspected cancer-causing substances, such as benzene, arsenic, and formaldehyde. Studies have shown that exposure to volatile organic compounds such as gasoline and diesel fuels are associated with a wide variety of deleterious health effects including respiratory diseases such as lung edema and haemorrhage, liver and kidney diseases and cancer (Bin-Mefrij and Alwakeel, 2016). Ekpenyong et al. (2013) reported that inhalation of gasoline fumes could interfere with ovarian functions leading to disordered menstrual characteristics and female sex hormone profiles as well as future reproductive impairment in women. Bin-Mefrij and Alwakeel (2016) revealed that exposure to fumes of gasoline and diesel fuel had implications on kidney and liver function. The burning of gasoline- and diesel fuel has been implicated in the production of isocyanic acid which contributes to adverse health outcomes such as cataracts, atherosclerosis, and rheumatoid arthritis (Jathar et al., 2017). According to Oseni (2016), exhaust from diesel fuel has resulted into irritation of the eyes and nose, asthma, chronic bronchitis and respiratory disorder. The emission of sulphur dioxide from the exhaust of gasoline and diesel-fuel powered engines has also been implicated in the formation of acid rain and particulate matter, with the latter being held responsible for respiratory illnesses, including increased frequency in bronchitis and asthma (Olatunji et al., 2015).

Studies have also linked premature death, cardiovascular and respiratory disorder to exposure to black carbon (Turner et al., 2015). There were indications that inhalation of, and/or exposure to, fumes had resulted into deaths (This Day, 2017; Obahopo, 2017). For example, a report indicated that between 2008 and 2014 no fewer than 10000 Nigerians died through inhalation of fumes from private electricity generators (Anyagafu, 2014). In May 2017, a widow and her three children in the Ikorodu area of Lagos, Nigeria lost their lives after being poisoned by generator fumes (This Day, 2017). A couple and their three children were reportedly suffocated to death from generator fumes at Oleh in Umeh Community, Isoko South Local Government Area of Delta State, Nigeria in October 2017 (Akuopha, 2017). A preliminary investigation revealed that two middle-aged women died of inhalation of generator fumes in a shop in the Oredo Local Government Area of Edo State on Tuesday, 12 December 2017 (Okere, 2017b). More recently, four Lagos-based family members were reportedly killed by fumes from a generator in the Irepodun Local Government Area of Kwara State on Wednesday, 21 July 2021 (Oyekola, 2021). In the US, acute carbon monoxide (CO) exposures from portable gasoline-powered generators have also resulted into death (Emmerich et al., 2016). Therefore, investments in solar pv mobile phones charging project will not only save grid electricity use, it will also provide some climate and health value at the societal level.

7. *CONCLUSION AND RECOMMENDATIONS*

Under the various assumptions made, this paper has shown that the solar pv mobile phones charging project has some financial benefits when evaluated from the perspective of an entrepreneur and the potential to support its own development. Investments in solar pv mobile phones charging project also have some added advantages of job creation, load reduction on the national grid, climate and health value. To promote investments in solar pv mobile phones charging project, it is recommended that governments should plan and implement pilot schemes in rural areas, provide financial incentives for would be rural investors, and educate rural dwellers on its potential advantages. Encouraging local production of solar pv equipment especially in developing economies by governments would help to stimulate cost reduction which is needed to promote the penetration and diffusion of this business concept in rural areas.

8. ACKNOWLEDGEMENTS

The author gratefully acknowledges the useful insights gained from: Engr. I. O. Akinwole and Mr. U. Yahaya, Department of Electrical Electronic Engineering and Engr. Dr. S. O. Ejiko, Department of Mechanical Engineering, the Federal Polytechnic, Ado Ekiti, Ekiti State, Nigeria.

REFERENCES

Acquah, M., Ahiataku-Togobo, W., & Ashie, E. (2017). Technical and socio-economic issues of small scale solar PV electricity supply in rural Ghana. *Energy and Power* 7(1), 10-21.

Adeoti, O., Ilori, M.O., Oyebisi O. O., & Adekoya, L. O. (1999). Engineering design and economic evaluation of a family-sized biogas project in Nigeria. *Technovation* 20(2), 103-108, doi:10.1016/S0166-4972(99)00105-4

Adeoti, O. (2016). Biomass electricity supply: case study Ekiti State, Nigeria. Proceedings of the International Engineering Conference of the Nigerian Society of Engineers, held in Uyo, Akwa Ibom State, Nigeria between 21 and 25 November, 2016. National Headquarters, National Engineering Centre, Abuja: NSE

Akindele, O. A. (2016). False adaptive resilience: the environmental brutality of electric power generator use in Ogbomoso, Nigeria. *World Environment* 6(3), 71-78, doi:10.5923/j.env.20160603.01

Akinyele, D., Belikov, J., & Levron, Y. (2018). Challenges of microgrids in remote communities: A STEEP model application. *Energies* 11, 432, doi:10.3390/en11020432

Akuopha, O. (2017). Couple, 3 children suffocate to death from generator fumes. Vanguard. https://www.vanguardngr.com/2017/10/couple-3-children-suffocate-death-generator-fumes/ (accessed 31 October 2017)

Aliyu, A. S., Dada, J. O., & Adam, I. K. (2015). Current status and future prospects of renewable energy in Nigeria. *Renew. Sust. Energ. Rev.,* 48, 336-346.

Ani, V. A. (2016). Design of a stand-alone photovoltaic model for home lightings and clean environment. *Frontiers Energy Research* 3, 54, doi: 10.3389/fenrg.2015.00054

Anyagafu, V. S. (2014). Nigeria records over 10,000 deaths through 'generator' fumes. Vanguard online. https://www.vanguardngr.com/2014/08/nigeria-records-10000-deaths-generator-fumes/ (13 September 2017)

Arsie, I., Rizzo, G., Sorrentino, M., Petrone, G., Spagnuolo, G., Cacciato, M., & Consoli, A. (2006). Hybrid vehicles and solar energy: A possible marriage? International Conference on Automotive Technologies ICAT 2006, November 17-18, 2006. Istanbul: ICAT

Barnwal, P., & Tiwari, G. N. (2008). Grape drying by using hybrid photovoltaic-thermal (PV/T) greenhouse dryer: An experimental study. *Solar Energy* 82, 1131-1144.

Bhutto, A. W., Bazmil, A. A., & Zahedi, G. (2012). Greener energy: Issues and challenges for Pakistan – solar energy prospective. *Renew. Sust. Energ. Rev.,* 16, 2762-2780.

Bin-Mefrij, M., & Alwakeel, S. (2016). The effect of fuel inhalation on the kidney and liver function and blood indices in gasoline station workers. *Advances in Natural and Applied Sciences* 11(1), 45-49.

CBN (2021a). Money market indicators (in percentage). Retrieved from https://www.cbn.gov.ng/rates/mnymktind.asp?year=2020

CBN (2021b). Inflation rates (percent). Retrieved from https://www.cbn.gov.ng/rates/inflrates.asp?year=2020

Chander, S., Purohit, A., Sharma, A., Arvind, Nehra, S. P., & Dhaka, M. S. (2015). A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperature. *Energy Reports* 1, 104-109.

Chaurey, A., & Kandpal, T. C. (2010a). A techno-economic comparison of rural electrification based on solar home systems and PV microgrids. *Energy Policy* 38, 3118-3129.

Chaurey, A., & Kandpal, T. C. (2010b). Assessment and evaluation of PV based decentralized rural electrification: An overview. *Renew. Sust. Energ. Rev.,* 14, 2266-2278.

Chen, W., & Bi, Y. (2017). Electricity price subsidy or carbon-trading subsidy: which is more efficient to develop photovoltaic power generation from a government perspective? *Mitig. Adapt. Strateg. Glob. Change* 23, 667–683, doi:10.1007/s11027-017-9754-z

DeGarmo, E. P., Canada, J. R., & Sullivan, W. G. (1979). *Engineering economy, 6th ed*. New York: Macmillan.

Ekpenyong, C. E., Davies, K., & Daniel, N. (2013). Effects of gasoline inhalation on menstrual characteristics and the hormonal profile of female petrol pump workers. *Journal of Environmental Protection* 4, 65-73.

Electricalnotes (2015). Calculate size of inverter and battery bank. Retrieved from https://electricalnotes.wordpress.com/2015/10/02/calculate-size-of-inverter-battery-bank/

Emmerich, S. J., Polidoro, B., & Dols, W. S. (2016). Simulation of residential carbon monoxide exposure due to generator operation in enclosed spaces. NIST Technical Note 1925. Retrieved from http://dx.doi.org/10.6028/NIST.TN.1925

Emodi, N. V., & Boo, K-J. (2015). Sustainable energy development in Nigeria: Current status and policy options. *Renew. Sust. Energ. Rev.,* 51, 356-381

FAO (2002). Country overview (Nigeria) – climate. Retrieved from http://www.fao.org/ag/agl/swlwpar/reports/y_sf/z_ng/ngtb131.htm

Finck, H., & Oelert, G. (1985). A guide to the financial evaluation of investment projects in energy supply. Schriftenreihe der GTZ, No. 163. Eschborn: GTZ.

FMST (2014a). Draft National Renewable Energy and Energy Efficiency Policy (NREEEP). Abuja: Energy Commission of Nigeria.

FMST (2014b). National Energy Masterplan (draft revised edition). Abuja: Energy Commission of Nigeria.

Gaddy, E. (2003). Photovoltaics for hybrid automobiles. In Proceedings of 3rd World Conference on Photovoltaic Energy Conversion (pp. 2827-2832). Osaka, Japan: IEEE.

Giwa, A., Alabi, A., Yusuf, A., & Olukan, T. (2016). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renew. Sust. Energ. Rev.,* 69, 620-641

Hollmuller, P., Joubert, J-M., Achal, B., & Yvon, K (2000). Evaluation of a 5 kWp photovoltaic hydrogen production and storage installation for a residential home in Switzerland. *International Journal of Hydrogen Energy* 25(2), 97-109

İçöz, E., Tuğrul, K. M., & İçöz, E. (2008). Research on ethanol production and use from sugar beet in Turkey. *Biomass and Bioenergy* 33, 1-7.

IEA (2018). Global energy and CO_2 status report 2017. Paris: IEA.

Ilori, M. O., Irefin, I. A., & Adeniyi, A. A. (1997). Engineering economy studies on the production of non-alcoholic beverages from some tropical crops. *Technovation* 17(11-12), 715-721.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC

Janjai, S., Lamlert, N., Intawu, P., Mahayothee, B., Bala, B. K., Nagle, M., & Müller, J. (2009). Experimental and simulated performance of a PV-ventillated solar greenhouse dryer for drying of peeled longan and banana. *Solar Energy* 83, 1550-1565.

Jathar, S. H., Heppding, C., Link, M. F., Farmer, D. K., Akherati, A., Kleeman, M. J., de Gouw, J. A., Veres, P. R., & Roberts, J. M. (2017). Investigating diesel engines as an atmospheric source of isocyanic acid in urban areas. *Atmospheric Chemistry and Physics* 17(14), 8959-8970.

Joshi, S. A., Dincer, I., & Reddy, V. B. (2009). Performance analysis of photovoltaic systems: A review. *Renew. Sust. Energ. Rev.,* 13, 1884-1897, doi:10.1016/j.rser.2009.01.009

Krauter, S., & Ochs, F. (2003). Integrated solar home system. *Renewable Energy* 29, 153-164

Leonics (2018). How to design solar PV system. Retrieved from *http://www.leonics.com/support/article2_12j/articles2_12j_en.php*

Mbamali, I., Stanley, A. M., & Zubairu, I. K. (2012). Environmental, health and social hazards of fossil fuel electricity generators: a users' assessment in Kaduna, Nigeria. *American International Journal of Contemporary Research* 2(9), 237-245.

Mpagalile, J. J., Hanna, M. A., & Weber, R. (2005). Design and testing of a solar photovoltaic operated multi-seeds oil press. *Renewable Energy* 31, 1855-1866.

Mumba, J. (1995). Development of a photovoltaic powered forced circulation grain dryer for use in the tropics. *Renewable Energy* 6(7), 855-862

NBS (2012). Annual abstract of statistics, 2012. Abuja: NBS.

NBS (2016). LSMS-Integrated surveys on agriculture general household survey panel 2015/2016. Abuja: NBS.

NCC (2021). Subscriber statistics. Retrieved from https://www.ncc.gov.ng/statistics-reports/subscriber-data

NERC (2021a). NESI – Transmission. Retrieved from https://nerc.gov.ng/index.php/home/nesi/404-transmission

NERC (2021b). NESI - Generation. Retrieved from https://nerc.gov.ng/index.php/home/nesi/403-generation

Norton, B., Eames, C. P., Mallick, K. T., Huang, J. M., McCormack, J. S., Mondol, D. J., & Yohanis, G. Y. (2009). Enhancing the performance of building integrated photovoltaics. *Solar Energy* 85, 1629–1664,doi:10.1016/j.solener.2009.10.004

Oanda (2021). Currency converter. Retrieved from https://www.oanda.com/currency/converter/

Obahopo, B. (2017). Family of four dies of generator fumes in Kogi. Vanguard online. Retrieved from https://www.vanguardngr.com/2017/08/family-of-four-dies-of-generator-fumes-in-kogi/

Obeng, G.Y., & Evers, H.-D. (2010). Impacts of public solar PV electrification on rural micro-enterprises: The case of Ghana. *Energy for Sustainable Development* 14, 223-231.

Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: Drivers and barriers. *Renew. Sust. Energ. Rev.,* 32, 294-301.

Okere, A. (2017). Generator fumes kill two in Edo. The Punch (Nigeria), December 13, p. 5.

Olatunji, S. O., Fakinle, B. S., Jimoda, L. A., Adeniran, J. A., & Adesanmi, A. J. (2015). Air emissions of sulphur dioxide from gasoline and diesel consumption in the southwestern states of Nigeria. *Petroleum Science and Technology* 33(6), 678-685.

Omer, M. A. (2002). Energy supply potentials and needs, and the environmental impact of their use in Sudan. *The Environmentalist* 22, 353-365

Oseni, M. O. (2016). Get rid of it: to what extent might improve reliability reduce self-generation in Nigeria? *Energy Policy* 93, 246-254.

Oyekola, T. (2021). Generator fumes kill four Lagos-based family members in Kwara. The Punch (Lagos), July 22, p. 9.

Park, C. S., & Sharp-Bette, G. P. (1990). Advanced engineering economics. New York: John Wiley & Sons.

Park, S. R., Pandeyb, A. K., Tyagic, V. V., & Tyagib, S. K. (2013). Energy and exergy analysis of typical renewable energy systems. *Renew. Sust. Energ. Rev.,* 30, 105-123.

Purohit, P., & Michaelowa, A. (2006). CDM potential of SPV lighting systems in India. *Mitig. Adapt. Strat. Glob. Change* 13, 23-46

Rahman, M. Z. (2011). Multitude of progress and unmediated problems of solar PV in Bangladesh. *Renew. Sust. Energ. Rev.,* 16, 466-473.

Razykov, T.M., Ferekides, C.S., Morel, D., Stefanakos, E., Ullal, H. S., & Upadhyaya, H.M. (2010). Solar photovoltaic electricity: Current status and future prospects. *Solar Energy* 85(2011), 1580–1608, doi:10.1016/j.solener.2010.12.002

Rizzo, G. (2010). Automotive applications of solar energy. In 6th IFAC Symposium Advances in Automotive Control (pp. 174-185). Munich, Germany: IFAC

Serpa, D. (2008). CO_2 emissions from fuel combustion. Retrieved from http://www.afteroilev.com/Pub/CO2_Emissions_from_Fuel_Combustion.pdf

Shaaban, M., & Petinrin, J. O. (2013). Renewable energy potentials in Nigeria: meeting rural energy needs. *Renew. Sust. Energ. Rev.,* 29, 72-84.

Standards Organisation of Nigeria (2015). Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures. Abuja: Standards Organisation of Nigeria.

Sunwatt India (2013). Why solar. Retrieved from http://www.sunwattindia.com/whysolar.html

The Federal Government of Nigeria (2015). Nigeria's intended nationally determined contribution. Abuja: Federal Ministry of Environment.

This Day (2017). Death from generator fumes. Retrieved from https://www.thisdaylive.com/index.php/2017/05/19/death-from-generator-fumes/

Time for Change (2018). CO_2 emission of electricity from nuclear power stations. Retrieved from https://timeforchange.org/co2-emission-nuclear-power-stations-electricity

Turner, M. D., Henze, D. K., Capps, S. L., Hakami, A., Zhao, S., Resler, J., Carmichael, G. R., Stanier, C. O., Baek, J., Sandu, A., Russell, A. G., Nenes, A., Pinder, R. W., Napelenok, S. L., Bash, J. O., Percell, P. B., & Chai, T. (2015). Premature deaths attributed to source-specific BC emissions in six urban US regions. *Environmental Research Letters*

10, doi:10.1088/1748-9326/10/11/114014.

World Bank (2021a). Access to electricity, rural (% of rural population) – Nigeria. Retrieved from https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=NG

World Bank (2021b). Rural population (% of total population). Retrieved from https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS

World Bank (2021c). Access to electricity, rural (% of rural population) – World. Retrieved from https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=1W

World Nuclear Association (2016). CO_2 implications of electricity generation. Retrieved from http://www.world-nuclear.org/information-library/energy-and-the-environment/co2-implications-of-electricity-generation.aspx

ACHIEVING SUSTAINABLE DEVELOPMENT GOAL (SDG)-7 IN SUB-SAHARAN AFRICA THROUGH ELECTRICITY PROSUMERISM

Kelechi Eke[1], Jibrin Abubakar[2], Ijeoma Anigbogu[3], Engr Babatope Ajayi[4]and Christopher Babayemi[5], 08068744486[1]; kelechai@yahoo.com[1], Egbin Power PLC[1, 2, 4,5]and Transmission Company of Nigeria PLC[3]

ABSTRACT

Sustainable Development Goal (SDG)7 seeks to ensure universal access to affordable, reliable, sustainable and modern energy by 2030. In realization of this objective, governments in Sub-Saharan Africa, in partnership with local and international agencies, have launched some initiatives such as: Power Africa, Electrification Financing Initiative and Energy Africa Campaign, aimed at improving electricity access in the sub-region. Progress has been slow, but remarkable. So far, only about Six Hundred (600) million people representing half of Sub-Saharan Africa's population have access to electricity. Electricity Prosumerism is a distributed power generation concept that can accelerate electricity access in the sub-region. The concept stimulates own-generation, minimizes transmission losses, reduces overall ownership cost and makes electricity more accessible, reliable and affordable. These attributes are essential for achieving SDG7 in a sub-region characterized by low per capita income of Seven Hundred and Sixty-Two United States Dollar ($762.00) only and high energy poverty. This paper examines how Electricity Prosumerism can be utilized to achieve SDG7 in Sub-Saharan Africa, challenges and proposed solutions.

Keywords: Electricity Prosumerism, Energy Poverty, Renewable Energy (RE), Sustainable Development Goal (SDG)-7, Sub-Saharan Africa

1 INTRODUCTION

Sub-Saharan Africa has the lowest electrification rate (44%) in the world; with about Six Hundred (600) million people unelectrified (Brookings, 2021; Economist, 2021; World Bank, 2021). Energy poverty in the sub-region (excluding South Africa) is very high, with a per capita electricity consumption of 124kWh – the lowest in the world (Africa Energy Portal, 2018; Institute for Advanced Sustainability Studies, 2016a). Electrification rate within the sub-region is highly uneven, characterized by higher rates in urban areas and much lower rates in the rural areas. These poor electrification indices are partly responsible for high rate of rural-urban migration, widening gap between the rich and the poor, as well as high unemployment and crime rates in the sub-region.

Sequel to the substantial success of the Millennium Development Goals (MDGs), the United Nations General Assembly in 2015 developed a blueprint – Sustainable Development Goals (SDGs) – to be used as the framework for benchmarking future global development (Sustainable Development Goals Fund, 2021; Wikipedia, 2021). The SDGs, a collection of 17 closely linked Global Goals, will elapse in 2030. Goal 7 of the SDGs focuses on Affordable and

Clean Energy.

Although Sub-Saharan Africa is blessed with abundant energy resources including fossil fuels, the region suffers from poor energy security. The sub-region is still a net importer of processed fossil fuels. According to the Institute of Advanced Sustainability Studies (2016b), the Sub-Saharan Africa energy situation is characterized by unreliable power supply (frequent grid outages), expensive and unaffordable electricity tariffs ($130 - $140/MWh which is among the highest in the world), and excessive dependence on unclean sources of energy (50% of businesses operate diesel back-up generators). Traditional biomass, an unclean energy source, remains the dominant source of energy in the sub-region, mostly for cooking. Useable energy is thus produced substantially from polluting sources. Thus, whereas energy in the sub-region is abundantly available in naturally occurring forms, it is not sufficiently available in processed and useable forms such as electricity.

Africa, in partnership with other governments and international agencies, have developed some initiatives aimed at improving access to electricity in the continent such as: Power Africa, New Deal for Energy in Africa, Energy Africa Campaign, Sustainable Energy Fund for Africa, Electrification Financing Initiative and African Energy Leaders Group (Mendoza, 2016).

Electrification can be achieved by either conventional power generation or via renewables. The Middle East hydrocarbon export embargo to Western Europe and the United States in the mid-1970's exposed the later's then vulnerability to hydrocarbon imports and weak energy security. This led to extensive investment in research and development in alternative energy especially, renewable energy. This consequently led to the discovery and deployment of more efficient processes for renewable energy utilization, steady decline in Levelized Cost of Electricity (LCOE) and increasing share of electricity consumption from renewables across the world.

The dominant global energy theme since the 1970's Middle East embargo has become the 3D's: Decarbonization, Decentralization and Digitalization. As part of its decarbonization vision, the European Union has set 2050 as its target year to attain carbon-neutrality (European Union, 2021). This has led to significant decarbonization of technology and supply chains in the global energy world. For example, due to the high carbon footprint associated with the coal industry, no new coal power plant licenses are being granted in western Europe and USA. Research and development investments in coal technology have also significantly declined.

Renewable energy has thus become the preferred method of electrifying unserved and underserved areas especially, in locations remote from the grid, often with low population density and abundant renewable energy resources.

The previous trend for renewable energy

deployment was via own-generation with Feed-In-Tariff (FIT) option for grid integration; a concept associated with prosumerism. Over time, the emphasis about the concept changed slightly to electricity generation in close proximity to consumers, with little or no transmission required; a concept associated with distributed generation. However, this has changed further through the introduction of Peer-To-Peer (P2P) energy trading; a concept that enables the trading of electricity between two or more consumers directly between themselves without the need for any intermediary such as the grid. This paper focuses on providing access to reliable electricity in Sub-Saharan Africa through electricity prosumerism, complemented by P2P energy trading.

2 ELECTRICITY PROSUMERISM AND ITS ENABLERS

Electricity prosumerism is the concept of an entity self-generating its electricity needs and exporting excess generation to third parties (Energy Community Regulatory Board, 2020; European Parliament Think Tank, 2021). The entity that engages in this act is called an electricity prosumer. Electricity prosumerism reduces over-dependence on grid or imported power. The exported energy from prosumers may or may not be through third parties. If the export does not require a third-party platform, the model is called Peer-to-Peer (P2P).

2.1 P2P is a business model based on inter-connected platform whereby electricity prosumers trade excess electricity generation directly to consumers without the need for a third party such as the grid (Hansen, Friis, Jacobsen and Gram-Hanssen, 2019; IRENA, 2020). P2P is also called 'Uber' or 'Airbnb' of energy. P2P is a strong business enabler to electricity prosumerism largely because of its diverse benefits which include:

a. Enhances energy penetration
b. Reduces grid congestion
c. Promotes decentralization by reducing the size of power plants required to be built
d. Reduces size of grid infrastructure
e. Reduces grid (transmission) losses since the prosumer is located close to the consumer
f. Provision of ancillary services to the grid
g. Enhances energy security by reducing power outages due to external perturbations such as natural disasters, wars, cyber-attacks, etc.
h. Deepens energy resilience against power outages
i. Improved access to electricity, etc.

The P2P business model has proved successful in some countries such as: Columbia, Germany, Malaysia, Netherlands, Portugal, UK and USA. Examples of successful P2P companies are: Transactive Energy Colombia Initiative

(Columbia); Lition (launched in 2018), Germany which enabled 20% lower cost of electricity for consumers and 30% increase in revenue for power producers; Sonnen Community (Germany); Sustainable Energy Development Authority (Malaysia); Vandebron (Netherlands); EU Clean Energy Package (CEP) – a P2P regulatory framework which created Citizens Energy Communities (CEC); Piclo (UK) and Brooklyn Microgrid (USA) – a P2P microgrid market based on blockchain technology (Anisie and Boshell, 2020; Lee, 2017 and Zhnag, Wu, Zhou, Cheng, Long, 2018).

Electricity prosumerism, in combination with P2P model, is an opportunity that offers a private-sector driven complementary alternative to conventional electricity generation that will accelerate access to electricity in Sub-Saharan Africa. The size/capacity of power generation required by electricity prosumers is often small; hence, the scale of the required investment is low and more affordable. This makes it attractive for Sub-Saharan Africa economies.

2.2 Another key business enabler to electricity prosumerism is Distributed Energy Resources (DER). DERs are small-scale power generation sources located in close proximity to consumers, often utilizing renewable energy resources (Capehart, 2016). Most electricity prosumers utilize DER technology.

3. CHALLENGES OF ELECTRICITY PROSUMERISM DEVELOPMENT IN SUB-SAHARAN AFRICA

Despite its benefits, electricity prosumerism development is faced with several challenges in Sub-Saharan Africa. These include:

3.1 Rejection of cost-reflective electricity tariffs. Most Sub-Saharan African countries have low Ability-To-Pay (ATP) and Willingness-To-Pay (WTP) for electricity due to low per capita income level. In these countries, electricity is thus regarded as a social good. Governments directly determine electricity tariff and, in most cases, it is not cost-reflective. This hampers electrification infrastructure development in general, and electricity prosumerism development in particular.

3.2 Inadequately incentivized renewable markets. Electricity prosumerism is substantially realized from renewable power generation. However, the Levelized Cost of Electricity (LCOE) from renewable power generation is higher than conventional power generation technologies. Furthermore, renewable power generation, unlike conventional power generation, does not yet have a sophisticated and mature global supply chain. Thus, in order for power generation from renewables to be attractive for investment, it is essential that it is incentivized for it to be cost-competitive. The incentives for renewable power generation in Sub-Saharan Africa is inadequate; thus, hampering electricity prosumerism development.

3.3 Threats from traditional power utilities. According to 2020 Electricity Regulatory Index Report (ESI-Africa, 2021) which surveyed 36 national electricity utilities in Africa, traditional power utilities identified electricity prosumerism as a threat to their business. These utility companies have utilized their strategic influence in their respective national economies, to frustrate the development of electricity prosumerism.

3.4 Low demand-side management maturity. Electricity prosumerism is substantially influenced by consumer behaviour. In other words, it is demand-side dependent. However, the demand-side market in Sub-Saharan Africa is grossly immature and characterized by low demand-side technology penetration. This has reduced the rate of development of electricity prosumerism in the sub-region.

3.5 Low penetration of disruptive technologies. The emergence of disruptive technologies such as net metering, smart metering, energy-efficient products and blockchain technologies has enabled the growth of electricity prosumerism in Western Europe and the United States where electricity prosumerism market is substantially mature. Unfortunately, the rate of utilization of these disruptive technologies in Sub-Saharan Africa is low, thus limiting electricity prosumerism development in the sub-region.

3.6 Little Distributed Energy Resources (DER) penetration. DER has already been identified as strong business enabler to electricity prosumerism. However, DER penetration in Sub-Saharan Africa is poor. This has mitigated against the development of electricity prosumerism in the sub-region.

3.7 Access to market data. Electricity data in Sub-Saharan Africa are often not readily available to the public. These data are essential for decision-making not only by government and regulators but also by investors and consumers. Limited availability and access to electricity market data hampers investors and consumers interests and active participate in electricity markets especially, electricity prosumerism.

3.8 Low level of awareness of electricity prosumerism. There is a low level of awareness about the benefits of electricity prosumerism in Sub-Saharan Africa especially, amongst electricity consumers. This has limited investment in and development of the market.

4 SOLUTIONS FOR ACHIEVING SGD 7 IN SUB-SAHARAN AFRICA THROUGH ELECTRICITY PROSUMERISM

The Technical, Economic, Commercial, Operational and Political (TECOP) challenges associated with conventional power generation, transmission and distribution in Sub-Saharan Africa must be avoided while developing electricity prosumerism. In order to achieve this, it is fundamental to ensure that an appropriate policy environment is created for a successful activation and development of electricity prosumerism. This includes:

4.1 Cost-reflective electricity tariff.

Governments in the sub-region should introduce and support cost-reflective electricity tariffs in order to attract investments in electricity prosumerism as well as other aspects of electricity infrastructure development. This will promote access to electricity for people in the sub-region especially, the rural population.

4.2 Incentivized renewable development. Governments should provide adequate incentives for renewable energy development, the bedrock of electricity prosumerism. This will engender attractive investments especially private investors, to electricity prosumerism via renewable energy schemes, and thus improve access to electricity and enable the realization of SDG-7 in the sub-region.

4.3 Protection of electricity prosumers from utility cartels. Traditional power utility companies have much larger financial and technical capacity than electricity prosumers. The former, being few in number, can form cartels such as the Association of Power Generation Companies (APGC) in Nigeria and influence Government and regulators in ways that may stifle the survival and development of electricity prosumers, whom they already perceive as business threats. Governments in the Sub-Saharan Africa should put in place measures to ensure that electricity prosumers are adequately protected from larger competitors.

4.4 Deepening demand-side technologies. Sus-Saharan Africa governments should create more awareness about the benefits of demand-side technologies e.g., battery storage technology and also develop and implement policies that will make these products affordable to people. This will stimulate and deepen the demand-side technologies market in the sub-region which are widely used by electricity prosumers.

4.5 Policies that encourage the deployment of disruptive technologies. Governments in Sub-Saharan Africa should put in place measures that will deepen the penetration of disruptive technologies e.g., smart meters and blockchain technologies. These are products vastly used by electricity prosumers. The wide acceptance and use of these technologies will enhance the growth of electricity prosumers in the sub-region.

4.6 Investment in Research and Development (R & D) of Distributed Energy Resources (DER) technologies. Since, electricity prosumerism is almost exclusively associated with DER technologies, it means that investment in research and development of DER technologies will support electricity prosumerism penetration in the sub-region.

4.7 Enhanced access to energy market data. Access to energy data is essential for decision-making by market participants in the energy market. It is therefore important for government and the organized private sector to provide access to accurate energy data to electricity prosumers for optimal decision-making (Leal-Arcas, Lesniewska, and Proedrou, 2018).

4.8 Market sensitization. Governments

should create the enabling environment for investment in electricity prosumerism and also embark on intensive sensitization of investors and consumers about the potentials of the market. Governments should create interactive fora between prosumers (investors) and consumers for enhanced understanding of market interests. This will engender participants interests in the market and thus promote the development of electricity prosumerism.

4.9 Integrability to other markets. In a rapidly changing energy world where consumer behaviour is continuously evolving, electricity prosumerism has to be adaptive to changes. More importantly, electricity prosumerism has to be scalable and integrable to emerging markets otherwise consumers may reject it due to inflexibility.

5. CONCLUSION

Electricity prosumerism can be utilized to achieve accelerated access to energy in Sub-Saharan Africa. Introducing cost-reflective electricity tariffs, incentivizing renewable energy development, providing access to energy data and promoting integrable options to other electricity markets are some of the changes that need to be presented to the policy environment to support the development of electricity prosumerism. Research and development in disruptive technologies is also essential in this regard. These, in combination with conventional energy generation, will enable Sub-Saharan Africa attain SDG-7.

REFERENCES

1. Africa Energy Portal (2018). Sub-Saharan Africa Power 2018, URL: https://www.africa-energy-portal.org/events/sub-saharan-africa-power-2018, (accessed 22/07/2021), p.1.
2. Anisie, A. and Boshell, F. (2020). The Benefits of Peer-To-Peer Electricity Trading for Communities and Grid Expansion, URL: https://energypost.eu/the-benefits-of-peer-to-peer-electricity-trading-for-communities-and-grid-expansion/, p.1.
3. Capehart, B.L. (2016). Distributed Energy Resources (DER), URL: https://www.wbdg.org/resources/distributed-energy-resources-der, accessed 10/08/21, p. 1.
4. Brookings (2021). Figure of the Week: Increasing Access to Electricity in Sub Saharan Africa, URL: https://www.brookings.edu/blog/africa-in-focus/2021/06/18/figure-of-the-week-increasing-access-to-electricity-in-sub-saharan-africa/, (accessed 22/07/2021), p. 1.
5. Economist (2021). More Than Half of Sub Saharan African Lack Access to Electricity, URL: https://www.economist.com/graphic-detail/2019/11/13/more-than-half-of-sub-saharan-africans-lack-access-to-electricity, (accessed 22/07/2021), p. 1.
6. Energy Community Regulatory Board (2020). Prosumers in the Energy Community,

p. 5.

7. ESI-Africa (2021). Snapshot of Africa's Energy and Power Sector, May 27, 2021, p.3.
8. European Parliament Think Tank (2021). Electricity 'Prosumers', URL: https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI(2016)593518, (accessed 15/06/21), p.1.
9. European Union (2021). 2050 Long-Term Strategy, URL: https://ec.europa.eu/clima/policies/strategies/2050_en, (accessed 30/07/21), p.1.
10. Hansen, A.R., Friis, F., Jacobsen, M.H. and Gram-Hanssen, K. (2019). Three Forms of Energy Prosumer Engagement and Their Impact on Time-Shifting Electricity Consumption, Proceedings of 2019 Summer Study organized by European Council for an Energy Efficient Economy, p. 39.
11. Institute for Advanced Sustainability Studies (2016a). The Future of Africa's Energy Supply, URL: https://www.iass-potsdam.de/sites/default/files/files/study_march_2016_the_future_of_africas_energy_supply.pdf, (accessed 15/07/21), p.17.
12. Ibid (2016b). p.16.
13. IRENA (2020). Peer-To-Peer Electricity Trading: Innovation Landscape, p. 2.
14. Leal-Arcas, R., Lesniewska, F. and Proedrou, I. (2018). Prosumers as New Energy Actors, Part of Springer Proceedings in Energy (SPE), p. 6.
15. Lee, Y.S. (2017). Policy Directions for Activating Energy Prosumer; A presentation made on Dec 12, 2017 during the 5th NEAESF, p.11.
16. Mendoza, N.B. (2016). 6 Initiatives Tackling African Electrification, URL: https://www.devex.com/news/6-initiatives-tackling-african-electrification-87692, 2 Feb 2016, p.1.
17. Sustainable Development Goals Fund (2021). Millennium Development Goals, URL: https://www.sdgfund.org/mdgs-sdgs, (accessed 10/07/21), p. 1.
18. Wikipedia (2021). Sustainable Development Goals, URL: https://en.wikipedia.org/wiki/Sustainable_Development_Goals, (accessed 05/06/21), p.1.
19. World Bank (2021). Universal Access to Sustainable Energy will Remain Elusive Without Addressing Inequalities, URL: https://www.worldbank.org/en/news/press-release/2021/06/07/report-universal-access-to-sustainable-energy-will-remain-elusive-without-addressing-inequalities, (accessed 22/07/2021), p. 1.
20. Zhang, C., Wu, J., Zhou, M., Cheng, M. and Long, C. (2018). Peer-to-Peer Energy Trading in a Microgrid, Applied Energy 220(2018), 1- 12, pp. 1 – 2.

EVALUATING THE POTENTIALS OF PIEZOELECTRIC ENERGY HARVESTERS (PEH) FOR ROAD INFRASTRUCTURE APPLICATION

[1]Kehinde, R.K., [1]Yakubu, A.S., [1]Abu, A.S.P., [1]Ekpenyong, E.E., [1]Belamo, J

[1]Nigerian Building and Road Research Institute, PMB 5065 Wuse GPO, Abuja, Nigeria

Corresponding author: kehinde.kamil@nbrri.gov.ng

ABSTRACT

Human activities are characterized by an uphill energy consumption profile and the associated demands have attracted Research & Development (R&D) activities to search for energy sources that combine good efficiency, profitability and environmental friendliness. Mechanical energy is readily available in the environment from vibrating structures, moving objects, & vibrations induced by flowing air or water and can be reused or converted to other forms of energy for various applications. One of such applications utilizes electromechanical conversion characteristics of piezoelectric material to capture, store and generate energy on micro level. This study presents an assessment of Piezoelectric Energy Harvester (PEH) technology in order to establish its viability and applicability for energy harvesting for road applications. Samples of PEH were inspected for cracks before use and stress was applied on samples stacked with adhesive in series to determine the electric output of the samples using the destructive compressive test machine, and 2.5kg proctor compaction rammer. Also, X-ray fluorescence analysis (XRF) was carried out on the samples to ascertain its' chemical composition. XRF result showed that the PEH samples contained a high percentage of Lead (Pb) and Zirconium (Zr) indicating the samples are ferroelectric material that is Lead Zirconate Titanate (PZT). However, a high proportion of silver was observed as a result of the coating applied to the PZT material. It was also observed that there is a relationship between stress and voltage on the PZT tranducer. A single PZT tile of 35mm diameter depending on the stress applied produced an average voltage of 0.5VAC – 51.1VAC. Furthermore, to evaluate its applicability, PEH panel circuit was developed with Polyvinylidene Fluoride (PVDF) sheet as casing material. The panel was tested to map out the average voltage that can be generated to power an LED luminaire. The applied stress measured a maximum voltage of 27.3VDC sufficient to power a DC type Light Emiting Diode (LED) lighting.

Keywords: Energy harvesting, Piezoelectric, Electromechanical Conversion, Ferroelectric, Electrical output

1. INTRODUCTION

Human activities are characterized by an uphill energy consumption profile that has negative concern on energy security and environmental sustainability. The associated effects have attracted R&D activities to search for energy sources that combine good efficiency, profitability and are environmentally friendly (Moure *et al.,* 2016). Within this issue, there have been increasing interests in sustainable energy sources. Amongst such technologies, is the use of piezoelectric materials as alternatives to the conventional electrochemical battery (Calio *et al.,* 2014; Kim *et al.,* 2011; Shu & Lien, 2006). Consequently, the possibility to avoid replacing or recharging of battery with limited life span compared to the working life of the devices to be powered has seen a dramatic rise in energy harvesting and offers a shift towards self-powered sources (Kim *et al.,* 2011; Shu & Lien, 2006).

Energy harvesting also referred to as energy scavenging is based on the philosophy to "capture minute amount of energy from one or more of the surrounding energy sources, accumulate them and store them for later use" (Kim *et al,* 2011). These surrounding energy sources include solar energy, acoustic noise, human motion and mechanical vibration to name a few. Among these surrounding energy sources, mechanical vibration offers a significant potential energy source that is abundant in nature and also resulting from human activities which can be easily harnessed through micro-mechanical systems for conversion to electrical energy. Piezoelectric materials based on fundamental structure of their crystal lattice behaves on the principle of the piezoelectric effect which converts mechanical strain into electrical voltage (Hossein *et al.,* 2016; Xiong *et al.,* 2016; Calio *et al.,* 2014). As such, the feasibility of harnessing energy parasitically offers a shift from the conventional approach of powering road infrastructures to the use of integrated piezoelectric pavements.

Several publications have been published on the potential and possibility of using piezoelectric materials to generate useable energy. For instance, Howells, in 2009 developed four proof of concept heel strike unit made of small piezoelectric generated fitted in the heel of a boot. Results show that average power produced by the heel strike system is much less than 0.5W which was caused from an opposing torque not completely cancelled. This leaves room for optimization thereby increasing energy output. Also, Fan *et al.,* (2017) evaluated the performance of piezoelectric energy harvester by scavenging energy from human motion through piezoelectric transduction as a feasible alternative to batteries for powering portable devices and realizing self-sustained devices. Result obtained indicate that the proposed PEH can scavenge energy from both the vibration and the swing and is capable of producing multiple peaks in voltage output during each stride and this is as a result of the superposition of different excitations.

In Xiong *et al.,* (2016), an energy harvester based on PEH was developed to harvest energy from pavement deformation in real-time. Result establishes a relationship between energy generated and axle loading with average output of the installed PEH at 3.106mW. Further analysis also shows that only 14.43% of the applied load was transferred to the piezoelectric material. As such, the design of the developed harvester can be improved. Madhuranath, *et al*., (2016) in his design model, considered integration of piezoelectric materials in tyres using the principle of a vibration based piezoelectric generator utilizing mechanical energy within a rolling tyre to serve as an energy source for moving vehicles. The result postulates the benefit of the system design to electric car application.

The earliest experimental result on crystals of tourmaline, quartz, topaz, cane sugar and Rochelle salt by Pierre and Jacques Curie in 1880 showed a great scope. Quartz and Rochelle salt exhibited most piezoelectricity. From 1880 to First World War the mathematics of direct and converse piezoelectricity has been developed. During Second World War the ferroelectric ceramic (Barium Titanate) was invented. Subsequently PZT (Lead Zincronium Titanate) was reported by Shirane at the Tokyo Institute of Technology. Various version of PZT subsequently became the prevalent piezoelectric ceramic material due to their major advantage over barium titanate (BaTiO⊠) ceramics, better reproducibility and higher speed of propagation. A majority of piezoelectric generators that has been fabricated and tested use some variation of PZT. Typically PZT is used for piezoelectric energy harvester because of its large piezoelectric coefficient and dielectric constant, allowing it to produce more power for a given input acceleration. In 1969, strong piezoelectricity was observed in PVDF (Polyvinylidene Fluoride) (Keawboonchua *et al.,* 2000; Engel *et al.,* 1997; Ottman *et al.,* 2002; Lefeuvre *et al.,* 2006; Roundy *et al.,* 2003; Williams *et al.,* 1996). The most easily available piezoelectric sensor is PZT and we have used two of its form one is in the form of rounded diaphragm and other is a PZT sheet. For a piezoelectric material to induce maximum charge it must be strained between its self-resonant frequency (SRF) ranges.

The use of piezoelectric in harvesting energy is practically a new approach that has not been studied thoroughly especially in Nigeria. Various factors such as the effect of traffic speed, traffic volume, traffic load, applicability in roads, walkways, and the effect of integrating into pavement and so on are still unknown. For instance, Jung, I., Shin, assessed the functionality of piezoelectric in road application by analyzing awareness and expertise of the technology. Research showed that awareness and expertise in this sector were limited with no established standard on implementation. Therefore, to create a basis for future development, this study seeks to assess Piezoelectric Energy Harvester (PEH) technology in order to establish its viability and applicability for energy harvesting for road applications.

2. MATERIALS AND METHOD

The research method presented by Xiong et al., (2015) was adopted in order to develop an energy harvester panel prototype consisting of piezoelectric ceramic tiles. The electric productivity of the energy harvester developed would be evaluated by measuring the output voltage generated. Since, the generated output is a function of the stress applied over a period of time, Fluke 289 multi-meter with data logging function was used to measure and record voltage data.

An overview of the data collection procedure and assembly of the piezoelectric panel is presented in the subsections 2.1 below. Notwithstanding, the first step was to check samples for cracks using a digital microscope to filter out samples with damage as that has an effect on electrical output. Figure 1 shows a piezoelectric sample without crack.

It is expected that authors will submit carefully written and proofread material. Careful checking for spelling and grammatical errors should be performed. The number of pages of the paper size A4 should NOT more than 12. Technical terms should be explained unless they may be considered to be known to the conference community.

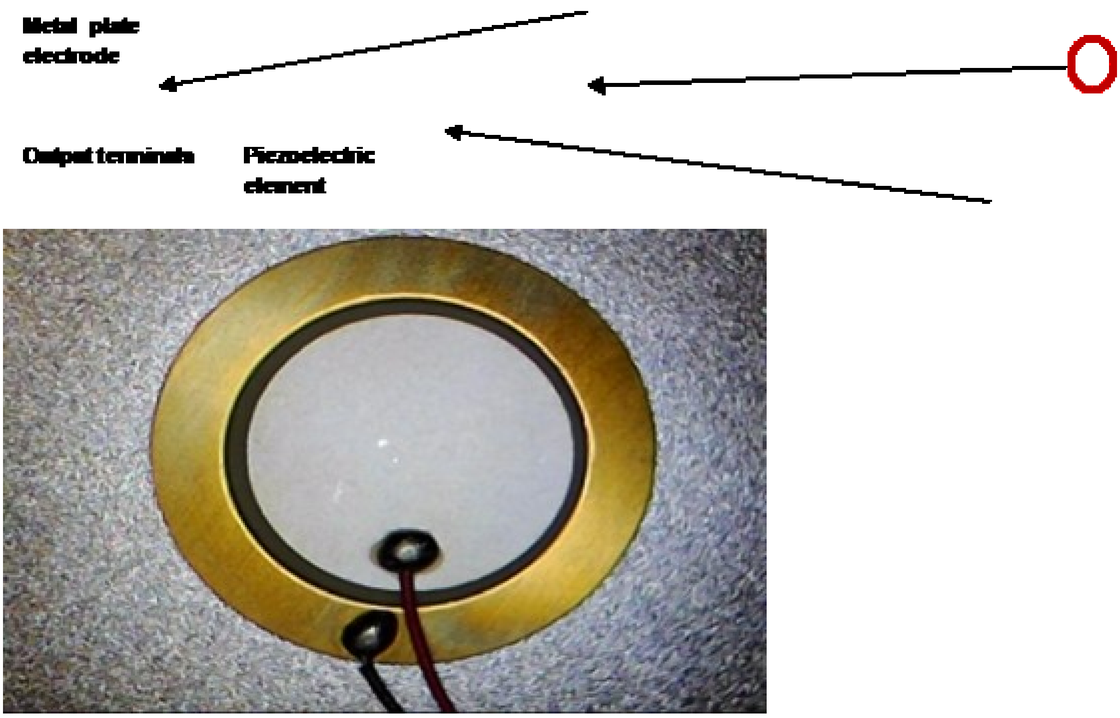


Figure 1: Piezoelectric Diaphragm sample without crack

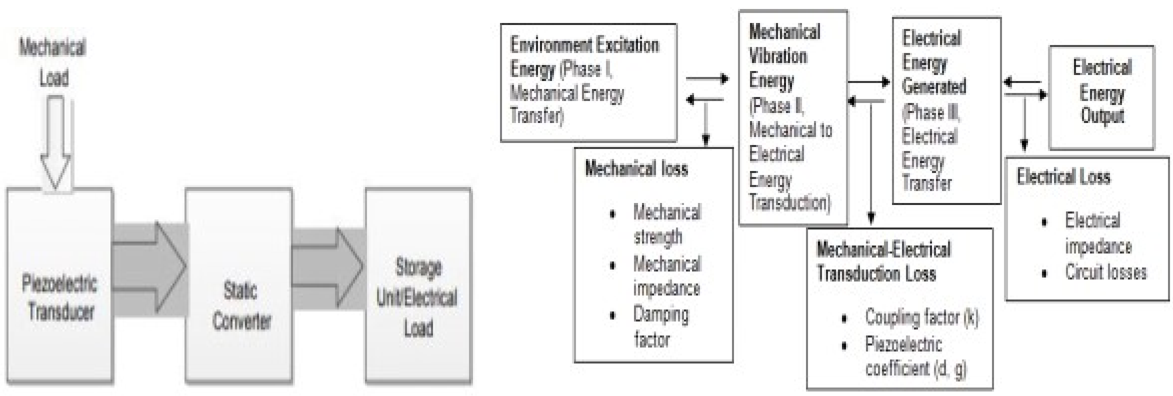


Figure 2: Schematic of a vibrating piezoelectric harvester model and the Energy conversion stages

The harvesting principle of electrical energy from mechanical energy is shown in Figure. 2. The piezoelectric transducer remains in direct contact with the source of vibration. When the vibration occurs, the piezoelectric transducer induces the electric charge. The rate of change of these induced charges with respect to time gives the alternating current pulses. A static converter is used before feeding the storage unit or the electrical load. The transducer used in this model are piezoelectric diaphragms or bender plate that consists of a piezoelectric ceramic plate (PZT), with electrodes on both sides, attached to a metal with conductive adhesive shown in Figure 1. The resonant frequency of these diaphragms is given by Helmholtz's equation (Ottman *et al.,* 2002).

$$f_o = \frac{c}{2\pi}\sqrt{\frac{4a^2}{d^2 h(t+ka)}} \quad (1)$$

Where f_o is the resonant frequency (Hz), C is the velocity of energy wave, a is the redius of ceramic diaphragm (cm), d is the diameter of the support, t is the thickness of support and k is the material constant. It is considered that piezoelectric transducers are operated under self-resonant frequency so that maximum charge can be induced.

2.1 Piezoelectric Material Composition

In order to understand the technology, the need to ascertain the chemical composition of piezoelectric material was necessary because the voltages obtained from piezoelectric materials (PZT) differ depending on the material composition. The study acquired sample of 35mm diameter of piezoelectric tiles based on availability. Each sample of 35mm diameter piezoelectric ceramic tiles was subjected to X-Ray Fluorescence analysis (XRF) tests; to determine the compositions of the piezoelectric element and metal plate.

2.2 Stacking of Piezoelectric elements

The piezoelectric diaphragm as seen in Figure 1 is made up of two electrodes and metal plate. The electrodes stick on both sides of the piezoelectric and are attached to the metal by adhesive as shown Figure 2. It was essential to evaluate adhesive suitable to transfer pressure effectively across the piezoelectric elements before mechanical testing. As such, samples of 35mm were stacked using three (3) types of adhesives for experimental setup. The adhesives were chosen based on their availability.

- Hot glue gum
- Top Bond: Contact cement adhesive
- Top Bond: General purpose white glue

The application of each adhesive was, per manufacture's specifications before subjecting the samples to any form of stress (Manufacturer's specified that bonds achieve full strength within 24 hours). The samples of 35mm piezoelectric element were stacked in pairs of four for mechanical testing and were all connected in series using different adhesives.

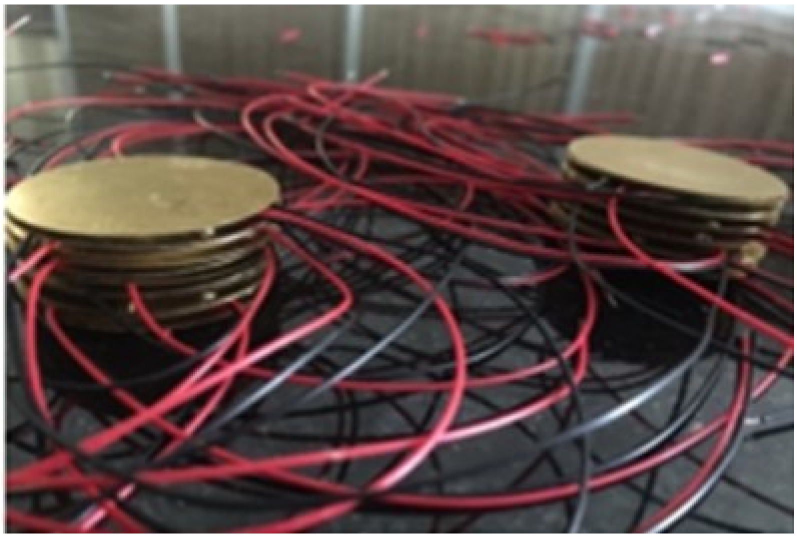


Figure 3: Stacked up of piezoelectric element

Figure 4: Mechanical testing using an Automatic Compression Machine (ACM) to apply pressure to the stacked piezoelectric tiles

Figure 5: Mechanical testing using a 2.5kg proctor compaction rammer to apply pressure to the piezoelectric tiles.

2.3 Mechanical Testing of PZT

The pressure applied to piezoelectric element is directly proportional to the electrical output generated (Xiong et al., (2015). Therefore, based on available equipment, pressures were applied to the stacked samples using compression machine and compaction rammer as shown in Figure 4 and Figure 5.

3. RESULTS AND DISCUSSION

3.1 Stacking of the PZT element

The following result was obtained as shown in Table 3, Table 4 and Table 5. For each of the adhesives considered. The top bond contact cement adhesive generated the highest voltage and current which shows that more stress is transferred. Thus, top bond contact cement adhesive was selected as the most reliable adhesive in term of power generation from stacking the piezoelectric tiles.

3.2 Material Composition PEH element

Table 1 and Table 2 present results obtained when the PZT tiles were subjected to XRF test to know the constituent elements. With emphasis on the piezoelectric element as seen in Table 1, the sample of 35mm diameter contain a high percentage of Lead (Pb) and Zirconium (Zr) indicating the samples is a ferroelectric material which is PZT (lead zirconate titanate). It was also observed that there is a high Silver content from result obtained. This is in agreement with Xiong et al.,

(2015) literature based on the fact that the surface of piezoelectric element is coated with silver to form the electrode. PZT is the most commonly used piezoelectric material because it gives the most optimal electrical output when compared to other piezoelectric materials.

Based on the materials composition, Lead being the key element is considered to cause cancer while zirconium is radioactive and also toxic to humans. This offers opportunity for research into more environmental friendly element having the piezoelectric effect.

Table 1: Elemental composition of the piezoelectric element, 35mm diameter

Compound	**Ti**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Sr**	**Zr**	**Nb**	**Ag**	**Ba**	**Yb**	**Hf**	**Re**	**Ir**	**Pb**
Conc. Unit %	0.665	0.018	0.034	0.058	0.01	0.013	1.16	5.525	0.088	64.3	0.11	0.02	0.15	0.008	0.22	2761

Table 2: Elemental composition of metal plate, 35mm diameter

Compound	**Si**	**Ca**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Nb**	**Ag**	**Sb**	**Tb**
Conc. Unit %	4	0.04	0.017	0.020	0.016	0.016	0.060	59.71	33.27	0.19	2.6	0.05	0.05

Table 3: Sample with applied hot glue gum

Type of Stress Application on the Bubble wrap	**Maximum Current (mA)**	**Maximum Voltage (V)**	**Average Current (mA)**	**Average Voltage (V)**	**Minimum Current (mA)**	**Minimum Voltage (V)**
Without any Force applied	0.1490	0.539	0.075	0.093	0	0
With Finger tapping	0.3450	32.414	0.123	11.513	0.046	0
Till sample fractures	0.1911	17.95	0.0269	2.52	0.046	0

Table 4: Sample with applied Top Bond: General purpose white glue

Type of Stress Application on the Bubble wrap	Maximum Current (mA)	Maximum Voltage (V)	Average Current (mA)	Average Voltage (V)	Minimum Current (mA)	Minimum Voltage (V)
Without any Force applied	0.1350	0.1500	0.0630	0.0570	0	0
With Finger tapping	0.3450	32.414	0.123	11.513	0.046	0
Till sample fractures	0	3.0520	0	0.1080	0	0

Table 5: Sample with applied Top Bond: Contact cement adhesive

Type of Stress Application on the Bubble wrap	Maximum Current (mA)	Maximum Voltage (V)	Average Current (mA)	Average Voltage (V)	Minimum Current (mA)	Minimum Voltage (V)
Without any Force applied	0.1710	0.1550	0.1240	0.0920	0.052	0
With Finger tapping	0.1770	39.60	0.1070	6.075	0	0
Till sample fractures	0.1770	39.60	0.1070	6.075	0	0

3.3 Mechanical Testing

Figure 6 and Figure 7 illustrate the electrical output against time when pressure is applied from the compression machine and compaction rammer respectively. It is worth mentioning that the present experimental setup focused on increasing the voltage with low current thus producing an overall power output of 8.25mW and 15.5mW.

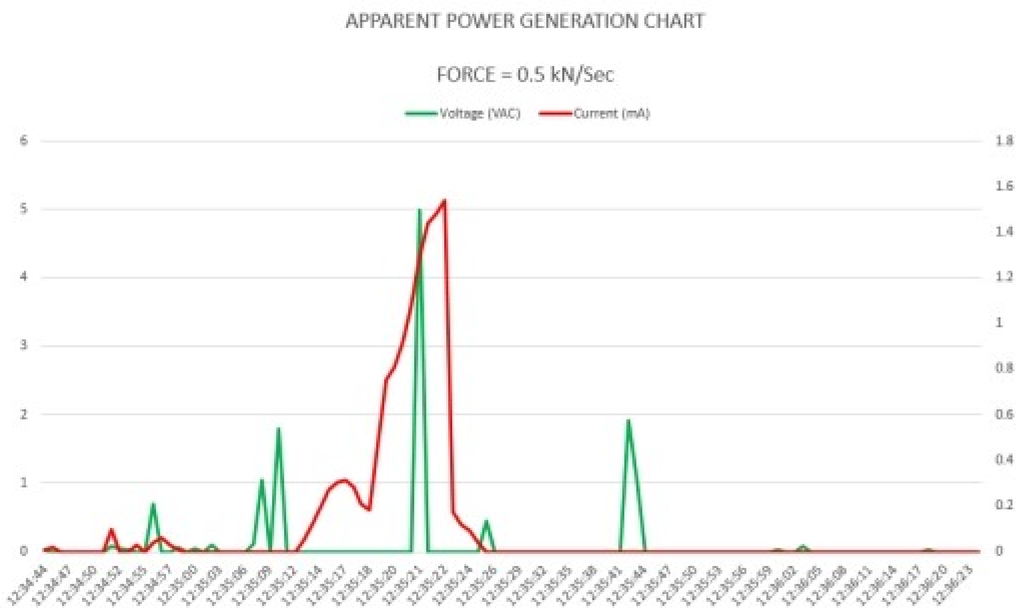


Figure 6: Electrical output from the compression machine

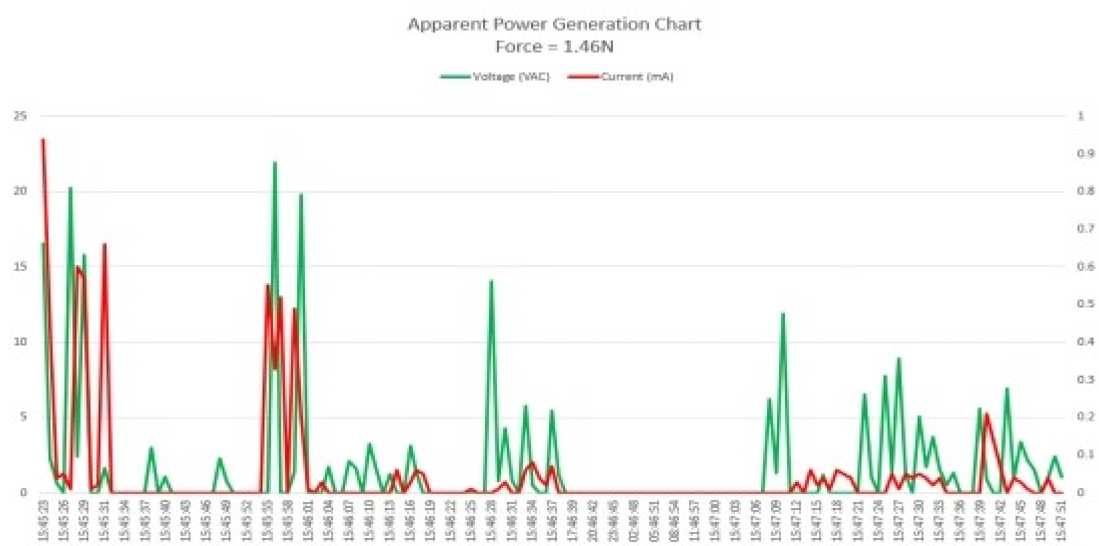


Figure 7: Electrical output from the compression machine

3.4 Assembling of the PEH panel

The harvesting principle of electrical energy from mechanical energy is shown in Fig. 9. The piezoelectric transducer remains in direct contact with the source of vibration. When the vibration occurs, the piezoelectric transducer induces the electric charge. The rate of change of these induced charges with respect to time gives the alternating current pulses. A static converter is used before feeding the storage unit or the electrical load.

Voltage of 0.5VAC – 21.9VAC generated as illustrated in the graphical interpretation. It was also observed that maximum output voltage in Table 3 to Table 5 exceeds that in Figure 6 and Figure 7. This is as a result of the type of stress applied. Oscillatory type of stress offer a higher energy yield compared to a gradually increasing static load like in the case of the compressive machine.

The assembly of the PEH panel consists of samples of 35 mm diameter piezoelectric element in series configuration contained within an engineering plastic; Polyvinylidene difluoride (PVDF) Sheet to reduce direct impact of stress that can cause damage while transferring much needed stress to generate an electrical output as presented in Xiong et al., (2015).

Figure 8 shows the circuit diagram of the piezoelectric generator when connected directly to an LED load adopted. Figure 9, shows an assembled panel rectified to power an LED load. As shown in Figure 8, a switch was introduced to break the continuous discharge of harvested energy that charges up the capacitor, thus the capacitor discharges to power the LED when the switch is toggled.

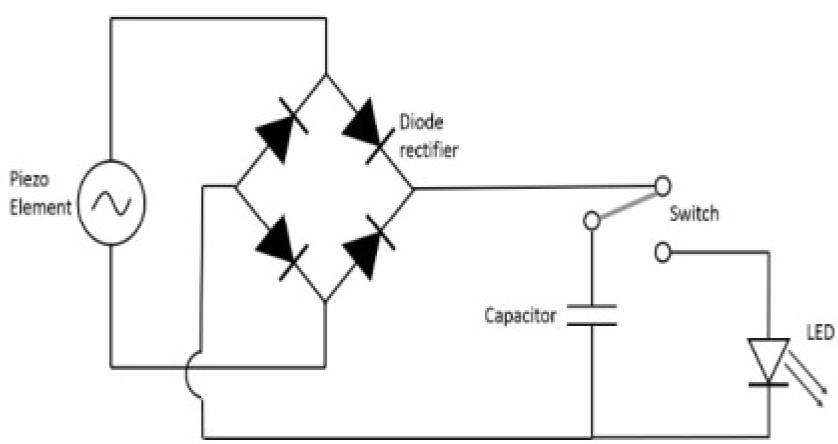


Figure 8: Circuit diagram of a piezoelectric generator connected directly to an LED Load

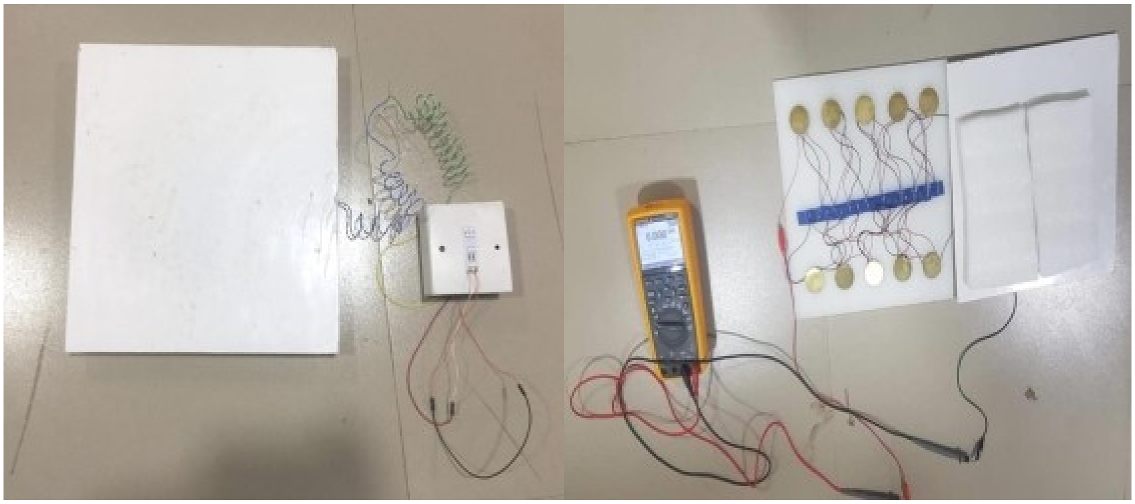


Figure 9: Piezoelectric harvester prototype with LED load

The continuous state of motion of the human foot as an input mechanical source provides an outstanding prospect to energy harvesting by utilization of human motion. Within one step multiple peaks in voltage output can be produced by the prototype piezoelectric energy harvesting panel. The panel produces steadily increasing RMS voltage output as the motion on the panel is enhanced. The prototype assembly operates well, realizing a maximum rectified voltage of 27.30V in a single step or stride.

4. CONCLUSION

This study evaluates the potential of piezoelectric ceramic tiles to harness energy which offers a shift from the conventional approach of powering road infrastructures to the use of integrated piezoelectric pavements. The main findings of the study include;

1) The results from the XRF show the samples are PZT with high proportion of Lead (Pd), Zirconium (Zr) and Titanate (Ti). The high Silver (Ag) content is as results of coating which forms part of the electrode.
2) The top bond contact cement adhesive generated the highest voltage and current which shows that more stress is transferred through this adhesive compared to other adhesive used.
3) By comparing the type of stress applied, oscillatory load applied produced a higher energy output in relation to the application of static load.
4) There is a relationship between stress applied & voltage output. However, equipment used cannot accurately establish a direct relationship. As such, further study need to be conducted to evaluate the relationship.
5) So far, an average voltage of 0.5VAC –

21.9VAC has been generated and it is expected to improve with other testing approach.

6) The prototype panel can produce gradually increasing RMS voltage output as the motion is enhanced. Also, the maximum rectified voltage realized is 27.30V DC in a single stride.

7) The performance of piezoelectric energy harvesters can be further improved by harnessing other electromechanical conversion mechanisms and experiments. Invariably, an all-inclusive optimization of the piezoelectric energy harvesters will certainly guarantee an enhanced performance.

ACKNOWLEDGEMENT

The authors would like to express their profound gratitude to the Nigerian Building and Road Research Institute for funding this research. In particular, the authors acknowledge the support of technical staff, researchers and management team for the active collaboration and fruitful discussions in carrying out this study.

REFERENCES

Caliò, R., Rongala., U. B., Camboni, D., Milazzo, M., Stefanini, C., De Petris, G., & Oddo, C. M. (2014). Piezoelectric energy harvesting solutions. Sensors, 14(3), 4755-4790.

Engel T.G., Keawboonchuay., C., & Nunnally, W.C., Energy conversion and high power pulse production using miniature piezoelectric compressors, IEEE Trans. Plasma Science., vol 28, no. 5, pp. 1338-1341.

Fan, K., Yu, B., Zhu, Y., Liu, Z., & Wang, L. (2017). Scavenging energy from the motion of human lower limbs via a piezoelectric energy harvester. *International Journal of Modern Physics B*, *31*(7), 1741011.

Howells, C. A. (2009). Piezoelectric energy harvesting. Energy Conversion and Management, 50(7), 1847-1850.

Jung, I., Shin, Y. H., Kim, S., Choi, J. Y., & Kang, C. Y. (2017). Flexible piezoelectric polymer-based energy harvesting system for roadway applications. *Applied Energy*, *197*, 222-229.

Keawboonchua., C & Engel., T.G., Factors Affecting Maximum Power Generation in Piezoelectric Pulse Generator Vol.1, pp 327 –330.

Kim, H. S., Kim, J. H., & Kim, J. (2011). A review of piezoelectric energy harvesting based on vibration. International journal of precision engineering and manufacturing, 12(6), 1129-1141.

Kour R, Charif A (2016) Piezoelectric Roads: Energy Harvesting Method Using Piezoelectric Technology. Innov Ener Res 5: 132.

Lefeuvre, E., Badel, A., C. Richard, Petit, C.L., & Guyomar, K., "A comparison between several vibration-powered piezoelectric generators for standalone systems," *Sens. Actuators A, Phys*., vol. 126, no. 2, pp. 405-416, Feb. 2006.

Moure, A., Rodríguez, M. I., Rueda, S. H., Gonzalo, A., Rubio-Marcos, F., Cuadros, D. U., & Fernández, J. F. (2016). Feasible integration in asphalt of piezoelectric cymbals for vibration energy harvesting. *Energy conversion and management*, *112*, 246-253.

Ottman, G.K., Hofmann, H.F., & G. A. Lesieutre, "Optimized piezoelectric energy harvesting circuit using stepdown converter in discontinuous conduction mode," *IEEE Trans. Power Electron*., vol. 18, no. 2, pp. 696-703, Mar. 2003.

Paul, D., & Roy, A. (2015). Piezoelectric Effect: Smart roads in green energy harvesting. *International Journal of Engineering and Technical Research (IJETR) ISSN*, 2321-0869.

Roshani, H., Dessouky, S., Montoya, A., & Papagiannakis, A. T. (2016). Energy harvesting from asphalt pavement roadways vehicle-induced stresses: a feasibility study. *Applied Energy*, *182*, 210-218.

Roundy. S, & Wright, P.K. A piezoelectric vibration based generator for wireless electronics, *Smart Materials and Structures*, 13 (2004) 1131-1142.

Shu, Y. C., & Lien, I. C. (2006). Analysis of power output for piezoelectric energy harvesting systems. Smart materials and structures, 15(6), 1499.

Shukla, A., & Ansari, S. A. (2018). Energy Harvesting from Road Pavement: A Cleaner and Greener Alternative. *Energy*, *5*(02).

Song, Y., Yang, C. H., Hong, S. K., Hwang, S. J., Kim, J. H., Choi, J. Y., & Sung, T. H. (2016). Road energy harvester designed as a macro-power source using the piezoelectric effect. *International Journal of Hydrogen Energy*, *41*(29), 12563-12568.

Starworko, M., Tadeusz, U., H., L. (2008) Modelling and simulation of piezoelectric elements – Comparison of available methods and tools. *Mechanics, Vol. 27, No. 4.*

Williams, C.B., & Yates, R.B, Analysis of a micro-electric generator for Micro systems, *Sensors and Actuators*, 52 (1996) 8-11.

Xiong, H., & Wang, L. (2016). Piezoelectric energy harvester for public roadway: on-site installation and evaluation. *Applied Energy*, *174*, 101-107.

Zhang, Z., Xiang, H., & Shi, Z. (2016). Modeling on piezoelectric energy harvesting from pavements under traffic loads. *Journal of Intelligent Material Systems and Structures*, *27*(4), 567-578.

CHARACTERIZATION AND PRODUCTION OF GROUNDNUT SHELL-RICE HUSK HYBRID BRIQUETTE USING LOW PRESSURE DENSIFICATION TECHNIQUE

. Muhammad[1,2], A. Adamu[1], M.B. Maina[1] and B.M. Tela[2]
. [1]Department of Mechanical Engineering, University of Maiduguri, Borno state
. [2]Nigerian Nuclear Regulatory Authority, Maiduguri office

ABSTRACT:

This work focused on briquetting of rice husk and groundnut shells to serve as an alternative source of fuel wood for domestic cooking. The briquettes were produced from the hybridization of groundnut shells and rice husk residues. Different proportions of the groundnut shell and rice husk (0%GS:100%RH, 25%GS:75%RH, 50%GS:50%RH, 75%GS:25%RH & 100%GS:0%RH) were mixed together with 5% gum Arabic as a binder and were manually compressed. ASTM D5142-02, standard was used to carry out the proximate and ultimate analyses of the residues. The compaction, density and relaxation ratios of the briquettes were also determined according to ASAE standard. Compressive strength was determined in accordance with ASTM 1037-93 (1995) using universal testing machine. The average compressive strength of briquette was 3030N/mm^2, while the higher heating value of briquettes was found to be 14162.56kJ/k. The results further showed that the briquette was effective in boiling water as it took the shortest time (6 minutes, 28 seconds) followed by kerosene with time of 7 minutes and 52 seconds. The efficiency of the briquettes by determined by using the ratio of work done in boiling the water and the energy consumed. Among the briquettes, 100% rice husk was the most efficient (10 minutes, 34 seconds) while the least efficient was the briquette with 75% groundnut shell and 25% rice husk combination with a water boiling time of 13 minutes and 22 seconds. The findings also showed that briquettes from the combination of rice husk and groundnut shell is a good alternative source of thermal energy. And it is an economical as well as environmental friendly means of waste disposal. The research further concluded that briquettes produced from agro-wastes is a cheap source of thermal energy for domestic applications

Keywords: Keywords: Groundnut-shell, rice-husk, briquette and low-pressure

1. INTRODUCTION

The demand for wood fuel is increasing at an alarming rate, while the supply is diminishing. Wood in the form of wood fuel, twigs and charcoal has been the major source of renewable energy in Nigeria, accounting for about 51% of the total annual energy consumption (Akinbami, 2001). The rate at which fuel wood are used as source of energy for cooking and other industrial activities is increasing geometrically by the day in Nigeria. The continuous felling of tress for fuel contributes to global warming, decreasing availability of fuel wood and menace of desertification and deforestation. Therefore, there is the need to consider alternative sources of energy for domestic and cottage industries and such energy sources should be renewable and accessible to low income earners in the society. Agricultural biomass residues are sources of renewable and sustainable biofuels, which can contribute significantly to mitigate the effect of greenhouse gas (GHG) emissions if properly managed and utilized (Akpenpuun et al., 2020). Large quantities of agricultural and forestry residues are produced annually in rural areas of Nigeria and vast of these residues are under-utilized or burnt with all the ecological problems associated with their disposal methods (Olorunnisola, 2007, Jekayinfa and Omisakin, 2005 and Tembe et al., 2014). A larger percentage of these wastes constitutesto environmental nuisance and carcinogenic gas emission when left to be burnt in open fields or dumpsites. These residues have poor performance characteristics such as low heating values and bulky in transportation and storage, however, studies have shown that such residues can be processed and upgraded into more useful fuel products such as briquettes similar to wood or charcoal (Olorunnisola, 2007, Oladeji, 200 and Bello, 2021).

Energy availability in the rural as well as urban areas of Nigeria is fast becoming a great challenge with the high cost of cooking gas and kerosene as well as environmental problems associated with firewood (Tembe, et al., 2014). According to a report by Olaoye and Kudabo (2017) agricultural residues such as straws, tree leaves, maize husks, grass, rice ground nut shells, banana leaves and sawdust can be used for briquette production, though some materials have better calorific value than others, the selection of feedstock is usually dependent on what is readily available. Briquette is an easy way to agricultural waste removal from the environment. This work studies the characterization and production of briquettes using groundnut shell and rice husk as feed stocks via low pressure densification process because the information on the use of low density compression techniques on the briquetting of groundnut shells and rice husk is limited in the literature.

Briquettes can be made out of any biomass material, although the choice of feedstock can determine its heating potential as a fuel (Ferguson, 2012). Depending on the material, the pressure and the speed of compaction, additional binders such as starch or clay soil, starch and or gum Arabic may also be needed to bind the matter together (Pallavi et el, 2013).

2 MATERIALS AND METHODS

2.1 Rice husk

Rice husk is a by-product of the rice milling process. This husk accounts for approximately 20.23% of total paddy rice weight (rice crop weight) (IRRI, 2008). There was significant production of this bio-waste in Nigeria (about 1,032,993.6 metric tonnes). And about more than 50% of the husks produced in a rice mill are burned on-site. Due to its low bulk density (90-150 kg/m^3) (Hwang, et al., 2011), this agro-residue has a large dry volume as shown in plate 1, and as a consequence, most rice husk can be made into pellets or briquettes to save storage space and transport the bio-waste economically. The particle size of the sieved rice husk was obtained by following the procedure highlighted in ASAE S 424.1 (2003) using manual riddle (sieves). Rice husk contains 75-90% organic matter such as cellulose, lignin, and rest mineral components such as silica, alkalis and trace elements (Kumar, et al., 2012).Due to its low density (90-150 kg/m^3), and specific surface area of 6 to 14 m^2 /g, the transportation of rice husk is relatively expensive as such it is burnt in the site, (Hwang, et al., 2011 and Nguyen, 2014).

Plate 1: Sieved rice husk

2.2 GROUNDNUT SHELL

Groundnut is a nutritious leguminous crop, grown mainly for seed and oil. Groundnut shells are the leftover product obtained after the removal of groundnut seed from its pod. Groundnut shells have

about 20% of the dried peanut pod by weight and a specific surface area of 950.069 (m^2 /g), that is, there is a significant amount of shell residual left over after groundnut processing (Ogunsuyi and Adejumobi, 2020). This is the abundant agro-industrial waste product which has a very slow degradation rate under natural conditions (Zheng et al., 2013). However, Groundnut shells contain various bioactive and functional components which are beneficial for mankind. Commercially, it is used as a feedstock, food, filler in fertilizer and even inbio-filter carriers. But most of the deserted groundnut shells are burnt or buried resulting in environmental pollution.

Plate 2: Ungrounded groundnut shells

Plate 3: Grounded groundnut shells

The rice husks as shown in plate 1and the groundnut shells as shown in plate 2 were sun dried and ground using a hammer mill and then sieved to uniform sizes of 2.00 mm particle size representing medium series. The procedure as highlighted in American Society of Agricultural Engineers standard (ASAE S 424.1 (2003)) was followed to determine the chosen particle size.

2.3 Binder and binding ratio: About 0.2kg of each of feed stocks (groundnut shell and rice husk) was used in producing each type of briquette based on percentage. For 100%GS, 0.2kg of groundnut shell was used, for 100%GS:25%RH (groundnut shell is 0.15kg and rice husk is 0.05kg), for 50%GS:50%RH (groundnut shell is 0.1kg and rice husk is 0.1kg), 25%GS:75%RH (groundnut shell is 0.05kg and rice husk is 0.15kg) and for 100%rh, 0.2kg of rice husk were used in formulating the briquettes. Since a low-pressure technique was employed, there was the need for a binding agent and 5% by weight of Gum Arabic as shown in plates 4 and 5 were used as binder in line with works of Musa (2007). Plates 6, 7 and 8 shows the briquettes produced from groundnut and rice husks.

Plate 4: Gum Arabic Plate 5: Gum Arabic dissolved in water for binding

Plate 6: Groundnut Shell Briquettes Plate 7: Rice husk Briquettes

Plate 8: Groundnut Shell-Rice Husk briquettes

2.4 Density

Three briquettes were randomly selected from each production batch of the briquettes produced for evaluation of physical properties. The mean compressed density of the briquettes was determined immediately after removal from the mould as a ratio of measured weight to calculated volume (Olorunnisola, 2007). The weights of produced briquettes were determined using a digital weighing balance, while the average diameters and heights of the briquettes were taken at 2 different positions using calipers to determine the volume. The volume of the doughnut shaped briquettes was determined by subtracting the outer volume from the inner volume to obtain the actual volume of the briquettes. The compressed and relaxed densities of the briquettes were determined at 0 minutes, 30 minutes, 1 hour, 24 hours and 7 days using the die dimensions and ASTM, (2004) standard method of determining densities. Density was determined for each briquette as ratio of briquette weight to volume. The density of briquette from both species was determined immediately after ejection from the mould and this was calculated from the ratio of the mass to the volume of briquette. The relaxed density of the briquettes was determined in the dry condition. Relaxed density can be defined as the density of the briquette obtained after the briquette has remained stable. It is also known as spring-back density. It was calculated simply as the ratio of the briquette's mass to the new volume (Oladeji and Lucas, 2014). Equations 1 and two were used to determine the briquette's volume and density.

$$volume of briquette = \frac{\pi}{4}\left(d_2^2 - d_1^2\right)L \quad (1)$$

d_1 diameter of the briquette before drying (m)

d_2 diameter of the briquette after drying (m)

$$Density\ of Briquette = \frac{weight of briquette}{volume of briquette} \quad (2)$$

Density ratio was calculated as the ratio of relaxed density to maximum density (Oladeji, 2012). The relaxation and compressed ratios of the briquettes were determined in accordance with the American Society of Agricultural and Biological Engineering (ASABE, S269.4.2003). Relaxation ratio was calculated as the ratio of compressed density to relaxed density as reported by (Akpenpuun, 2020). The compaction and relation ratios were determined and calculated using equations 3 and 4as reported by (Oladeji and Lucas, 2014).

$$Relaxation\ ratio = \frac{compressed\ density}{relaxation\ density} \quad (3)$$

$$Compaction\ Ratio = \frac{Compressed\ density}{bulkdensity} \quad (4)$$

2.5 Determination of ash content

The Ash content was determined according to procedure adopted by Oyelaran, (2014) where 1 gram of briquette sample was measured into known weighted ash tray with lid. The sample was then transferred into a high temperature carborlite furnace already set at 825^{0}C and heated for 1 hour. Then, the ash tray is taken out from the furnace and it is cooled in the desiccators until it reaches room temperature and final weights (W_3) were recorded. The ash content was calculated using equation 5 (Oyelaran et al, 2015).

$$\%Ashcontent = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad (5)$$

W_1 weight of empty crucible, (g) W_2 weight of crucible + sample, (g) W_3 weight of crucible + sample after heating, (g)

2.6 Dimensional stability

The method used for this was as described by Olorunnisola (2007). In this method, the length and diameter of the five representative briquettes from each production batch was measured at 0, 30, 60, 1440 and 7200 minutes.

2.7 The afterglow time

The afterglow time was also evaluated and determined. This became necessary in order to estimate how long the individual briquette would burn before restocking when they are used in cooking and heating. The procedure described by Musa (2007) was used to determine the afterglow time, One piece of oven-dried briquette was ignited over a Bunsen burner and after a consistent flame was established, the flame was blown out. The time in seconds within which a glow was perceptible was recorded.

2.8 Volatile matter (VM) determination

The dried samples of the briquettes left in the crucibles were covered with a lid and placed in an electric furnace maintained at 925°C for seven minutes. The crucibles were first cooled in air, then insidedesiccators and weighed again. Losses in weights minus the moisture content as shown in equation 6 were reported as volatile matter on percentage basis (Awulu et al., 2015).

$$\text{VM\%} = \text{Weight lost} - \text{moisture content} \qquad (6)$$

2.9 Determination of compressive strength

Plate 9 depicts the testing of the compressive strength of the briquettes. The compressive strength of the briquettes was investigated by using a universal testing machine. Compressive strength was determined in accordance with ASTM 1037-93 (1995).

Plate 9: Determining compressive strength using universal testing machine

3. RESULTS AND DISCUSSION

3.1 Densities

Figure 1 depicts the highest normal and relaxed densities of the briquettes. The briquette with mixing ration of 50%GS:50%RH exhibits the most outstanding properties of maximum density of 3387.56kg/m^3, relaxed density 1573.32kg/m^3 and relaxation ratio value of 2.15 respectively. The density obtained in

this work compares well with densities of notable biomass fuels such Daniellia + groundnut briquettes with density of 2320 kg/m3 reported by Tembe (2014),

The density ratio for all the briquettes is almost constant, 25%GS:75%RH and 0%GS:100%RH has the highest density ratio of 0.55 each. And 50%GS:50%RH has the least value of 0.46, while 75%GS:25%RH and 100%GS:0%RH has density ratios of 0.47 and 0.49 respectively. An average of relaxation ration of 1.98 was recorded by all the briquettes as shown in Figure 2 and these values are almost the same with what was obtained by Olorunnisola (2007) a relaxation ratio of between 1.80 and 2.25 coconut husk briquetted and Oladeji et al. (2009) obtained values of 1.97 and 1.45 for groundnut and melon shell briquettes respectively and according to the authors such relaxation ratio are good enough because this gives an indication of the relative stability of the briquette after compression as such the briquettes can be handled or transported with ease because of their stability.

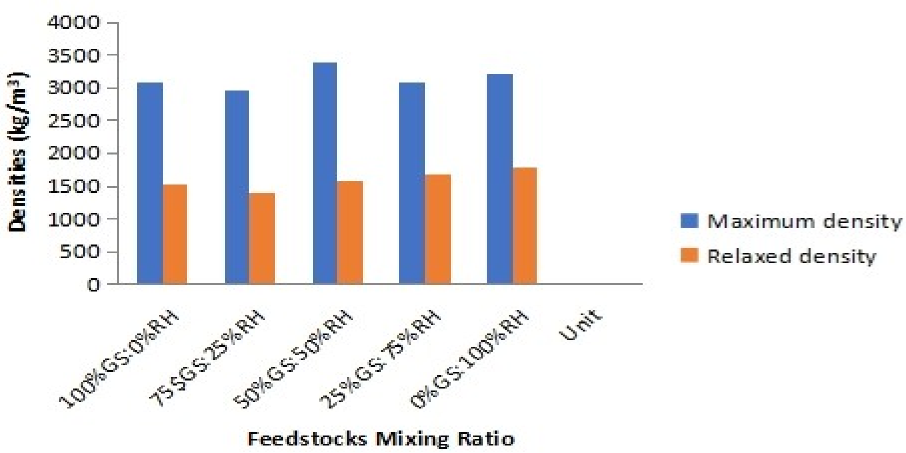
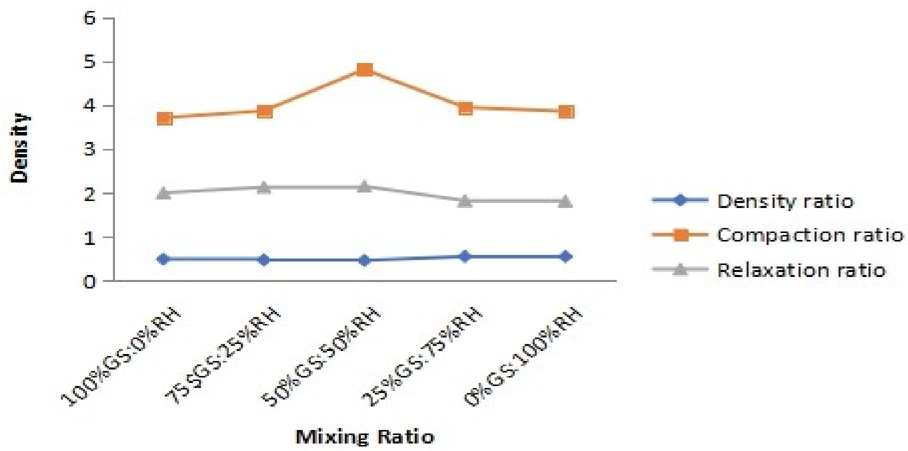


Figure 1: Maximum and relaxed densities of the briquettes



.

Figure 2: Initial, Compaction and Relaxation Density Ratios

3.2 Ash content and volatile matter

The moisture content of the briquettes was determined in accordance with ASTM-E871-82 (2013) and the moisture content slightly decreases as the percentage quantity of RH increases. Highest moisture content of 5.41% was recorded for 100% GS briquette, while 100% RH recorded the least moisture content of 3.96%. The ash content of the briquettes were determined in accordance with ASTM standard E1755 – 01. Figure 3 depict that the briquettes with 100% GS showed highest ash content value of 9.32% and 100% RH briquette has the least ash content. ASTM standard E872 – 82 procedure was used in determining the volatile matter content of the briquettes and the briquettes with 50%GS:50%RH and 100% RH recorded highest and lowest values of volatile matter of 80.13% and 69.74% respectively. The results of the investigation as shown in Figure 3 shows that the briquette produced from 100% rice husk content has the least weight of 0.190kg, low moisture as well as ash and volatile matter contents. According to Ifa et. al. (2020) a good bio-briquettes should have lower ash content of 2–10% and the results of the research showed that all the briquettes have ash contents lower than 10%, therefore they are good source of energy.

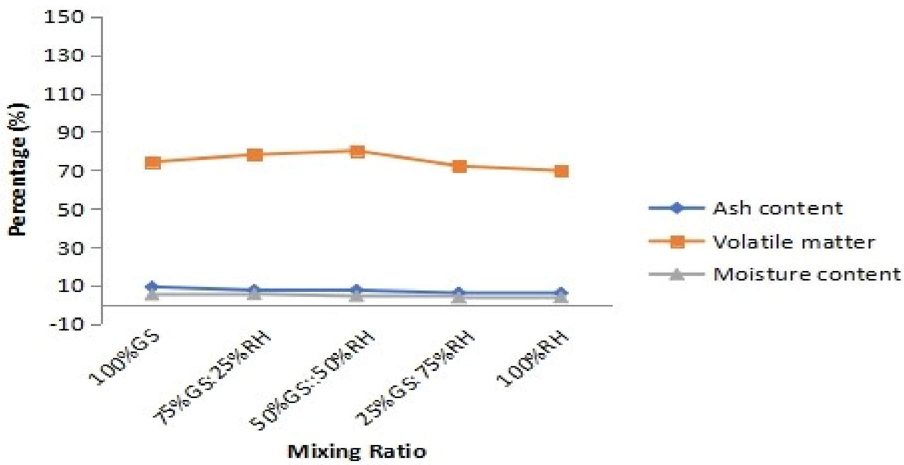


Figure 3: Ash, volatile matter and moisture contents of the briquettes

3.3 Dimensional stability

The results of the dimensional stability showed that 0%GS:100%RH had the longest length while 100%GS:0%RH briquettes has the lowest length. There appears to be an increase in the length as the proportion of RH in the combination increases up to 100%GS:0%RH. It is a well established fact that briquettes and/or pellets compressed in a closed cylinder have a tendency to expand as the pressure is released. The expansion takes place primarily in the direction in which the load is applied, i.e., longitudinal direction. Table 1 shows the increase in length with time of briquettes from the various GS-RH mixtures. The observed linear expansions were generally minimal. Briquettes produced using 100%GS:0%RH exhibited the largest linear expansion of about 8mm; briquettes produced from the different ratios of 75:25, 50:50, 25:75 and 0:100 groundnut shell-rice husk exhibited the least expansion. The compressive strength for the feedstock was found to be reasonable. The briquettes with 100%GS:0%RH exhibit the highest compressive strength of 5.63Kn/m^2 while briquette with 0%GS:100%RH has the least compressive strength of 1.02Kn/m^2 as shown in Figure 4.The implication of this is that, briquettes will suffer less damage during transportation and storage. (Olaji 2014).

Table 1: Length and diameter of briquettes after ejection

Type of briquette GS: RH (%)	Length of briquette after ejection (cm)	Diameter of briquettes (cm)
100:0	8.5	6.2
75:25	8.6	6.4
50:50	8.6	6.2
25:75	8.8	6.5
0:100	9.0	6.4

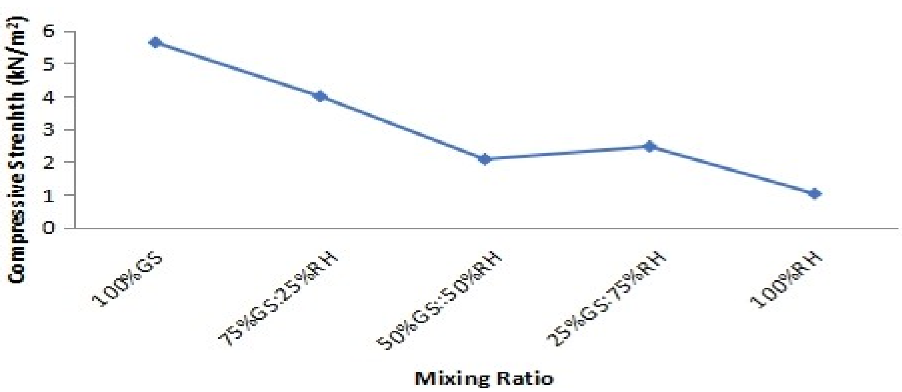


Figure 4: Compressive strength of the briquettes

3.4 Afterglow time and flame propagation rate

Briquette with 100%RH recorded a highest flame propagation time of 0.11 cm/sec, this is may be due to its low moisture content of 4% and high heating value of 14162.56 Kj/kg, while the briquettes from other mixing ratios recorded an average value of flame propagation time of about 0.08 cm/sec. In addition, Figure 5 shows that the briquette with 25%GS:75%RH has the longest afterglow time of 271 sec, followed by briquette with mixing ration of 50%GS:50%RH with an afterglow time of 267 sec while briquette 75%GS:25%RH has the least afterglow time of 238 sec. The afterglow time and the flame propagation values are good enough and have the implication of that the briquettes will be ignited more easily and burn with intensity for a long time (Olaji 2014).

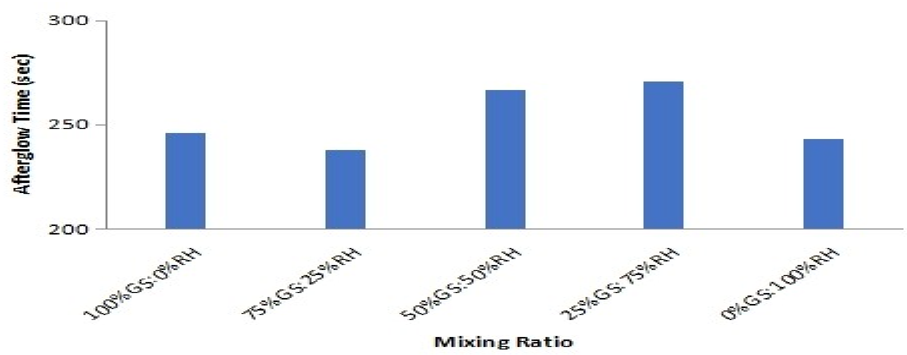


Figure 5: Afterglow and flow propagation times of GS:RH briquettes

3.5 Heating Value

Figure 6 depicts the heating values of various GS:RH briquettes according to different mixing ratios. The heating values were determined according to ASTM B711-87 (2004) standard. The Figure showed that the calorific value of the briquettes increases as the RH content increases. The briquette with 0%GS:100%RH rice husk has higher heating value of 14162.56kJ/kg and while briquette with mixing ratio of 100%GS:0%RH recorded the least calorific value. However, this heating value compares favourably with those reported by Enweremadu, et al., (2004) for cowpea-14,372.93 kJ/kg and soy-beans-12,953 kJ/kg respectively, and 2,600 kJ/kg for groundnut as reported by (Musa, (2007). In addition, Olaji (2014) reported that this heating value is sufficient enough to produce heat required for household cooking and small scale industrial cottage applications,

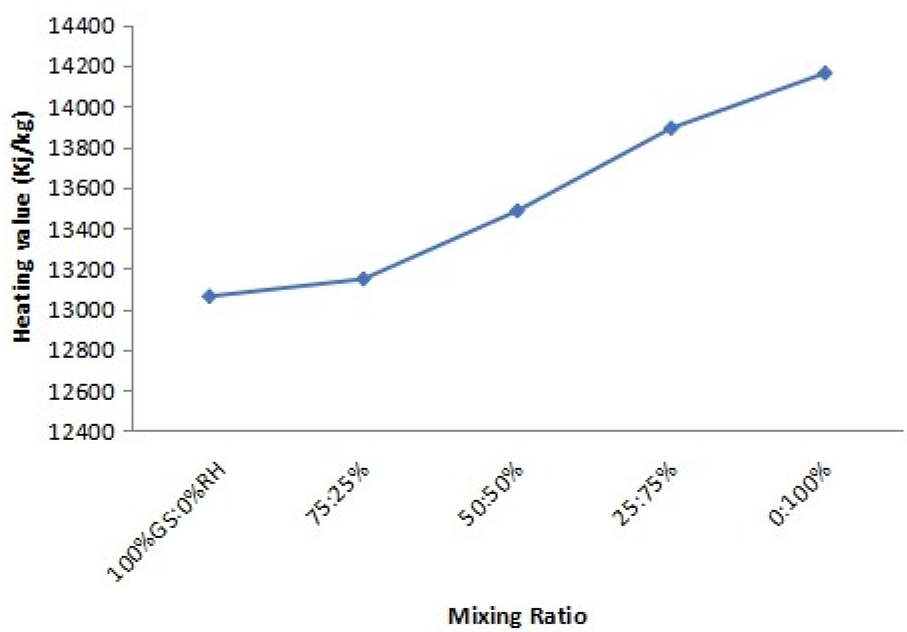


Figure 6: Heating value of various GS:RH briquettes

4 CONCLUSIONS AND RECOMMENDATIONS

Different proportions of the groundnut shell and rice husk were bounded with gum Arabic to produce briquettes in this work. The compaction, density and relaxation ratios of the briquettes were determined. The results of the investigation showed that the briquettes produced from groundnut shell and rice husk are effective and can be used as a replacement of fuel woods. The research further concluded that briquettes produced from agro-wastes is a cheap source of thermal energy for domestic applications that briquettes produced from groundnut shell and rice husk would make good biomass energy.

REFERENCES

Akinbami, J.F.K. (2001). Renewable Energy Resources and Technologies in Nigeria: present situation, future prospects and policy framework. Mitigation and Adaptation Strategies for Global Change 6:155-181

Akpenpuun, TD; Salau, RA; Adebayo, AO; Adebayo, OM; Salawu J. and Durotoye, M (2020) Physical and combustible properties of briquettes produced from a combination of groundnut shell, rice husk, sawdust and wastepaper using starch as a binder. J. Appl. Sci. Environ. Manage. Vol. 24 (1) 171-177. https://dx.doi.org/10.4314/jasem.v24i1.25

ASABE S424.1. (2003). Method of determining and expressing particles size of chopped forage materials by screening". 606-608. ASAE: St. Joseph, Michigan

Enweremadu, C.C., Ojediran, J.O., Oladeji, J.T. and Afolabi, L.O. (2004). Evaluation of energy potentials in husk from soybean and cowpea. *Science Focus* 8: 18-23.

Ferguson, H. (2012). Briquette Businesses in Uganda. The potential of briquette enterprises to address the sustainability of Ugandan biomass fuel market. GVEP International 73 Wicklow Street, London, UK

Ifa, L., Yani, S., Nurjannah, N., Darnengsih, D., Rusnaenah, A, Mel M., Mahfud M. and Kusuma, H.S. (2020). Techno-economic analysis of bio-briquette from cashew nut shell waste. Heliyon. https://doi.org/10.1016/j.heliyon.2020.e05009

Jekayinfa, S. and Omisakin, O. (2005). The energy potentials of some agricultural wastes as local fuel materials in Nigeria". Agricultural Engineering International: the CIGR Ejournal. Vol. VII. Manuscript EE 05 003. May, 2005.

Kumar, S., Sangwan, P., Dhankhar, R., Mor, V. and Bidra, S (2013). Utilization of rice husk and their ash: A review. Resource Journal of Chemical and Environmental Science, 1(5), 126-129.

Musa, N.A. 2007. "Comparative Fuel Characterization of Rice husk and Groundnut shell Briquettes". NJRED. 6(2):23-26

Ogunsuyi, H.O and Adejumobi, I.B (2020) Pyrolysis of Groundnut Peels and Shells for BioBased Products (Bio- Oil and Bio-Char), International Journal of Research and Innovation in Applied Science Vol. 5(2) 74-78.

Oladeji, J.T. (2012). Comparative Study of Briquetting of Few Selected Agro-Residues Commonly Found in Nigeria". Pacific Journal of Science and Technology. 13(2):80-86.

Oladeji, J. T., and Lucas E.B. (2014). Densification and Fuel Characteristics of Briquettes produced from Corncob. Rep Opinion; 6(7):71-76

Olorunnisola, A.O., (2007) "Production of Fuel Briquettes from Waste paper and Coconut Husk Admixtures" Agricultural Engineering International: The CIGR E Journal Manuscript EE 06 006 pp123-128

Oyelaran, O. A., Bolaji, B. O., Waheed, M. A. and Adekunle, M. F., (2015). Characterization of Briquettes Produced from Groundnut Shell and Waste Paper Admixture. Iranica Journal of Energy and Environment, 6 (1): 34-38.

PREGA, N. T. E., 2004. Demonstration of Rice Husks-fired Power Plant in An Giang Province A

Pre-Feasibility Study Report (Final Draft Report), Hanoi: Viet Nam Institute of Energy .

Tembe, E.T., Otache, P.O. and Ekhuemelo, D.O. (2014) Density, Shatter index, and Combustion properties of briquettes produced from groundnut shells, rice husks and saw dust of Danielliaoliveri. Journal of Applied Biosciences, 82:7372 – 7378. http://dx.doi.org/10.4314/jab.v82i1.7

Wilaipon, P., (2008) "The Effects of Briquetting Pressure on Banana Peel Briquette and the Banana Waste in Northern Thailand" American Journal of Applied Sciences 6 (1):167-171

Zheng, W., Phoungthong, K., Lü, F., Shao, L.M., He, P.J., (2013). Evaluation of a classification method for biodegradable solid wastes using anaerobic degradation parameters.

Waste Manag. 33 (12), 2632–2640.

NOMENCLATURE

Cv Heating value of the fuel (residue) (kJ/kg)

D_1 Diameter of the briquette before drying (m)

D_2 Diameter of the briquette after drying (m)

FC Fixed carbon (%)

GS Groundnut shell

RH Rice husk

W_1 weight of empty crucible, (g)

W_2 weight of crucible + sample, (g)

W_3 weight of crucible + sample after heating, (g)

FC fixed carbon (%)

Vm volatile matter(%)

THEME FOCUS:

OPPORTUNITIES AND RISKS FOR INVESTMENTS IN ENERGY MIX PROMOTION

AN OVERVIEW OF ENERGY CONSUMPTION IN TURNING PROCESS

Lawal, S. A.,J. Abutu, K. A. Olaiya, and E. I. Awode

Mechanical Engineering Department, Federal University of Technology Minna

Mechanical Engineering Department, Taraba State University Jalingo

Mechanical Engineering Department, Lagos State Polytechnic

Mechanical Engineering Department, Air Force Institute of Technology Kaduna

ABSTRACT:

An overview of energy consumption in turning process was undertaken to establish the quantity of energy consumption in turning process. Researches conducted and reported in this area were examined to evaluate energy consumption characteristics in turning, and their relationship between process energy consumption and process variables for machining characteristics. Optimisation of cutting parameters in order to reduce energy consumption, challenges and prospects of energy consumption in turning process were highlighted.

Keywords: Consumption, energy, process, machining

1. INTRODUCTION

Energy costs associated with turning processes represent an expense presently beyond the control of manufacturers (Simoneau and Meehan, 2015). As a result, many manufacturing industries have begun to consider how to reduce energy consumption demands while still maintaining or increasing process efficiency. The manufacturing sector consume energy which converts raw materials into finished products (Peng et al., 2014). Zhao et al. (2016) have revealed that the manufacturing sector accounts for about 90% of the global industrial energy consumption with the machining sector accounting for about 83% of the entire energy consumption. Therefore, it is important for the manufacturing sector to find ways of reducing the energy consumption. Diaz et al. (2010) have also reported that energy-efficient machining has been an area strongly targeted for energy reduction because of its importance and size. In machining processes, energy consumption basically represents a large percentage of total cost. Electricity is the major part of energy resource (Figure 2) into the modern machining processes. In automotive industry, for example, electricity counts up for over 50% of total energy consumption [15], and generates more than two thirds of greenhouse gas emissions and a variety of air pollutants [16]. Although emerging research on green energy, including solar photovoltaic, wind, and fuel cell, manages to supply partially for current machining systems, the high energy-efficient machining systems that demand less energy remain important and highly desirable.

Gutowski et al. (2006) have suggested that processing parameters optimization, energy efficiency improvement and standby time reduction can help in the reduction of machine tools energy consumption and achieve sustainable manufacturing. Turning is also one of the main energy consuming practices in the manufacturing sector and has been identified as a main target for energy reduction in recent years (Moradnazhad and Unver, 2016). Zhao et al. (2016) have also reported that to ensure processing quality, selection of high energy efficiency processing route and processing program, it is important to evaluate the effective energy consumption characteristics in a turning processes. The energy consumption characteristics evaluation technique highlighted by the authors are energy efficiency calculation and energy consumption prediction. As a result, it is necessary to propose a simple and accurate energy efficiency computational model at the infant stage of the process.

Several work has been carried out on energy efficiency in turning. These literatures have made it helpful for other researchers to understand the machine tools energy characteristics and adopt targeted energy saving measures (Mori et al., 2011). Also, Aramcharoen et al. (2014) have also revealed that the power consumption of spindle is the largest in turning operations. Fang et al. (2012) have reported that it is required to achieved a credible prediction of energy consumption of machine tools by analysing the power consumption of their various components is in order to create techniques of saving energy during machining processes and increase energy efficiency.

2. ENERGY CONSUMPTION IN TURNING

The first step towards reducing the total amount of energy consumed during turning operations is by analysing the energy consumption of cutting tools (Moradnazhad and Unver, 2016). Yoon et al. (2013) in their study categorised energy consumption of cutting tools into spindle energy, stage energy, basic energy and material removal energy. Stage energy and spindle energy, which are the energy required for spindle rotation and stage movement, have a power relationship based on rotational speed and feed rate while basic energy represents the energy consumption of auxiliary sub-units and control systems, which are assumed to be constant. The authors identified material removal energy as the energy consumed during the material removal process. Vijayaraghavan and Dornfeld (2010) and Rajemi et al. (2012) have also revealed that in turning process, electrical energy consumption is classified into the idle, run-time, and production. The authors reported that the idle mode represent the mode at which machine is ready for operation and no material removal occur while the run-time mode signifies the mode at which auxiliaries such as motor for the spindle and pump for the cutting fluid are put. Though, no material removal action occur at this mode. In addition, the authors also revealed that in the production mode, material removal occurs which varies and depends on the applied load towards the machine.

In the earlier work of Kara and Li (2011), an empirical model was developed to predict energy consumption in machine tools. The model was machine tool specific and highly dependent on process parameters (feed rates, cutting speeds and depth of cut). The work of the authors was thereafter improved by Diaz et al. (2010) through incorporating energy consumption predictions for tool paths with varying material removal rate. Though the model developed neglected energy consumptions that occur outside of the cutting process. Vijayaraghavan and Dornfeld (2010) also used complex event processing methodology in monitoring and analysing the energy consumption of cutting tools and other manufacturing equipment. The authors also developed a framework for temporally analysing the energy consumption of machine tools, which can be extended to other types of environmentally relevant data streams in manufacturing systems in order to improve their environmental efficiency. The energy efficiency model mostly used in turning is presented in Eqn. 1 (Zhao et al., 2016). This equation does not consider the cutting power of feed axes and the coolant pump power in machining.

$$\eta = \frac{P_c}{P_{in} + P_{rfo}} x100$$

(1)

$$P_{in} = P_u + P_c$$

(2)

Where; P_c is spindle cutting power, P_{in} is spindle input power which includes the no-load power (P_u) and the cutting power (P_c) – Eqn. 2 while P_{rfo} is standby power consumption.

Nur et al. (2021) have revealed that power consumption can be an indicator of tool conditions and as a design criterion of the machining input during turning process. The authors reported power consumption can be calculated as the product of the cutting force and the cutting speed (Eqn. 3). The authors also highlighted the three cutting forces in turning operation which include; the tangential force in the direction of the main cutting action, radial force in the direction toward the axis of the workpiece and feed force in a parallel direction to the workpiece axis. Astakhov and Xiao (2008) revealed that when determining power consumption, the tangential cutting force is commonly used to represent the cutting force considering it makes the majority among the three force components. This simplification was rooted in the use of orthogonal cutting theory in the relationship between machining power and cutting force. Contrarily, the turning process of hardened steels is gaining ground with empirical evidence that it can be done, to a certain extent, as a finishing process to get net shapes or near-net shapes of cylindrical or conical parts (Nur et al., 2021). Elmunafi et al. (2015) and Grzesik et al. (2016) also observed that for turning hardened materials like steels, where a lower depth of cut is mostly used, the radial and feed forces are not negligible. As a result, Grzesik et al. (2016) revealed that feed force is the lowest among the three, though, its value is not too small to be neglected. Therefore, for turning processes of hardened materials such as steels, the resultant of the three forces component is used.

$$P_c = V_c \times F \qquad (3)$$

Where Pc is the power consumption (W), Vc is the cutting speed (m/min), and F is the resultant cutting force (Newton).

Nur et al. (2015) investigated the effect of cutting parameters on power consumption by applying design of experiment approach and revealed that turning operation, power consumption decreases with the decrease of feed rate and increase of the cutting speed. Also, Oda et al. (2012) revealed that to reduce the energy consumption of the peripheral equipment, it is important that details of the energy consumption of peripheral equipment during a cycle is investigated. The authors further revealed that coolant related equipment such as the coolant pump consumed approximately 54 % of energy, followed by the hydraulic equipment, coolant cooler, and the equipment related to the servo spindle. Also, Kara and Li (2011] revealed that the total energy consumption (E) for a turning process (Eqn. 4) is a summation of the energy consumption during setup (Es), when performing material removal (E_t), for tool change, (E_{ct}) to fabricate the cutting tool (E_c) and in the manufacture of the workpiece material (E_w). The authors also reported that if the workpiece material is given depending on the product and the machine shop has limited control over the energy contained in the particular workpiece material (E_w). Therefore, this factor can be omitted during the turning process.

$$E = E_s + E_t + E_{ct} + E_c \qquad (4)$$

Where, E_s is the energy used during machine setup and can be calculated using Eqn. 5 while E_t is the machining energy consumption which can be calculated using Eqn. 6 (Nur et al., 2017). Also, E_{ct} is the energy used during the replacement of a tool and can be calculated using Eqn. 7 while E_c is the sum of energy consumed to fabricate each cutting edge on a cutting tool (Eqn. 8).

$$Es = P_0 \times t_1 \qquad (5)$$

Where, P_0 is the power in Watt in idle and run-time modes (power consumed by all machine modules for a machine operating at zero load) and t_1 is the time in seconds required for machine setup.

$$E_t = (P_0 + k\beta)\, t_2 \qquad (6)$$

Where k is specific machining energy (Ws/mm^3), β is material removal rate (mm^3/s) and t_2 is the accumulated material removal time of the turning process (s).

$$E_{ct} = P_0 \times t_3 \times \frac{t_2}{T} \quad (7)$$

Where, t_3 = the time for a replacement tool (s) and T = tool life (s), which is the same as t_2,

Therefore, $\frac{t_2}{T} = 1$ (Nur et al., 2021).

$$E_c = Y \times \frac{t_2}{T} \quad (8)$$

Where, Y can be obtained from the total energy per insert (MJ) for material and manufacturing process as reported in Handbook of Machining and Metalworking Calculations and compiled by Walsh (2001).

3. Specific energy consumption

Specific energy consumption (SEC) is the energy consumption required by a machine tool to remove $1cm^3$ of material, which is dependent on material removal rate (MRR) and the workpiece material itself (Simoneau and Meehan, 2015). The Specific energy consumption technique does not take into account the energy consumed outside the cutting process (coolant, positioning, setup and standby) and can be calculated using Eqn. 9 (Olaiya et al., 2020). Zhao et al. (2016) have reported that large depth of cut and feed speed within allowable range will help to reduce specific energy consumption and machine tool energy consumption while, high tool wear will lead to the rapid increase in SEC and machine tool energy consumption in turning. The authors therefore suggested that the degree of tool wear should be controlled throughout the work process.

$$SEC = \frac{P_i}{Vc \times f \times dc} \quad (9)$$

Where Pi = power consumption, V_C = cutting speed in mm/min, f = feed rate in mm/rev and dc = depth of cut in mm.

In addition, Zhao et al. (2016) also highlighted the different steps involved in specific energy consumption prediction method in turning based on the Back-Propagation (BP) neural network These steps include; Prediction of the SEC in J/mm^3 according to the processing parameters in turning as shown in Fig. 1, computation of the total material removal volume in mm^3 according to the machining feature and processing parameters and computation of machine tools energy consumption in turning. Ithipri et al. (2015) utilised response surface methodology to investigated specific energy consumption as an energy efficiency indicator for minimizing the energy intensity of a given machined product in turning operations. The authors found that increase in depth of cut and cutting speed decreases the SEC in the turning operations. The authors attributed this to the fact that as machining parameters increases, material removal rate also increases thereby reducing the specific energy consumption.

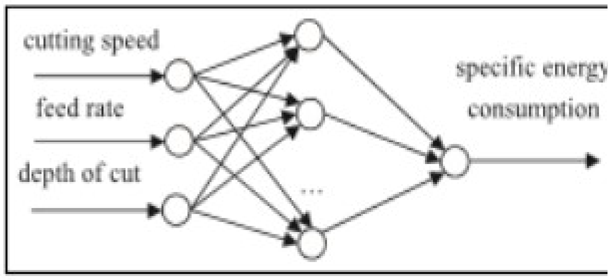


Fig. 1: The network model for prediction of specific energy consumption (Zhao et al., 2016).

Li et al. (2016) studied and optimize cutting parameters for minimizing SEC by means of different soft computing methods and integrating Taguchi. The authors compared four machining parameters schemes using different optimization objectives and found that a trade-off point can be drawn between the low processing time and high energy efficiency. Also, Pawanr and Garg (2019) focused on determining optimum cutting parameters in minimizing SEC during turning of Al 6061 using Taguchi design method. The authors revealed that to minimize SEC, feed of 0.12mm/ rev, cutting speed of 46.2m/min and depth of cut 1mm. the authors also found that the developed energy consumption maps can be utilised in correlating the region of minimum SEC with selected machining parameters. Olaiya et al. (2020) utilised response surface methodology and multi-response optimisation technique to investigate the effects of cutting variables (cutting speed, feed rate and depth of cut) on specific energy consumption under different cutting environment using AISI 304 alloy steel. Orthogonal turning operations were carried out in dry and wet conditions with mineral oil based and vegetable oil based cutting fluids. The authors found that the optimum multiple performance of the vegetable oil-based cutting fluid was obtained with reduction in energy consumption from 527.18J/mm^3 in dry turning to 141.50J/ mm^3.

4. CHALLENGES AND FUTURE RESEARCH DIRECTION

Turning is one of the most fundamental and important machining processes that is widely used in most manufacturing industries. Energy costs associated with turning operation represent an expense currently beyond the control of manufacturers. As a result, there is need for these industries to consider how to reduce energy consumption demands while still maintaining process efficiencies. Several works has been carried out on improving energy consumption in turning with the aim of understanding the machine tools energy characteristics so as to adopt targeted energy saving measures. This research area has been receiving serious attention and a lot have been achieved, but these achievements have not been translated into commercial application.

5. CONCLUSION

A comprehensive review of energy consumption in turning process has been emphasized in this study. It is evident that the way towards achieving an energy-efficient turning process is through a well-established energy models, rapid and effective energy optimisation techniques and proper adoption of the data which will help enhance energy-efficient turning processes. Also, the need for data obtained from these review work to evolve from workshop will address the current gap in attaining an energy-efficient turning process.

REFERENCES

Aramcharoen A and Mativenga PT. (2014). Critical factors in energy demand modelling for CNC milling and impact of toolpath strategy. Journal of Cleaner Production. 78: 63–74.

Astakhov, V.P and Xiao, X. A (2008). Methodology for practical cutting force evaluation based on the energy spent in the cutting system. Machining Science Technology, 12, 325–347.

Bruzzone, A., Anghinolfi, D. Paolucci, M. and Tonelli, F. (2012). Energy-Aware Scheduling for Improving Manufacturing Process Sustainability: A Mathematical Model for Flexible Flow Shops, CIRP Annals – Manufacturing Technology, 61(1), 459-462.

Diaz, N. Ninomiya, K. Noble, J. and Dornfeld, D. (2012). Environmental Impact Characterization of Milling and Implications for Potential Energy Savings in Industry, 5th CIRP Conference on High Performance Cutting, 518-523.

Diaz, N., Helu, M., Jayanathan, S., Chen, Y., Horvath, A., Dornfeld, D. (2010). Environmental analysis of milling machine tool use in various manufacturing environments. In: Proceedings of the 2010 IEEE International Symposium on Sustainable Systems and Technology.

Elmunafi, M.H.S., Noordin, M.Y., Kurniawan, D. (2015). Effect of cutting speed and feed in turning hardened stainless steel using coated carbide cutting tool under minimum quantity lubrication using castor oil. Adv. Mech. Eng. 2015, 7, 1–7.

Fang K, Uhan N, Zhao F, et al. (2012). A new shop scheduling approach in support of sustainable manufacturing. In: Proceedings of the 18th CIRP international conference on life cycle engineering, Technische Universita¨ t Braunschweig, Braunschweig, Germany, 2–4 May 2011, 305–310.

Grzesik, W., Denkena, B., ˙Zak, K., Grove, T. (2016). Bergmann, B. Energy consumption characterization in precision hard machining using CBN cutting tools. Int. J. Adv. Manuf. Technol. 85, 2839–2845

Gutowski T, Dahmus J and Thiriez A. (2006). Electrical energy requirements for manufacturing processes. In: Proceedings of the 13th CIRP international conference of life cycle engineering, Leuven, 31 May–2 June 2006. Leuven: Katholieke Universiteit Leuven.

Ithipri, E., Ossia, C.V., Okoli, J.U. (2015). Modeling the Specific Energy in Turning Operations by Taguchi L32 Orthogonal Array Design, International Journal of Scientific & Engineering Research, 6(5), 567-575

Kara, S. and Li, W. (2011). Unit Process Energy Consumption Models for Material Removal Processes, CIRP Annals – Manufacturing Technology, 60(1), 37-40.

Li, C., Xiao, Q., Tang, Y., Li, L. (2016). A method integrating Taguchi, RSM and MOPSO to CNC machining parameters optimization for energy saving, Journal of Cleaner Production, 135:263–275

Moradnazhad, M. and Unver, H. O. (2016). Energy efficiency of machining operations: A review, Proceedings IMechE Part B: Journal of Engineering Manufacture, 1–19.

Mori M, Fujishima M, Inamasu Y, et al. (2011) A study on energy efficiency improvement for machine tools. CIRP Annals: Manufacturing Technology, 60: 145–148.

Nur, R., Kurniawan, D., Noordin, M.Y. and Izman, S. (2015). Optimizing power consumption for sustainable dry turning of treated aluminum alloy, Procedia Manufacturing 2, 558 – 562.

Nur, R., Mohd Yusof, N. M., Sudin, I., Nor, F. M. and Kurniawan, D. (2021). Determination of Energy Consumption during Turning of Hardened Stainless Steel Using Resultant Cutting Force, Metals, 11, 565. https://doi.org/10.3390/ met11040565

Nur, R., Noordin, M.Y., Izman, S., Kurniawan, D. (2017). Machining parameters effect in dry turning of AISI 316L stainless steel using coated carbide tools. Proc. Inst. Mech. Eng. E J. Process. Mech. Eng. 231, 676–683.

Oda, Y., Kawamura, Y. and Fujishima, M. (2012). Energy Consumption Reduction by Machining Process Improvement, 3rd CIRP Conference on Process Machine Interactions (3rd PMI), Procedia CIRP 4, 120 – 12.

Pawanr, S. and Garg. G. K. (2019). Selection of optimum Cutting Parameters for Minimization of Specific Energy Consumption during Machining of Al 606, Journal of Physics: Conference Series, 1240, 012064

Peng T, Xu X and Wang LH. (2014). A novel energy demand modelling approach for CNC machining based on function blocks. Journal of Manufacturing System, 33: 196–208.

Peng, T. and Xu, X. (2014). Energy-efficient machining systems: A critical review, The International Journal of Advanced Manufacturing Technology, 72(9-12):1389-1406.

Rajemi, M.F., Mativenga, P.T., Aramcharoen, A. (2010). Sustainable machining: Selection of optimum turning conditions based on minimum energy considerations. Journal of Cleaner Production, 18, 1059–1065

Simoneau, A. and Meehan, J. (2015). Investigating Peak Power and Energy Measurements to Identifying Process Features in CNC End milling, Energy and Power, 5(2), 25-31.

Simoneau, A. and Meehan, J. (2015). Investigating Peak Power and Energy Measurements to Identifying Process Features in CNC Endmilling, Energy and Power, 5(2), 25-31

Vijayaraghavan A and Dornfeld D. (2010). Automated energy monitoring of machine tools. CIRP Annals: Manufacturing Technology, 59(1): 21–24.

Walsh, R.A. (2001). Handbook of Machining and Metalworking Calculations; McGraw-Hill Education: New York, NY, USA.

Yoon HS, Moon JS, Pham MQ, et al. (2013). Control of machining parameters for energy and cost savings in micro-scale drilling of PCBs. Journal of Cleaner Production, 54: 41–48.

Zhao, G., Hou, C., Qiao, J. and Cheng, X. (2016). Energy consumption characteristics evaluation method in turning, Advances in Mechanical Engineering, 8(11), 1–8.

DESIGN AND CONSTRUCTION OF A FABRIC DRYER POWERED BY LOW TEMPERATURE WASTE HEAT RECOVERED FROM TETRAFLUOROETHANE (R-134A) REFRIGERATOR.

[1]ONYEOCHA E.I.E., [2]Nwigwe K.N, [2]Ogueke N.V. and [3]Anyanwu E.E.
[1]National Board for Technical Education, Polytechnic Programmes Department, Plot 'B' Bida Road, P.M.B. 2239, Kaduna, Nigeria.
[2]School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Nigeria

ABSTRACT

A dryer integrated with and utilizing the waste heat recovered from tetrafluoroethane (R134a) refrigerator is presented. It comprises of a 150W refrigerator with its condenser unit retrofitted to serve as a heat recovery mechanism (dryer). The refrigerator with ozone friendly R134a refrigerant is based on vapour compression cycle (VCC). The dryer component is powered by waste heat from superheat and condensation regions of the VCC. An extractor fan rated 30.8W facilitates dissipation of heat and air movement in the dryer. The maximum design dryer and evaporator temperatures are 50^{O}C and 5^{O}C respectively. The overall performance of the machine was based on dryer and evaporator temperatures, Coefficient of Performance (COP), Specific Moisture Extraction Rate (SMER) and Energy utilization ratio (EUR). Experimental temperatures of 49^{O}C maximum and 1^{O}C minimum were observed in the dryer and evaporator respectively. COP of 10.09, SMER of 0.22kg/kWhr and EUR of 0.92 were obtained indicating that the ratio energy derived/energy consumed is 10 times; 1 kWhr energy was used to extract 0.22kg moisture from fabric as well as provide 150W refrigeration; and 92% of the waste heat was actually utilized for drying. Therefore, this dual purpose system is energy efficient. Drying of fabrics makes this system an option for entrepreneurship development in laundry business.

Key Words: Waste Heat Recovery, Refrigeration, Dryer, evaporator, Temperature.

1. INTRODUCTION

Up to 20% of the energy input used in many industrial and commercial energy processes is rejected to the environment as flue gas (Energy Solutions Center, FoodPro, 2007). This rejected energy may potentially be recaptured as useful energy (Lalovic et al., 2005). The increasing cost of energy in the past years aroused the need for using more efficient energy systems (Al-Kayiem and El-Rahman, 2011). The solution to the ever-increasing energy demand, greenhouse gas emissions, depleting reserves of fossil fuels and increase in cost of goods is energy conservation. Waste-heat recovery systems, among others, contributed to making the energy costs of Japanese products 20% less than those of many of their competitors (Eastop and Mackonkey, 1992). Recovering and re-using rejected heat is known as waste heat recovery (Mozzo, 2007). Heat recovery technology provides a means to effectively recover waste heat and convert it to useful purposes, thus offsetting the fuel that should have been burnt to achieve same purpose and hence save costs.

The Siemens Switzerland Limited, Building Technologies Group (2010) recommended that out of the three regions of the Heating Ventilating and Air Conditioning (HVAC) equipment condenser namely, the superheat, the latent heat and the sub-cooled regions, heat can be recovered from the hot refrigerant in the superheat and latent heat regions for drying purposes.

In this work, such heat was recovered from a domestic refrigerator condenser and used for drying operation while the cooling effect in the evaporator was used for refrigeration purposes. Both the condenser and evaporator were designed based on the distributed parameter models suggested by (Hongtao, Reinhard and Vikrant, 2010). The system is designed to perform the dual functions of domestic refrigerator and heat pump simultaneously by utilizing the condenser heat that should have been rejected to the surroundings to provide useful service of fabric drying and at the same time employ the evaporator cooling effects for useful cooling. The equipment ensures a year round fabric drying which is a major challenge in the rain forest region, especially during the rainy season.

The patented design (Anyanwu et al, 2015) of the Integrated Tetrafluoroethane (R-134a) Refrigerator Waste Heat Recovery Dryer (ITRWHRD) is illustrated in Fig. 1.

It consists of a conventional refrigeration unit utilizing environmental friendly refrigerant (R-134a) and an integrated dryer utilizing the refrigerator waste heat for drying operations. The refrigerator unit consists of a compressor, condenser, throttle device and evaporator. While the dryer unit consists of a drying chamber, extractor fan, a drain pipe, and air vent. The refrigerator unit and the dryer unit together form the ITRWHRD. The ITRWHRD is an insulated rigid rectangular three sided box divided into the upper and lower compartments by an insulated partition. The upper compartment is the dryer while the lower compartment is the refrigerator. The dryer sits atop the refrigerator. Fabrics are placed in the dryer to dry. The throttle device is the capillary tube. The lower chamber (refrigerator) is comprised of the evaporator which receives the sub cooled refrigerant coming from the condenser. Heat is absorbed by the refrigerant in the evaporator which results in a phase change from liquid to vapour while producing cooling in the process. The refrigerant in the vapour phase is sucked by the compressor which subsequently compresses it to high pressure and temperature before discharging it in the condenser tubing wound in the dryer. The super heat and latent heat of the refrigerant vapour in the condenser is rejected in the dryer.

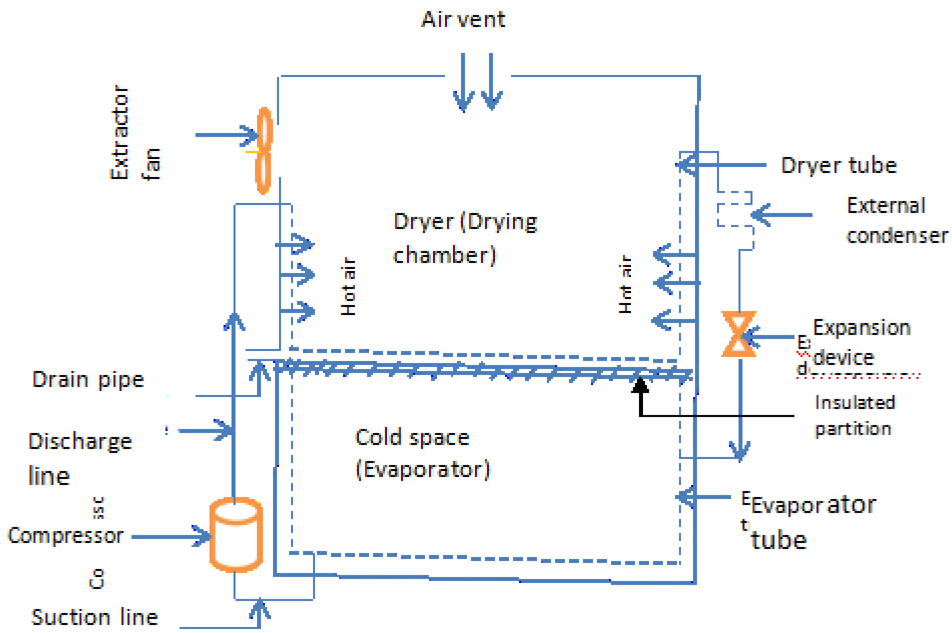


Fig. 1 Major components of ITRWHRD

This leads to the condensation of the refrigerant. Part of the dryer tubing is extended outside (surroundings) to form the external condenser where sub cooling of the condensed refrigerant takes place on its way to the throttling device. The refrigerant is expanded in the throttling device before it flows into the evaporator; and the cycle repeats. The dryer and refrigerator sections have separate hinged doors and are separated by an insulated partition. The outer wall material for the ITRWHRD is constructed with galvanized steel in order to prevent corrosion, give good surface appearance and higher quality finish when painted, prevent cracking and loss of adhesion when the steel is formed into any shape, ensure durability and resistance to scratches from abrasion and provides tensile strength.

2. SELECTION OF EVAPORATOR TEMPERATURE

The selection process for the evaporator temperature and the design of the evaporator are not discussed here. However, the cold space, evaporator refrigerant and evaporator superheat temperatures were chosen as 5 ^{O}C, -2 ^{O}C and 5 ^{O}C respectively.

3. SELECTION OF DRYER/ CONDENSER TEMPERATURE

Damewood (2003) identified low heat drying temperatures for light cotton fabrics in the range of 49-52 ^{O}C. In this work, the materials considered for drying are light cotton fabrics. Consequently, an average dryer temperature of 50 ^{O}C is chosen.

However, according to Althouse et al (1996) the temperature of the refrigerant in an air cooled condenser is approximately 17^{O}C to 19^{O}C warmer than the environmental temperature. Hence choosing 19^{O}C above average environmental temperature, T_a in Owerri of 33^{O}C (Meoweather, 2014), the condenser temperature for this work is 52^{O}C. The refrigerant was to be superheated by 5^{O}C at the exit section of the evaporator tubing in order to prevent some refrigerant leaving the evaporator as liquid, which is useful cooling potential wasted (Desai, 2007). Superheating also forestalls liquid refrigerant arriving the compressor with the tendency to wash the lubricating oil from the walls of the cylinder, accelerating wear and causing damage to the valves or the cylinder head. With the 5^{O}C superheat, the entry temperature at the condenser therefore, is the sum of the superheat (5^{O}C) and the condenser temperature (52^{O}C), that is 57^{O}C. For effective heat transfer between the condenser and the surroundings, the condenser refrigerant will be sub cooled at least 10K above the temperature of the surroundings (Prasad, 2007). Since the environmental temperature, T_a within Owerri is 33^{O}C (Meoweather, 2014), the condenser refrigerant therefore will be sub cooled to environmental temperature plus 10K, that is 43^{O}C. The sub cooling will be achieved in the dryer surroundings using the ambient air.

4. GENERAL DESIGN PARAMETERS/ SPECIFICATIONS

Table 1. Determined design parameters

Refrigerant	R-134a
Dryer temp, (Damewood, 2003)	50^{O}C
Cold space temp, (Bingqiang et al., 2012)	5^{O}C
Evaporator refrigerant temp., (Althouse et al., 1996)	-2^{O}C (2.72 bar)
Evaporator superheat temp.	5^{O}C
Condenser refrigerant temp, (Althouse et al., 1996)	52^{O}C (13.86 bar)
Ambient air temp for Owerri (Meoweather, 2014)	33^{O}C
Condenser sub-cooled temp., (Prasad, 2007)	43^{O}C
Condenser degree of superheat	5^{O}C

5. THERMODYNAMIC STATES OF REFRIGERANT IN THE SYSTEM COMPONENTS

Compression (process 1-2) as in Fig. 2, (Roy, 1997): Compression process is estimated using The Steady Flow Energy Equation (SFEE).

From SFEE, (Eastop and McConkey, 1992): $\Delta h + \Delta KE + \Delta PE + q - w = 0$, Where h, KE, PE, q and w stand for enthalpy, kinetic energy, potential energy, heat input and work input through the system respectively.

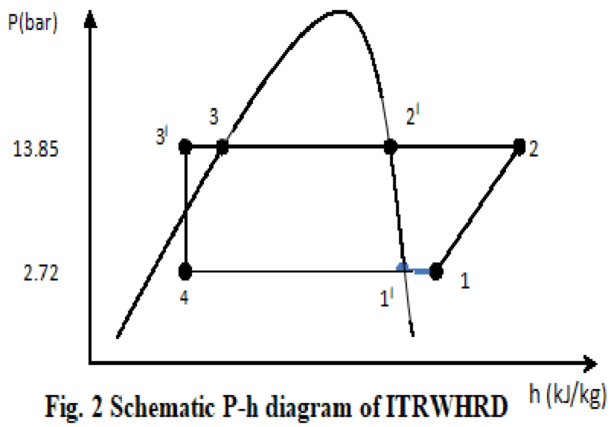


Fig. 2 Schematic P-h diagram of ITRWHRD

Since the compressor is losing its heat input to the environment at the time of compression,

q = 0; changes in KE and PE are negligible. Hence SFEE reduces to:

$\Delta h - w = 0$ 1

In terms of the initial and final states of the compression process:

$W_{12} = h_2 - h_1$ 2

Condensation (process 2-3^I): The superheated vapour from the compressor rejects heat in the condenser, thus cooling to a saturation state of T_2^I. It further rejects heat resulting in its condensation to T_3 and subsequent sub cooling to T_3^I. During condensation process, there is no work transfer and changes PE and KE are often negligible (Cengel, 2006). From Fig. 2, heat transferred during the condensation process consists of the portion for de-superheating ($h_2 - h_2^I$), that for phase change (h_2^I-h_3), and for refrigerant sub cooling (h_3-h_3^I).

Thus SFEE reduces to: $\Delta h + q = 0$ or $-\Delta h = q$

In terms of the initial and final states of the condensation process:

$q_{23}^I = (h_2-h_2^I) + (h_2^I-h_3) + (h_3-h_3^I) = h_2-h_3^I$ 3

That is the total heat released at the condenser during condensation.

The actual heat dissipated in the dryer for drying purposes:

$q_{23} = (h_2-h_2^I) + (h_2^I-h_3)$ 4

Expansion (process 3^I- 4): The liquid refrigerant expands from state 3^I to state 4 (Fig. 2) with some of the liquid refrigerant flashing in the process, the process is adiabatic and q = 0. Changes in elevation, velocity and work input = 0. Thus, from SFEE, dh = 0.

That is, $h_4 - h_3^I = 0$ or $h_4 = h_3^I$ 5

Evaporation (process 4-1): There are no moving parts, changes in elevation and velocity are often negligible; hence, SFEE reduces to:

$\Delta h + q = 0$, thus:

$\Delta h + q = 0$, thus, $q_{14} = h_1-h_4 = h_1 - h_3^I$ 6

q_{14} = heat transferred in the evaporator per unit refrigerant mass = refrigerating effect.

6. DIMENSIONS OF THE DRYER

The considerations for the choice of the inner dimensions of the dryer are made as follows:

WIDTH: The choice of its breadth is such as will conveniently accommodate the hangers that will be used to hang clothes inside it. An average hanger is about 40cm to 42cm based on physical measurement. With an additional allowance of at least 5cm the inner width of the dryer box is rounded off to 50cm.

LENGTH: The inner length is such as will accommodate the hanger rod inside it. The hanger rod will carry ten clothes with the air gap of about 5cm in between clothes and 2.5cm air gap between the dryer wall and each of the two clothes at both ends of the dryer. Hence a convenient length of 50cm is chosen as the length of the hanger rod and the inner length of the dryer.

HEIGHT: The height is such as can contain an average length of a pair of trousers. The reporter's pair of trousers physically measured at 96cm. A gap of 3cm is provided between the dryer roof and the hanger rod with another 1.0cm gap between the down side of the hanging trousers and the dryer floor. Hence an average of 100cm height will be required for the dryer. The 1.0cm gap to the dryer floor will ensure that the trousers do not touch the floor of the dryer and furl. Furling of the trousers will reduce the area of the clothing material (trousers) that will be exposed to the heat and air current that are meant to effect drying.

In summary the inner dimensions of the dryer box are chosen as:

Length = 0.5m; Width = 0.5m and Height = 1.0m

7.0 7. THERMAL DESIGN OF THE DRYER

The heat, Q_d required for drying is equivalent to the heat required to raise the ambient air temperature, T_a of 33^OC (Owerri, Nigeria) to the dryer temperature, T_d, 50^OC is estimated as:

$$Q_d = \dot{m}_a c_a (T_d - T_a) \quad (7)$$

$$\dot{m}_a = \rho_a A_a v_a \quad (8)$$

$$A_a = \pi D^2/4 \quad (9)$$

Where: $\dot{m}a$, D, Aa, ρ_a, c_a and v_a are mass flow rate of air into dryer through the circular air vent, diameter of circular air vent, area of circular air vent, density of air at ambient temperature, specific heat capacity of air at ambient temperature and velocity of air flowing into the dryer respectively. v_a is measured by anemometer as = 1.04m/s, D = 0.102m as measured, ρ_a and c_a are $1.1559kg/m^3$ and 1.0061kJ/kgK respectively (Holman, 2001)

8. SELECTION OF DRYER/ CONDENSER PIPING MATERIAL

Copper pipe is selected for this work because of the following advantages (Althouse et al, 1996): (i) it is compatible with all halogenated refrigerants including R-134a (ii) It is resistant to corrosion (iii) It is cheap and easy to install.

8.1 Design of Dryer/ Condenser Pipe (Tubing)

In designing for the condenser/ dryer tubing, the following choice and assumptions were made:

(i) Type L (medium thick wall) copper tube of 0.0045m outer diameter and 0.0028m inner diameter was selected based on American Standard Safety Code for Mechanical Refrigeration Code (CSA B52)

(ii) The condenser tubing wound round the dryer is assumed to make a good thermal contact with the aluminum plate covering it. By so doing the aluminum plate provides a larger surface for heat transfer, and hence acts as a fin.

From Fig. 2, the actual heat required in the dryer, Q_d according to Siemens Switzerland Limited, Building Technologies Group (2010) includes: (i) The heat released by the refrigerant vapour as it de-superheats from state 2 to state 2^I, that is, $\dot{m}_R\ (h_2 – h_2^I)$, and (ii) The heat of condensation released into the condenser from saturated vapour state 2^I to saturated liquid state 3, $\dot{m}_R\ (h_2^I – h_3)$

The heat released as the refrigerant sub cools from state 3 to state 3^I, $\dot{m}_R\ (h_3 – h_3^I)$ is rejected outside the dryer (surroundings).

Therefore, the actual heat required in the dryer is given by:

$$Q_d = \dot{m}_R\ [(h_2 – h_2^I) + (h_2^I – h_3)] = \dot{m}_R\ (h_2 – h_3) \qquad 10$$

Substituting values into equation (10), yields $\dot{m}_R$.

The selected dryer/ condenser copper tube parameters are;

Outer diameter, d_{co}; Inner diameter, d_{ci}, inner cross sectional area, A_{ci}

$$A_{ci} = \pi d_{ci}^2/4 \qquad 11$$

The length of tubing that can dissipate the heat released by the refrigerant vapour as it de-superheats from state 2 (57^{O}C) to saturated state 2^I (52^{O}C) can be estimated as follows:

Vapour properties of R-134a at 57^{O}C superheat region refrigerant entry temperature, Desai (2007) are: Density, ρ_{vc2}; dynamic viscosity, μ_{vc2}; specific heat capacity, C_{pvc2}; and thermal conductivity, k_{vc2}

The mean velocity of vapour, u_{mc2} in the condenser tubing is given by;

$$u_{mc2} = \dot{m}_R / \rho_{vc2} A_{ci} \qquad 12$$

Reynolds number of the vapour at the superheat region, Re_{c2}, is used to establish the superheat flow regime of the refrigerant inside the copper tube and is given as;

$$Re_{c2} = \rho_{vc2}\ U_{mc2}\ d_{ci}/ \mu_{vc2} \qquad 13$$

$Re_{c2} > 2300$, therefore the refrigerant flow regime is turbulent.

For turbulent flow in a smooth pipe such as the condenser, (Holman, 2001) recommended the use of Dittus and Boelter's cooling correlation to find the convection heat transfer coefficient, h_{c1}, that will convect away the refrigerant heat in the pipe (tubing) as follows:

$$\text{Nusselt Number, } Nu_{c2} = 0.023\ Re_{c2}^{\ 0.8} Pr_{c2}^{0.3} \qquad 14$$

The Prandtl number, Pr_{c2} of the superheat flow region is given) as;

$$Pr_{c2} = C_{pvc2}\mu_{vc2}/ k_{vc2} \qquad 15$$

Substituting for Pr_{c2} and Re_{c2} into equation (14) gives Nu_{c2};

$$\text{But, } Nu_{c2} = h_{c2}d_{ci}/k_{vc2} \qquad 16$$

Substituting for Nu_{c2}, d_{ci} and k_{vc2} into equation (16) yields h_{c2};

h_{c2} is the convection heat transfer coefficient required to dissipate heat from the superheated refrigerant in the condenser to the dryer (drying chamber).

Similarly, the refrigerant enters the condensation (phase change) region (2^I - 3) at the saturation temperature of 52^{O}C as represented in Fig. 2. To establish the heat transfer coefficient required to convect heat from the refrigerant at the condensation region to the drying chamber, the vapour properties of the R-134a refrigerant at the entry saturation temperature of 52^{O}C are:

$\rho_{vc2}{}^I$; $\mu_{vc2}{}^I$; $C_{pvc2}{}^I$ and $k_{vc2}{}^I$

Mean velocity of vapour, $u_{mc2}{}^I$ in the condensation region tubing is given by;

$$u_{mc2}{}^I = \dot{m}/ \rho_{vc2}{}^I A_{ci} \quad 17$$

Reynolds number of the vapour, $Re_{c2}{}^I$, is used to establish the condensation flow regime of the refrigerant inside the copper tube and is given as;

$$Re_{c2}{}^I = \rho_{vc2}{}^I u_{mc2}{}^I d_{ci}/ \mu_{vc2}{}^I \quad 18$$

Since Re > 2300, the refrigerant flow regime is turbulent.

Dittus & Boelter's cooling correlation for turbulent flow in a smooth tube is used to find the Nusselt Number, $Nu_{c2}{}^I$ and convective heat transfer coefficient, $h_{c2}{}^I$, in the condensation region (Holman, 2001) as follows;

$$Nu_{c2}{}^I = 0.023\, Re_{c2}{}^{I\ 0.8} Pr_{c2}{}^{I\ 0.3} \quad 19$$

The Prandtl number, $Pr_{c2}{}^I$ of the condensation flow region is also commonly expressed in heat transfer calculations as;

$$Pr_{c2}{}^I = C_{pvc2}{}^I \mu_{vc2}{}^I / k_{vc2}{}^I \quad 20$$

$$Nu_{c2}{}^I = h_{c2}{}^I d_{ci}/k_{vc2}{}^I \quad 21$$

Substituting for $Nu_{c2}{}^I$, d_{ci} and $k_{vc2}{}^I$ into equation (21) yields $h_{c2}{}^I$

$h_{c2}{}^I$ is the convection heat transfer coefficient required to convect heat from the condensing refrigerant to the drying chamber.

Average heat transfer coefficient, $h_{c22}{}^I$ in the superheat and condensation regions of the condenser is given in equation (22) as:

$$h_{c22}{}^I = \frac{1}{2}(h_{c2} + h_{c2}{}^I) \quad 22$$

Similarly average temperature in the superheat and condensation regions as the refrigerant cools from T_{c2}, 57^{O}C to $T_{c2}{}^I$, 52^{O}C is given as:

$$T_{c22}{}^I = \frac{1}{2}(T_{c2} + T_{c2}{}^I) \quad 23$$

From section 7.0: the heat rejected by the condenser refrigerant in the superheat and condensation regions is equal to the heat received by the drying chamber to heat up the ambient air from T_a, 33^{O}C to dryer temperature, T_d, 50^{O}C and that is estimated as Q_d.

Thus, average temperature difference between the condenser and the dryer, T_{cd} is:

$$T_{cd} = (T_{c22}{}^I - T_d) \quad 24$$

The surface area, A_{sc23} and length of tubing, L_{c23} required for the superheat and condensation regions can be estimated with equation (25) as:

$$\dot{m}(h_2 - h_3) = Q_d = h_{c22}{}^I A_{sc23} T_{cd} \quad 25$$

Substituting the values of the parameters in equation (25) yields A_{sc23}

$$\text{But, } A_{sc23} = \pi d_{ci} L_{c23} \quad 26$$

Substituting the values of the parameters in equation (26) yields L_{c23}

L_{c23} is the minimum length of copper tubing required in the superheat and condensation regions to dissipate heat from the condenser refrigerant into the dryer (drying chamber).

8.2 Fouling Factor Effects in the Condensation Region

Fouling takes place in the condensation region due to the presence of oil in the condenser and/ or low refrigerant velocities. The oil film on the internal surface of the tube causes resistance to heat flow. Besides, at low velocities (and the consequent pressure drop), vapour bubbles formed by the boiling action of the refrigerant tend to cling to the tube walls. This will decrease the amount of interior wetted surface and present additional resistance to heat flow. The fouling takes place in the condenser mixture region where there is the presence of liquid refrigerant. Holman (2001) estimated fouling effect in tubes mathematically as:

Fouling factor = $1/f_{dirty}$ 27

Where: f = fouling factor or fouling heat transfer coefficient. For refrigerant liquid;

$1/f = 0.0002 m^{2O}C/W$ (Holman, 2001). This gives f as $(0.0002)^{-1} = 5000 W/m^{2O}C = 5 kW/m^{2O}C$

Hence for the condensation region;

Fouling heat transfer coefficient, $f_{c2^I3} = 5 kW/m^{2O}C$ 28

From Fig.2; given the condensation region of refrigerant average temperature, T_{2^I3} from state 2^I to state 3 of 52^OC, and discharging the refrigerant's heat content into the dryer at the temperature, T_d of 50^OC; A_{sc2^I3}, the surface area of the condenser tubing that can compensate for fouling effects can be found using equation (29) as:

$\dot{m}\,(h_{2^I} - h_3) = f_{c2^I3} A_{sc2^I3} (T_{2^I3} - T_d)$ 29

Substituting for the quantities into equation (29) yields A_{sc2^I3};

$A_{sc2^I3} = \pi d_{ci} L_{c2^I3}$ 30

Substituting for A_{sc2^I3} and d_{ci} in equation (30) yields L_{c2^I3}

L_{c2^I3} is the length of tubing required to compensate for fouling effects in the condensation region 2^I3.

8.3 Total Length of the Tubing for Superheat and Condensation Regions

The calculated length of tubing for the condensation and superheat regions, L_{c23T} is given as the sum of the tube lengths calculated for the regions. It is common practice to add a certain length as safety factor to compensate for frictional losses occasioned by the roughness associated with local bending of pipes (Roy, 1997). The length added as factor of safety for this work is 10% of the calculated total condenser tubing length.

Thus,

$L_{c23T} = (L_{c23} + L_{c2^I3}) + 0.1(L_{c23} + L_{c2^I3})$ 31

The pipe (tubing) is wound inside the insulated drying chamber and covered with aluminium plate. The tubing is directly connected to the pipe coming from the compressor discharge line. This is to ensure that the superheated vapour coming from the compressor discharges its heat content into the dryer for maximum heating.

9. DRYER DESIGN SPECIFICATIONS

Table 2. Dryer/ condenser design parameters

Heat required in the dryer (Design)	0.1659kW
Length of dryer hanging rod	0.5 m
Gap between dryer roof and hanging rod	0.3 m
mass flow rate of refrigerant ($\dot{m}_R$) (Design)	0.001 kg/s
Dryer dimensions (Design) LxWxH = 0.5m x 0.5m x 1.0m	
Dryer air mass flow rate ($\dot{m}_a$) (Design)	9.7×10^{-3}kg/s
Dryer Tube material Copper	
Tube inner diameter, d_{ci}	2.8mm
Length of tube for the dryer	9.38m
Outer wall material	Galvanized steel plate

10. EXPERIMENTAL METHOD

The integrated ITRWHRD is such that an extractor fan to remove moist air from the drying operation is located at the upper side of it, while an air vent with a removable lid is located on its roof to ensure continuous exchange of air between the drying chamber and the surrounding environment. A drain pipe is connected to the base of the dryer for removal of dripping water from the materials being dried in the dryer.

The condenser of the system is installed in such a way that part of it is within the dryer and the remaining part is exposed to the ambient environment. The condenser section located within the dryer receives hot refrigerant vapour coming from the compressor. The hot refrigerant vapour loses part of its heat content to the air within the dryer thus raising the dryer air temperature. This subsequently reduces the dryer air relative humidity thereby increasing the rate of moisture removal from the material to be dried. On the other hand, the condenser section exposed to the ambient environment loses heat to the ambient air thus ensuring full refrigerant condensation and sub cooling to the required design temperature. The sub-cooled refrigerant from the portion of the condenser exposed to the ambient environment enters the evaporator through the expansion device. Temperature variations and drying rates were monitored uninterrupted by powering the system with generating set. Readings were taken at regular intervals of 10 to 15 minutes for drying rate experiments and 30 minutes for temperature monitoring.

Weight loss of the product inside the drying chamber is also constantly monitored by the use of digital hanging scale. The digital hanging scale has three major parts, namely, the stainless hook at one end, the hanger (handle) at the other end and the digital box (in between the two ends) which displays the mass of cloths hung on the hook in kilograms. For continuous operation, the hook of the hanger is lowered inside the drying chamber through the air vent on the roof of the drying chamber while both the digital box and handle are held outside the drying chamber.

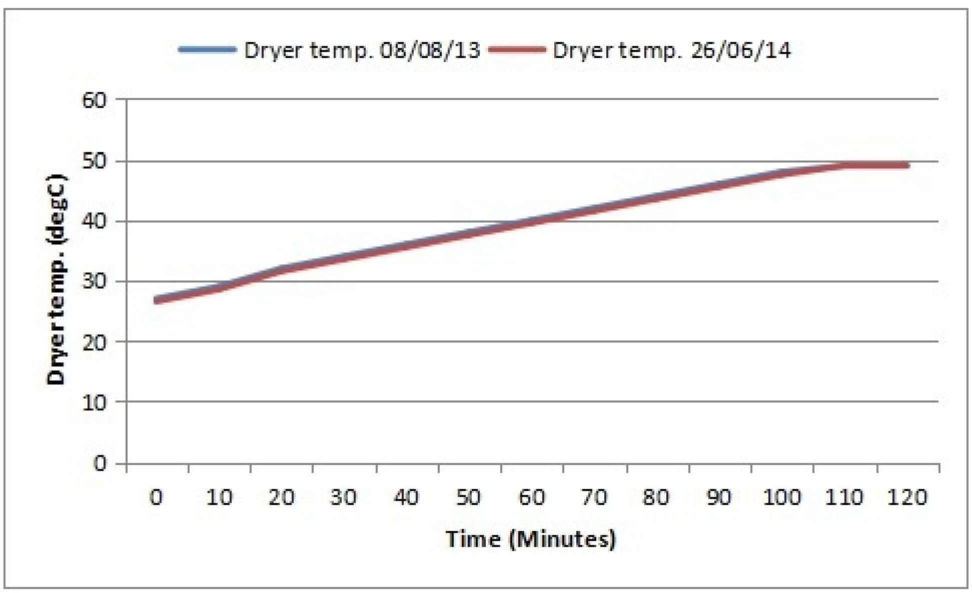
The stainless hook carries the wet cloth to be dried, while the handle serves to support the whole weight of the hanging scale and wet cloth on any outside platform. The reading of the weight (kg) displayed on the digital scale is taken every 15 minutes without opening the door of the drying chamber. This is expected to avoid influx of outside air which may reduce the temperature of the dryer. In this way the amount of moisture removed from the cloth is observed periodically. The dryer temperature is observed by installing $100^{O}C$ mercury in glass thermometer. The bulb of the thermometer is held in a slit cut in a thick carton paper sheet. The paper sheet, 15cm x 15cm is placed loosely on the 10cm diameter air vent located on the roof top of the ITRWHRD in such a way as not to hinder free flow of outside air into the dryer. Both the hook of the hanging digital scale and the bulb of the mercury in tube thermometer are passed through the carton paper sheet placed on the 10cm diameter air vent into the drying chamber. In this position, the bulb of the thermometer comes in contact with the hot air being circulated in the dryer and continuously reads the dryer temperature. This ensures that there is no need to open the dryer door before the temperature of the dryer could be read.

11. RESULTS AND DISCUSSIO

Fig. 3. Dryer temperature variations under unloaded condition and with extractor fan switched off for August 8, 2013 and June 26, 2014 experimental runs.

Fig. 4. Dryer temperature variations (unloaded) for August 9, 2013 and June 28, 2014 when the extractor fan was on.

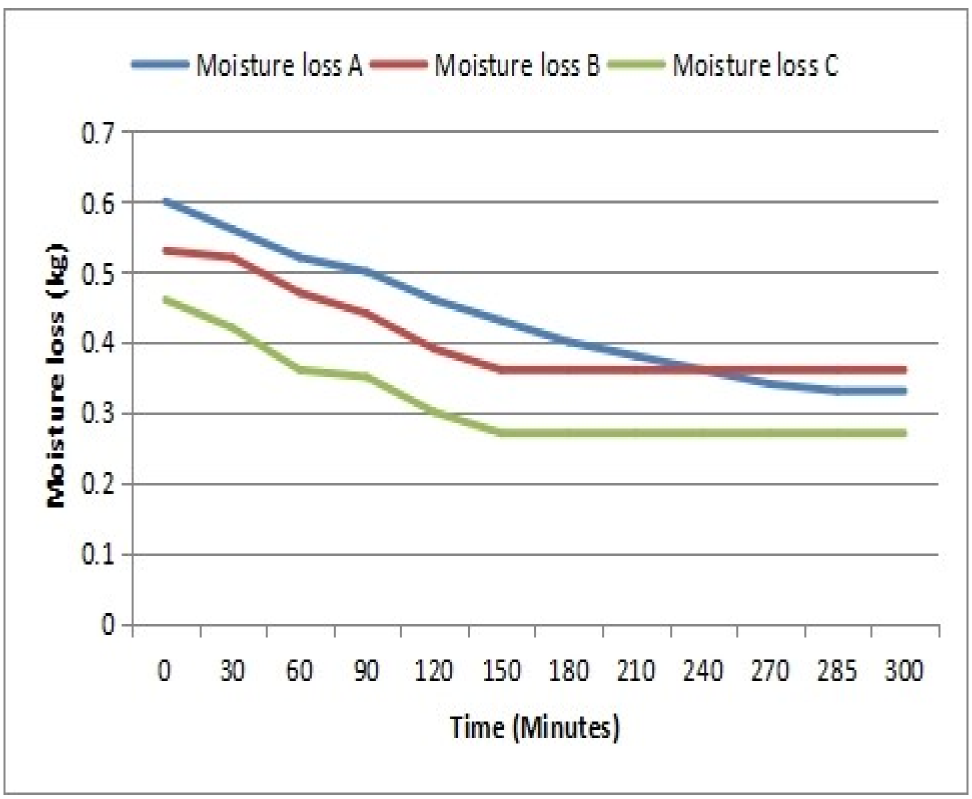
N




Dryer temp. 09/08/13
Dryer temp. 28/06/14
Dryer tmp. (deg C)
0
5
10
15
20
25
30
35
40
45
50
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Time (Minutes)

0.27kg, 4.75hrs 0.17kg, 2.5hrs 0.19kg, 2.5hrs

Fig. 5. Moisture loss of fabrics A, B and C over time



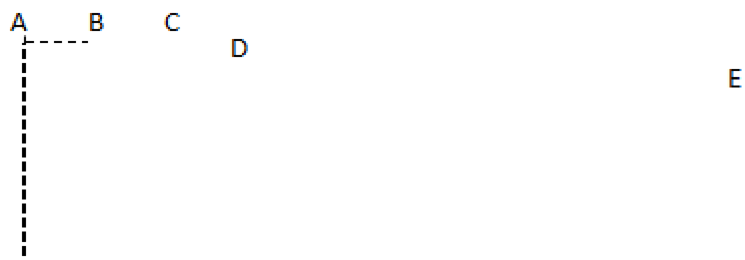
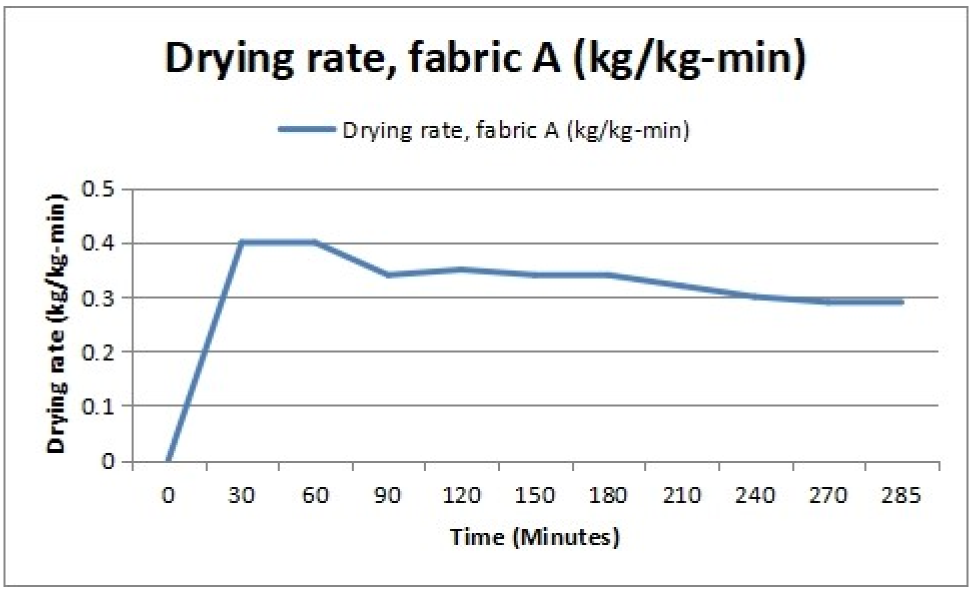


Fig. 6. Drying rate for fabric A. Run of July 9, 2014.



The results of the heating (drying) experimental runs of the ITRWHRD are presented graphically in Figs 3 to 6. They show the measured drying temperature variations and moisture loss with time for the heating operations.

11.1 Drying Temperature without Load

Fig 3 shows a typical plot of temperature variations with time (with extractor fan switched off). The drying chamber temperature increases from initial value of 27 and 26.5^{O}C to about 49 ^{O}C. The asymptotic profile at 49 ^{O}C horizontal indicates that the drying chamber temperature attained its maximum value after about 105 minutes of the system operation. Near steady drying chamber temperature increases did not commence until around 10 minutes after commencement, which means that the initial period was used in heating the chamber to temperatures above its ambient. For the experimental runs (when the extractor fan was switched on from commencement of compressor operation), the asymptotic profile at about 45^{O}C horizontal indicates that the drying chamber temperature attained its maximum value after about 130 minutes at 45^{O}C (Fig 4)

11.2 Moisture Loss Rate from Drying Cloth

This refers to the rate of dehydration of the fabric (cloth) being dried in the drying chamber (dryer) at 30 minutes intervals. Fabrics A, B and C were examined at the drying temperature of 45^{O}C. Drying conditions were 26- 28^{O}C db, 25- 26^{O}C wb, and 80- 86% RH (Fig. 5). Fabric A lost 0.27kg of moisture in 4¾ hours, fabrics B and C lost 0.17kg and 0.19kg of moisture in 2½ hours respectively. Fabric A has higher moisture retention capacity and took longer time (4¾ hours) to dry. This means that the rate of moisture loss also depends on the texture of materials. Drying curves of the fabrics have similar configurations.

Moisture loss rate, $r = (m_{w2} - m_{w1})/ (t_2 - t_1)$ 32

m_{w2} = the mass of wet cloth (fabric), m_{w1}= the initial mass of dry cloth (fabric) before it is wetted; t_1 = the initial time before the drying operation begins; t_2 is the final time at which the wet cloth is dried back to its initial mass. Fig. 6 reveals the observed drying behaviour for fabric A at an average drying temperature of 45^{O}C. It shows that the drying pattern of the fabric follows the general drying behaviour. This is because the three major stages represented on general drying graphs are equally observed on the graph of drying rates for the fabric. The stages according to Kawongolo, (2012), are:

Stage A – B: This section is the "warming – up" period during which the solid material is heated by conduction so that the surface temperature comes in equilibrium with the drying air conditions. This seems to take place within the first 30 minutes of the drying operation

Stage B – C: This section represents the "constant – rate" period during which the surface of the material remains saturated with liquid water because the movement of water within the material to surface is the same as the rate of evaporation. It lasted for about 30 minutes. C is the critical point

Stage C – E: T

This section represents the "falling rate" period during which the drying rate slowly decreases until it approaches zero at the "equilibrium moisture content" (i.e. when the material comes to equilibrium with the drying air).

12. DATA REDUCTION METHODS

Ilhan (2009) suggested some energy equations that can be used to evaluate the performance of a typical heat pump dryer like the ITRWHRD. The equations were modelled as steady flow processes and analyzed by employing steady flow conservation of mass (for both dry air and moisture). The equations are for evaluating the coefficient of performance (COP), energy utilization ratio (EUR) and specific moisture extraction rate (SMER).

12.1 Coefficient of Performance (COP_{ws}) of the whole system

For a heat recovery system, Ilhan (2009) suggested the coefficient of performance of the whole system (COP_{ws}) as:

$COP_{ws} = (Q_d + Q_{ev})/ (P_F + P_C) = \dot{m}_R [(h_2 - h_3) + (h_1 - h_4)]/ (P_F + P_C)$. 33

Where: Q_d and Q_{ev} are dryer heat and heat absorbed from the evaporator respectively; P_F and P_C stand for power input to the extractor fan and compressor respectively and are given by:

$P_C = I_C V$ 34

I_C is the current drawn by the compressor (as indicated by the clamp-on ammeter), V is supply voltage (220V)

Similarly, $P_F = I_F V$ 35

Substituting values gives $COP_{ws} = 10.09$

COP_{ws} shows that the energy derived from the ITRWHRD is 10 times the energy consumed by it, hence it is efficient. Since higher COP_{ws} equate to lower operating cost, the ITRWHRD can be said to be energy efficient.

12.2 Specific Moisture Extraction Rate (SMER)

$SMER = (w_2 - w_1)/ (P_C + F_C)$ 36

For the sample fabric used for the experimentation, fabric A, $(w_2 - w_1)$ is the mass of moisture removed per given drying period. 270g of moisture was removed per 285min = 56.84g/hr.

Substituting the above values into equation (36), SMER is obtained as = 0.19kg/kWhr

This means that the ITRWHRD will consume 1kW of energy to extract 0.19kg of moisture from fabric A, and also provide 150W of cooling at the evaporator.

Similarly for fabric B: mass of moisture removed during drying is 170g per 150min = 68g/hr. Hence, for fabric B: SMER = 68/303.6 = 0.22g/Whr = 0.22kg/kWhr

This means that the ITRWHRD will consume 1kW of energy to extract 0.22kg of moisture from fabric B, and also provide 150W of cooling at the evaporator.

This 1kW of energy used in the ITRWHRD for drying could have been wasted into the environment as condenser heat (in the case of a normal domestic refrigerator), or the 150W of cooling wasted as unwanted cooling in the case of a conventional heat pump). Thus the dual purpose ITRWHRD conserves energy.

12.3 Energy Utilization Ratio (EUR)

EUR ascertains how much of the total energy supplied in the condenser that is actually utilized in the dryer. It is given as:

$EUR = \dot{m}_R (h_2 - h_3)/ \dot{m}_R (h_2 - h_3^I) = (h_2 - h_3)/ (h_2 - h_3^I)$ 37

Substituting the enthalpy values from Fig. 2 into equation (37):

EUR = 0.92

EUR shows that about 92% of the heat supplied by the ITRWHRD was actually utilized for drying. Hence, only 8% of the available heat for drying in the condenser was lost to sub-cooling of the refrigerant in the ambient air outside the drying chamber.

13. CONCLUSION

The dryer unit of ITRWHRD was successfully designed and constructed using locally available technology. Design of the cold space (evaporator) was not shown as part of this work. Design dryer temperature was $50^{O}C$, but what was realized through direct measurement was $47^{O}C$ with extractor fan switched on and the cold space loaded with 40 kg of water.

The COP_{ws}, SMER and EUR showed that ITRWHRD is an energy efficient system.

In the extensive literature review undertaken, no example of previous work on reversed heat engine producing useful cooling and heating effects simultaneously was noted. The reported ITRWHRD, successfully designed and constructed using locally available technology, addressed this deficiency.

REFERENCES

Al-Kayiem, H. and El-Rahman, M (2011), Ribbed Double Pipe Heat Exchanger: Analytical Analysis, Journal of Engineering Science and Technology, Vol. 6, No. 1 (2011) 39 – 49

Althouse, A.D, Turnquist, C.H. and Bracciano, B.S. (1996), Modern Refrigeration and Air Conditioning, The Goodheart-Willcox Company, Inc., Illinois

Anyanwu, E., Ogueke, N., Nwigwe, K., Onyeocha, E. (2001), Development And Performance Evaluation of an Integrated Tetrafluoroethane Refrigerator-Waste Heat Recovery Dryer, Ph.D Thesis, Federal University of Technology, Owerri, Nigeria.

Bingqiang1, H., Chunling, L. and Guangdong, J. (2012), The Research on Optimal Control of Hvac Refrigeration System, International Journal of Computer Science Issues, Vol. 9, Issue 5, No 2.

Damewood, C. (2003), Clothes Dryer Temperatures, http://www.ehow.com/facts_7567993_clothes-dryer-temperatures.html.

Desai, P.S. (2007), Modern Refrigeration and Air Conditioning for Engineers, Romesh Chandra Khanna Publishers, 2-B Nath Market, Nai Sarak, Delhi- 110006

Eastop, T.D. and McConkey, A. (1992), Applied Thermodynamics for Engineering Technologists, Fifth Edition, Longman ELBS, Pp 485 – 528.

Energy Solutions Center, FoodPro (2007), Flue Gas Heat Recovery, Version 1.0.www.thermalenergy.com.

Hongtao, Q., Reinhard, R., and Vikrant, A. (2010), A Review for Numerical Simulation of Vapor Compression Systems International Refrigeration and Air Conditioning Conference at Purdue, July 12-15, 2010.

Ilhan, C. (2009). Energy Analysis of Pid Controlled Heat Pump Dryer, Scientific Research Journal, 188-195 Published Online November 2009 (http://www.scirp.org/journal/eng).

Kawongolo, J.B. (2012), Phase Change Boundary Condition for Heat Conduction Problem: The Drying Problem, file:///c:/Users/Jesus/Downloads/Dryer paper4.htm

Lalovic, M., Radovic, Z. and Jaukovic, N (2005), Characteristics of Heat Flow in

Mozzo, L (2007), Energy Auditing, Handbook of Energy Audit and Environmental Management, Edited by J.P. Abbi and Shashak Jain, New Delhi.

Prasad, M. (2007), Refrigeration and Air Conditioning, Second Edition, New Age International (P) Limited.

Roy, J.D. (1997), Principles of Refrigeration, Fourth Edition, Addison Wesley Longman, Singapore, PP102-130.

Siemens Switzerland Limited. (2010), Heat Recovery in the Refrigeration Cycle, An Extract of Training Module by Siemens Ltd. Building Technologies Unit, www.siemens. com/buildingtechnologies

Holman, J.P. (2001), Heat Transfer, Eight Edition, McGraw-Hill lnternational Book Company.

Cengel, Y.A., Boles, M.A. (2006), Thermodynamics: An Engineering Approach, Seventh Edition. Mcgrawhill Higher Education

Patented photograph of Integrated Tetrafluoroethane (R-134a) Refrigerator-Dryer

Proceedings of the 2021 National Engineering Conference
of the Nigeria Society of Engineers [NSE] .
Printed in Nigeria

ASSESSMENT OF CONTAMINATED OIL ON THE PERFORMANCE OF POWER TRANSFORMER

Agu Lugard S. and Ogbuefi Uche.C.
lugard.agu.pg91181@unn.edu.ng, ucchsamo@gmail.com
Department of Electrical Engineering, University of Nigeria, Nsukka, Enugu State

ABSTRACT

Power transformers are one of power system components that are used at high voltage levels, and the oil serves as both an effective electrical insulation and coolant to the windings. For effective power delivery of any power system one of the major components of such systems is the power transformer need proper care. For the singular purpose of transforming different voltages and currents of one electrical circuit to another it is no gain saying that the power transformer should be in the best state in order to deliver as anticipated. It has been a challenge for power engineers to maintain steady supply of electricity especially in Nigeria of which one peculiar reason for that is unavailability of some power transformers in the network as a result of damage. As have been identified, one of the causes of power transformers packing up, this paper reviewed the adverse effect of contaminated oil and its impact on the performance of power transformers. Hence recommend that Research centers, institutions, and utility centers should be equipped with complete testing kits, equipment to ensure timely examination and detection of these adverse effects.

Keyword: High Voltage, Power Transformer, Transformer oil, Insulation, Coolant, and Windings

1. INTRODUCTION

The utmost importance of power transformers as a key component in high voltage transmission and distribution systems regarding energy utilities and consumers cannot be overemphasized. However, the subsequent failures of power transformers in most part, are as a resultant effect of transformers approaching or exceeding their designed life expectancy. Based on analysis, about 30% of total failures of transformers are as a result of insulation/oil contamination [1]. Therefore, it is essential to understand the failure mechanisms/processes so that the proper measures can be taken in view of preventing failure and remove the immense cost caused by the failure in terms of asset loss and business interruption [2]. Oil is an essential part in power transformers. It serves as both the electrical insulation and coolant and is in direct contact with metals, iron core and the paper insulation. This implies that the transformer oil is very easy to be contaminated [3, 4]. Transformers with aged paper insulation can readily contaminate its oil by the formation of contaminants such as metal filings or cellulosic residual. During operation, present within the transformers are non-uniform fields.

These contaminants tend to move towards high field regions due to di-electrophoresis (DEP) forces and could form a bridge over a period of time. The bridge may potentially act as a conducting path between two different potentials within the transformer structure, leading to partial discharges or insulation failure. Previous work on cellulosic particles has demonstrated that pre-breakdown phenomena are closely related to the level of contamination [5]. In order to meet the energy requirements of the 21st century, demand for HVDC transformers has increased as a direct consequence of the sheer popularity synonymous with renewable energy sources like solar which has paved way for the building of long distance DC transmission lines [6, 7]. Some parts of these HVDC converter transformers experience combined effect of AC and DC electric field as revealed by analysis on operational HVDC [8]. HVDC systems in operation today are mostly based on line-commutated converters (LCC).

This configuration uses a three-phase bridge rectifier or six-pulse bridge that contains six electronic switches. Each of these switches connecting one of the three phases to one of the two DC rails. A phase change only every 60° and considerable harmonic distortion is produced at both the DC and AC terminals when this arrangement is used [9]. When two units of six pulse converters are connected in series, star or delta configuration are used on the DC side for harmonic cancellation. LCC HVDC transformers are placed between converter and AC bus bar and before the AC harmonic filters. These transformers have to withstand DC stress and low order harmonics. An LCC HVDC convertertransformer is also subjected to a DC offset voltage depending upon the position with respect to ground [10].

Power Transformers: The power transformers as electrical devices are types of transformers that are used to transmit electrical energy in any component of the electronic or electrical circuit between the distribution primary circuits and the generator. These transformers are utilized in distribution networks to interface step down and step up voltages. The usual form of power transformer is fluid immersed, and the life cycle of these instruments is approximately 30 years. Power transformers can be divided into three types based on their apparent power ranges. They are large power transformers, medium power transformers, and small power transformers [11].

i. The range of large power transformers can be from 100MVA and beyond
ii. The range of medium power transformers can be from -100MVA
iii. The range of low power transformers can be from 500-7500kVA

Voltages are transmitted by these power transformers. They keep low voltage - high current circuit at one section of the transformer and on the other side of the transformer, they keep high voltage - low current circuit. The working principle of power transformer is based on Faraday's law of electromagnetic induction. This explains the power network into areas where every gear attached to the system is designed per the rates set by the power transformer.

2.1 Structure of Power Transformer

The structure of the power transformer is modeled with metal that is covered by sheets. It is fixed into either a shell type or core type. The structures of the transformer are wound and attached, employing conductors to produce three 1-phase or one 3-phase transformer. Three 1-phase transformers need each bank isolated from the extra parts and thus provide continuity of service once one bank flops. A single 3-phase transformer, whether the core or shell type, will not perform even with one bank out of service. The 3-phase transformer is cost-effective to produce, and it has a lower footprint and operates comparatively with higher efficiency [11].

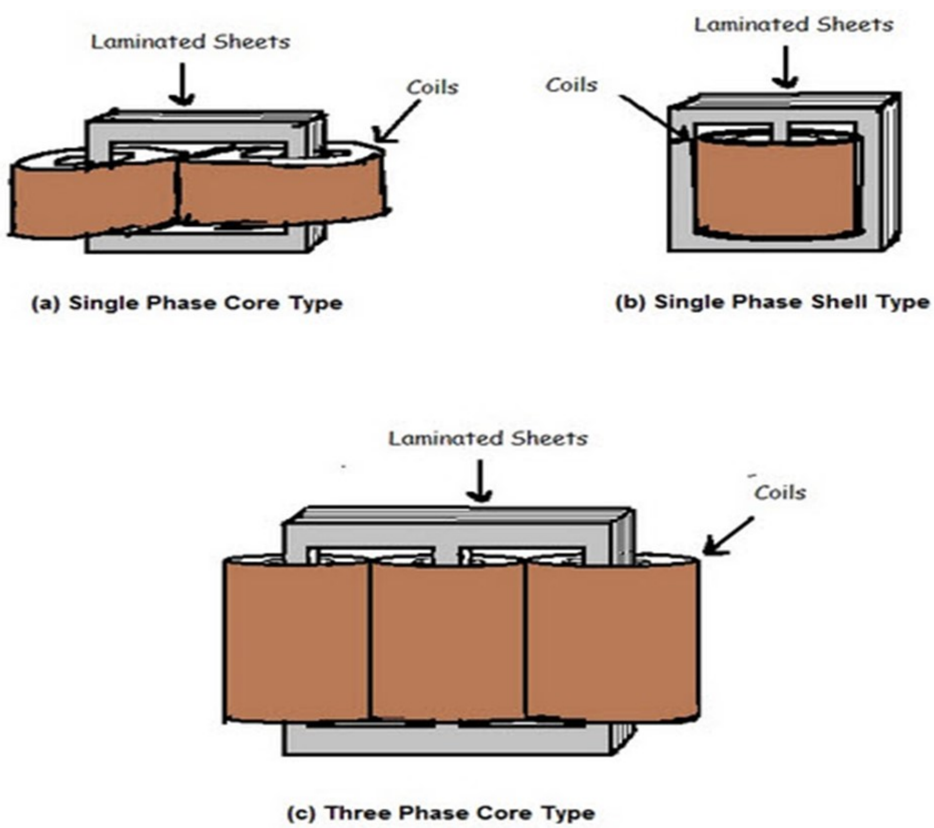


Fig. 1: Transformer Core Types [12]

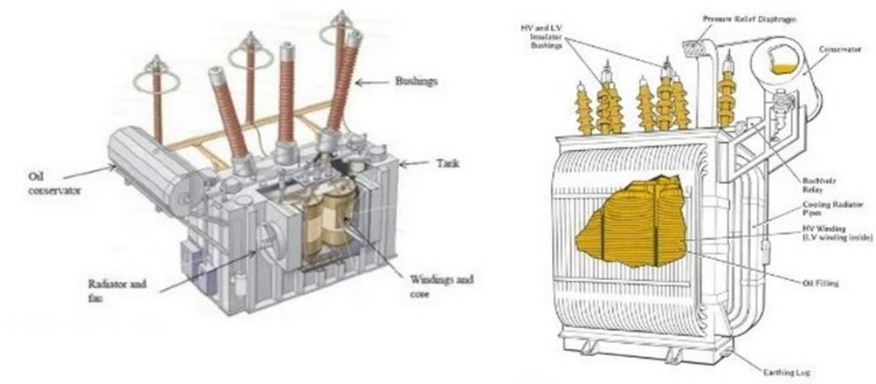


Fig.2: Pictorial View of some Oil Filled Power Transformer [13]

The structure of the transformer is enveloped in a fire retardant particular fluid inside a tank. The conservatory on top of the liquid tank allows for the increasing oil to cover it completely. The charger of the load drains to the side of the tank varies the number of turns on the low current-high voltage section for superior voltage adjustment. The bushings of the tank allow for parts to precisely enter and exit the system without damaging the outer shell. The power transformer can be operated beyond its low rating as long as it stays within the 65ºC increase of the temperature. Transformers (ONAF) are built-in with special fans that cool the center of the transformer for operating on the above standard operation to a point below the certified temperature.

2.2 Transformer Insulating Materials

The key components of a power transformer in carrying out its fundamental function of transforming voltage and current are the primary and secondary coils of the power transformer. Both the primary and secondary coils of the transformer are insulated with some materials. In addition to the primary and secondary coils, there are several other essential components and accessories. One of the most critical components of a transformer is the insulating material. Adequate insulation between different active parts of the transformer is very essential for its safe operation. Optimum insulation is not only necessary to isolate coils from one another, or from the core and tank, but also guarantees the safety of the transformer against accidental over voltages. Insulating Materials are of different types like solid and liquid insulations;

(a) Solid Insulation: The transformer contains solid insulation materials commonly found in it, such as pressboard, paper, transformer board and are formed from the cellulose found in plants. For a very long time, cellulose insulation with its counterpart mineral oil has majorly played a vital role as the main insulation system for transformers. Cellulose paper, tapes, and cloths have also been widely used. They provide excellent dielectric strength and low dielectric loss, and hence impregnated paper is now commonly accepted as the insulation pillar of the electricity industry. Paper and pressboard insulation derivedfrom pure cellulose have an excellent capacity for being impregnated with oil, thereby improving their insulation properties many times over. In addition, such solid insulating materials are easy to mold and wrap around coils, and can be made of various dimensions as per requirements.

(b) Liquid Insulation – Oil: Oil is an equally important part of a transformer's overall insulation. Oil, like paper/pressboard, is a product of nature containing a variety of impurities of speculative nature and amount.The main function of insulating oil in a transformer is to provide electrical insulation between the various energized parts; it also acts as a protective coating layer to prevent oxidation of the metal surfaces.Another important function of the oil is to enhance heat dissipation. Power losses in transformer cores and windings is a direct consequence of both the cores and windings getting heated up during operation. Oil takes heat away from the core and windings by the process of conduction and carries heat to the surrounding tank, which is then radiated out to the atmosphere.

2.3 Transformer Oil Degradation

Major factors influencing the degradation of transformer oil include: excessive heating, oxidation, contamination, partial discharges, and related by-products.

(a) Thermal Degradation: One of the most severe factors influencing the degradation of transformer oil is excessive temperature rise, and it is estimated that increase of 8 – 10 °C in temperature approximately doubles the rate of oil degradation. Oil decomposition, produces several by-products at elevated temperature, which further accelerates the ageing process of both liquid and solid insulation inside the transformer.

(b) Oxidation: Chemical reaction as the aftermath of oxidation of oil which causes a breakdown of bonds. The main oxidation products of oil include water, carbon dioxide, carbon monoxide, acids, and sludge. In addition, the presence of dissolved metals such as iron, copper, etc. acts as a catalyst to accelerate the oil degradation process. As oxygen has two free electrons, any ingress of air in oil makes it more susceptible to an auto-oxidation process. These free radicals can easily break the hydrocarbon chains in oil and produce peroxides. Under heat, these peroxides decay to produce more free radicals, and thus the oxidation process compounds as a chain reaction process.

(c) Contamination: The insulation property of oil is greatly affected by the presence of water in oil, either in dissolved form or suspended form. Thermal degradation of cellulose and oil will produce water internally. In free breathing units, water may also be absorbed from the atmosphere.

(d) Partial Discharges: Owing to excessive thermal stress or spurious electric discharges due to high electrical stress, gas may emanate in oil. The decomposition of the gas which emanated from the oil, produces hydrogen and hydrocarbon gases as its by-product.Because of the variation in permittivity of the gas and the liquid insulation surrounding it, the electrical stress across the gas voids will be very high. Such high electrical stress in the gas pockets will promote further partial discharges and can cause progressive deterioration of the oil.

2.4 Measures to Minimize Oil Degradation

As previously discussed earlier, oxidation is the major cause of transformer oil degradation in free-breathing transformers. To prevent the entering of air inside the transformer during the breathing process, nitrogen gas cushion transformers can be used, where dry nitrogen is used to fill up the tank space above the oil so as to minimize the exposure of oil to oxygen. Also, adding oxidation inhibitors such as DBPC to new oil effectively prevents the ageing of the oil. The presence of metals accelerate the ageing process of oil. Amino group inhibitors added, can eliminate this influence. Temperature is one major dominant factor of oil degradation. The oil temperature can be limited to safe values by the use of cooling tubes that aid in the heat convection and dissipation process. Cooling efficiency can further be improved by artificial cooling techniques such as forced fan cooling, forced oil cooling, or water cooling. Large transformers are very often equipped with pumps in the oil line and also in the water line to enhance cooling [14].

2.5 Pressboard Dust in Oil

Although the suspended particle theory cannot explain all the phenomena observed before a liquid breakdown, extensive experimental studies have shown that conducting particles accumulate in high electric field will move towards the region of highest electric field intensity due to di-electrophoresis [5, 15, 16]. Even if oil undergoes important cleaning procedures during its production, impurities can still contaminate oil during storage and shipping. This is particularly the case during operation where cellulose paper fragments, due to electrical and thermal stresses,will become present in the transformer oil [1]. Fibrous dust particles from pressboard insulation were investigated in [1]. The experiment was conducted as follows:

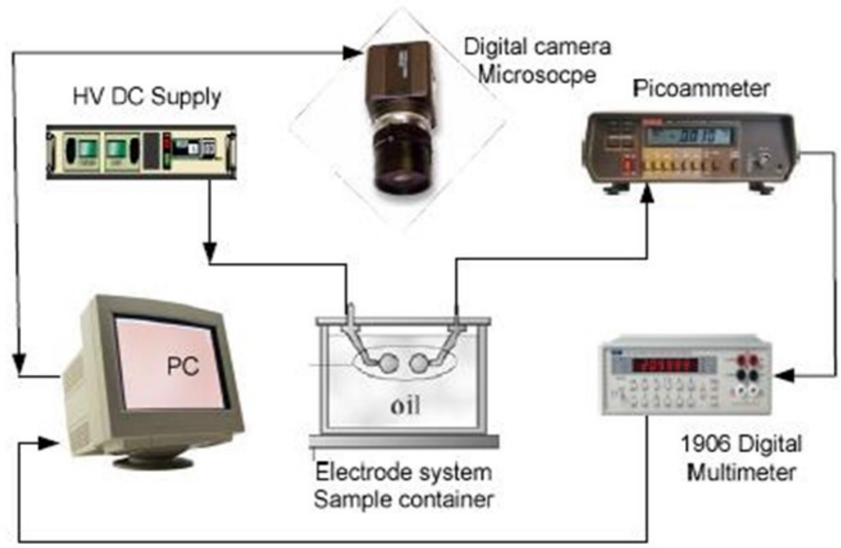


Fig. 3: Experimental Setup Used for the Observation of Dust Particles Accumulation in Transformer Oil [5].

3.0 PREVIOUS EXPERIMENTAL SETUP

Basically, two spherical electrodes of 10 mm diameter, spaced to 10 mm, were in the middle section of a sample tank, filled with 300 ml of transformer oil that completely submerged the electrodes. The goal of the test was to observe the bridge formation across the electrodes and to measure the current flowing through the electrode gap when three different DC voltages of 2 kV, 7.5 kV and 15 kV were applied to the sample tank. The typical experimental setup is summarized in Figure 3.0. For each level of contamination, the same measurements were made. After switching on the power supply, contaminant particles were moving back and forth in the electrode gap. After a while, the particles started to attach to the two electrodes and, then, connected themselves to form a partial bridge at the surface of the electrodes. The bridge kept growing until a complete bridge was formed. The first important result is that the bridge formation was accelerated when greater DC voltages were applied. And the second important result was that the complete bridge was thicker when dust particle concentration was increased.

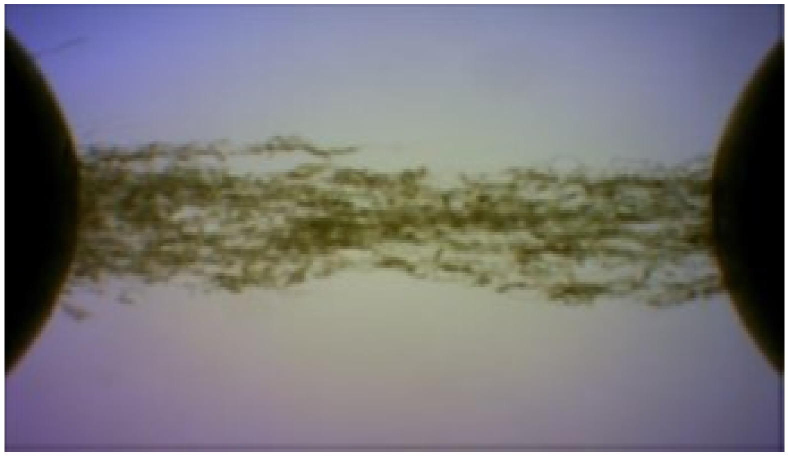


Fig.4. Optical microscopic images of bridging in contaminated transformer oil with 150-500 μm pressboard fiber, concentration level 0.002% [17].

4. CONCLUSION

Based on the reviewed experiments, it is evident that the contaminated transformer oil has a negative effect on the performance of power transformers as they might lead to field bridging, which can damage the transformer. This as seen in the reviewed experimental set up shows clearly that when a transformer oil is contaminated with certain kinds of particles or impurities, when powered there exist a back and forth movement of such particles which further leads to the formation of a bridge between electrodes and can lead to internal explosion capable of damaging the transformer over time. Hence the behavior of particles in the transformer oil need to be thoroughly examined in other to preempt unnecessary breakdown of power transformers especially when already deployed to the utilities. And timely maintenance by refilling the contaminated transformer oil as soon as detected should be a cultural practice. Research centers, institutions, and utility centers should be equipped with complete testing kits, equipment to ensure timely examination and detection of these adverse effects.

REFERENCES

[1] V. Sokolov, "Experience with the refurbishment and life extension of large power transformers," in Minutes of the Sixty-First Annual International Conference of Doble Clients, 1994, pp. 6-4.

[2] V. Kogan, J. Fleeman, J. Provanzana, and C. Shih, "Failure analysis of EHV transformers," Power Delivery, IEEE Transactions on, vol. 3, pp. 672-683, 1988.

[3] M. G. Danikas, "Breakdown of transformer oil," Electrical Insulation Magazine, IEEE, vol. 6, pp. 27-34, 1990.

[4] T. O. Rouse, "Mineral insulating oil in transformers," Electrical Insulation Magazine, IEEE, vol. 14, pp. 6-16, 1998.

[5] G. Chen and M. H. Zuber, "Pre-breakdown characteristics of contaminated power transformer oil," in Electrical Insulation and Dielectric Phenomena, 2007. CEIDP 2007. Annual Report - Conference on, 2007, pp. 659-662.

[6] B. R. Andersen, "HVDC transmission-opportunities and challenges," in AC and DC Power Transmission, 2006. ACDC 2006. The 8th IEE International Conference on, 2006, pp. 24-29.

[7] W. Youhua, Z. Wenfeng, W. Jianmin, X. Dong, Z. Ping, and L. Jiangui, "Stray Loss Calculation of HVDC Converter Transformer," Applied Superconductivity, IEEE Transactions.

[8] L. Shu, L. Yilu, and J. De La Ree, "Harmonics generated from a DC biased transformer," Power Delivery, IEEE Transactions on, vol. 8, pp. 725-731, 1993.

[9] High-voltage direct current. Available:http://en.wikipedia.org/wiki/Highvoltage_direct_currentn, vol. 22, pp. 5500604 -5500604, 2012.

[10] C. R. B. Colin Bayliss, Brian J. Hardy, Transmission and Distribution Electrical Engineering.

[11] linguip.com/blog/what-is-power-transformer/

[12] elprocus.com

[13] electrical4u.com

[14] Lundgaard LE, Hansen W, Linhjell D, Painter TJ. Aging of oil-impregnated paper in power transformers. IEEE Transactions on Power Delivery 2004; 19(1): 230–239.

[15] H. Moranda, K. Walczak, and H. M. Grzesiak, "Dynamics of bridge creating in contaminated oil at AC voltage and analysis of accompanying partial discharges," in XIII International Symposium on High Voltage Engineering Netherlands, 2003.

[16] M. Ossowski, J. Gielniak, H. Moronda, and H. Moscicka-Grzesiak, "Oil resistance at different phases of bridge mechanism development at direct voltage," in XIII International Symposium on High Voltage Engineering Netherlands, 2003.

[17] Shekhar Mahmud, George Chen, Igor Golosnoy, "Influence of Contamination on the Electrical Performance of Power Transformer oil", PhD thesis, Faculty of Physical Sciences and Engineering, School of Electronics and Computer Science, University of Southampton, April, 2015.

DESIGN AND FABRICATION OF A MOTORIZED CASSAVA GRATING MACHINE

[1]E. S. Baranzan, [1]E. S. Yayock and [2]M. Sani

[1]Agricultural and Bio-Environmental Engineering Technology Department, School of Agricultural Technology, Nuhu Bamalli Polytechnic, Zaria, Kaduna State, Nigeria.
[2]Agricultural and Bio-Environmental Engineering Technology Department, School of Engineering Technology, The Federal Polytechnic, Bauchi, Bauchi State, Nigeria.
Corresponding e-mail: besamuel14@nubapoly.edu.ng 08088156826/08160094192

ABSTRACT

Post-harvest and storage losses are enormous because of poor handling facilities for agricultural produce in Nigeria. There is also the need for a hygienic processing of cassava prevalent condition in the commercial grating areas of this staple food show a susceptibility to food contamination. This problem leads to undue scarcity of the produce immediately after harvest season. In order to address this problem, an improved cassava grating machine where the materials, the tubers of cassava being grated, can be properly monitored was designed, fabricated and tested. The performance evaluation of the fabricated machine was carried out to be efficient. The tests conducted with 23.336kg of cassava with the improved fabricated cassava grater, shows that the actual capacity of the machine, the efficiency, percentage loss and through put capacity of the machine were 309.099kg/hr, 94%, 5.956% and 328.676kg/hr respectively.

Keywords: Design, Cassava, motorize, Grating, performance

1. INTRODUCTION

Manual grating is tedious time consuming and usually result in injuries to the fingers of the operator. Furthermore, the manual grating of cassava leads to non-uniform quality products. It is also observed that most of cassava grater in use are usually corroding (reducing service life) due to the acidic nature of cassava fluid and material used for the fabrication. To ensure all cassava products are free from any taste odour or infected by iron contents hence the need to modify the design and use appropriate material for fabrication.

Cassava (manihotesculentacrantz) is a starchy tuberous root crop belonging to the family of Euphurbiaceac (United State Department of Agriculture, 2018). After rice, sugar, and maize, it is the fourth source of dietary energy in the tropical region and the ninth globally. It is also the staple food of roughly 800 million people worldwide in the developing countries, cassava is considered as drought, war and famine crop (Burns et al., 2010). It is commonly grown by low-income and smallholder farmers because of its tolerance to low soil fertilizer, drought and most pest and diseases (Howeler et al., 2013).

Thus, dependence on this crop will expectedly rise in the coming years with aggravation of climate change

A major limitation of cassava is its rapid post-harvest physiological deterioration. It should be processed immediately after harvest because it is highly perishable. Deterioration normally starts within 48 to 72 hours after it is taken from the ground (Smith et al., 1994). Hence, it is crucial that the tubers are processed as early as possible (Ajao et al., 2013). Moreover, processing the cassava decreases it cyanide content which is poisonous. Consequently, this prolongs the products shelf life, reduces post-harvest losses, and prevent contamination of the products which will convert the crop to a safer and more merchantable form (Doydora et al., 2017). In rural areas, manual processing of cassava is practical. This traditional way of grating cassava is done by manually rubbing the peeled tubers against a roughened surface of galvanized mild steel on a wood or metal frame. Manual grating is tedious, time consuming and usually result in injuries to the fingers of the operator furthermore, the manual grating of cassava leads to non-uniform quality products. The quality can differ from one operator to another, and even with the same person (Jekayinfa et al., 2003). As to cassava processing, a number of equipment has been designed to replace manual grating. These include mechanized grater, motorized grater, hammer mill disk grater and hand grater (Odebode, 2018). Considering the difficulties from manual grating and limitations from mechanized equipment's, this research was carried out to develop, fabricate and evaluate a cassava grater that would lessen and relieve the problems encountered by local cassava farmers. This technology is also hoped to be more adoptable to farmers because of its less complex design, easier operation and use of locally available materials.

2. MATERIALS AND METHOD

2.1 Design considerations

The general considerations in designing this motorize cassava grating machine were

i. Considering the safety of the operators

ii. The machine should fulfill its basic task of grating cassava.

iii. Producing a machine that can be easily be assembled and disassembled to ease transportation.

iv. Ease of Feeding into the hopper

v. To design a cassava grater with less cost, which can be accessible and affordable by peasant and small-scale farmers.

2.2 Description of the Machine.

The grating machine consists mainly of the inlet (hopper), the grating drum, a shaft, two bearings driven by a 6HP electric motor through a v-belt and pulley arrangement and a frame as shown in (Figure 1).

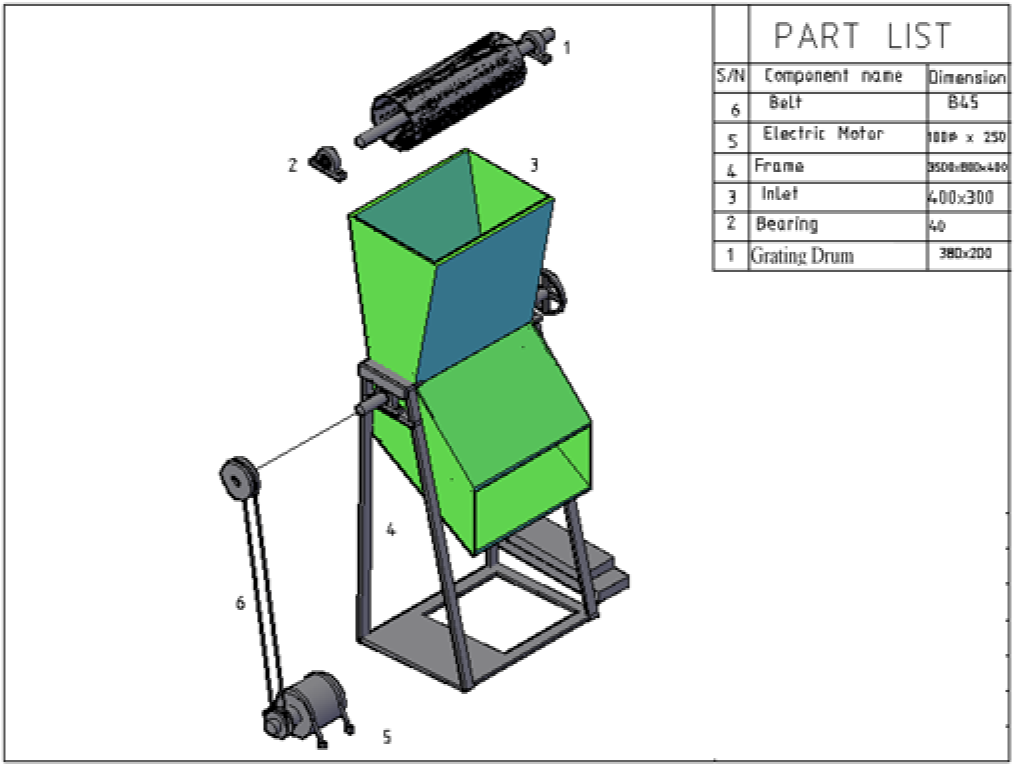


Figure 1: Exploded view of the cassava grater showing the different components

Table 1: Summary of Machine Construction Processes

S/N	Component	Construction Materials	Quantity
1	Frame	2 by 2 angle iron (3mm)	1
2	Hopper	Mild steel 20mm	1
3	Shaft	Mild steel 20mm	1
4	Drum	Stainless steel (2mm)	1
5	Perforated sheet	Stainless steel (1mm)	1
6	Discharge Chute	Mild steel sheet (1.5mm)	1

2.3 Mode of Operation

The machine was designed in such a way to make its operation simple. When mechanically operated, the machine will be coupled to an electric motor by a v-belt with the aid of pulleys on the machine shaft and electric motor. When the cassava is fed through the hopper, the grating drum grate the cassava into pulps or mash and then been discharge /Collected through the outlet chute.

2.4 Machine components design

2.4.1 volume of hopper, mm^3

The volume of hoper was calculated as given in equation 1 by (Igbozulike , Oyinloye, Diabana, & Ihenko, 2018)

$$V = \frac{h}{3}\{A_1 + A_2 + \sqrt{A_1 + A_2}\} \quad ---(1)$$

Where;

V = Volume of hoper, mm^3

A_2 = Area of base of the hopper, mm^2

A_1 = Area of top of the hopper, mm^2

$h = height\ of\ the\ hopper, mm$

2.4.2 Mass of hopper, kg

The mass of hoper was calculated using equation 2 (Eric, et al 1982)

$$m = \rho V \quad ---(2)$$

Where;

m= Mass of hopper, kg

ρ = Material density, kg/mm^3

V = Volume of hopper material, mm^3

2.4.3 Volume of grating drum cylinder

The volume of grating drum cylinder was calculated by equation 3 (Adejumo,1995)

$$V_c = \pi r^2 L \quad ---(3)$$

Where;

V_c = Cylinder volume, mm^3

r = cylinder radius, mm,

L = drum length, mm

2.4.4 Force acting on the cylinder drum

The force acting on the cylinder drum was calculated using equation 4 by (Ndaliman, 2006)

$$F = v \rho g \quad ---(4)$$

Where;

F = Force acting on the cylinder drum, N

v = Volume of the cylinder drum, mm^3

ρ = density of material, kg/m^3

g = Acceleration due to gravity, m/s^2

2.4.5 Speed ratio

The speed ratio of the larger pulley on the machine shaft to the smaller pulley on the electric motor was calculated using equation 5 by (Khurmi and Gupta, 2005)

$$N_1D_1 = N_2D_2 \quad ---(5)$$

Where;

N_1 = Speed of electric motor = 1440rpm

N_2 = Speed of machine driving shaft, rpm =?

D_1 = Diameter of motor pulley = 30mm

D_2 = Diameter of machine pulley = 180mm

2.4.6 Belt length

According to Khurmi and Gupta (2008), the length of the open belt was given by equation 6 as

$$L = 2x + \frac{\pi}{2}(d_1 + d_2) + \left(\frac{d_2 - d_1}{4x}\right)^2 \quad ---(6)$$

Where,

x = distance between pulley centers, mm

d_1 = driving (electric motor) pulley diameter, mm

d_2 = driven (machine shaft) pulley diameter, mm

2.4.7 Belt velocity

Belt velocity was calculated as in equation 7 by (Khurmi and Gupta, 2008)

$$v = \frac{\pi D N}{60} \quad ---(7)$$

Where;

V=Belt velocity, m/s

D=Diameter of pulley, mm

N= Speed of pulley, rpm

2.4.8 Determination of grating torque

The grating torque was calculated using equation (8) according to Khurmi and Gupta, 2008)

$$T = \frac{60P}{2\pi N} \quad \text{---(8)}$$

T = grating torque on the shaft, Nm

P = Power rating of the motor, W

$N =$ Speed of electric motor, rpm

2.4.9 Belt tension

The belt tension was calculated using equation (9) according to Khurmi and Gupta, 2008)

$$P = (T_1 - T_2)\,V \quad \text{---(9)}$$

P = Power required to drive the grating drum, W

T_1 & T_2 = Tension of tight and slack side of the belt, N

V = Belt velocity, m/s

2.4.10 Pulley weight

The pulley was made of cast iron (Khurmi and Gupta 2008). The weight of pulley was calculated from equation 10 (Hannah and Hillier 1999)

$$W_p = m_p \times g \quad \text{---(10)}$$

Where;

W_p = pulley weight, N

$m_p = mass\ of\ pulley, kg$

$g = acceleration\ due\ to\ gravity,\ m/s^2$

2.4.11 Shaft design

The shaft considered for satisfactory performance was chosen to be rigid enough while transmitting load under various operating condition. To achieve this, a solid circular shaft was considered for analysis of combined torsional and bending stress.

To obtain the shaft diameter, equation 11 was used as given by (Khurmi and Gupta, (2005) as reported in Mohammed A, (2018))

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad \text{---(11)}$$

Where;

M_b = Bending moment, Nm

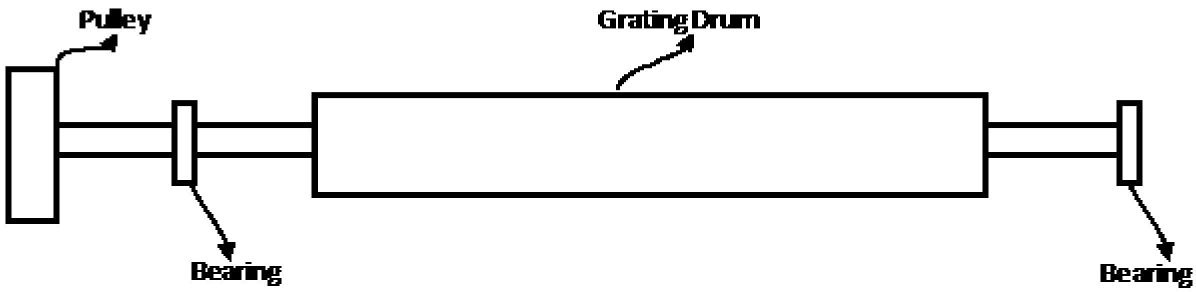
M_t = Torsional moment, Nm

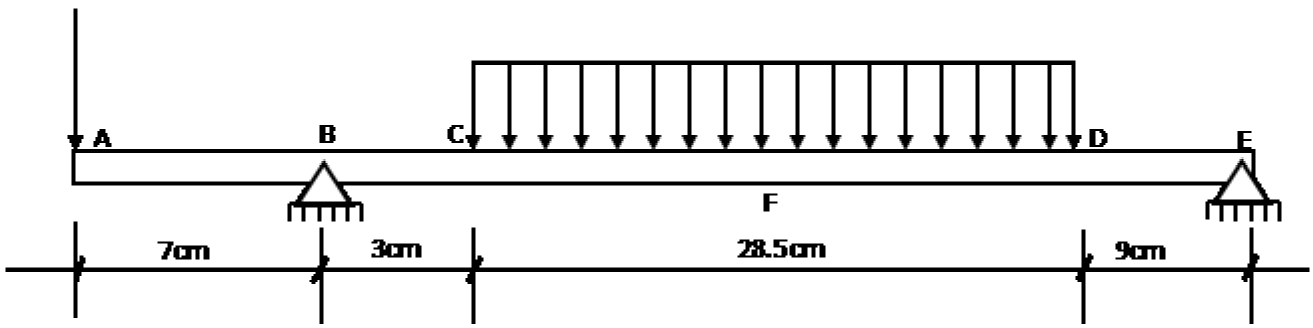
K_b = Combine shock and fatigue factor applied to be bending moment,

S_S = Allowable shear stress for shaft with key

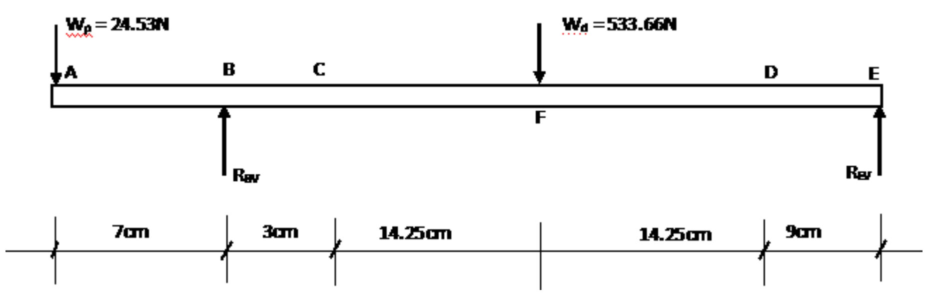
d = Shaft diameter, m

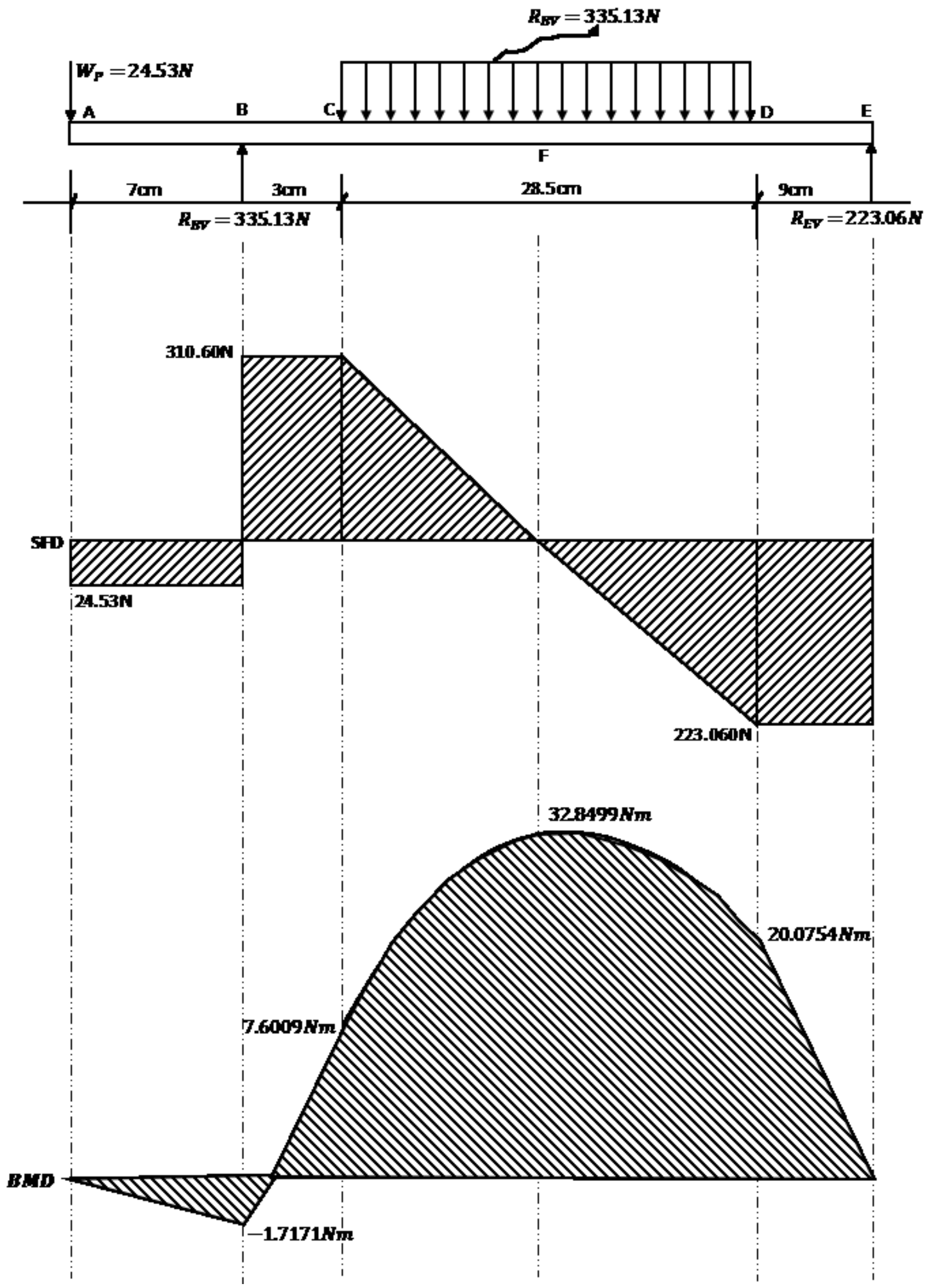
2.4.11.1 shaft loading:


Pulley
Grating Drum
Bearing
Bearing


A
B
C
D
E
F
7cm
3cm
28.5cm
9cm

FBD:


Wp = 24.53N
Wd =533.66N
A
B
C
D
E
F
7cm
3cm
14.25cm
14.25cm
9cm



2.4.12 Machine frame Design

The frame is one of the major parts of the machine on which all other parts are rested. It is made of an arrangements of angle irons (2×2 inches). The angle iron is welded together to form the frame work. The welding provides very rigid joints. This is in line with the modern trend of providing rigid frames. This provides the strength and rigidity for the overall machine. (Rufus & Odo, 2018).

2.5 Performance evaluation of the machine

The machine operational parameters such as throughput capacity, performance efficiency and Actual Capacity were determined using the following expressions as given by Darlene U.E. et al (2019).

2.5.1 Actual Capacity, A_c (kg/hr):

The actual capacity, efficiency, percentage loss and through put capacity was calculated using equation (12), (13), (14) and (15) respectively according to (Darlene , Guillermo , Michelle , & Jane, 2019)

$$A_c = \frac{W_r}{T} \quad \text{---(12)}$$

Where:

A_c = Actual Capacity of the machine (kg/hr)

W_r = Weight of Cassava recovered (kg) = 21.946kg

T = Time of grating (hr) = 0.071hr

2.5.2 Efficiency, $E_f\,(\%)$:

$$E_f = \frac{W_r}{W_f} \times 100\% \quad \text{---(13)}$$

Where:

E_f = Efficiency of the machine (kg/hr)

W_r = Weight of Cassava recovered (kg)

W_f = Weight of Cassava fed into the machine (kg)

2.5.3 $$\text{PercentageLoss} = \frac{W_f - W_r}{W_f} \times 100\% \quad \text{---(14)}$$

Where:

W_f = Weight of Cassava fed in (kg)

W_r = Weight of Cassava recovered (kg)

2.5.4 Throughput capacity T_c (kg/h):

$$T_c = \frac{W_f}{T} \quad \text{---(15)}$$

Where

W_f = Weight of Cassava fed into the machine (kg)

T = Time taken to grate the cassava (hr)

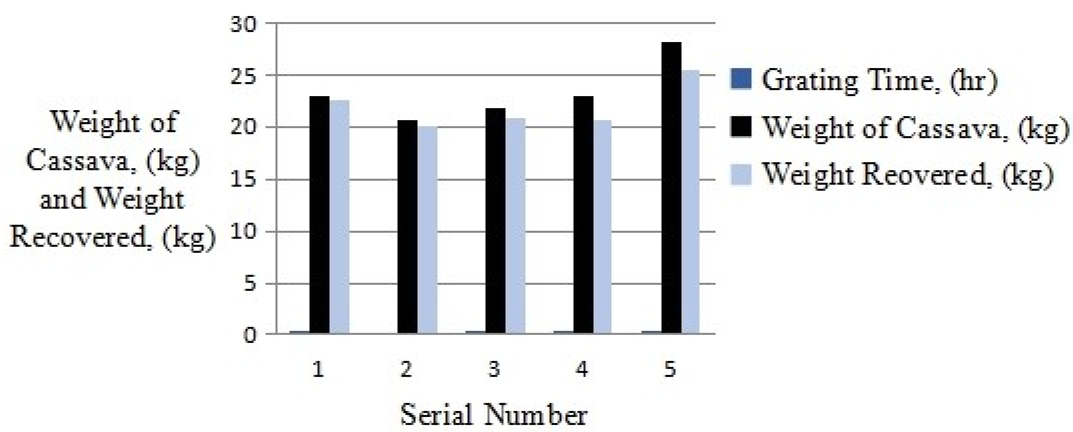
3. RESULTS AND DISCUSSION

Table 4: Results obtain from test conducted by the grater in five (5) replications

S/No.:	Weight of Cassava(kg) w_f	Weight Recovered (kg) w_r	Grating Time (hr) T	Actual Capacity (k/hr) A_c	Grating rate (kg/hr) T_c
1.	22.930	22.530	0.081	278.148	283.086
2.	20.720	20.150	0.060	335.833	345.333

3.	21.860	20.800	0.073	284.932	299.452
4.	22.960	20.750	0.063	329.365	364.444
5.	28.210	25.500	0.078	326.923	361.667
Total	**116.680**	**109.730**	**0.355**	**1555.201**	**1653.982**
Mean	**23.336**	**21.946**	**0.071**	**311.040**	**330.796**

Figure 2: A Graph of Weight of Cassava, (kg) and Weight Recovered (kg) against Grating Time (hr)



3.2 Discussion of Results

Cassava was grated in five (5) replications, the total weight of cassava fed in, the total weight recovered and time taken to grate the cassava were noted and recorded as shown in the table above.

As seen from the table above, average weight of 23.336kg of cassava which was fed into the machine was grated in 0.071hours and as a result, a total of 21.946kg was recovered after the grating. From the performance evaluation, results show that the actual capacity of the machine, the efficiency, percentage loss and through put capacity of the machine were 309.099kg/hr, 94%, 5.956% and 328.676kg/hr respectively. These results obtained shows remarkable improvement compared to that obtained by (Ndalima, 2006), which is at 60% which was powered by human effort. The result also showed a remarkable improvement compared to the result obtained by (Aideloje, Okwudibe, Jimoh, & Olawepo, 2018), the through put capacity was 55.379kg/hr. This results also showed improvement compared to that obtained by (Yusuf, Akpenpuun, & Iyanda, 2019), they obtained an efficiency of 90.91% and a through put capacity of 102.9kg/hr. Darlene , Guillermo , Michelle , & Jane, (2019) showed remarkable improvement in their results in which they were able to get an efficiency of 91.56% and grating capacity of 283.26kg/hr, however compared to the present study, it is an amprovement on the values.

Table 3 Bill of Engineering Measurement and Evaluation

S/N	Materials	Size	Quantity	Unit Price ₦	Amount ₦
1	Bearings	2x3mm	2	1,500	3000
2	Pulley	1½ x0.5mm	1	2,800	2,800
3	Angle Iron	Ø25mm	2	1,200	2,400
4	Shaft	Ø15mm	1	1,500	1,500
5	Sheet Metal	Ø25mm	½	40,000	20, 000
6	Electrode	Gauge 12	½ packet	3,000	1,500
7	Drum/grating Sheet	½ x2mm	¼	14,000	3,500
8	Bolt and nut	Ø19mm	4	125	500
9	Hitch	-	2	100	200
1 0	Transport		-		4,500
11	Workmanship		-		10000
12	Paint				1500
	Total				**56, 100**

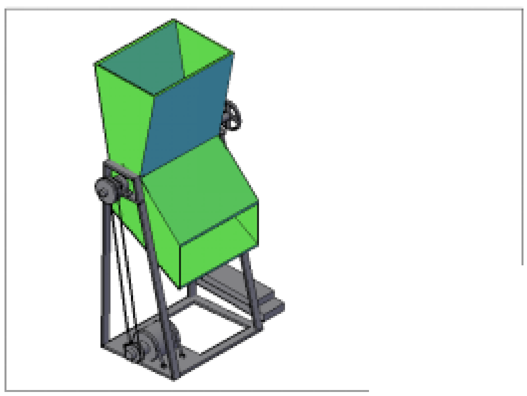


Figure 3: Isometric View of the cassava grater

4. CONCLUSION

The motorized cassava grating machine was constructed and can grate cassava faster and better than the traditional way of grating which will eventually reduce human drudgery in grating. The performance evaluation shows that the actual capacity of the machine, the efficiency, percentage loss and through put capacity of the machine were 309.099kg/hr, 94%, 5.956% and 328.676kg/hr respectively.

The machine is affordable, easy to handle and maintain since the cost of production is low about 56,100 which will reduce during large scale production.

The machine is expected to last for 10 years or more, based on the construction materials selected and quality of fabrication work, which makes the machine to be durable and withstand any force applied to it.

REFERENCES

Adejumo S. O. (1995). Construction and evaluation of an engine operated bur.

Ajao K. R., Ayilara S. O. and Usman I. O. (2013). Design and fabrication of a home scale pedal powered cassava grater (Annals of Faculty of Engineering Hunedoara). *International journal of Engineering,* 11(3), 61-64.

Burns, A., Gleadow, R. M. Cavagnaro T. R (2010). Cassava, the drought, war and famine 178 crop in a Chaning environment. Sustainability2, 3572-3607.

Darlene , U. E., Guillermo , P. P., Michelle , O. S., & Jane, S. M. (2019). Design, Fabrication and Performance Evaluation of Motor-Operated Cassava Grater. *Mindanao Journal of Science and Technology, 17* , 227-241.

Doydora, K.J Bodod R.J, Lira, J.A and Zamoramos, M.B (2017) Design, Fabrication and preformation evaluation of electric motor driven cassava (manihotesculenta) grater with juice extractor. *Philippine Journal of Agricultural economics,* 1 (1) 17-28

Eric, O., Franklin, D.J., and Holbrook, L.H (1982). Machinery Herdbook, 21stEdition, Industrial press, Inc New York. Pp 24-26

Hannah, J. And Hillior, M.J. (1999) Applied Mechanics third edition person Education limited, harlow, England Pp 445

Howeler, R, lutaladio, N; and Thomas, G (2013) save and grow: Cassava, A guide to sustainable production intensification Rome: food and Agricultural organization of the united nations Retrieved from http://www fao.org/3/a-i3278e.pdf

Igbozulike , A. O., Oyinloye, G. M., Diabana, P., & Ihenko, S. N. (2018). Development and Performance Evaluation of a Pedal Operated Paddy Rice Winnower for Small Scale Rural Farmers in Nigeria. *Proceedings of 19th International Conference and 39h Annual General Meeting of the Nigerian Institution of Agricultural Engineers (NIAE), 2018* (pp. 52 - 57). Eko: NIAE.

Jekeyinfa, S. O. Olafinihan T. O., and Odewole, G.A. (2003). Evaluation of a pedal-operated cassava grater, *Lautech journal of Engineering and technology.* 1(1), 82-86.

Khurmi, R.S., and Gupta, J.K (2005) Development of small-scale sugarcane juice extractor using a screw processing system. Advance material research Pp 699-709

Khurmi, R.S., & Gupta, J.K. (2008) A textbook of machine design, 14th edition New Delhi Eurasia publishing horse (PVT) limited, Ram Nagar india Pp 1230

Muhammed, A., Sunday, O. Omoakhalen A.I, and Imuran, A.S, (2018). Development and Performance Evaluation of Automated Cassava-Grating Machine Applied Science Reports, Vol. 17, No. 2, 2017, Available at SSRN: https://ssrn.com/abstract=3200907 or http://dx.doi.org/10.2139/ssrn.3200907

Ndaliman M. B., (2006). Design and construction of a pedal operated cassava grinder. Unpublished manuscript.

Odebode, S.O., (2018) Appropriate technology for cassava processing in Nigeria: Users point of view. *Journal of international woman's studies* 9(3), 269-286

Rufus , O. C., & Odo, F. (2018). Eco Innovation In Cassava Grating Machine Design. *World Journal of Engineering Research and Technology WJERT, 4*(3), 381 -395. Retrieved from www.wjert.org

Smith D.W, Sons, B.G, Oneil D.H (1994) Cassava testing evaluation of Agricultural machinery and equipment principle and Practices silsoe Research institute, U.K: food and agricultural organization of the united nations

United state department of Agriculture (USDA) (2018) Agricultural research Service National plant Germplasn system Grermplasm resources Information Network (GRIN-Taxonomy).

THEME FOCUS:

ENERGY MIX FINANCING AND REGULATIONS

ENERGY MIX IN NIGERIA – FINANCE AND REGULATION

Abimbola Olashore
Lead Advisory Partners Limited,
Plot 281 Ajose Adeogun Street Victoria Island Lagos
Phone: 08034030223, Email: aolashore@yahoo.co.uk

ABSTRACT

Energy mix is a group of different primary energy sources from which secondary energy for direct use - such as electricity - is produced. Energy mix refers to all direct uses of energy, such as transportation and housing, so it is not to be confused with power generation mix, which refers only to generation of electricity. In the Nigerian environment, there is a thin line between energy mix and power generation mix. Over the years power generation in Nigeria has been mainly from hydro and gas-fired thermal power plants with hydro 2,380MW accounting for approximately 16.7% of total generation potential. Thermal plants 10,142MW accounts for approximately 83.3% of total generation potential. Total electricity potential is estimated at 12,522MV. However, with the increasing challenges of climate change (negatively affecting hydro-generated power) and weak gas distribution infrastructure (causing irregular supply of gas to thermal stations) there is an urgent need to look into the prospect of supplementing current power generation infrastructure with renewable energy. Renewable energy (RE) resources hold great potential for meeting the energy needs of Nigeria, a country that is aptly described as an energy deficient nation. With abundant RE resources such as biomass, strong winds, unlimited solar potentials, hydro and geothermal resources, Nigeria has sufficient RE resources that could potentially provide a significant proportion of the country's expanding energy needs. The Nigerian renewable energy market is still at its developmental state, but we have seen significant traction in the last ten years owing to increasing awareness, funding activities, the involvement of development finance institutions and non-governmental institutions. This article looks critically into what has been achieved so far in the area of renewable energy in Nigeria, the financing of renewable energy projects and current regulation. With respect the issues financing of RE projects in Nigeria, one of the greatest challenges facing promoters of RE projects in Nigeria is the difficulty of mobilizing the needed investible funds for such projects from the financial markets. Another challenge has to do with the cost disadvantage that renewable energy projects suffer in relation to conventional energy projects. The next issue is related to the lack of experience and familiarity with RE projects among stakeholders especially policy makers, financiers and bankers add to the difficulties that RE projects suffer in Nigeria. Other issues that makes it difficult for RE investors to raise funds from the local capital market has to do with the absence of venture capital firms, the very low debt profile of the market. Financing RE projects in Nigeria is also hindered by weak regulatory and institutional arrangements just like many other developing countries. With respect to RE regulation in Nigeria, Nigeria's renewable energy market is still largely new and not sophisticated enough to ascribe special values to electricity from renewable energy in terms of green attributes or renewable energy credits. Another issue is that the Building and construction permits are issued by the applicable state governments, and timelines for these vary from state to state. Thirdly, under the current regulatory framework, renewable energy project proponents in Nigeria find the cost and applicable timelines for as provided by the Environmental Impact Assessment Act (EIA) as unfavourable. We also delved into the achievements of other countries in the area of financing and regulation with respect to renewable energy and targets for achieving a desired mix. Based on this we are able to make recommendations that will enhance optimum energy mix in Nigeria that can have positive social impacts, including decreased energy bills for low-income individuals, decreased dependency on public utilities, an improved environment from reduced pollution, and job creation.

Keywords: mix energy, mix energy generation, EIA, Capital market, geothermal sources, renewable energy, regulatory framework

1. INTRODUCTION

In order to meet its energy needs, each country uses the types of energy available to it, in different proportions. This is what is generally referred to as energy mix. While the numbers vary significantly from one country to another, it is generally known that fossil fuels dominate the energy mix at the global level, accounting for over 80% of the total.

The term "energy mix" therefore, can be defined as the blending of a number of primary sources of energy designed to meet a country's energy needs. This would normally comprise of fossil fuels such as oil, natural gas, coal, nuclear energy and other sources of renewable energy. The other sources of renewable energy include, wood, other bio-energies, hydro, wind, solar and geothermal.

The composition of the energy mix varies greatly from one country and can change significantly from time to time. Variables affecting such changes include:

- The availability of usable resources domestically or the possibility of importing them
- The extent and type of energy needs to be met
- Policy choices determined by historical, economic, social, demographic, environmental and geopolitical factors

These differences can be noticed by comparing the global, European and French energy mixes, for example. Since the Industrial Revolution, society's development has been largely driven by fossil fuels. As the global population grows and the world becomes more developed, the demand for energy is increasing as well.

In 2018, the consumption of primary energy amounted to the equivalent of about 13.86 billion metric tons of oil, compared to about 11.27 billion tons in 2006. Primary energy is comprised of commercially traded fuels, including modern renewable energy sources used to generate electricity. The largest share of primary energy consumption worldwide is attributed to oil, followed by coal and natural gas. Nuclear energy has fallen out of favour over the last decade in some countries, while hydropower has become increasingly popular.

In Europe, renewable energies (15.5%) and nuclear (10.3%) are more developed, but fossil fuels remain the dominant energy source (74.2%). Looking at only France, the breakdown shows a completely different picture due to the strong presence of nuclear (38.5%). The proportion of renewables is below the European average at 10.4%, while coal makes up a negligible 3.4% of the total.

In China and India, coal represents almost 60% of the energy mix. Both countries are leading major drives to develop solar and wind power, but the needs of their rapidly growing economies mean that the share of these renewable energies remains low. For the same reason, they are also having great difficulty reducing the proportion of coal, which they have in abundance at low costs. Historically, the United States has largely been powered by coal and oil. But coal consumption has decreased considerably over the last decade due to the boom in shale gas and renewable electricity. The country has closed a third of its mines since the start of the century.

With the present accelerated erosion of the ozone layer caused by global warming, we are now approaching a critical time in our history when we are faced with the decision to either continue burning fossil fuels and contributing to climate change or to switch to clean energy, making the role of renewable energy sources more and more important. The amount of renewable energy as a share of total primary energy consumption reached an all-time high of 13.6% in 2017. China and Russia had the highest energy potential from hydropower as of 2015, amounting to 2,140 and 1,670 terawatt hours per year respectively, which will hopefully give these countries a strong incentive to invest in hydroelectric.

In other environment particularly in developed countries, energy mix points to all direct uses of energy, such as transportation and housing. It important to note that the phrase energy mix should not be confused with power generation mix, which refers only to generation of electricity. In Nigeria, however, there is a thin line between energy mix and power generation mix. Therefore, we shall approach the presentation of this article, bearing this assertion in mind.

In this article, we shall be looking at energy mix in Nigeria from the perspective of finance and regulation. This begins with a summary of the energy situation in Nigeria. Then followed by an examination of the financing and regulating aspects of renewable energy projects in Nigeria. We are deliberately focussing on renewable energy because we believe that developing this subsector would go a long way in achieving optimal energy mix in Nigeria. In this article, we shall also examine the financing and regulating aspects of renewable energy projects in India, a fast growing economy that Nigeria could learn from.

We have deliberately chosen India as an example because of certain similarities it has with Nigeria. India has been a federal republic since 1950, governed in a democratic parliamentary system. The federal structure is similar to Nigeria except in the system of governance (Nigeria operate a Presidential system of governance). It is a multicultural, multilingual, multi-religion and multi-ethnic society just like Nigeria. India also has a fast growing population as we have in Nigeria. India's population grew from 361 million in 1951 (Nigeria 37.9 million) to 1.393 billion (Nigeria 206.1 million) in 2020. From being a comparatively destitute country in 1951, India has become a fast-growing major economy and a hub for information technology services, with an expanding middle class.

2. CURRENT ENERGY SITUATION IN NIGERIA

Energy supply in Nigeria (especially electricity and refined petroleum) has been inadequate and unreliable in spite the country's rich endowment in hydrocarbon resources and its heavy reliance on them. This has transformed Nigeria into an energy deficient nation compelling widespread dependence on diesel-based generators by different classes of electricity consumers. Currently only 40% of urban and 10% of rural residents have access to electricity. Per capita consumption of energy at about 212 kWh is one of the lowest in the world. The consequences of this on business competitiveness and the social lives of the people have been enormous.

Deficient supply of modern fuels has also forced a heavy reliance of households on biomass resources such as fuel wood, corn stocks, animal dung, among others, for domestic energy use despite their inefficiencies and health risks. Modern fuel scarcity in the economy and failing electricity supply create a dual energy crisis for Nigeria. Studies report that small scale businesses suffer the most from Nigeria's energy poverty. They spend a large proportion of their capital (about 20-25% of their investment) on back-up generating facilities thus turning the Nigerian economy into a generator economy. The economic cost of inadequate and unreliable electricity to the Nigerian economy is huge. They cost the Nigerian economy close to 4% of the country's GDP. Nigeria's energy supply can be altered with the use of RE resources which the country is well endowed with. This could potentially change its current economic status and thus release its growth potentials.

Electricity Demand and Supply in Nigeria

Projections by various research groups suggest an expected steady, sustained increased rate in electricity demand effective 2015 going forward. The J. Olayande & A. Rogo (2008) & Renewable Master Plan projected that demand for electricity in Nigeria will reach 116GW (gigawatts) by 2030. Same estimates put the demand at 45GW as at 2020. The Energy Commission of Nigeria also projected increase in electricity demand from 51GW in 2020 to 119GW by 2030.

On the supply side, Nigeria has 25 grid-connected Power Generating Plants with a total installed capacity of 12.56GW. Unfortunately, these plants can only boast of an available capacity of 3.88GW. This is due to the fact that a number of these plants are unavailable for evacuation to the national grid because of the peculiarity of Nigeria's system – for instance lack of maintenance and repair requirements, trip offs, faults and leakages. Most of these plants are fired by fossil (natural gas) thermal power (85%, i.e., 22 Gas Plants generating 10,632MW) whilst the remaining 15% are accounted for by 3 hydroelectric power plants – Jebba, Kainji and Shiroro Power Stations generating 1,930MW (Africa-EU RECP, 2016).

Renewable Energy Potential in Nigeria

Renewable energy (RE) resources hold great potential for meeting the energy needs of Nigeria, a country that is aptly described as an energy deficient nation. With a huge RE resources such as biomass, strong winds, unlimited solar potentials, hydro and geothermal resources, it is believed Nigeria has sufficient RE resources that could potentially provide a significant proportion of the country's expanding energy needs. For example, the country has a solar radiation of between 3.5 kWh/m²/day at the coastal areas and 9.0 kWh/m²/day at the northern boundary. This presents a great opportunity for Nigeria to get RE at low cost as well as minimize her dependence on fossil fuels. In terms of wind resources, the country has an annual average of 2-4m/s at 10m height mainland which has significant potential to contribute to electricity production The country also has sufficient endowment of other RE resources such as hydro resources (a potential for 14,750 MW electricity generation), biomass resources (which run into millions of tons) and geothermal resources among others.

Table 1: Estimated Potential Energy Electricity Potential (MW)

Energy Source	Estimated Potential (MW)	Estimate Percentage (%)
Wind – On-Shore	1,600	1.70
Wind – Offshore	800	0.85
Solar PV Panels	7,000	7.45
Geothermal	500	0.53
Biomass	50	0.05
Small & Large Hydro	64,000	68.12
Nuclear Power	20,000	21.29
TOTAL	**93,950**	**100**

Source: GIZ, 2015

Table 1 above depicts estimated Renewable electricity potentials in Nigeria. The numbers are derived from the RE technologies including biofuels. Nigeria's RE Master Plan (REMP 2005, 2012 Revised) planned to increase on-grid renewable electricity supply from 13% of total electricity generation in 2015 to 23% in 2025 and to 36% by 2030. This would enable renewable electricity to account for 10% of Nigeria's total energy consumption by 2025 (ECN, Nov 2012; REMP 2012 Revised). From the same table, we can see that Small- and Large-Hydro are the prominent power source of renewable electricity accounting for about 68%

followed by nuclear power which accounts for 21.9%.

Government's Electric Power Sector Reform (2013) had initially set ambitious targets to increase installed hydroelectric power to 5.69GW, thermal to over 20GW and renewables to 1GW capacities by 2020. These targets (which were obviously missed) were aim at diversifying Nigeria's energy mix to reduce the age-long dependence on natural gas with its attendant environmental concerns.

Financing and Regulating Renewable Energy Projects in Nigeria

Looking at the current electricity situation in Nigeria, we can safely conclude that the demand for electricity greatly outstrip the supply. We have also noticed that to bridge this gap, the country needs to develop its renewable energy potentials. From the estimates given by the Energy Commission of Nigeria, the current demand gap can be estimated at 47.20GW which is the difference between the estimated demand for 2020 and current available supply from the national grid. If we consider the RE potentials in Nigeria, we can see that the country is capable of generating 93.95GW (93,950MW) in renewable electricity which is more than enough to bridge the supply gap. This can only be achieved under an enable environment which can attract investment (finance) supported by a welcoming regulatory regime. Developing the RE resources of the country will be of immense benefit to the nation in terms of ensuring the security of its energy supply and enhancing the wellbeing of the nation's environment.

Financing Renewable Energy Projects in Nigeria

Energy projects generally demand high levels of financing, which most promoters in Nigeria can rarely cover on their own. RE projects are not left out. The financing for RE projects like other infrastructural projects, is closely connected to the development of the financial sector. Therefore, RE projects have very high start-up costs relative to the expected monetary returns, and lengthy payback periods. They therefore, typically require long-term maturity loans.

The problem of financing RE project is twofold: first, RE firms generally need long-term loans, whose availability in turn is positively linked to the development of the banking system. In Nigeria, the banking sector is the major source of external financing and access to bank credit is a serious problem especially for small- and medium-sized companies. As a consequence, RE projects in Nigeria are at a particular disadvantage. Second, RE firms have limited access to financing because RE projects compete against fossil fuel projects, which have a longer track record, relatively lower up-front costs, shorter lead times, and often favourable political treatment.

Impediments to Financing Utility Scale Renewable Energy Projects in Nigeria

Renewable energy projects would normally require enormous financial resources and long construction and pay back periods. Meeting the financing needs of such projects in a country with an undeveloped financial market is really a daunting challenge. Though such projects have low operational costs, the time they normally take to repay their investments usually make them unattractive to investors. Though the private sector seems to be interested in the Nigerian energy sector especially the RE subsector, there are several of challenges that slow down the pace of private investment in Nigeria's electricity sector. One of the greatest challenges facing promoters of RE projects in Nigeria is the difficulty of mobilizing the needed investible funds for such projects from the financial markets.

Another important barrier to renewable energy financing has to do with the cost disadvantage that renewable energy projects suffer in relation to conventional energy projects. This arises due to the failure by stakeholders to account for the implicit costs such as social and environmental costs associated with conventional energy projects. This failure reduces the competitiveness of RE projects in the eyes of investors and other stakeholders.

Closely related to the above is that RE projects are relatively new in Nigeria. Stakeholders lack requisite experience in funding or promoting private sector utility scale renewable projects. Though there are few utility scale private sector RE projects such as the 2,600 MW hydro plant in Mambilla (Mambilla project is still at the engineering drawing stage), the 700 MW hydro plants in Zungeru, the 300 MW expansion of the hydro plant in Gurara, Dadin Kowa 34MW hydro project and a few others, none of such projects have become operational despite government support for such projects. The lack of experience and familiarity with RE projects among stakeholders especially policy makers, financiers and bankers add to the difficulties that RE projects suffer in Nigeria, as occurs in many developing countries in raising funds for RE investment.

Other issues that makes it difficult for RE investors to raise funds from the local capital market has to do with the absence of venture capital firms, the very low debt profile of the market and the instability resulting from internal conflicts.

The successive devaluation of the Naira poses serious currency risks to promoters of RE projects. This happens due to many reasons. First, with the devaluation of the Naira the cost of imports of the machinery and spare parts has increased astronomically. Tariffs may not readily adjust. The country's multiyear tariff order (MYTO) allows only a gradual increase in tariff. Additionally borrowing or raising funds from abroad will put the project at risk.

The attractiveness of RE projects may be less because the viability of such projects may be affected by the willingness to pay for electricity from RE sources by consumers of electricity in Nigeria. Given the prevailing economic difficulties being experienced in the country due to low commodity prices especially oil (many workers are unable to get their salaries on time and the minimum wage is less than 20 dollars), one may not hastily conclude that consumers would be willing to pay a premium for green electricity. Raising finance for RE projects will therefore, be challenging due to issues associated with willingness to pay by consumers.

Financing RE projects in Nigeria is also hindered by weak regulatory and institutional arrangements just like many other developing countries. These breed unfavourable regulatory and political climates which translate into a lack of sufficient supportive investment policy regimes. The absence of a credible and consistent policy regime for RE investments is a major barrier to RE project investment in most developing countries, Nigeria included.

Technical constraints in the industry also hinder RE projects financing. Most developing countries have a major infrastructure shortage that potentially negatively impacts energy projects. Poor or inadequate transmission and distribution infrastructure in most developing countries hinder additional generation capacity that could materialize through new RE projects. For example, Nigeria's transmission and distribution infrastructure cannot wheel and distribute power beyond 5,000MW. Thus new investment that can result from RE projects may not be readily transmitted and distributed to the consumers through the national grid. There is also a general lack of human capital sufficiently skilled on RE projects. In fact, sufficient knowledge and capacity on RE projects is lacking among the project stakeholders in many developing countries including Nigeria.

Regulating Renewable Energy Projects in Nigeria

Nigeria's electricity sector is primarily regulated by the provisions of the Electric Power Sector Reform Act 2005 (EPSRA), which among other responsibilities, establishes the Nigerian Electricity Regulatory Commission (NERC) as the apex sector regulator and authorises it to make rules, regulations, and policies relating to Nigeria's electricity sector.

Among other things, the EPSRA also establishes the Rural Electrification Agency (REA) which is charged with: expanding the main grid; developing isolated mini-grid systems; and promoting renewable energy power generation. The REA is also mandated to set up and administer a Rural Electrification Fund (REF) which is to promote, support and provide rural electrification programmes to achieve more equitable regional access to electricity.

In recent years, the focus on renewables has become stronger and it is growing to become a focus of the Federal Government of Nigeria (FGN)'s electricity policy. This has resulted in the introduction of policy and regulatory instruments geared towards stimulating investment in renewables and both NERC and the REA have played key roles.

In 2015, the Federal Executive Council approved the National Renewable Energy and Energy Efficiency Policy (NREEEP) which is broadly geared at removing barriers that put renewable energy and energy efficiency at economic, regulatory, or institutional disadvantages and providing a conductive political environment that will attract investments in the renewable energy and energy efficiency arena.

Riding on this federal policy mandate, Nigerian Bulk Electricity Trading Limited (NBET), the government-owned utility which serves as a central counterparty between generators and retail distributors, executed power purchase agreements with 14 solar photovoltaic IPP developers, demonstrating a drive to adopt renewable energy sources as viable electricity generating sources. However, implementation of those projects appears to have stalled, with the Federal Government seemingly choosing to focus on promoting off-grid solar projects.

Also in 2015, NERC issued the Regulations on Feed-In-Tariff for Renewable Energy Sourced Electricity in Nigeria (REFIT). This applies to energy generated and supplied through the national grid and orders that NBET and electricity distribution companies shall, as a matter of priority, purchase 50 per cent of the renewable energy electricity capacity limit established by the regulations.

In line with the policy's priority of diversifying Nigeria's on-grid energy mix, REFIT also provides a special tariff framework for renewables, in the form of feed-in-tariffs which were designed to be attractive to private investors. The feed-in-tariff must be approved by the NERC and shall be fixed (subject to periodic reviews). REFIT nevertheless has its limitations, as it only applies to renewable projects with a capacity of between one MW and 30 MW.

In 2017, the NERC issued the Mini-Grid Regulations, which creates a framework for the establishment and operation of mini-grids in

Nigeria. Mini-grids are defined as 'any electricity supply system with its own power generation capacity, supplying electricity to more than one customer and which can operate in isolation from, or be connected to a Distribution Licensee's network',[3] generating up to one MW[4] of generation capacity.

A key objective of the Mini-Grid Regulations is to accelerate electrification of unserved areas and underserved areas. To this end, the NERC prescribes a simplified process for the establishment of certain kinds of mini-grids, under which projects do not need to be licensed but may simply register with NERC. To provide financial relief to developers, there is also a compensation mechanism for mini-grid projects to cover the possibility of the national grid eventually extending to cover the area(s) served by the mini-grid

Renewable Energy Sector Regulators and Key Counterparties

Below is the list of major regulators of the energy sector who are responsible for implementing and enforcing laws enacted by the government. Enforcement involves the monitoring and investigation of businesses within the sector for compliance.

Nigerian Electricity Regulatory Commission

NERC is responsible for granting all licences and approvals with respect to the entire electricity value chain (generation, distribution, transmission, trading, system operations, metering, etc.).

Transmission Company of Nigeria (TCN)

The TCN is currently the only entity licensed for transmission of electricity and consists of the market operator, the system operator and the transmission service provider.

Nigerian Bulk Electricity Trader (NBET)

Nigerian Bulk Electricity Trader (NBET) is currently the sole holder of a bulk purchase and resale licence in Nigeria. NBET enters into bulk PPAs with generation companies and independent power producers (IPPs) for the bulk purchase of power, which is then resold to the relevant Discos in Nigeria under a vesting contract.

Nigerian Electricity Management Services Agency (NEMSA)

The Nigerian Electricity Management Services Agency (NEMSA) has responsibility for ensuring the enforcement of technical standards in the power sector and conducting inspections of electricity projects

National Environmental Standards and Regulations Enforcement Agency (NESREA)

NESREA is responsible for enforcing compliance with environmental laws, guidelines, policies and standards. Pursuant to the provisions of the NESREA (Electrical/Electronics Sector)

Regulations 2011, NESREA also issues permits to entities involved in new or used electrical electronic equipment manufacturing, processing, recycling, and power generation, transmission or distribution.

Impact

The Nigeria's legal framework for the use and development of renewable energy is incoherent and inadequate to meet social, economic and environmental development needs of the country. The extant legal framework on renewable energy is narrow in scope and not detailed. The Federal Government must do more to overcome all the challenges associated with the formulation of coherent legal regime on renewable energy to guarantee energy efficiency, security and sustainability in Nigeria. The existing policies on renewable energy are scattered in various policy documents which are incoherent and narrow in scopes.

3. FINANCING AND REGULATING RENEWABLE ELECTRICITY PROJECTS IN INDIA

India, a country in South Asia, is the second-most populous country, the seventh-largest country by land area, and the most populous democracy in the world. In recent times, India's energy sector is experiencing a transition with increasing penetration of renewable energy in the energy mix. India's capacity to generate electrical power is 373 gigawatts, of which 42 gigawatts is renewable. The country's usage of coal is a major cause of greenhouse gas emissions by India but its renewable energy is competing strongly. India emits about 7% of global greenhouse gas emissions. India is world's 3rd largest consumer of electricity and world's 3rd largest renewable energy producer with 38% (136 GW out of 373 GW) of total installed energy capacity in 2020 from renewable sources. In 2021 Renewable Energy Country Attractiveness Index (RECAI) ranked India 3rd behind USA and China.

One of the major impediments in the process of such a transition is to secure the necessary finance to achieve the transformative goal of producing 175 gigawatts of renewables by 2022. The problem gets compounded with limited budgetary resources available, conjugated with difficulties associated with mobilizing private capital for the sector.

The genesis of renewable energy development in India could be traced back to the global oil crisis in late eighties. The Government of India has been, since then, striving consistently to develop renewable energy sector with a set of strategic policy and regulatory measures. Given the constitutional status of energy as a concurrent item—entry 38 in the concurrent list—strategic policy initiatives are framed from time to time both by the federal government as well as provincial governments to expand the renewable energy sector.

However, the most recent policy thrust to transit to a greener energy regime is manifested in the

Government of India's transformative energy vision to produce 175 GW of renewable energy by 2022. Solar power has been given a place of pride in the renewable basket with the specific policy pronouncement of the Jawaharlal Nehru National Solar Mission (JNNSM). Similar policy-level initiatives, such as provision of 24 X 7 power availability across the country by 2019, are clear reflections of the thrust laid on renewable energy. This emphasis also further reiterated by India's global climate pledges made to UNFCCC through Intended Nationally Determined Contributions (INDCs).

Green Energy Finance in India

Renewable Energy Financing In India: Incentives and Instruments

Renewable energy financing in India reveals some interesting evolution and patterns. A variety of incentives and instruments are present in the Indian market to support renewable energy financing. The present section attempts to briefly highlight the most important incentive schemes and instruments of renewable energy financing in India. Historical analysis of the incentive structures for the renewable energy could be traced back to the year 1992 with the creation of a separate Ministry at the center, rechristened later as the Ministry of New and Renewable Energy (MNRE) in 2006. Since the very beginning, various incentives have been provided from time to time to accelerate the growth of the renewable energy sector in India.

Given that technical contours of the renewable energy sector are different from other economic sectors, attempts have been made by the Government of India long ago, in 1987, to create a non-banking, dedicated financial institution, called the Indian Renewable Energy Development Agency Limited (IREDA), as a Government of India enterprise to promote renewable energy projects through financial assistance. This institution works under the aegis of the Ministry of New and Renewable Energy (MNRE) of the Government of India and offers financial support to renewable energy projects by offering soft loans, counter guarantees, securitization of future cash flows, etc.

Apart from the above, there exist a host of banking and non-banking institutions offering various financial services to accelerate renewable energy growth in India. Apart from that, there have been efforts made to create new institutions, mechanisms, and instruments to drive renewable energy development by providing alternative funding avenues. This section briefly highlights all of them.

National Clean Energy and Environment Fund (NCEEF)

NCEEF is one such funding mechanism available to support, inter alia, renewable energy financing in India. The fund was created to support entrepreneurial ventures and research in the clean energy technologies by mobilizing funds through a cess on coal of INR 400 per ton known as Clean Environment Cess. The fund has been operational since 2011–12 and is primarily aimed at mobilizing additional resources to support clean energy development. Part of the fund gathered from the NCEEF is utilized by IREDA to lend to banks at a 2% rate so that this money can be lent to various renewable energy projects at a concessional rate of interest not exceeding a 5% rate.

Recognition of Priority Sector Lending

Considering the importance of the sector and the need for mobilizing capital by the private sector, RBI has categorized the renewable energy sector as a priority sector lending in April 2015. The primary purpose of such categorization, inter alia, is to enhance employability, build basic infrastructure, and strengthen the competitiveness of the economy. The RBI guidelines suggest that 40% of the net credit of banks should be lent out to the priority sectors. However, there is cap put on the bank loans for renewable energy projects. The loan ceiling has been kept at $2.3 million per borrower (INR 15 Crore) for renewable energy projects such as solar power generators, biomass-based power generators, wind mills, micro-hydel plants, and for non-conventional-energy-based public utilities viz. street lighting systems, and remote village electrification.

Soft Loans from IREDA

IREDA extends loans to the renewable energy project developers that bear low interest rates. The funding is routed through various modes, such as direct lending and lending through various financial intermediaries such as providing various lines of credits to NBFCs, and underwriting of debts etc. IREDA also uses the NCEEF to provide subsidized debt at a 5% rate of interest to renewable energy projects through select banks. IREDA often sources funds from international agencies and banks to provide such loans for renewable energy projects.

Green Banks

Green banks have emerged as an innovative tool for accelerating clean energy financing globally. Such dedicated financial institutions are proved to be a successful mechanism for leveraging the limited public finance to mobilize the required private capital into the sector. The first such effort in India can be traced back to the Indian Renewable Energy Development Agency (IREDA)'s plan in May 2016 to explore becoming the first green bank in the country. This idea was conceptualized with an understanding that it would utilize limited public funds to mobilize private funds in order to meet the overarching clean energy goals of India.

Green Bonds

Green bonds are innovative market-based financing instruments. They are fixed-income financial instruments for raising funds for projects that are environmentally beneficial in nature. The risk holdings in the case of green bonds are similar to those of other bonds. Green bonds do have to also acquire the desired credit rating to attract institutional financing.

Infrastructure Debt Fund

This is again an innovative financing instrument for renewable energy financing in India. These funds can be created to accelerate and further the long-term debt in infrastructure projects. The current regulatory regime allows such funds to be lent to PPP projects. Such funds have been floated in the market by L & T IDF, Indiainfra debt, and IDFC IDF. Infrastructure debt funds can start investing in projects after one year of their operation.

The challenges of financing renewable energy in India are intricately associated with the structure of the industry and investment character for the industry, which are largely shaped by the instrument types and sentiments of the investor. Given the capital-intensive nature of the sector and private sector led sectoral development, attracting the required type and size of investment continues to be a major roadblock for the sector. Over the years an array of innovative financing instruments and tools have been devised and employed; however, mobilizing adequate finance on cheap terms is very challenging. In particular, labour and construction costs are significantly lower in India and more importantly, recently there has been a dramatic fall in the renewable energy prices in particular prices of solar and wind energies.

Green Energy Regulation in India

Electricity remains heavily regulated despite the entry of private generators. A forest of policies and regulations guide power development under the EA, 2003 (amended in 2007); Hydro Power Development Policy, 2006 (amended in 2009); Mega Power Policy, 2009; Rural Electrification Policy, 2006; Tariff Policy, 2006 (amended in 2009 and revised in January 2016); and National Electricity Policy, 2005. Further, the Central Electricity Authority specifies construction and safety standards for electricity installations and supply, and provides technical advice on power planning.

Electricity regulators—Central Electricity Regulatory Commission and the State Electricity Regulatory Commissions—specify business regulations, which govern their functioning and prescribe the procedures for tariff determination, service standards, grievance redress and the code for grid management. Currently, Coal India Limited, a government-owned company, is the largest supplier, making the coal price administered rather than a market price. Moreover, generation tariff is regulated selectively for government-owned companies and for the private generators that do not enter via the competitive bidding route. Similarly, transmission, distribution, and retail supply tariffs are regulated to balance a complex structure of cross-subsidy paid by larger customers to partly subsidise supply to small users and agriculture. With respect to renewable energy the government regularly come out with some initiatives to boost the renewable energy subsector.

Below are Some Initiatives by Government of India to Boost India's Renewable Energy subsector

- In April 2021, the Central Electricity Authority (CEA) and CEEW's Centre for Energy Finance (CEEW-CEF) jointly launched the India Renewables Dashboard that provides detailed operational information on renewable energy (RE) projects in India.
- In April 2021, the Ministry of Power (MoP) released the draft National Electricity Policy (NEP) 2021 and has invited suggestions from all stakeholders such as Central Public Sector Undertakings, Solar Energy Corporation of India, power transmission companies, financial institutions like Reserve Bank of India, Indian Renewable Energy Development Agency, HDFC Bank, ICICI Bank, industrial, solar, and wind associations, and state governments.
- In March 2021, Haryana announced a scheme with a 40% subsidy for a 3 KW plant in homes, in accordance with the Ministry of New and Renewable Energy's guidelines, to encourage solar energy in the state. For solar systems of 4-10 KW, a 20% subsidy would be available for installation from specified companies.
- In March 2021, India introduced Gram Ujala, an ambitious programme to include the world's cheapest LED bulbs in rural areas for Rs. 10 (US$ 0.14), advancing its climate change policy and bolstering its self-reliance credentials.
- To encourage domestic production, customs duty on solar inverters has been increased from 5% to 20%, and on solar lanterns from 5% to 15%.
- In November 2020, the government announced production-linked incentive (PLI) scheme worth Rs. 4,500 crore (US$ 610.23 million) for high-efficiency solar PV modules manufacturing over a five-year period.
- In October 2020, the government announced a plan to set up an inter-ministerial committee under NITI Aayog to forefront research and study on energy modelling. This, along with a steering committee, will serve the India Energy Modelling Forum (IEMF), which was jointly launched by NITI Aayog and the United States Agency for International Development (USAID).
- India plans to add 30 GW of renewable energy capacity along a desert on its western border such as Gujarat and Rajasthan.
- Delhi Government decided to shut down thermal power plant in Rajghat and develop it into 5,000 KW solar park
- The Government of India has announced plans to implement a US$ 238 million National Mission on advanced ultra-supercritical technologies for cleaner coal utilisation.
- Indian Railways is taking increased efforts through sustained energy efficient measures and maximum use of clean fuel to cut down emission level by 33% by 2030.

While the main regulators of electrify namely, Central Electricity Regulatory Commission and the State Electricity Regulatory Commissions are busy with compliance issues the regulation of renewable energy subsector is carried out mainly through policy reviews and regular initiatives, some of which are mentioned above. The Nigeria's regulatory framework for the use and development of renewable energy appears incoherent and centred around the main regulator (NERC). As a result, the regulatory environment seems inadequate to meet social, economic and environmental development needs of the country. While enacted laws are the bedrock of development, changes in circumstances can render a law inadequate under a new era. Therefore, there is a need to have regular policy reviews and pronouncements to aid the development of RE resources in Nigeria in order to guard against this, as it done in India.

4. RECOMMENDATIONS

To fast-track investment in Nigeria's RE, government needs to intensify efforts towards creating a robust and functional financial services sector that could channel investible funds to RE projects. This needs to be supported by adequate and practicable regulations aimed at achieving this objective. This is not going be an easy task.

Finance

Creation of a functional market to assist in mobilizing finance for RE projects is essential. The important steps would involve the following:

- Creating a Ministry for Renewable Energy or an independent Department

a. This Ministry or Department should be run by professionals and technocrats

b. The ministry should focus on developing a desired level of renewable energy that will contribute to an acceptable level of energy mix for Nigeria.

- Encouragement of venture capital investment in Nigeria as a way of easing the process of raising funds for investors in RE projects.

a. Improving the legal and regulatory environment could help in this regard.

b. Such encouragement can come from an independent ministry or department.

c. Continuous reforms towards aiding ease of doing business in Nigeria needs to be intensified to support this

- There is a need for Nigeria to strengthen its institutions to support infrastructure investments by the private sector

a. Legal and regulatory institutions in order to give sufficient confidence to the investing public to invest in Nigeria's RE.

b. Normally investment in infrastructure projects require complex contractual agreements that in turn require strong institutions to implement.

c. Manpower shortage is evident and needs to be reversed especially in areas related to RE investment and project management

d. Massive investment is required to develop and upgrade these infrastructures.

e. Therefore, the private sector may need to be incentivized to be able to make investment at least in the distribution segment of the industry.

Regulation

There is the need for a legal regime that is favorable to growth and sustainability. Strong regulatory environment aids the development of a robust infrastructure financing possibilities. The enactment and execution of the new energy policy should be done promptly. This can be encouraged in the following ways:

- Need to look at the creation of an independent government department whose sole purpose is to promote the development of renewable energy in Nigeria.

a. This law should harmonise existing policies on renewable energy that are currently scattered in various policy documents among various regulators and counterparties mentioned above.
b. This should address the issue of the current policy regime which appears to be incoherent and narrow in scopes.

- The government needs to embark on an aggressive enlightenment of Nigerians on the new energy policy and on the need for large scale marketing campaign for full acceptability of the energy policy by Nigerians.

a. In India, we have noted the frequency of government pronouncement and initiatives on renewable energy.
b. Over 10 pronouncements have been made this year alone.
c. Nigeria could learn from India in this regard

- The Federal Government should integrate renewable energy into the energy system by making use of renewable energy a matter of national priority to meet electricity demands with supplies.

a. This requires political will and unalloyed commitment of the government for sustainability of renewable energy systems in Nigeria.
b. We see a lot of this by both the federal and state governments in India.

- There is the need to initiate renewable energy markets though legislation to jump start its development

a. Profit oriented renewable energy in Nigeria necessitates formation of energy markets for her countryside populace energy consumption.
b. To develop such commercial market, there is a need to intensify investments in renewable energy growth in the country.
c. We also note that the Indian government's initiative to increase tariffs on imported solar panels in order to encourage local production. By so doing a market is being created.

- There is the need for clear guidelines or benchmarks for law makers on the best approach to adopt for enactment of legal framework and formulation of stringent policies on renewable energy utilization and developments

a. This should be with clear understanding of the impacts and the benefits of renewable energy use in achieving energy security, efficiency, and sustainability in Nigeria.

5. CONCLUSION

This article has concentrated mainly of the development of renewable energy sources in Nigeria. This is with the belief that developing renewable energy sources would move Nigeria towards the achievement of optimum energy mix. In Nigeria, several government initiatives are quite visible in an attempt to develop renewable energy subsector. But a lot more needs to be done. In order to achieve this, it is pertinent for the authorities to create an enabling environment for this to be achieved. The policy environment must be such that investors would be comfortable to invest in renewable energy in Nigeria. Inconsistency and lack of continuity in regulatory and policy environment would be bad for investors and financiers, both foreign and local. Electricity projects, just like any infrastructural projects are long term in nature as such projects requires long gestation periods between investment and dividend. With the right policies in place Nigeria can enjoy positive social impacts, including decreased energy bills for low-income individuals, decreased dependency on public utilities, an improved environment from reduced pollution, and job creation.

REFERENCES

1. IEA. 2015. India Energy Outlook 2015. Paris: International Energy Agency. https://www.iea.org/publications/freepublications/publication/IndiaEnergyOutlook_WEO2015.pdf
2. Ado Ahmed - Overcoming the Challenges of Financing Utility Scale Renewable Energy Projects in Nigeria - AEE Energy Forum – First Quarter 2018 Africa-EU RECP (2016). Africa-EU Renewable Energy Cooperation Programme.
3. Akinbami, J.F. (2001) ‘Renewable energy resources and technologies in Nigeria: present situation, future prospects and policy framework’, Mitigation and Adaptation Strategies for Global Change, Vol. 6, No. 2, pp.155–182.
4. Central Bank of Nigeria (CBN) (2009) Statistical Bulletin, Vol. 20, November [online] http://statistics.cbn.gov.ng/cbn-onlinestats.
5. Eghosa Ekhator and Godswill Agbaitoro - Energy law and policy in Nigeria with reflection on the International Energy Charter and domestication of the African Charter - Chapter · March 2020
6. Emmanuel Omoniyi Falobi - The Role of Renewables in Nigeria’s Energy Policy

Mix - IAEE Energy Forum / First Quarter 2019

7. FGN (2014) Clean Technology Fund Investment Plan for Nigeria. Revised Report of the Vision 2020
8. Foster,V and Steinbuks, J., (2008) Paying the Price of Unreliable Power Supplies; In-House Generation of Electricity in Africa. Africa Infrastructure Country Diagnostic National Technical Working Group on Energy Sector.
9. Joseph Omojolaibi - Financing the alternative: Renewable energy in the Nigerian economy - International Journal of Environment and Sustainable Development · January 2016
10. Gopal K. Sarangi - GREEN ENERGY FINANCE IN INDIA: CHALLENGES AND SOLUTIONS - ADB Working Paper Series – NO. 863 August 2018
11. Olusola Joshua Olujobi - The legal sustainability of energy substitution in Nigeria's electric power sector: renewable energy as alternative - https://doi.org/10.1186/s41601-020-00179-3
12. Olusola JOSHUA Olujobi, Oluwatosin Michael Olujobi and Daniel Ufua THE LEGAL REGIME ON RENEWABLE ENERGY AS ALTERNATIVE SOURCES OF ENERGY IN NIGERIA'S POWER SECTOR: THE IMPACTS AND THE POTENTIALS - Article in Academy of Strategic Management Journal · December 2020
13. Oluwaseun Viyon Ojo - An Overview of the Legal and Regulatory Framework for Renewable Energy Projects in Nigeria: Challenges and Prospects - (2017) Unilag Law Review 1 Vol 1| No. 1
14. Peter Kayode Oniemola - POWERING NIGERIA THROUGH RENEWABLE ELECTRICITY INVESTMENTS: LEGALFRAMEWORK FOR PROGRESSIVE REALIZATION - AFE BABALOLA UNIVERSITY: J. OF SUST. DEV. LAW & POLICY VOL. 6: 1: 2015
15. India 2020 - Energy Policy Review - INTERNATIONAL ENERGY AGENCY
16. India Energy Outlook 2021 - INTERNATIONAL ENERGY AGENCY
17. Yoshino, N., and Taghizadeh-Hesary, F. 2015. "Analysis of Credit Risk for Small and Medium-Sized Enterprises: Evidence from Asia." Asian Development Review. 32(2): 18–37.

INVESTIGATING THE EFFECTS OF ENERGY METERING ON THE ECONOMY OF USERS AND SUSTAINABILITY OF ELECTRICITY IN MEIRAN, LAGOS, NIGERIA

O. O. Awolola and S. Enemona
Department of Mechanical Engineering, The Federal Polytechnic, Ilaro, P.M.B. 50, Ilaro, Ogun State, Nigeria
Email: olalekan.awolola@federalpolyilaro.edu.ng
Mobile No: +234-8027955316

ABSTRACT
Nigeria is a country in the West Africa sub-region that has been characterized by the low availability of electricity for both domestic and commercial end users for decades. This challenge emanates from the generation, transmission, and distribution of electrical energy. The little power available was not properly metered to the end users. However, the issue of metering is on the front burner of the government, which issued a policy of prepaid energy metering. This study is aimed at investigating the effect of proper metering on the economy of the end users as well as the energy availability and sustainability of the system. The method adopted is the administration of questionnaires through Google form to about sixty consumers in the Meiran area (at latitude 6°39'22" and longitude 3°15'48") in the Alimosho local government area of Lagos. The result shows that 90% of the respondents attested that with the introduction of the prepaid energy metering system, there is relief in their economy and improved service delivery from the energy distribution company (disco). The paper concludes that the introduction of proper energy metering will reduce wastage, which in turn will improve the availability and sustainability of energy for the general populace. The study recommends that every consumer be properly metered, which will make the business of energy providers a viable business.

Keywords: generation, transmission, distribution, energy, disco, consumer

1. INTRODUCTION

The unavailability of power has been at the front burner of discussions in Nigeria for many years back. Oyedepo et al (2015) in their paper on energy consumption at Covenant University, Ota made reference to Bordass et al (2001) who referred to the significance of energy availability in the economic growth, social and political development of every nation. Before the reformation of power policy, the National Electrical Power Authority (NEPA) had been the only authorized company to supply electricity in Nigeria. This company was owned by the Federal Government of Nigeria, whose responsibilities were power generation, transmission, and distribution. This government-owned company was later renamed Power Holding Company of Nigeria (PHCN) under a private organization.

In 2018, the National Electricity Regulation Commission (NERC) made a policy that every consumer must be metered, which gave rise to the issue of prepaid metering systems in large numbers under the policy of Meter Asset

Providers (MAPs) (Olanrewaju and Suaanu-Deekae, 2019).

Ikeja Electric Distribution Company (IkEDC), a distribution company that oversees some Local Government Areas (LGAs) in Lagos state, includes Alimosho local government area where Meiran is situated. With the introduction of MAPs, some houses have been metered with prepaid metering systems. This survey is aimed at the consumer's feelings towards the program and how it has affected the supply of electricity from the disco. The prepaid metering system is a smart technological solution to control bill payment refusal, reduce electrical theft and corruption (Debasish and David, 2020). This metering system equally improves electricity accessibility and the financial viability of electric utilities (Debasish and David, 2020). Prepayment meters have advantages which allow consumers to budget for their energy consumption based on the funds' availability, which could not be possible under an

estimated billing system. In the long run, it helps one to avoid debt. **Makanjuola** et al (2015) investigated the problems emanating from using prepaid meters in Nigeria, focusing on a case in Badagry. According to a survey carried out on 200 consumers and some staff members of Eko Electric Distribution Company, the results show that the introduction of prepaid meter is a good measure of ensuring customer satisfaction and equally ensuring prompt revenue collection by the discos.

2. BACKGROUND OF THE STUDY

Energy distributions in Nigeria were not well metered before the hike in population (Adetona, 2011) and indiscriminate building construction, energy distribution was metered via analog energy meter types. These types were susceptible to manipulation by consumers via bypass connection from the grid to the meters and to the electricity utilities of the consumers. Before the prepaid meter policy, there were indiscriminate billing systems which did not reflect energy utilization by a customer.

During one of the lead author's discussion sessions with a consumer, he narrated his experience with one of the distribution companies that his line was disconnected from the pole, which he refused to connect since he wasn't available at that time for period of about a year and the distribution company continued to bill his apartment. A marketer was to sit in the office and project the energy consumption by consumers where supply is unavailable. Another resident narrated his ordeal, saying that the faulty transformer feeding that area had not served them for more than six months. The marketer continued billing them for the first two months until uproar emerged in the community before the billing stopped. Most often than not, this billing are mostly based on projections given by the company to the marketer.

3. METHODOLOGY

The survey was carried out in the Meiran area of Alimosho LGA of Lagos state. The questionnaire was done on Google form and sent through groups and individuals' whatsapp platforms to receive feedback on the questions raised in the questionnaire. There are 15 questions raised, which include: the profile of the respondent like age, the house or apartment type, types of bills used before the arrival of prepaid meters, and average monthly consumption, among others. Various residents were also contacted for unstructured interviews in addition to the structured questionnaires that were initially administered through Google form. These respondents were not on prepaid meters, but on post-paid or estimated billing systems. A personal communication was established with one of the staff of Ikeja Electric Distribution Company (IkEDC). The responses from the questionnaire were analyzed by using simple descriptive statistics of frequency and percentages.

4. RESULTS AND DISCUSSION

The outcomes of the study are presented in simple descriptive statistics of frequency and percentages presented on tables. A total of sixty correspondents were administered a questionnaire via Google form. There were other forms of discussions/interviews conducted with other respondents to give validity to the obtained results through the administration of the questionnaire.

From Table 1, the following results and discussion emanated.

Gender: The gender distribution of the respondents is 40 males and 20 females. These are not necessarily house owners, since Ikeja Electric Distribution Company (IkEDC) allowed tenants to apply when landowners could not provide the needed documents for registration.

Age bracket - All the respondents are adults, which imply that they understand the contents of the questionnaires as they are affected. Hence, they would have gotten experience on the issue of energy meters in Nigeria.

Type of Apartment - According to this result, those living in 3-bedroom flats are the most respondents, while those living in duplexes have the fewest number of people. Those in the 3-bedroom apartment are middle class earners, who would have experienced the issue of indiscriminate billing most of the time.

Nigerian Electricity Regulatory Commission (NERC) policy on metering in Nigeria- Every one of the respondents welcomed the idea of proper metering, saying it was a relief for them. This will allow for proper monitoring of energy consumption. This was equally discussed by Makanjuola et al (2015) when he alluded to the fact that this would allow for proper budgeting for energy usage.

What type of billing system does the Disco use for you before the policy? More than 75% of the respondents talked about estimated billing, which cannot be predicted, and most of the postpaid were not read to pick the right answer. The same process was applied most of the time.

Most of the time, with post-paid meters, the marketer claimed that he did not have access to the meter, so an estimated bill was presented. (RVI, male, 45, resident of Meiran).

When have you started using a prepaid meter? - The respondents started using the prepaid meter at least 2 years ago. The distribution of these meters is gradual, with only 25% of the respondents stating they have used the meter more than 3 years ago. This was corroborated by a staff which said it was only a million meters that were released to Discos (A staff of Ikeja Electric, 2021)

Your average monthly energy consumption - Half of the respondents stated that the average monthly consumption is between 100 and 200 kWh, and only about 17% used more than 400 kWh. The following is the response of one of the interviewees:

Before now, I had an estimated bill of 200-250kWh per month and, with the same apartment and electrical facilities, the highest consumption of electricity recorded with the prepaid billing system was 110kWh. **(RVI, male, 48, a resident of Meiran).**

Table 1: Elements of questionnaires and responses

Questions	Elements	Frequency	Percentage (%)
Gender	Male	40	66.67
	Female	20	33.33
Age bracket	18-30	15	25
	31-40	15	25
	41-50	15	25
	50 and above	15	25
Type of Apartment	2 bedroom flat	10	16.67
	3 bedroom flat	30	50
	Duplex	5	8.33
	Bungalow	0	0
	Others	15	25

Do you welcome the Nigerian Electricity Regulatory Commission (NERC) policy of metering every electric energy consumer in Nigeria?	Yes	60	100
	No	0	0
	No really	0	0
Type of billing system does the Disco use for you before the policy?	Post paid metering billing	15	25
	Estimated billing	45	75
Since when have you started using prepaid meter?	2 years	45	75
	3years		
	Above 3 years	15	25
What is your average monthly energy consumption?	100 -200kWh	30	50
	201-300kWh	20	33.33
	301-400kWh		
	Above 400kWh	10	16.67
Do you prefer the prepared billing to other type of billing?	Yes	60	100
	No	0	0
Does this help you in energy conservation?	Yes	50 (83.33%)	50 (83.33%)
	No	10 (16.67%)	10 (16.67%)
Does this help you on energy economy?	Yes	55 (91.67%)	55 (91.67%)
	No	5	8.33%
With prepared meter, how is energy supply from Discos?	Better	40 (66.67%)	40 (66.67%)
	Worse	0	0
	No difference	20 (33.33%)	20 (33.33%)
In your opinion, do you think there is energy wastage in Nigeria?	Yes	45 (75%)	45 (75%)
	No	15 (25%)	15 (25%)
Does prepaid metering system of energy will reduce the wastage?	Yes	55 (91.67%)	55 (91.67%)
	No	0	0
	Not really	5	8.33%

Does this type of metering system improve the services of Discos?	Yes	35 (58.33%)	35 (58.33%)
	No	0	0
	Not really	25 (41.67%)	25 (41.67%)
What is your attitude to energy consumption now?	Careful	50 (83.33%)	83.33%)
	Carefree	5	8.33%
	Conservative	5	8.33%

Do you prefer the prepared bill to other types of billing? **-** Every one of the respondents prefers a prepaid billing system. This may be as a result of their preference for using as they pay, which excludes extra financial burden that may arise through power disconnection and reconnection.

Does this help you with energy conservation? **-** More than 83% of the respondents attested to the fact that this system assists in energy conservation and avoidance of energy wastage, which was equally corroborated by **Miyogo** et al. (2013) where it was stated that respondents in Kenya confirmed that the prepaid billing system has made them careful in their energy consumption.

Does this help you with the energy economy? - There is an energy economy as a result of conservation. About 90% of the respondents attested to this, which will bring about financial benefit to the energy users as they conserve and avoid wastage.

How is the energy supply from **Discos**? - There are more than 60% of respondents who attest that there is improved energy supply with the prepaid metering system. It was only 33% of the respondents that could not differentiate between the two services. The supply must be improved to achieve the needed revenue collection from the consumers.

Is there energy wastage in Nigeria? - On energy wastage in Nigeria, 75% of the respondents confirmed this, while only 25% declined. This wastage can be curbed with this prepaid metering system, which means no payment is made, no energy is supplied, and there would not be an issue of energy utilization without paying. This will reduce the amount owed by consumers, potentially forcing the Discos into bankruptcy.

Does the prepaid metering system for energy reduce waste?
In the same vein, 92% of respondents opined that the prepaid metering system would reduce wastage. This was equally attested to by Makanjuola et al (2015) that power is only consumed whenever it is needed.

Does this type of metering system improve the services of Discos? - More than 58% of respondents said the Disco's services had improved, while 42% said there had been no change. The services must improve since they can only generate funds from supply because the era of unwarranted billing of disconnections and reconnections fees is not obtainable under the prepaid system.

What is your attitude to energy consumption now? - With the prepaid metering system, the attitude of the users has changed. This could be seen from the attestation of about 83% of respondents who are careful in their consumption, while 8% are either carefree or conservative. With this, there would be availability of energy to be distributed to other users who are mostly in need of it, for example, the manufacturing sub sector of the economy.

5. CONCLUSION AND RECOMMENDATION

The following can be concluded from the study:

- The introduction of prepaid metering systems is a welcome development in the energy sector for consumers;
- This has reduced the financial burden that used to emanate from the estimated billing system.
- It aids in energy conservation and utilization efficiency.
- This helps in the elimination or reduction of energy wastage, thereby improving the services of the discos.
- With this, energy sustainability is ensured.
- It is recommended that each consumer should be metered appropriately.

REFERENCES

Adetona, Z. A. (2011). Tackling the Challenges of power Generation in Nigeria through Empirical Data Analysis. Faculty of Technology, International Conference, Obafemi Awolowo University, Ile-Ife, September 25-29, 2011

Bordass B, Cohen R, Standeven M and Leaman A (2001), 'Assessing building performance in use 3: Energy performance of the probe buildings', Build Res Inf , 29(2):114-28.

Debasish, K. D. and David, I S. (2020). Prepaid metering and electricity consumption in developing countries, Energy Insight obtained at www.cse.org.uk assessed 27th August, 2021

Ikeja Electricity Distribution Company (2021), No of meters released to Discos, a personal discussions from a staff

Makanjuola,N.T., Shoewu O., Akinyemi, L.A. and Ajose, Y., (2015)Investigating the Problems of Prepaid Metering Systems in Nigeria. The Pacific Journal of Science and

Technology.http://www.akamaiuniversity.us /PJST.htm. volume 16, Number 2. November 2015 (fall)

Miyogo, C. N., Ondieki, N. S. and Nashappi, N. G. (2013).An Assessment of the Effect of Prepaid Service Transition in Electricity Bill Payment on KP Customers, a Survey of Kenya Power, West Kenya Kisumu, American International Journal of Contemporary Research, Vol. 3 No. 9; pg 88-97.

Olanrewaju, A. A. and Suaanu-Deekae, K. J. (2019) electricity metering system in Nigeria: An Examination of regulatory and policy initiative to bridge the gap obtained from www.bsum.edu.ng vol 9 article 7 assessed on 7th September, 2021

Oyedepo, S. O, Adekeye T, Lerarno, R.O, Kilanko, O , Babalola, O.P, Balogun A. O and Akhibi M. O (2015). A Study on Energy Demand and Consumption in Covenant University, Ota, Nigeria. International Conference on African Development Issues (CU-ICADI) 2015: Renewable Energy Track.

NIGERIA'S FAST DISAPPEARING FORESTS AS AN IMPENDING ENVIRONMENTAL AND ENERGY CRISIS: A REVIEW

E. O. Atanda[1]., S.N. Onuoha[1]., M.A.Obomeghie [2] and S.N.Achekuogene[3]
[1]Department of Agricultural & Bio-Environmental Engineering Technology, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
[2]Department of Electrical & Electronics Engineering Technology, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
[3]Department of Mechanical/Transport Section, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
Email: olugbenga_atanda@yahoo.com; sollywise2000@gmail.com; mayoboms@yahoo.com; billans4u@yahoo.com

ABSTRACT

Wood is a product of felled trees from the forest. Fuel-wood is the most patronized source of energy in the rural areas in Nigeria for domestic cooking. Statistics show that many of the trees felled from the forests in Nigeria were used as fuel-wood and coal in the rural areas. Wood is also the immediate source of energy after the sun to the farmers, as wood and other crop residues are readily available as fuel for on-farm processing of crops such as rice, oil-palm, cassava, among others. This paper examines Nigeria's fast disappearing forests as an impending environmental and energy crises. Deforestation has been identified as a major threat to both environmental and energy crisis in Nigeria. The impending environmental and energy crisis in Nigeria are such that there is the continuous removal of forest trees either by bush burning or indiscriminate felling without replacing them. Moreover, the rate of deforestation should be drastically reduced to the barest minimum because of its adverse effect on the climate, environment and economic usefulness of forest trees. The paper discusses the status of forestry and environmental crisis in Nigeria. It highlights major benefits of forests to the environmental and economic development of Nigeria. Some effects of deforestation on the environment such as encouragement of soil erosion, loss of useful organic matter, reduction in the amount of rainfall in the area concerned, among others were discussed. It also identifies some causes of deforestation in Nigeria to include unfavourable climatic factors, farming activities, mining/industrialization, natural disasters, timber exploration, among others. The paper further suggested management practices for saving Nigerian forestry from both environmental and energy crisis to include proper forest regulations, selective exploration, discouragement of deforestation, regeneration, afforestation and taunya farming.

Keywords: Forest, Environmental, Energy, Farming, Trees, Farmers

1. INTRODUCTION

Nigeria is naturally endowed with vast expanse of forest land, the swamp forests in the extreme Southern part of the country, the tropical rainforest in the South-Western axis and the wooded savannah in the Middle belt. Nigeria ranks among the countries of the world with abundant forest resources (Ogundele *et al.,* 2016). Mfon *et al.,* (2014) stated that forests in Nigeria occupied about 110,890km^2 , that is, forests is about 12.18% of vegetation cover of the country. The world as a whole is blessed with wide expenses of forestland. These forest areas provide the means of livelihood for nearly 500million forest dwellers and nearby residents or settlers who depend directly on food, fibre, folder, fuel and other resources taken from the forest (World Bank, 1991).

The forest according to Food and Agricultural Organization is "any vegetal formation with a minimum of 10percent crown cover of trees (minimum height of 5metres) or bamboos, generally associated with wild flora, fauna and natural soil conditions, and not subject to agricultural practices" (FAO, 1991). Going by this definition, forests are predominantly trees and woody vegetation growing more or less closely together. The forest protects and regulates water resources, protects against soil erosion, serves as carbon sequestration, stores and cycles nutrients, breaks down and absorbs pollution and performs other functions such as stabilising the climate, among others. Besides the production of biological resources, one other function of the forest is its significant role in the sustainability of our environment (Okekunle, 2002).

Most Nigerians have always depended on the forest for their survival, economic development as well as environmental amelioration. The level of community nutrition is sometimes linked to fuel wood availability and cost while others depended directly on forest for their livelihood; among them are high numbers of forest and wood workers (Aliyu *et al.,* 2014). This is apart from contributing substantially to the Gross Domestic Product (GDP). In spite of its importance, the natural forest has continued to deplete rapidly in the world especially in Africa continent and particularly in Nigeria (Ogundele *et al.,* 2016).

Deforestation all over the globe is threatening the sustainability of the environment but has had bad effects in Nigeria due to their high rates. Deforestation puts at risk all aspects of the environment, the economy and the citizens of the country (FORMECU, 1996). In Nigeria, the scenario is not different, as regional breakdown of deforestation from 1979 to 1995 shows that total forest declined by 48% in the North Central, 7% in the North East, 60% in the North West, 53% in the South East, 13% in the South-South and 12% in the South-West (FORMECU,1996). In the year 2000, the forest cover was estimated at 13.5million hectares compared to 17.5 million hectares in 1990 (FAO, 2001) indicating a forest cover loss of close to four hundred thousand hectares per annum with a decline of about 2.6%. Forest/woodlands now stand at only 13% of the total land area (FAO, 2001).

Sadly, however, the Nigerian Government is yet to take appreciable measures towards halting the decline in our environmental quality (Mohammed *et al.,* 1996). To this end, Nigerian forests have been left to the fate of taking care of themselves, a responsibility they cannot shoulder while under the onslaught of logging (Okekunle, 2002). Consequently, all the forest reserves and natural forests are fast disappearing with the attendant problem that comes with it. The impending environmental and energy crisis in Nigeria is so visible that the populace can almost feel the impact as majority of the trees felled from the forests especially in the rural areas are used as fuel wood and coal. This has further put lot of pressures on available natural forests and forest reserves in Nigeria since majority of the farmers who cuts these forests in Nigeria live in the rural areas. In addition, fuel wood and coal has being the most patronized source of energy in these rural areas for their day to day domestic activities and on-farm processing of crops such as rice, oil-palm, cassava, among others. This paper therefore examines the causes of Nigeria's fast disappearing forests that have resulted to an impending environmental degradation and energy crises. To achieve this objective, the paper discusses the status of the forestry and its attendant impact on environmental growth of Nigeria. It highlights major benefits of forests to the environmental and economic development of Nigeria. It identifies some effects of deforestation on the environment as well as some causes of deforestation in Nigeria. The paper further suggested management practices for saving Nigerian forestry from both environmental and energy crises.

2. STATUS OF THE FORESTRY AND ENVIRONMENTAL CRISIS IN NIGERIA

Forest constitutes the greatest celebration of nature to appear on the face of the planet since the first flickering of life (Myers, 1985). They are exceptionally complex ecologically, and they are remarkably rich biotically. According to the Food and Agriculture Organization (FAO, 1991), about one-third of the world's land area is forested. With respect to the Nigerian environment, the total forest area of all types in the country was estimated at about 360,000 km^2 which is about one – third of the country's total land area of 983,213 km^2. Out of these areas, savannah is about 773,789km^2 whereas 133,717km^2 is rainforest (Nigeria Yearbook, 1975). Generally, forests are found as a climatic climax in the Southern part of the country which then changes to savannah woodland and ultimately grassland as we move northward. Nigerian forests are grouped into three different formations namely: mangrove forest, fresh water swamp forest and lowland rainforest as shown in Table 1.

Table 1: Area of Vegetation Types in Nigeria

Vegetal Type	Area (Km^2)	Percentage of total land area
Mangrove/Coastal Forest	12,782	1.3
Fresh Water Swamp Forest	25,563	2.6
Lowland Rain Forest	25,372	9.7
Derived Savannah	75,707	7.7

Guinea Savannah	400,168	40.7
Sudan Savannah	342,158	34.8
Sahel Savannah	31,463	3.2

Source: Egboh (1990): Forestry Policy in Nigeria, University of Nigeria Press

According to Mortimore (1989), drought incidence is on the increase everywhere in the country as aridity is intensifying in areas north of latitude 11^0N. Former fixed dunes are being mobilised; agricultural lands are becoming less productive as desertification spreads its wings; fadama lands are drying out; gully erosion is defying solution; floods are becoming more frequent and more devastating. Waters and land in crude oil producing areas are becoming more increasingly polluted by oil spills; the continuous flaring of gas and bush burning add to the problem of greenhouse gases in our immediate atmosphere, while our industrialists continue to discharge poisonous gases, toxic solids and dangerous effluents into our air, land watercourses.

Akinsanmi (1999) stated that Nigerian environmental problems vary depending on the region and geographical location. While the arid North's environmental problems include desertification, shortage of water, dust and sand dunes encroachment; the environmental problems in the South include deforestation, coastal erosion, urban sanitary problems and oil pollution. Whereas water and air pollution are mainly featured in industrial and urban areas, land degradation and soil erosion are common problems in many states of Nigeria. A World Bank Environmental Report in 1990 identified the principal environmental problems facing Nigeria and which requires immediate attention to include land degradation, vegetation and forest degradation as well as air and water contamination.

3. MAJOR BENEFITS OF THE FOREST TO THE ENVIRONMENTAL AND ECONOMIC DEVELOPMENT OF NIGERIA

Forest is very important for several reasons. It is very necessary for government to encourage the planting of trees because of its usefulness in the following ways:

i. Provision of food: Forest including savannah provides food such as fruits, bush meat, vegetables, among others.
ii. Provision of fuel: Dead forest wood serves as firewood or source of fuel used for cooking and other purposes.
iii. Provision of medicinal herbs: The forest also provides medicinal herbs used by local healers and pharmaceutical industries.
iv. Provision of employment and income: Forest provide employment to some people, for example, forest guards and those involved in lumbering activities. It also provide source of income to the rural people.

v. Forest serves as wind-breaks: Forest, especially in the Northern part of Nigeria, serves as wind-break, thereby reducing the speed of wind and controlling wind erosion.

vi. Formation of rain: Forest, because of their cool environment, help in the condensation of water vapour, resulting in the formation of rain.

vii. Prevention of soil erosion: Forest helps to absorb water splash on the soil and also due to vegetative cover, soil erosion is prevented. It also checks desertification and control floods.

viii. Addition of nutrients to the soil: Forest adds nutrients or improves the fertility of the soil through the decay of fallen leaves.

ix. Home of wild animals: Forest serves as the home of all wild animals like lion, tiger, antelope, rabbit, snakes, among others.

x. Forest serves as tourist centres: Forest, because of its beautiful scenery serve as tourist centre.

xi. Provision of foreign exchange: Forest serves as a source of revenue to the government. It also provides foreign exchange earnings for the country through the export of timber and its bye-products.

xii. Provision of timber: Forest provides timber for construction works like furniture, canoes and other domestic and industrial constructions.

xiii. Provision of pulp: Forest provides pulp used for tissue and paper making

xiv. Beautification of the environment: Forest trees planted around homes, industries and offices help to beautify the environment.

xv. Reduction of atmospheric pollution: Forest help in the purification of the air by removing carbon dioxide and adding oxygen to the atmosphere during photosynthesis.

xvi. Source of raw materials: Forest provides raw materials such as gum, latex, resins, ropes, dyes, fibres, rubber, palm-produce, oil seeds for both domestic and industrial purposes.

xvii. Research/educational purpose: Forest provides avenues to carry out Research/educational purposes.

4. SOME EFFECTS OF DEFORESTATION ON THE ENVIRONMENT

Deforestation has some negative effects on the environment and these include:

i. Deforestation encourages and also increases soil erosion.

ii. It leads to loss of organic matter, resulting in the loss of soil fertility.

iii. It reduces the amount of rainfall in the area. It can causes destruction of watershed.

iv. It decreases soil moisture retention.

v. It decreases the leaching of plant nutrients.

vi. It destroys the micro-climate and warns up the environment.

vii. It also reduces the forest fauna (wild life) population in the area concerned.

viii. It may lead to desert encroachment as sand particles are more likely to drop in areas without trees.

ix. It depletes the supply of forest produce (raw materials) to industries like timber.

5. SOME CAUSES OF DEFORESTATION IN NIGERIA

Distinguishing between the agents of deforestation and its causes is very important in order to understand the major determinants of deforestation (Chakravarty *et al.,* 2012). The agents of deforestation are those slash and burn farmers, ranchers, loggers, firewood collectors, infrastructure developers and others who are cutting down the forest. Causes of deforestation are the forces that motivate the agents to clear the forests (Chakravarty *et al.,* 2012).

i. Similarly, Pearce and Brown (1994) identified two main forces that affect deforestation such as Competition between humans and other species for the remaining ecological niches on land and in coastal regions. This factor is substantially demonstrated by the conversion of forest land to other uses such as agriculture, infrastructure, urban development, industry and others.

ii. Failure in the working of the economic systems to reflect the true value of the environment. Basically, many of the functions of tropical forest are not marketed and as such are ignored in decision making. Additionally, decisions to convert tropical forests are themselves encouraged by fiscal and other incentives. This latter factor has been termed indirect cause of deforestation but remained by far the most important.

Though the forests contribute substantially to the Gross Domestic Product (GDP), but the policies to regulate human interference with the forests contribute substantially to the GDP. The policies to regulate human interference with the forests so as to safeguard against depletion of this important resource have not been seriously pursued. This therefore reflects a government fiscal policies working at cross purposes with the value of the forest resources. In addition, most incentives which the government is expected to provide for the people to serve as alternative to forest resources are not provided, for example, the high cost of fossil fuels has forced people to utilize firewood and charcoal as alternative energy, high rate of unemployment has made people to turn to forest for means of survival and therefore has resulted to serious forest depletion. Furthermore, defective forest policies of the government greatly encourage deforestation, for instance most laudable policies like afforestation programmes, rainforest management (such as enrichment planting, taungya system, among others), creation of forest reserves, in–situ conservation processes among others are underfunded and neglected. The resultant effect of this is further deforestation.

Notwithstanding of the above scenarios, the following factors have been attributed to contribute substantially to deforestation in Nigeria:

i. Unfavourable climatic factors: Persistent and prolonged drought can lead to death of forest species. Also, wind blasts can destroy vegetation on its path.

ii. Farming activities: Man's farming activities can cause forest destruction through the use of forest land for crop production or grazing livestock, practising of bush fallowing or shifting cultivation which progressively leads to deforestation because the short fallow periods do not allow for sufficient forest regeneration.

iii. Timber exploitation: The practice of selective elimination of certain tree species in a natural forest causes deforestation. Also, the exploitation of timber for furniture, export, among others can cause deforestation.

iv. Mining/Industrialization: Forest trees are destroyed when the land is cleared for excavation for mining minerals. Also, petroleum exploration and sitting of industries involves clearing of forest.

v. Natural Disasters: Fire is the most serious problem to which forest are exposed, especially during the dry season. Bush burning is caused by fire used by farmers. Such fire may extend to the forest, thereby destroying tree species. Other natural disasters which can cause deforestation include landslide, earthquakes, volcanic eruptions and prolonged flooding.

vi. Timber exploitation: Government inadvertently introduces policies that can encourage felling of fuel woods and timber exploitation.

6. SUGESTED MANAGEMENT PRACTICES FOR SAVING NIGERIA FOREST FROM BOTH ENVIRONMENTAL AND ENERGY CRISIS

In order to ensure the continuous supply of timber from the forest and to save Nigeria forest from both environmental and energy crisis, the following suggested management practices are further suggested for adoption:

1. Forest Regulations: These are laws promulgated by government in form of edicts, decrees and bye-laws to prevent people from exploiting or indiscriminate tapping of forest resources. These regulations, therefore, ensure the prevention of forest resources. Forest regulation in Nigeria include the prohibition of bush burning; ban on indiscriminate cutting of timber trees; encouraging people to plant trees; ban on collection of leaves and firewood from the forests; ban on farming in forest reserves; ban on the cutting down of under-aged trees, among others. In addition, interested farmers or lumbers are expected to obtain license from regulating government ministry so as to secure permission to enable them cut down trees for human needs. The felling quantity should be based on the number of forest stands which must be determined before felling.

2. Selective Exploration: Selective exploration is the process of cutting only mature trees in a forest. It is a way of concentrating certain selected species of timber in a forest reserve. The system allows for the

cutting of older trees while the younger ones remain as cover to the surface of the forest. Some advantages of selective exploration include:

i. It ensures the concentration of selected species of timber in a forest.
ii. It protects the soil from erosion.
iii. It ensures the continuous supply of timber.
iv. It serves as a revenue base for the government.
v. It prevents indiscriminate felling of timber by giving licenses to saw millers by state forestry department of the ministries of agriculture and natural resources.
vi. It also prevents illegal felling of trees and farming by using forest guards to police the forest.
vii. Undesirable species of timbers are eliminated by this method.

3. Discouragement of deforestation: Deforestation is the continuous removal of forest stands (trees) either by bush burning of indiscriminate felling without replacing them. Economic trees such as iroko, obeche, omo, mahogany, among others are cut down so that they can be used for various purposes such as furniture like tables, chairs, doors, among others. Uncontrolled deforestation should be discouraged and if possible reduced to the barest minimum because of its adverse effects on both on the climate and the environment.

4. Regeneration: Regeneration is the process of forest re-growth after it has been exploited. It is a deliberate government policy in the restoration of deforested area after exploitation to balance the ecosystem. There are two main types of regeneration and these include natural regeneration and artificial regeneration. In natural regeneration, there is re-growth of new plants from old stumps. Under favourable environment, there exists the growth and development of new trees or volunteer trees from old stumps. The artificial regeneration on the other hand involves the natural planting of new forest seedlings in a deforested area. In the words, forest trees are established deliberately in a plantation. Some advantages of natural regeneration include: it is less expensive when compare with artificial regeneration; it does not require formal stages in plantation establishment; it brings about the stabilization of natural ecosystem in the area of its establishment; it does not require special management skills, etc.

5. Afforestation: Afforestation is the process of establishing forest plantations in any area. It involves the complete removal of natural vegetation before planting new forest species. In Nigeria, it is popularly referred to as tree planting campaign in which two seedlings of trees are recommended to be planted to replace any one plant harvested. Early stages of afforestation may include taungya farming (which is the planting of trees and crops on the same piece of land) to maximise the use of land and protect seedlings. Afforestation has many advantages as it leads to addition of organic

matter resulting in an increase in soil fertility; it provides a regular supply of raw material such as timber for industries; it prevents desert encroachment; it increases the forest fauna (wild life) in the area concerned; it builds-up the micro-climate and cools up the environment; it prevents the leaching of plant nutrient, among others.

6. Taungya farming: Taungya farming involves the planting of both food crops and forest trees on the same piece of land. In other words, it is a system which involves the integration of agriculture with forestry. Some conditions that may favour the practice of taungya farming include:

i. Scarcity of land: Taungya farming can easily be practised where land is scarce.
ii. Over-population: Land becomes scarce where there is over – population which can lead to the practice of the system.
iii. Unemployment: Mass underemployment or unemployment does lead people to practise taungya farming.
iv. Government policies: Government can put in place policies which will make people practise taungya system.
v. Low standard of living: This factor does force people to resort to the practice of taungya system as a means of alternative way of increasing their standard of living.
vi. Granting of incentive: Incentives such as loans to farmers can help them to take part in additional farming.

7. CONCLUSION

Deforestation in Nigeria has been mainly attributed to the rural farmers and grassroots poor people whose means of survival were basically embedded in the forests but on the other hand are been denied access to available forest resources. Other agents of forests depletion are mainly developmental projects oriented found in the Nigerian economic sectors like agriculture, oil and gas, transport, mining and materials, amongst others that contributed to technological growth. Persistent deforestation is further compounded by the fact that the majority of the Nigerian populace lacked in-depth knowledge of the consequences of deforestation. Ways of reducing deforestation must therefore go hand in hand with improving the welfare and environmental knowledge of the rural farmers and the populace otherwise they would fail. Urgent mitigating measures and strategies would remain elusive since these will vary from region to region and will change over time. Effective implementation is very essential including stakeholders participation, development of management plans, monitoring and enforcement of the suggested management practices for saving Nigerian forests from both environmental and energy crisis. The stakeholders should recognize the critical roles of government at the three levels of administration and also empower the civil society and the private sector to take proactive role in reducing deforestation by working in conjunction with government.

8. REFERENCES

Akinsanmi, F.A. 1999: Updating Environmental Information. Invited Lead Paper presented at the 26th Annual Conference of Forestry Association of Nigeria held in Maiduguri, Borno State, 7th to 12th November, 1999.

Aliyu, A., Modibbo, M.A.,Medugu, N.I and Ayo,O. 2014: Impacts of Deforestation on Socio- Economic Development of Akwanga in Nasarawa State. International Journal of Science, Environment and Technology, 3(2):403-416.

Chakravarty, S., Ghosh, S.K., Suresh, C.P.,Dey, A.N and Shukla, G. 2012: Deforestation: Causes, Effects and Control Strategies In: A.Okia (ed) Global Perspectives on Sustainable Forest Management. Available online at http:/www/Intechopen.com/books/global-pespectives-on-sustainable-forest-management/deforestation-causes-and-control strategies.

Egboh ,E.O. (1990): Forestry Policy in Nigeria, University of Nigeria Press, Nsukka, Nigeria

FAO, 1991: Food and Agriculture Organization Second Interim Report on the State of the Tropical Forest, Forest Resources Assessment 1990 Project Mimeo. Paper presented at the 10th World Forestry Congress in Paris, France.

FAO, 2001: State of the World's Forests. Food and Agriculture Organization, Rome.

FORMECU, 1996: Statistics of Forest Reserves in Nigeria. Forestry Management, Evaluation and Co-ordinating Unit, Benin, Nigeria.

Mfon, P., Akintoye, O.A., Mfon, G., Olorundami, T., Ukata, U and Akintoye, T.A. 2014: Challenges of Deforestation in Nigerian and the Millennium Development Goals. International Journal of Environment and Bioenergy, 9 (2):76-94.

Mohammed, R, Jimeta, U and Gisilembe,A,M. 1996:Legislation and the Environment: Towards a more effective regulatory framework in the Savannah and Sahel belts of Nigeria In: Issues in Environment Monitoring in Nigeria, The Nigerian Geographical Society, Pp 129-132.

Mortimore, M.J. 1989: Adapting to Draught: Farmers, Famine and Desertification in West Africa, Cambridge,

Myers, N. 1989: Deforestation Rates in Tropical Forests and their Climatic Implications.

Nigeria Yearbook, 1975: Times Press Limited, 120Pp.

Ogundele, A.T., Oladipo, M.O and Adebisi, O.M. 2016: Deforestation in Nigeria: The Needs for urgent Mitigating Measures. IIARD-International Journal of Geography and Environmental Management, Volume 2 No1 Pp 15-26.

Okekunle,A,T. 2002 : The Role of the Forests in the Amelioration of the Nigerian Environment
The Nigerian Field, Volume 67:31-33 , April, 2002 Edition, Publication of the Nigerian Field Society.

Pearce, D and Brown, K.1994: Saving the World's Tropical Forests In: K. Brown and D.Pearce (eds) The Causes of Tropical Deforestation. The Economic and Statistical Analysis of factors giving rise to the loss of the tropical forest, UCL Press, Pp 2-26.

World Bank, 1991: The Forest Sector, a World Bank Policy Paper, Washington, D.C, World Bank.

Proceedings of the 2021 National Engineering Conference
of the Nigeria Society of Engineers [NSE] .
Printed in Nigeria

STRIVING FOR EXCELLENCE ENGINEERING PRACTICE THROUGH ENERGY MIX IMPLEMENTATION STRATEGIES AND SUSTAINABLE POLICY

Oluwadare Joshua Oyebode
Civil and Environmental Engineering Department
Afe Babalola University, Ado-Ekiti
Ekiti State, Nigeria
oyebodedare@yahoo.com

ABSTRACT

Energy mix is needed for optimal performance of industries, strategic management of engineering resources and enhanced opportunities in energy sector. This paper identified criteria for excellent engineering practice through energy-mix implementation strategies and sustainable policies. Challenges confronting excellent implementation of proper energy mix were highlighted. Salient points and way forward were carefully checked and relevant discussions were made. Findings revealed that there are issues traceable to inadequate energy mix that culminates into under supply of energy, lack of capacity for expansion, deficit of sustainable policy regarding energy-mix and lack of circular economy and inadequate quality assurance. Nigeria as a nation need to key into global activities, and this places a premium of emphasis on energy efficiency. It was concluded that infrastructural development in power, transportation and energy sector require a solid foundation in energy mix for viable investment and the combination of adequate proportion of various sources of energy should be encouraged to prevent environmental pollution and energy deficit in Nigeria. Hence, there is need to strive for excellence engineering in practice through strategic energy-mix implementation, job creation, effective energy management, improvement of energy security, capacity building and sustainable policy. Regulatory bodies, engineering family, stakeholders, educators, investors and every tier of government have a special role to play in the formulation of the sustainable policy being sought for energy-mix implementation.

Keywords: Sustainable Policy, Energy Mix, Implementation, Engineering Practice, Strategic Management

1. INTRODUCTION

Striving for excellence engineering practice is critical requirement for energy mix implementation strategies and sustainable policy. The realization of the need to objectively tackle the prevalent, persistent and multi-faceted problems of energy resulted in the introduction of energy mix for excellence delivery, optimal power generation and productivity in residential and industrial areas in Nigeria.

Affordable and Clean Energy is one of the sustainable development goals that require urgent and strategic energy mix intervention for its realization. Most construction and manufacturing industries in Nigeria have been affected due to inadequate power supply and lack of adequate attention to energy mix. There is great need to strive for excellence engineering practice through energy mix implementation strategies and sustainable policy.

Engineers must continue to fulfill obligations to clients, ensure business viability and strive for excellence and robustness in the application of engineering principles. In addition, by adopting a sustainable development perspective, they must extend their role to ensuring that the real needs of all present end users are met, as well as recognizing impacts (and the opportunity for mitigation and benefit) on both the natural environment and future generations.

2. LITERATURE REVIEW

The destruction of the ecosystem, due to the strong emission of greenhouse gas into the atmosphere by humans has led to significant damage to wildlife, human health, and flora (Nematchoua et al, 2020).

Engineers must adopt a transparency in their business practices and a willingness to accept that by-products of construction activities may affect the well-being of people or damage the environment. Recent trends have seen increasingly tight environmental constraints being imposed on engineering activity. Indeed, the ability to mitigate environmental impacts successfully has been seen in the minds of many engineers as evidence that sustainability is being addressed and achieved. The areas of social equity, equal rights for development, democracy, public participation and empowerment are included in this aspect of the framework. Justice through participation calls for broad involvement and, through this, a willingness to share knowledge and achieve mutual learning (Fenner et al., 2006).

Energy transition follows when an economy changes from one significant source of energy to another. Past transitions largely occurred at national and sometimes regional level. Conversely, because of globalization, the present energy transition will likely encompass many regions of the globe (Stevens, 2019).

Cost and time overruns have become a cankerworm within the Nigerian construction industry today as well as lack of good quality work of its end product which do not provide many of the clients' value for money. Many constructions projects development have failed owing to the various technical and financial pressures of cost limit, quality and value optimization (Oyebode, 2019).

Achieving smart sustainable cities represents an instance of urban sustainability, a concept that refers to a desired state in which a city strives to retain the balance of socio-ecological system through sustainable development as a desired trajectory. The central role of cities in sustainable development is clearly reflected in the Sustainable Development Goals (SGDs) of the United Nations 2030 Agenda for Sustainable Development, which is about making cities resilient and sustainable (SDG Goal 11) (UN, 2015).

Smart sustainable cities represent a manifestation of sustainable urban development as a process of change and a strategic approach to achieving the long-term goals of sustainability. Urban planning (also referred to as city planning and urban development) is a governmental function in most countries worldwide. It is practiced on the neighborhood, district, city, metropolitan, regional, and national scales with land use, environmental, transport, local, metropolitan, and regional planning representing more specialized foci (Bibri, 2018). The environmental and human health risks are often not explicitly considered in lean initiatives that can affect customers & stakeholders throughout the product life cycle, and the manufacturing enterprises working with lean strategies have the possibility of costs sub-optimization and waste reduction from a lifecycle viewpoint (Mor et al., 2015).

Organizational behavior and stakeholder processes continually influence energy strategy choices and decisions. Although theoretical optimizations can provide guidance for energy mix decisions from a pure physical systems engineering point of view, these solutions might not be optimal from a political or social perspective (Weijermars et al.,, 2012).

The achievement of sustainable development goals (SDGs) depends on the access of modern, sufficient, and efficient energy to all people. Currently, developing countries including sub-Saharan Africa (SSA) are the most vulnerable to the environmental problems associated with the use of non-renewable energy. All countries are striving to develop and use sustainable renewable energy (RE) with zero, low, or neutral greenhouse gas emissions (Bishoge et al., 2020). To support advancements in data center sustainability, a regulatory environment is important, providing standardized requirements and evaluation methods. Energy use for ICT is ever more increasing and so are concerns on the sustainability of data centers. The use of a natural cold source can be a direct use or an indirect use. In direct use, outdoor air is directly introduced; humidity control and filtration are required. In indirect use, heat exchange equipment is used. The crucial point in using a natural cold source is the efficiency of the heat exchange between indoor and outdoor air (Rong et al., 2016).

Metrics and the regulatory environment are a useful framework to support actions. Several indicators have been introduced to assess the state of the art and future targets of single aspects of efficiency (energy efficiency, carbon impact, use of resources) (Manganelli et al., 2021).

Energy is tightly linked to the three dimensions of sustainable development: economic, environmental, and social. Energy services are obviously essential to economic and social development. To contribute to this ongoing development, the main issue in the energy sector will be to control the consumption of natural energy resources. In fact, we must set up a system for better compatibility of current living standards with the conservation of energy resources for future generations. Figure 1 presented cogent aspects of sustainability in major sectors.

Figure 1: Three Spheres of Sustainability

Energy transition (ET) is a major change from a dominant model to a different paradigm in energy system. It means moving from a socioeconomic and technological system to a different one, as regards energy supply and use. Figure 2 indicates the progression of energy from primeval ages till date. The third energy transition is transformation from fossil-fuel to renewable energy. Environmental considerations account most for this energy transition.

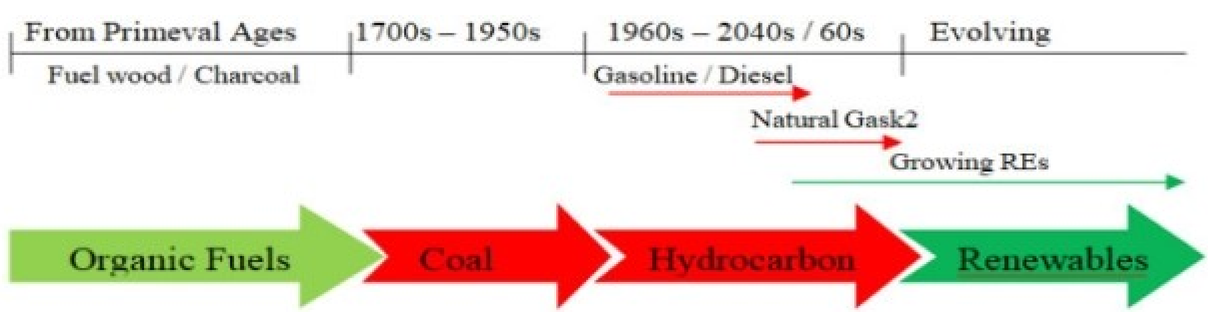


Figure 2: Progression of energy from primeval ages till date

3. METHODOLOGY

Methodology adopted includes secondary data from literature and interaction with notable experts in energy sector. Criteria for excellent engineering practice through energy-mix implementation strategies and sustainable policies were identified. Challenges confronting excellent implementation of proper energy mix were identified. Renewable energy is the current trends and many researches are going on in this direction. Figure 1 indicates a typical example of energy efficient building for green technology.

Table 1 also presented renewable potential and their current utilization in Nigeria.

Figure 3: Zero net building for Green Technology and Energy Efficiency

Table 1: **Renewable potential and their current utilization in Nigeria**

Resources	Amount	Current Use
Large hydropower	11,250 MW	1930 MW (17.1%) used
Small hydropower	3,500 MW	64.2 MW (1.83%) used
Solar	4.0–6.5 kWh/m^2/day	27% Capacity Factor (Negligible)
Wind:	2–4 m/s @ 10 m hub height	
- Onshore wind	1,600 MW	Negligible use
- Offshore wind	800 MW	Negligible use
Geothermal	500 MW	Negligible use
Biomass (Non-fossil fuel):		
Municipal waste	30 million tonnes/year	0.5 kg/capita/day
Fuel wood	11 million hectares of forest	43.4 million/tonnes/yr consumed
Animal waste	1.05 tonnes/day	Negligible use
Agricultural residues	91.4 million tonnes/yr produced	Negligible use
Energy crops	28.2 million hectares of arable land	8.5% cultivated

Source: (Adewuyi et al., 2020)

4. CHALLENGES CONFRONTING EXCELLENT IMPLEMENTATION OF PROPER ENERGY MIX IN NIGERIA

Challenges confronting excellent implementation of proper energy mix include:

i. Lack of adequate reconnaissance survey and feasibility studies for holistic and energy mix implementation system.

ii. Lack of sustainable policy and implementation strategies

iii. Lack of encouragement and funding for engineers and researchers on energy related fields.

iv. Lack of data, enforcement and documented standards

v. Lack of proper repair and maintenance of energy systems and equipment.

vi. Inadequate training, manpower development and capacity building in energy sector.

vii. Inadequate attention to health, safety and environmental guidelines.

4.1 Criteria for Energy Mix Implementation

Engineers can strive for excellence engineering practice through energy mix implementation strategies, viable development, national economic growth and sustainable policy. To scale up energy service delivery, implement predictable, supportive and consistent government policy and regulation that prioritizes or incentivizes energy access.

The continuous growth in size, complexity and energy density of data centers due to the increasing demand for storage, networking and computation has become a worldwide energetic problem. The emergent awareness of the negative impact that the uncontrolled energy consumption has on natural environment, the predicted limitation of fossil fuels production in the upcoming decades and the growing associated costs have strongly influenced the energy systems engineering work in the last decades.

In order to ensure the sustainability of energy supply and subsequently the sustainable economic development of the country, the government has to intensify the further implementation of renewable energy and energy efficiency programs. Moreover, instead of flaring gas in Nigeria, the gases can be converted to methanol and used as a fuel for both domestic and industrial use. With good energy efficiency practices and products, the burning of fossil fuel for energy will be greatly minimized. The ability of Nigeria to mitigate the impact of growing global energy transition is premised on developing economic capacity (highly diversified economy), resource management and adoption of renewable in its energy mix. The pursuit of sustainable energy is strongly associated with political will and the necessary socio-economic structure, which differs across the regions of the world.

Massive deployment of renewable energy systems in Nigeria has great future if only the right political and legislative framework can be put in place. Energy poverty is a major barrier to national development, effective engineering practice in Nigeria and high level of investments required to scale up Africa's energy systems. Figure 4 identifies percentages for various sources of energy in a typical location while Figure 5 presented Global energy consumption from 2000 to 2019.

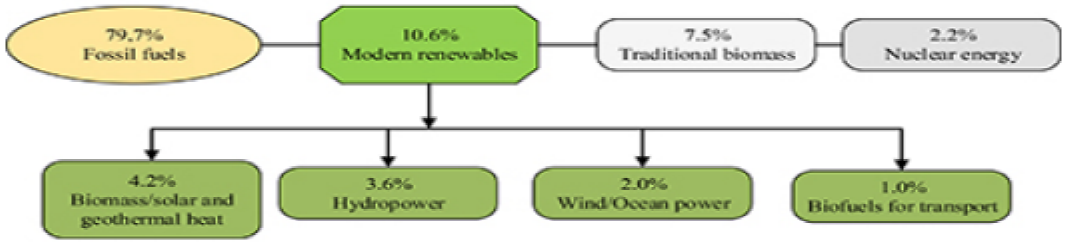


Figure 4: Percentages for various sources of energy

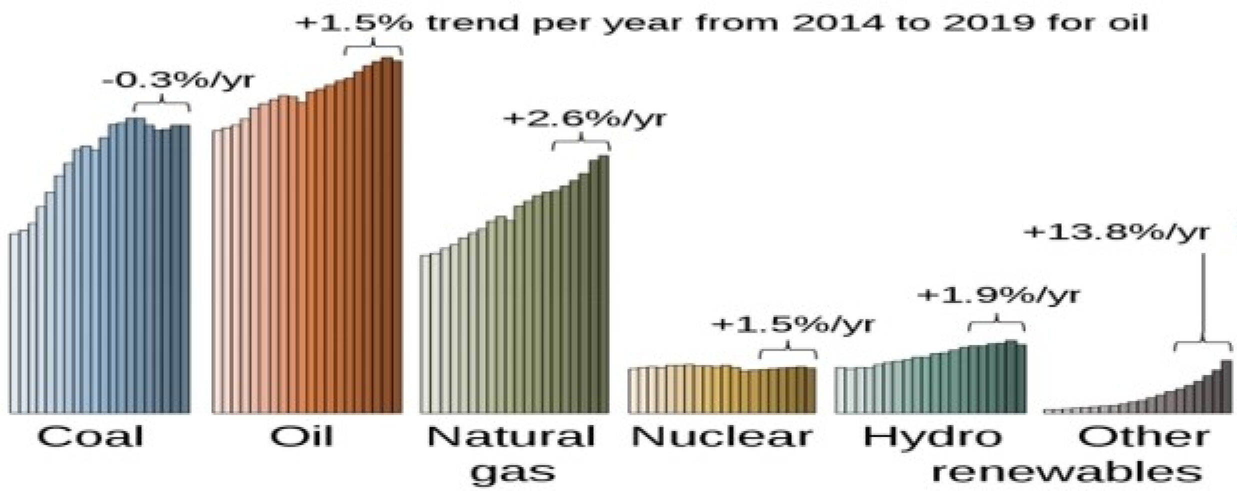


Figure 5: Global energy consumption from 2000 to 2019

Findings revealed that there are issues traceable to inadequate energy mix that culminates into under supply of energy, lack of capacity for expansion, deficit of sustainable policy regarding energy-mix and lack of circular economy and inadequate quality assurance. Nigeria as a nation need to key into global activities, and this places a premium of emphasis on energy efficiency. Coal, oil, and natural gas remain the primary global energy sources even as renewables have begun rapidly increasing. Table 2 presented hydropower projects under development in Nigeria.

Table 2: Hydropower projects under development in Nigeria

Power station	Capacity (MW)	Location (State)
Zungeru	700 MW	Kaduna
Mambilla	3050	Niger
Gurara II	360	Taraba
Gurara I	30	Kaduna
Itisi	40	Kaduna
Kashimbilla	40	Taraba

Source: (Falobi et al., 2020).

The policy design cycle is indicated in figure 6.

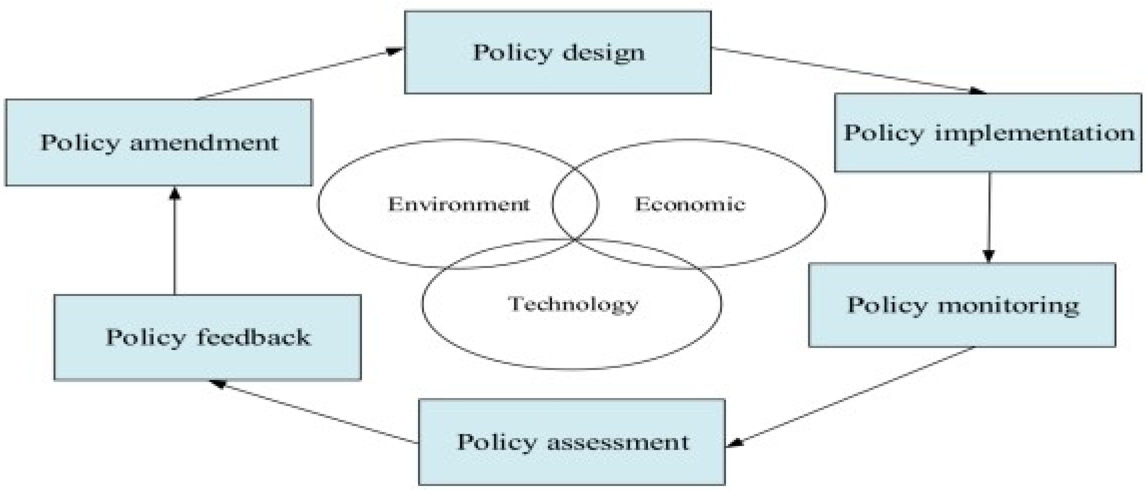


Figure 6: The policy design cycle

Source: Source: (Lu et al., 2020)

Prioritize access to free energy for the energy-deprived, and modernization of traditionally free and local energy sources. Reduce energy waste to support affordability and maximize availability, through measures such as retrofits to homes and businesses. Affordability must be the fundamental consideration in delivering sustainable energy access. Figure 7 presented energy increase, fuel shift, hybridization and deep decarbonation relationship.

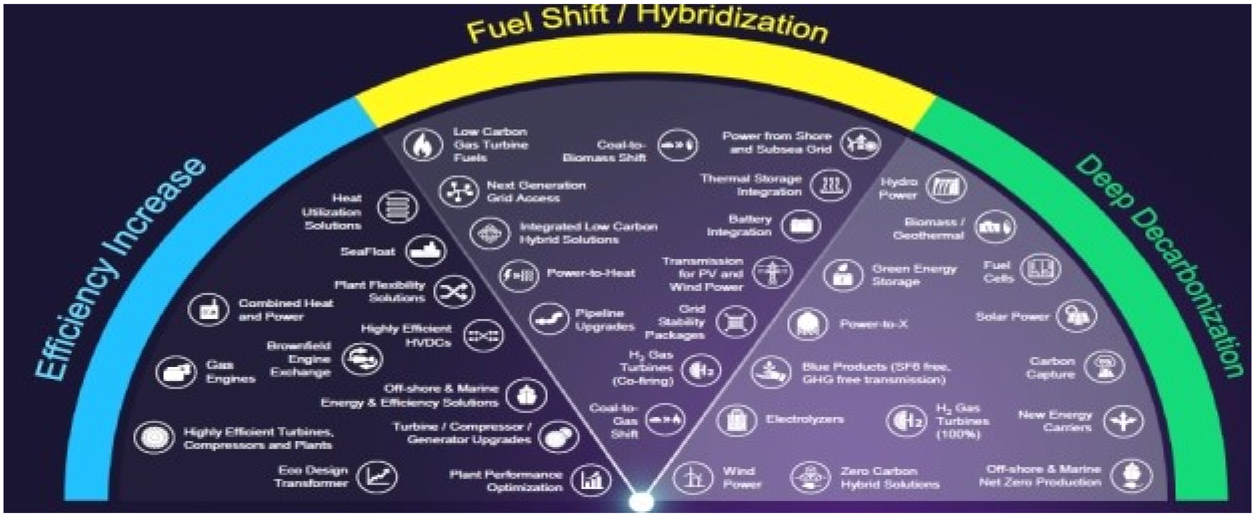


Figure 7: Energy increase, fuel shift, hybridization and deep decarbonation relationship

5. CONCLUSIONS

Infrastructural development in power, transportation and energy sector require a solid foundation in energy mix for viable investment and the combination of adequate proportion of various sources of energy should be encouraged to prevent environmental pollution and energy deficit in Nigeria. Hence, there is need to strive for excellence engineering in practice through strategic energy-mix implementation, job creation, effective energy management, improvement of energy security, capacity building and sustainable policy.

Access to clean and modern energy is critical to fostering a lasting social and economic development and for achievement of sustainable development goals. The importance of policy to energy transitions is critical. Policymakers frequently depend on policy instruments such as price mechanisms to set out sustainable energy without considering the issues of justice and greater political and economic concerns of ownership of the energy system, the technologies that are employed and how the energy is utilized.

Out of all energy resources, we consider green power (solar, wind, biomass and geothermal) as the cleanest form of energy. From an engineering perspective, energy demand may be reduced by: improving the thermodynamic efficiency of energy conversion devices such as boilers and engines; preserving, heat, light, momentum or materials in passive systems, such as houses, cars and steel bars; or reducing demand for final energy services.

Strategies and action plan must be deployed to manage the supply, procurement, cost and efficiency of energy across all areas of engineering works for the benefit of our nation. Renewable energy and energy efficiency have a cross-cutting effect on the economy and demands special attention from all sectors of any economy.

6. RECOMMENDATIONS

Recommendations include the following:

i. Nigerian society of engineers, regulatory bodies, engineering family, stakeholders, educators, investors and every tier of government have a special role to play in the formulation of the sustainable policy being sought for energy-mix implementation.

ii. There is need to ensure universal access to modern energy services; doubling the global rate of improvement in energy efficiency; and doubling the share of renewable energy in the global energy mix.

iii. Healthy public private partnership for design, construction and implementation of energy projects, laws and policies.

iv. Use a variety of efficient energy sources, equipment and appliances at a variety of scales, as the traditional power sector alone will not and cannot deliver an end to energy poverty. States must play an important policy role in regulating the energy market, ensuring that deprived communities are guaranteed access.

v. Ensure access to adequate financing for small enterprises, social enterprises and end-users of renewable technologies.

vi. Establish an independent technology assessment mechanism to assess the ecological and health impact of new technologies at international, regional and national levels.

vii. Implementation strategies and legal structures should be put in place to strengthen the use of energy mix and renewable energy sources.

viii. Involvement of engineers, energy professionals and policy experts in all energy projects.

ix. Establish an agency to promote the use of energy-efficient products and ensure the appropriate practices.

x. Develop and imbibe energy efficiency technologies and creation of awareness on renewable energy and energy efficiency.

xi. Training, continuous learning and professional development are crucial for effective management, excellence professional practice, energy mix implementation strategies and sustainable policy will strengthen our energy sector.

REFERENCES

Adewuyi OB, Kiptoo MK, Afolayan AF, et al. (2020) Challenges and prospects of Nigeria's sustainable energy transition. *Energy Rep* 6: 993-1009. doi: 10.1016/j.egyr.2020.04.022

Bibri, S. E. (2018). Backcasting in futures studies: a synthesized scholarly and planning approach to strategic smart sustainable city development. *European Journal of Futures Research*, *6*(1), 1-27.

Bishoge, O. K., Kombe, G. G., & Mvile, B. N. (2020). Renewable energy for sustainable development in sub-Saharan African countries: Challenges and way forward. *Journal of Renewable and Sustainable Energy*, *12*(5), 052702.

Falobi EO (2020) The role of renewable in Nigeria's energy policy mix. *Int Assoc Energy Econ (IAEE)* Energy Forum/First Quarter 2020: 41-46.

Fenner, R. A., Ainger, C. M., Cruickshank, H. J., & Guthrie, P. M. (2006, December). Widening engineering horizons: addressing the complexity of sustainable development. In *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* (Vol. 159, No. 4, pp. 145-154). Thomas Telford Ltd.

Lu, Y., Khan, Z. A., Alvarez-Alvarado, M. S., Zhang, Y., Huang, Z., & Imran, M. (2020). A critical review of sustainable energy policies for the promotion of renewable energy sources. *Sustainability*, *12*(12), 5078.

Manganelli, M., Soldati, A., Martirano, L., & Ramakrishna, S. (2021). Strategies for Improving the Sustainability of Data Centers via Energy Mix, Energy Conservation, and Circular Energy. *Sustainability*, *13*(11), 6114.

Mor, R., Singh, S., & Bhardwaj, A. (2015). Learning on lean production: A review of opinion and research within environmental constraints. *Operations and Supply Chain Management: An International Journal*, *9*(1), 61-72.

Nematchoua, M. K., Asadi, S., & Reiter, S. (2020). Influence of energy mix on the life cycle of an eco-neighborhood, a case study of 150 countries. *Renewable Energy*, *162*, 81-97.

Oyebode, O. J. (2019). Input of Effective Cost Control in the Management of Construction Works and Architectural Excellence in Nigeria.

Rong, H.; Zhang, H.; Xiao, S.; Li, C.; Hu, C. Optimizing energy consumption for data centers. Renew. Sustain. Energy Rev. 2016, 58, 674–691. [CrossRef]

Stevens P (2019) The geopolitical implications of future oil demand, Research Paper. *The Royal Institute of International Affairs: Chatham House*, 1-42.

United Nations (2015) Transforming our world: the 2030 agenda for sustainable development, New York, NY. Available at: https://sustainabledevelopment.un.org/post2015/transformingourworld

Weijermars, R., Taylor, P., Bahn, O., Das, S. R., & Wei, Y. M. (2012). Review of models and actors in energy mix optimization–can leader visions and decisions align with optimum model strategies for our future energy systems? *Energy Strategy Reviews*, *1*(1), 5-18.

NATURAL GAS AS A SOURCE OF POWER SUPPLY

[1]Aliemeke B. N. G., [2]Ehibor, O. G. & [3]Omoakhalen, A. I.
[1,2,3] Department of Mechanical Engineering, Auchi Polytechnic, Auchi.

ABSTRACT

The economic growth and social development of any nation depends largely on the sufficiency of its power and energy sector. In order to bring about the realization of the Sustainable Development Goals (SDG) for 2030 as canvassed by the United Nations it is imperative that provision of adequate energy to drive key sectors of global economy must be brought to the fore.. Nigerian is known to be capable of generating about 11900MW of electricity from various gas power stations in the country. Nigeria has been confronted with massive exportation of Natural gas as means of generating revenue without taking into cognizance of the fact that she is inadvertently shortchanging the power sector which is left with of little quantity of gas to run the gas stations for the production of electricity. Analysis of the production and consumption rate data carried out showed that between 2000 and 2019 the flared gas reduced from 65% to 17%. The major challenges that have acted as drawbacks for the Natural gas production are insecurity, poor governmental policies, corruption, vandalization of production equipment by criminals and host community unrest. Some recommendations were made on how to increase gas production and utilization for robust and improved power supply.

Keywords. Natural gas, power supply, electricity and energy.

1. INTRODUCTION

Energy security is the bedrock required for any country to takes its place in the comity of nations. It is an important requirement for the enhancement of human capital and economic development for any continent (Okpare, Tanno & Oniyemofe, 2009). Africa has been known to be deficient in the provision of adequate power supply to drive the various key sectors of its economy as a result has brought untold had hardship to the region since tremendous and revolutionized industrialization can not come to play in at

the face of gross dearth of power supply (Okpare, Oniyemofe & Edward, 2010). For a country to develop fast it will be imperative to generate power from utmost available resources within its environment. In targeting the realization of the Sustenance Development Goals for availability of power and energy for 2030 all hands must be on deck to ensure that power and energy is made abundant to drive key areas of the social, economical and environmental developmental sectors (Akorede, Ibrahim, Amuda, Otueoze. & Olufeagba, 2017). Nigeria as a country is capable of producing over 12,000MW of electricity for her citizens but often times this is not realizable as a huge amount of the natural gas required for energy production are flared into the atmosphere thereby amounting to colossal waste. Also, a portion of the natural gas produced in Nigeria is exported to earn foreign exchange for the country leaving the power sector with a meager amount of the mineral (Akuru & Okoro, 2014).

It is worthy of note that energy is a great influencer of enomomy as it lead generation of huge output for companies and massive employment for citizens the nation (Akorede, Hizam, & Pouresmaeli, 2010). The degree and amount of economic activities been turned out in any nation is a function of the amount of energy put to use in the powering of the production, transport and service sectors. Energy has been seen as driving force required man to convert raw materials to transformed products and provision of economy based useful services (Babajide, 2017).

Modern energy required for the production of power supply is obtained from crude oil, natural gas, wind power plants, hydro power plant, nuclear and solar power plants (Abdulkareem & Odigure, 2010). In carrying out the production of the energy using the power plant important components such as combustion chamber, compressor, turbine, intercoolers, reheaters and heat exchangers are required to work efficiently to increase power outputs, thermal efficiency, work ratio and cycle efficiency (Ahaotu, 2006).

One of the greatest priviledges Nigeria as a country relishes on is the situation of vast deposit of crude oil in her soil. This crude oil is the chief source of natural gas which required for energy and power generation. Nigeria is known to have over 190 trilion cubic feet of gas in its reserves and she is ranked 25th greatest producer of natural gas in the world (Ajayi & Ajanaku, 2009).

The greatest bottleneck manufacturing sectors, service providing industries and good standard of living suffers is lack of adequate power supply that is advertently linked to underutilization of natural resources within our environment (Biose, 2019). In attaining a considerable height in provision of energy, attention and effort must be geared towards timely exploration of the natural gas resource so as to obtain the full benefits of the conversion into energy. The application of natural gas as a source of power supply is right direction for any developing nation as ours.

2. METHODOLOGY

There are basically two main types of power generating plants in Nigeria. They are thermal or fossil fuel power plant and hydro electric power plant. The Nigeria power supply mix is reputed to be dominated by the use of thermal (gas fired) power plant. The thermal power plant comprises mainly of natural gas fired and coal fired power plants (Akpan, 2009).

2.1 Production of the Natural Gas

Natural gas is a kind of fuel which has its formation similar to that of non-renewable of fossil fuel as a result of the decay of dead animals and plants over 250 million years ago (NEED Project, 2017). It is actually applied in heat engines to generate energy used in the production electricity through the turbine of the gas plant. the gas is a mixture of hydrocarbon and non-hydrocarbon gas formed under the earthcrust. The natural resource is comprised of methane, ethane, propane, butane, carbon-dioxide and other minor gaseous constituents (Uchegbulam, Opeh. & Atenaga, 2014). The odourless, colourless, non toxic natural gas has methane as it largest constituent followed by ethane, propane and butane.

In production of dry quality of the natural gas a technical separation of the hydrocarbon and some accompanying fluids must be observed. In exploration of the gas from the earthcrust the following processes are observed. Probing the rock surfaces to trace any evidence of the natural gas. Application of explosions and heavy weights on the earth crust in response of the reflected sound waves from the rocks

The earth gravitational pull on the rock masses is measured and recorded appropriately

For a well ascertained seismic results drilling of the natural gas deposit is recommended. Extraction of the deposit is carried out and transported to the distilling processing plant where it is cleansed before been separated fractionally into components with methane maintaining a composition of about 90% as the chief constituent. Other gases present are ethane, propane, butane, pentane, carbon dioxide, nitrogen and some inert gases.

The produced natural gas is transported from source point to its final point through underground pipes. The speed of the gas decreases with distance as result of collision of the gas particles as such a gas booster compressor station is required after every 50km to increase the the pressure of the gas.

Gas is stored in reservoirs during hot seasons to ensure it is available in cold season.

2.2 Power Generation in Nigeria

Over the years our generation of power has revolved around the use of oil, gas and hydroelectricity. Electrical power in Nigeria is generated mainly from hydroelectricity and gas power plant. Majority of the gas turbine plants are located in the southern part of the country because of the utmost availability of natural gas and other related natural resources in the region (Udok & Akpan, 2017).

Recently, some coal excited hydroelectric power stations have come the fore in Nigeria (Ajumogobia & Okeke 2015). In power generation, the processed natural gas is transported to the gas turbine plant where it mixes with air in the compressor. The product from the compressor is moved into the combustion chamber where it is met with intense heat.the combustion product is the energy required to power the turbine which in turn generate electricity.

2.3 Natural Gas Produced Electricity

Natural gas accounts for about 88% of the total electricity generated in the National grid while the remainder is produced using hydropower. Plants.

3. RESULTS AND DISCUSSION

The capacity and status of the various thermal gas plants (Natural gas fired) in Nigeria are stated on Table 1.0.

Table 1.0: Natural gas fired thermal plants in Nigeria

Power station	Location	Installed Capacity	Status	Year completed
AES barge (IPP)	Egbin	270MW	Non opertional	2001
Aba (IPP)	Abia state	140 MW	Non operational	2012
Afam IV – V	Afam, Rivers	726MW	Partially operational	2010
Afam VI	Afam, Rivers	624 MW	operational	2015
Alaoji	Abia state	1026 MW	operational	2015
Calabar	Cross river	561MW	Non operational	2014
Egbema	Imo state	338 MW	Non operational	2013
Egbin	Lagos state	1324 MW	Partially operational	2007
Geregu I	Kogi state	414 MW	Partially operational	2012
Geregu II	Kogi State	434 MW	Partially operational	2009
Ibom	Akwa Ibom	190 MW	Partially operational	2009
Ihonvor	Benin city	450 MW	Partial operational	2013
Okpai	Delta state	480 MW	Operational	2005
Olorunshungo I	Ogun state	336 MW	Partially operational	2007
Olurunshungo II	Ogun State	675 MW	Partially operational	2012
Omoku I	River State	150 MW	Operational	2005
Omoku II	Rivers State	225 MW	Non operational	Incomplete
Omotosho I	Ondo State	336 MW	Partially operational	2005
Omotosho II	Ondo State	450 MW	Partially operational	2012

Sapele I	Delta State	1032 MW	Parttially operational (380MW)	1978-1981
Sapele II	Delta State	450 MW	Partially operational	2012
Transorp Ughelli	Delta State	900 MW	Partially Operational	1966-1990 (4 phases)
Ibom	Akwa Ibom	191 MW	Operational	2010
Azura	Benin city	450 MW	Opeational	2018

The coal fired thermal plant stations are shown on Table 2.0

Table 2. Coal fired thermal plant stations

Power stations	Location	Installed Capacity	Status	Year of completion
Itobe power station	Kogi State	1200 MW	Non operational	2020

The hydro electric power station current status and capacity are summarized on Table 3.0

Table 3. Hydro electric power stations in Nigeria

Hydro electric station	Location	Installed Capacity	Status	Year of completion
Kainji	Niger state	800 MW	Operational	1968
Jebba	Niger state	540 MW	Operational	1985
Shiroro	Niger state	600 MW	Operational	1990
Zamfara	Zamfara state	100 MW	Operational	2012
Kano	Kano state	100MW	Operational	2015
Dadin Kowa		40 MW	Operational	2018
Mambila	Taraba state	3050 MW	Non Operational	2024 (proposed)

The result shown from the table is as given:

Table 4.0: Comparisons of production of the power plants

Type of power plant	Total power in MW	Percentage of Power(%)
Gas turbine	3629	51.78
Hydroelectric	2180	31.10
Coal	1200	17.21
Total	7009	

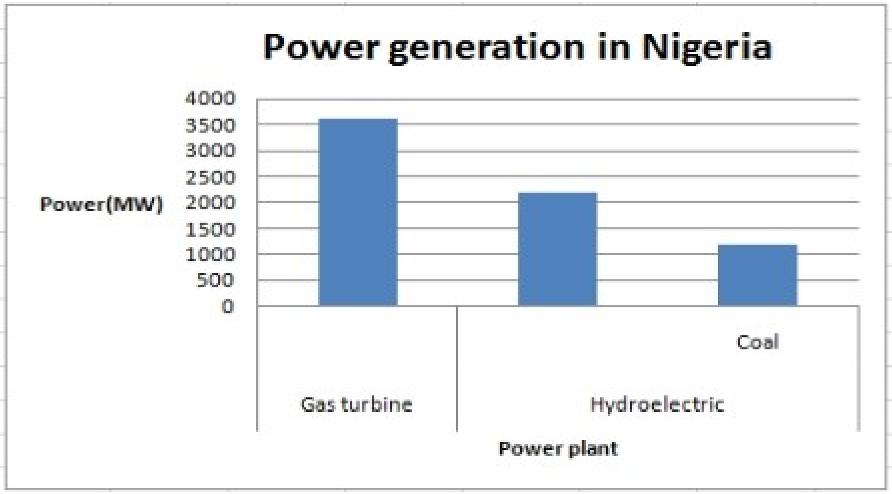


Fig. 1 Power plant comparisons

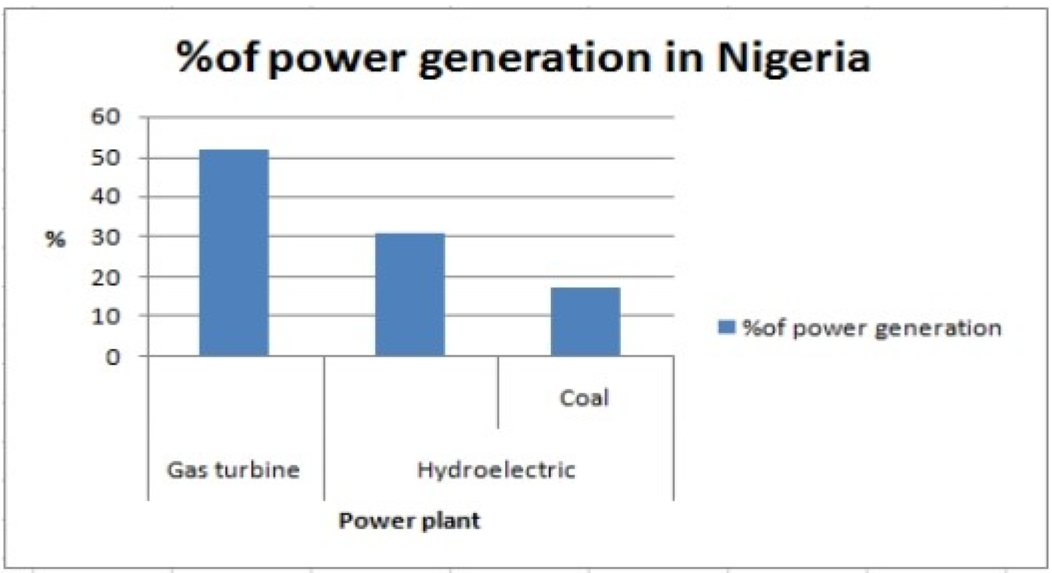


Fig. 2: Percentage comparisons of Nigerian power plants

3.2 Challenges in Production of Natural gas

- Environmental Hazard: Gas flaring remains one of the worst agent of pollution.
- Ineffectiveness of the government of the day to create an enabling environment in the gas industry has been a major setback in the production of power and energy.
- Lack of adequate funding in the gas sector has not encouraged the availability of the natural resources in the requisite quantity.
- The Government inability to embrace and sponsor latest technology in the gas sector has been a major hindrance power production. The present transmission network in the country is

outdated and will require total overhauling vis a vis system upgrade

- Insecurity challenge in the Niger Delta part of Nigeria has been an explicable hindrance to the production of natural gas for the production of energy as pipelines carrying petroleum products are often attacked by restive youths and sometimes the oil and gas workers are kidnapped from various oil platforms and formations.
- Corruption among the regulatory bodies of the oil and gas sector has also been a major set back in the adequate production of electricity.

3.3 Suggestion on the way forward for the sector

Suggestions on the way forward for the gas sector are predicated on the outright adherence to practicable ethics inherent in the oil and gas sector.

- Gas flaring should be discouraged forthwith and defaulters made to suffer penalty
- Government should ensure that adequate provision of facilities is made ready for the gas sector.
- Attention should be paid to the various power plants across the entire country.
- Energy companies should be encouraged to invest in the production of natural gas in the country. Enabling environment should created for participation of local and foreign investors.
- The nation's renewable energy blueprint plan drafted, in 2005 should be implemented without further delay to complement the various power plants energy production.

4. CONCLUSION

For a stable and dependent economy power generation is the right direction to go. This study reveals the growth and challenges associated with the gas power plant sector in Nigeria This profound study shows that 51.7% of power production is thermal gas power plant while hydroelectric capacity has 38.4%. It amounts to a huge waste when power plants are built and to put into operation to achieve its required capacity. The has a great potential to generate beyond the 5000MW it presently generates if the various gas and hydro electricity plants are made to work to 70% of design capacity. The existing transmission lines must be revamped and enlarged to accommodate the ever-increasing load. Multinationals firms must be encouraged in power and energy investment by creating the enabling political and economical environment for them to operate.

REFERENCES

Abdulkareem, A. and Odigure, J. (2010). Economic Benefit of Natural Gas Utilization in Nigeria: A case study of the food processing industry. *Energy Sources, 5*(23), 106-114.

Ahaotu, J. O. (2006). An evaluation of the potentials of Natural gas in the economic development of Nigeria, Masters Thesis, Department of Mechanical Engineering, Faculty of Engineering, University of Nigeria, Nsukka.

Ajayi, O. O. & Ajanaku K. O. (2009), Nigeria's Energy Challenge and Power Development: the way forward. Energy and Enviroment, 20(3), 411-413.

Ajumogobia and Okeke (2015). Nigerian Energy Sector: Legal and Regulatory Overview. Available at: http://www.ajumogobiaokeke.com/wp-content/uploads/2018/01/2b13946e4257859eb7988150d1c620a2.pdf . Accessed on November , 20202

Akpan, S. E. (2009). The Production and Utilization of Natural Gas Resources in Nigeria: A Review. The Nigerian Annual International Conference and Exibition, Abuja, pp. 3-5

Akorede, M. F., Ibrahim, O. Amuda, S. A., Otueoze,A. O. and Olufeagba, B. J. (2017). Current Status and Outlook of Renewable Energy Development in Nigeria. *Nigerian Journal of Technology, 36*(1), 196-212.

Akorede, M.F., Hizam, and Pouresmaeli (2010), Distributed energy resources and benefits to the environment", *Renewable and sustainable energy Review* 14(4),724-734.

Akuru, U B and Okoro, O. I.(2014) " Renewable Energy Investment in Nigeria: A review of the Renewable Energy Master Plan", *Journal of Energy in Southern Africa, 25*(3), 14-19

Babajide, N. (2017). Economic and Environmental Implication of High Gas Dependence for Electricity Generation in Nigeria. 10th NAEE/IAEE International Conference, April 23-26, 2017. PTDF conference centre, Abuja Nigeria, pp. 1-17

Biose, H. (2019). Gas Production and Utilization in Nigeria: A long term perpective. *International Journal of Engineering Technologies and Management Research, 6*(5) 58-72..

Okpare ,A, O. , Tanno, k. O. and Oniyemofe, C. O. (2009) "in search of a viable solar power development in Nigeria: A case study from selected states in the six geopolitical regions of the country", Nigerian Journal of Research and Production, 15(1) ,145-149.

Okpare A. O. , Oniyemofe, C. O. and Edward, B. A (2010). "Ensuring power energy availability through energy control and conservation for sustainable national development in Nigeria". *International Journal of Engineering Science*, *2*(2), 68-72.

Uchegbulam, O., Opeh, R. N. and Atenaga, M. O. (2014). Assessment of Power Generation Resources in Nigeria, *IOSR Journal of Applied Physics*, *6*(2), 44-50.

Udok, U. and Akpan E. B. (2017), Gas Flaring in Nigeria: Problems and Prospects. *Global Journal of Politics and Law Research*, *5*(1)16-28.

THEME FOCUS:

PUBLIC PRIVATE PARTNERSHIPS (PPP) AS VERITABLE TOOL FOR SUSTAINABLE ENERGY

Proceedings of the 2021 National Engineering Conference
of the Nigeria Society of Engineers [NSE] .
Printed in Nigeria

DESIGN AND IMPLEMENTATION OF A 3.0KVA SOLAR POWERED SYSTEM AT THE DEPARTMENT OF MECHANICAL ENGINEERING STAFF OFFICES THE FEDERAL POLYTECHNIC ILARO

Chapi, S. P[1]., Adio, M. A[2]. Ramonu, O. J[3]. Babarinde, F. B. Irmiya[4]
[1,2,3]The Department of Mechanical Engineering, The Federal Polytechnic Ilaro
[4]The Department of Electrical Engineering, The Federal Polytechnic Ilaro
Corresponding author: mayowa.adio@federalpolyilaro.edu.ng

ABSTRACT

*Electricity is a driving force for meaningful academic research and development. Electricity generation inNigeria is far below the optimum level, hence, its supply has become epileptic and can no longer sustain any meaningful academic and productive work. Since itsproduction and supply in Nigeria have become a very huge challenge, alternative means of generating it should be a welcome development.The earth is said to receive directly from the sunlight above 1366W approx. of solar energy every day, which makes solar energya non-vanishing renewable source of energy, which is in abundance, free and eco-friendly. It will be highly sustainable in Nigeriafor the greater part of the year, since the sunlight is always at its peak, providing a viable alternative to producing electrical energy. This paper designed and developeda 3.2 KVa Solar Powered Systems to energize non-motorized electric appliances such as lamps, laptops computers and ceiling fans with 2080, 9600 and 6400 watt-hours respectively, whose total daily power output stands at 2260watts in the departmental offices of the academic staff of the Department of Mechanical Engineering. This total requirement of approximately 2260watts has guided the authors' judgement in considering this low-cost design: PV panel Peak Watt Rating (Wh) of 3005.75W, an inverter size of 3.2KVa and six (6) batteries with a combined estimated value of **904AH.**The total cost of the project is estimated to be about Two Million Naira only (**₦2,000,000**).*

Keywords: Design, implementation, solar, powered, staff, and offices

1. INTRODUCTION

Renewable energy has generated more interest in recent time as a viable alternative to the conventional energy due to increasing prices of the fast depleting fossil fuel. The solar energy is the most prominent among all the renewable energies for its sustainable energy source, which is abundantly and readily available for generation of electricity.

Solar photovoltaic system is a modern technology used in the conversion of sunlight into electrical energy. This system has many advantages over other conventional electricity power generation systems. For example, absence of noise, wear and tear, make this source of power generation highly preferable. The solar photovoltaic system is used mainly for electricity power generation from solar energy for various applications.

The configuration of the solar photovoltaic system is a simple one. The process of generation involves the conversion of sunlight into electrical energy by the photovoltaic modules, storage and delivery of the electrical energy by the battery into usable form. The battery charging level regulation, is done by the charge controller to regulate the level of charging to and its discharge from the battery. The output of the batteries can be used directly to power certain low DC Voltage loads in the office such as computer systems and bulbs. The DC voltage can also be converted to AC voltage with the aid of an inverter to run AC-loads.

Solar photovoltaic system has high potential to provide electricity power for both the departmental staff offices and academic staff where access to constant electricity supply for research works and other academic engagements have become a challenge. The solar system provides an alternative source of electricity power supply to supplement the existing epileptic national power supply generally and in Ilaro, Ogun state, in particular. Epileptic power supply in the country generally, contributes mostly to low productive man power and lack of cutting-edge research works in academics. These consequently, have negatively impacted the economy of the Nation. Solar photovoltaic system can be connected in series and parallel to produce sufficient current and voltage required for daily use in the departmental offices.

The solar photovoltaic system designed with installed capacity of approximately 3006 W, in the department, will generate sufficient electrical energy to both departmental and academic staff members' offices to meet their daily energy demands at any point in time during the day and night time without depending on government utility grid.

The term "Renewable energy" covers all forms of energy generated from natural resources such as sunlight, wind, water (or hydro power), tidal, geothermal heat, biomass and biofuels. These natural resources are harnessed and are in abundance to constantly replenished such that each of them has distinctiveness that determines where and how they are applied (Federal Ministry of Environment, 2013), since almost all renewable energy sources are derived directly or indirectly from the Sun. It releases more energy per hour than the earth expends in one year. It is free from pollutants, greenhouse gases and highly secured from geo-political constraints and conflicts. The amount of solar energy reaching the Earth's surface is about 100,000 TW (Yeramilli, 2012). The total global primary energy consumption in 2012, was 12,476.6 million tons of oil equivalence or 145,103 TWh. The BP Statistical Review of World Energy, that is, BP 2020 report, reveals that it is certain the global annual energy consumption can be availed by solar energy in every 88 minutes or about 6000 times total annual energy usage yearly. It is the world's most abundant and constantly permanent energy source that reflects different appearances depending on the earth's surface landscape (Sen, 2008). In essence, solar energy will play a pivotal role and will serve as a panacea and a sure guarantor to developing countries' energy needs in the future as well as across the globe. In particular, Nigeria is favourably located in a belt in the West African Sub-region and lies between longitudes 3 degrees and 14 degrees and latitudes 4 degrees and 140 degrees, being just above the equator, which receive abundant sunshine all the year round (NEP, 2003 and ECN-UNDP, 2005). It was estimated that the annual daily average of total solar radiation varies from about 12.6MJ/m^2/day (3.5kWh/m^2/day) in the coastal region to about 25.2MJ/m^2/day (7.0kWh/m^2/day) in the far north, thus making her to have an estimated 17,459,215.2 million MJ/day (17.439TJ/day) of solar energy, falling on its 923,768km^2 land area.

There is an estimated average of 18.9MJ/m^2/day (5.3kWh/m^2/day) over a whole year, an average of 6,372,613PJ/year (E1770 thousand TWh/year) of solar energy that falls on the entire land area, which is highly sustainable. Despite these huge potentials, solar energy has not been fully and sufficently harnessed or deployed in the country as a solution to its acute power deficit which the country is currently experiencing. Nigeria presently struggles to produce 4516.7MW from the national grid, while as at December 2012, Germany, Italy, China and USA had installed capacities of 32509, 16987, 8043 and 7665 respectively, inspite of the fact that Germany, is located in temperate region. Inspite of the fact that Nigeria has good and viable solar applications options ranging from stand-alone toPico units to any large scale grid connected applications. If this Nigeria's huge solar potential can be harnessed, the man-hour loss occasioned by low energy availability, would be a thing of the past. If all hands can be on deck, the huge researches and developments potentials in Nigeria, can be translated into massive, meaningful and sustainable developments. It is an under- statement to say, this in turn, will have a significant effect on the quality of education and learning that will enhance both the trainers and the trainees in Nigeria.

Below are some of the benefits of using renewable energy as reported by Ikponmwosa, 2014:

i) It has low operational and maintenance costs.

ii) It has a high mean time between failures.

iii) It is noiseless and nomoving parts are involved during operation.

iv) Different PV panels sizes or modules are abundantly available over a wide range of power ratings.

Most researches so far carried out on solar energy in the country, as the alternative source of energy, are only skewed towardapplying it as solutions to drive small scale businesses, grow economy and to compliment low power generation from the national grid, rather than using it to solve the ever-epileptic and inadequate supply, and in addition, massively deploying it into solving the problem of frustration and obvious lack of any meaningful academic research works in almost all our tertiaryinstitutions in Nigeria, which in turn, would have massively enhanced the quality and service delivery lacking in our hitherto centres of excellences Nigerian institutions were known for and highly sought after in early 70s. This is the reason whyhe need for this alternative source of power, which is the main focus of this work.

3. METHODOLOGY

3.1. MATERIALS/EQUIPMENT

Determination of the Total Daily Power (Wh)

Table 1.1: Non-Motorized Electric Appliances

S/N	A Hours/day	Appliances	B (AxE) Energy (Wh)	C Ratings (W)	D Quantity	E Total watts (C x D)
1	8	Lamps	2080	26	10	260
2	8	Laptop computers	9600	120	10	1200
3	8	Ceiling Fans	6400	80	10	800
		Total	**18, 080**			**2, 260**

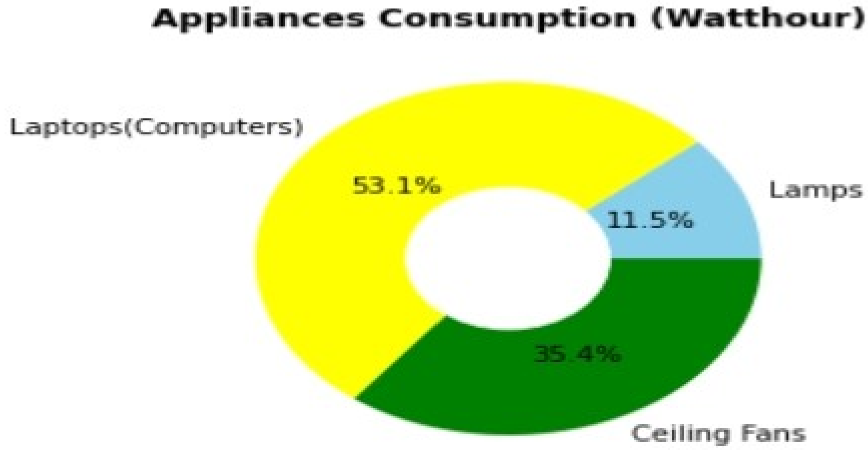


Figure 3.1: Appliances consumption representation in the Department of Mechanical Engineering.

Determination of the total PV Energy needed

Table 3.2: Determination of the total PV Energy needed:

Parameters		Analysis	Remarks
Controller efficiency, ηce	**0.9**	Efficiency Factor $\frac{1}{\eta ce x \eta B \ x \eta Ec}$ = 1.33	PV energy needed = F_c x Daily power consumption
Battery efficiency, η_B	**0.85**		= 1.33 x 18080
			= 24046 Wh
Electrical cable efficiency, η_{Ec}	**0.95**		

Table 3.3: Determination of total PV panel Peak watt Rating (Wh):

Parameters	Analysis	Remarks
Average Daily Sunshine	**Peak watt Rating =** $\frac{total\ PV\ needed}{Average\ Daily\ Sunshine}$	
PV energy needed = *24046 Wh*	PWR = $\frac{24046\ wh}{8h}$ = 3005.75W	

Table 3.4: Determination of the PV panel size (W):

Parameters	Analysis	Remarks
PV Panel Rating = 100W, 150W, 200W	Number of PV panels = Total peak watt rating = $\frac{3005.7W}{200W}$ = **16, 200W, 24V**	**Connection should be in series.**

Table 3.5: Determination of the Inverter Size:

Parameters	Analysis	Remarks
Power factor, cos Ø = 0.80 Inverter efficiency, η_I= 0.98 Starting current factor for motorized appliances = 2.5 Wattage of motorized appliances = 0	Total wattage of all appliances = Wattage of non-motorize appliances + 2.5x Wattage of motorized 3.828KW +2.5 x 0 = **3.828kW** **Inverter Power (KW)=** $\frac{Total\ Wattage\ of\ all\ Appliances}{Inverter\ Efficiency}$ $\frac{2.26kw}{0.98}$ = 2.31kw **Inverters size (kVA)** = $\frac{Inverter\ Power}{Power\ Factor}$ = $\frac{2.31*10E3}{0.80}$ = 2883VA	Inverters are rated in KVA, thus the KW is converted to KVA by dividing KVA by 0.8 3.0kVA, 24V (Approximated Value should be used)

Table 3.6: Determination of the Battery Size:

Parameters	Analysis	Remarks
Depth of Discharge, D_o D = 60% =0.6 Total daily Energy consumption =18080Wh Battery voltage, V =12	$\frac{Total\ Energy\ Consumption}{voltage}$ $\frac{18080\ wh}{12*0.6}$ **= 904 AH** **Number of Batteries required** $\frac{Total\ Battery\ Capacity}{Battery\ Ratings}$ = $\frac{904AH}{150AH}$ **= 6**	**Series/Parallel connection**

Table 3.7: Determination of Charge Controller Capacity:

Parameters		Analysis	Remarks
Numbers of PV modules	**16**	Charge controller size = Numbers of PV modules x I_{SC} x Multiplying Factor.	**12-48V, 100A**
Short Circuit Current I_{SC}	**5**		
Multiplying Factor	**1.25**	16x 5 x 1.25 = 100A	

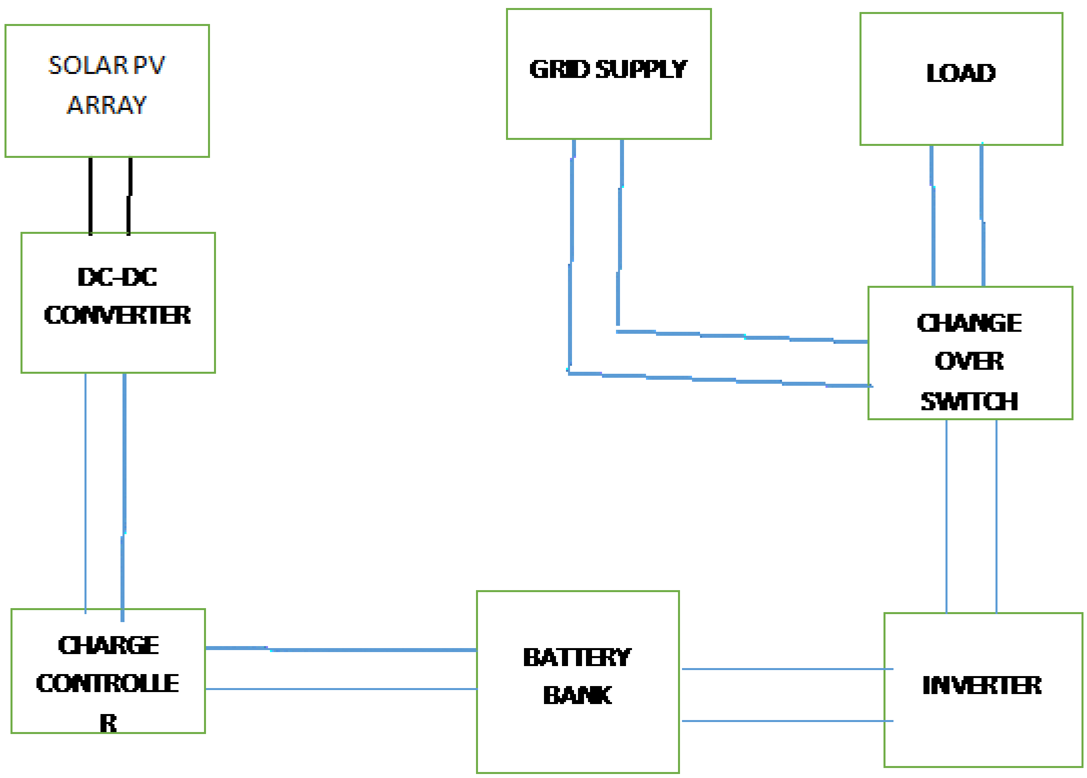


Figure 3.1: Layout diagram for the design and implementation

4. RESULT AND DISCUSSION

Lack of steady power supply to our academic environment, has dampened the academic staff's zeal for any meaningful academic research work. Hence, the reason for embarking on searching for viable alternative power solution to making fruitful academic career worthwhile. Solar energy power solution, from all indications, has shown to provide the appropriate solution. Therefore, the outcome of this project, which is to generate 3.0KVA to power the Departmental staff offices, when implemented will surely enhance meaningful research works and improve productivity of the academic staff.Furthermore, the outcome of the design has shown that the design is viable and it is ready for implementation if funds are available. The implementation phase of this work will entail, testing/runningthe appliances or gadgets such as laptops, a central printer, and electric fan, personal phones, etc., being used in members of staff offices concurrently. This solar option isadjudged to be quite suitable and best fit alternative source of power that can adequately carry these appliances vis-à-vis the power audit earlier done at the design stage. The expected results of the test/implementation of this system will affirm the suitability of this solar solution with the carrying capacity for the envisaged loads. With this design, its implementation, will surely be a panacea for the epileptic and incessant power outages occasioned by lack of adequate generating capacity to provide adequate power supply from the national grid to meet our national power demands.

The outcome of this research work and its implementation, no doubt will assist the faculty staff daily power requirements for both administrative and academic power supply needs. This in turn will guarantee churning out qualitativeacademic wors, which will no doubtpositivelyimpacton the quality of service delivery to our teeming students.

5. CONCLUSION

In this research, the objectives of this work have been clearly outlined. It is believed that implementation of this project will go a long way in opening up a new vista of opportunities to the Polytechnic at large, Departmental administrative andAcademic Staff, this research group and the students they teach and mentor into becoming great academic minds.

6. RECOMMENDATIONS

This is the first phase of this project for there are two other locations where we have the departmental staff offices situated that the next phase should be extended to.

REFERENCES

BP Statistical Review of World Energy. Available online: ⟨http://www.bp.com/content/dam/bp/pdf/statistical-review/statistical_review_of_world_energy_2013. pdf⟩; February 2013 [accessed 10.02.20].

Energy commission of Nigeria and United Nations Development Programme (ECN-UNDP) Renewable Energy Master plan (REMP) final draft report available online:

⟨http://www.iceednigeria.org/workspace/uploads/nov.-2005.pdf⟩; 2005 [accessed26.10.13]

Renewable Electricity Policy Guidelines (2006). Federal Ministry of Power and Steel, Abuja. Available online:

Federal Ministry of Environment (2013) "Renewable Energy" Federal Ministry of Environment. Retrieved 10/02/13 at http://environment.gov.ng/specialunits/renewable-energy/

Ikponmwosa, O, Olawale, S, Adedayo B.A, Egbune, D, Abanihi, V. (2014).Solar Energy Potential and its Development for Sustainable Energy Generation in Nigeria: A Road Map to Achieving this feat. *I.J.E.M.S., VOL.5 (2): 61-67.*

NationalEnergyPolicy2003.EnergyCommissionofNigeria,Abuja.Availableonline:

⟨http://osgf.gov.ng/payload?id=ff0bfcf6-2376-4a37-9fe6-51b73e550fbc⟩; [accessed 11.2.20].

⟨http://webcache.googleusercontent.com/search?q=cache:S8fLu2h74doJ:www.iceednigeria.org/ workspace/uploads/dec.-2006.pdfþ&cd=3&hl=en&ct=clnk&gl=ng⟩; 2006[accessed11.02.2020

Sen Z. (2008). Solar energy fundamentals and modeling techniques: atmosphere, environment, climate change and renewable energy. London: Springer-Verlag Limited

Yeramilli, A, Tuluri, F. (2012) Energy resources utilization and technologies. 1st ed. Hyderabad: BS Publications

DESIGN AND IMPLEMENTATION OF A SOLAR MINI -GRID FOR A SUSTAINABLE AND ECONOMIC POWER SUPPLY IN THE UNIVERSITY OF JOS

Gwaivangmin, B.I., Bakare, G.A., Haruna, Y.S and Amoo, A.L

Electrical and Electronics Engineering Department
Faculty of Engineering and Engineering Technology
Abubakar Tafawa Balewa University Bauchi

ABSTRACT

Electricity supply is a major component in the development of the Education sector, its inevitable utilization results into soaring electricity bills which may be an encumber to educational an institution as government funding continues to dwindle by the day as a result of the harsh global economic circumstances. Finding other means of sustainable and economic power supply is paramount. The University of Jos, alike other educational institution is faced with harsh economic situations especially with the COVID-19 pandemic. The institution's electricity bills has surge due to expansion and frequent tariff increase by the Regulatory agency and the distribution company. This paper presents the design and Implementation of a Solar PV Mini-grid with details of energy consumption relative to supply from the Jos Electricity Distribution Company (JEDC). Results show the implementation of Solar Mini Grid would cost the institution about ₦1, 067b which would have a lifespan of over 25 years. On the other hand continues consumption of power from JEDC which averages at ₦25M every month would cost the institution about ₦1, 15b for 46 months. Solar minigrid installation will be stable and sustainable power source for the institution.

Keywords: Energy, Implementation, Mini-Grid, Solar Potovoltaic, Sustainable.

1. INTRODUCTION

Electricity is an essential component in the economic development of every nation, if properly utilized can change the fortune of a nation. The provision of this critical component by government to its consequents is marred by several challenges since most of the sources of electricity generation require huge capital investments. Building power plants require not only huge capital investment but the time factor is also paramount. Another factor militating against the full utilization of electricity to better the life of the common man and institutions where the common man will benefit is the electricity tariff. For years government have been subsidizing the electricity tariff, but government has started a gradual removal of electricity tariff leading to the present high tariff being experienced in Nigeria.

The education sector requires electricity supply 24 hours a day considering the importance of teaching and research in our higher institutions;

this will not just be made available at without cost. With the new regime of continues tariff increase the education sector is faced with high consumption of electricity translating into huge electricity bills to pay. Whereas electricity is growing geometrically in the Universities the financial capacity of the Universities is growing arithmetically leading to a gap between electricity consumption and the capacity of the University to pay the electricity bills. Considering the challenges being faced in electricity consumption and payments the Solar Mini-Grid is being proposed for the provision of electricity in the University of Jos.

2. LITERATURE REVIEW

There are several literature materials on the implementation of Solar mini-Grid all geared towards provision of stable and sustainable power supply to the consumers.

Adejuyigbe et. al (2013) **developed** a solar photovoltaic power supply system **as an** alternative to the government own utility power supply, which because of its unreliability and epileptic nature has paralyzed the day-to-day office work activities. According to Oni and Bolaji (2011) the generated voltage from the solar power source increases with the increase in solar radiation. Johnson and Ogunseye (2017) submitted that in a building the PV system's daily production far exceeds energy demand in the building. According to NREL (2014) distributed solar photovoltaic (PV) systems have the potential to supply electricity during grid outages resulting from extreme weather or other emergency situations. As such, distributed PV can significantly increase the resiliency of the electricity system. Oghogho et.al (2014) pointed out that Nigeria needs to reposition herself by investing in the invaluable Solar resource to secure the energy future of our economy. Attia et. al (2016) proposed an electronic design that can be used as DC power supply for PV systems. Solar energy could be effectively used as an alternative source of power for any PV system. All PV systems need suitable and stable DC power supply for proper functioning of the included electronic circuits. Agboneye and Odiase (2017) proposed a standalone photovoltaic mini-grid optimal design method that can be implemented reliably and economically. Saulo and Omondi(2015) developed a standard procedure for the design and analysis of a mini-grid connected solar PV systems using PV modules connected in an array field. The standard procedure developed was validated in the design of a 20 kVA mini-grid connected solar PV system for Nanyuki town in Laikipia County, Kenya. The analysis and evaluation of the load capacity requirements for the solar mini-grid were done. Data collected from SWERA were compared with the local load requirements. Optimization of the load versus production capacity of the solar system was carried out. The results showed that a mini-grid system of 20 kVA might be developed at a capital cost of US$ 56,000 to cater for 8400 households including a school and dispensary. Analyses of the simulation results show that the project when implemented will supply about 61 KW·h electricity per day or 22.2 MWh annually, which is about 15% of Nanyuki's annual electricity consumption. El-Houari et al. (2019) proposed the design, simulation, and optimization of a stand-alone photovoltaic system (SAPV) to provide non-polluting electrical energy based on a renewable source for a rural house located in Tazouta, Morocco. Real monthly electrical demands and hourly climatic conditions were utilized. Elshenawy et al. (2017) worked on the use of solar (photovoltaic) energy to supply the electrical energy for a household of about 50m^2 in a rural area situated in Shalateen (Egypt). Design and installation of the stand-alone photovoltaic system according to the daily electrical load for the house and the irradiation data related to the location are detailed. The sizing of each system components (photovoltaic, mechanical structure, battery, inverter and charge controller) was studied. They also worked on economic analysis for the system in terms of life cycle cost and electricity unit cost. They found out that the unit cost of electricity using the installed PV system was $0.201/kWh. It encouraged the use of this efficient system and clean energy in development plans at rural communities.

2.1 Solar Photovoltaic (PV)

According to Saulo and Omondi (2015) photovoltaic systems are composed of interconnected components designed to accomplish specific goals ranging from powering a small device to feeding electricity into the main distribution grid. More specifically, PV devices convert sunlight into DC electricity. Such energy is transferred to the load or to the utility grid by means of a subsystem.

There are two main classifications:

(i) Stand- alone systems

(ii) Grid connected systems.

The main distinguishing factor between these two categories is that in stand- alone systems the solar energy output is matched with the load demand. When a PV system is interconnected with the main grid, it may deliver excess energy to the grid or use the grid as a backup system, in case of insufficient photovoltaic generation. Stand – alone systems are mostly used in the cases of rural electrification.

This work is focused on design and implementation of solar PV mini-grid that is grid connected that would give room for the public power supply as a backup as well as the diesel generators where the public power is not available.

3. MATERIALS AND METHODS

3.1 Study Area

The University of Jos is by reputation, the one of most prestigious higher education institution in the North of Nigeria and the country. Founded in 1971 as a satellite campus of the University of Ibadan, then officially established as a separate institution in 1975, has been considered an elite institution known for academic excellence. It is located in Jos, Plateau State latitude 9°55’48” and Longitude 8°53’24” The University receives power supply from the Jos Electricity Distribution Company (JEDC). This supply accounts for about 98% of the institution's energymix, with the balance provided by expensive and environmentally unfriendly diesel power.

3.2 Results and Analysis

The Load used for this study is the Load Demand on the 11kV dedicated feeder of the University of Jos. The university supply is from a 7.5 MVA, 33/11kV dedicated transformer for use only by the University. There are 13 transformers 11/0.415kV.

According to Gwaivangmin (2021) electricity supply on the dedicated feeder is available for 22-23 hours per day which means public power supply from JEDC serves the University between 92-96 % daily. The balance 4-8 % is for the generating sets.

3.3 Load Forecast

For proper sizing the Solar PV Plant ANFIS enhanced PSO load Forecast was carried out using the primary data from the network analyzer of the 11kV dedicated feeder.

The load demand test data was analysed using a PSO trained ANFIS and Mean square Error of 32.0797 and root mean square error of 5.6639 were obtained. The Error mean of -0.027779 and Error standard deviation of 5.6924.

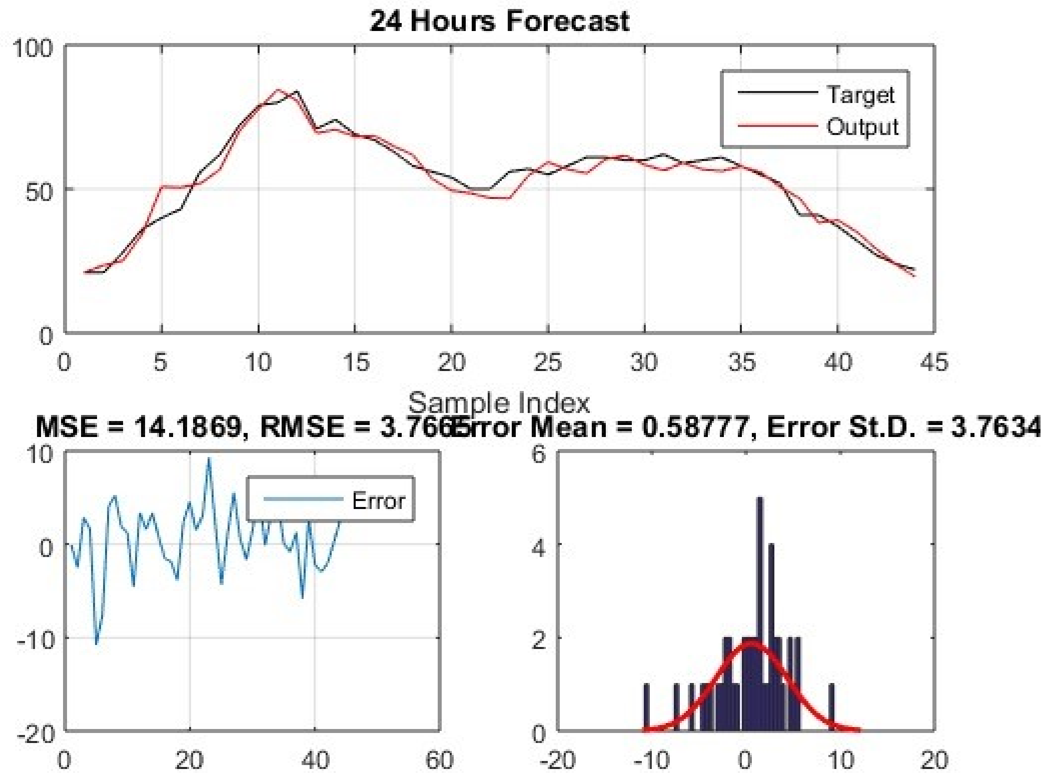


Figure 1. 24 Hours Load Demand Forecast for the 11kV Dedicated Feeder.

The load demand data was analysed using a PSO trained ANFIS a forecast for the next 24 hours was carried out and Mean square Error of 14.1869 and root mean square error of 3.7665 were obtained. The Error mean of 0.58777 and Error standard deviation of 3.7634.

Table 1. ANFIS –PSO Load Forecast for the next 24 Hours

Time(Hours)	Load (kW)
0:30	335.33
1:00	335.33
1:30	304.84
2:00	304.84
2:30	320.01
3:00	320.01
3:30	426.78

4:00	548.71
4:30	609.68
5:00	655.41
5:30	853.55
6:00	945.01
6:30	1,097.43
7:00	1,204.12
7:30	1,219.36
8:00	1,280.33
8:30	1,082.19
9:00	1,127.92
9:30	1,051.70
10:00	1,021.22
10:30	960.25
11:00	884.04
11:30	853.56
12:00	769.82
12:30	762.10
13:00	762.10
13:30	853.56
14:00	868.80
14:30	838.31
15:00	884.04
15:30	929.77
16:00	929.77
16:30	914.52
17:00	914.52
17:30	945.01

18:00	899.28
18:30	914.52
19:00	929.77
19:30	884.04
20:00	838.31
20:30	838.31
21:00	624.92
21:30	624.92
22:00	563.96
22:30	487.75
23:00	411.54
23:30	365.81
24:00	335.33
Total	**36,832.60**

3.3 Meteorological Data

The average monthly 2020, meteorological data for Jos, Plateau State is shown in Table 2.

Table 2. Solar Energy and Surface Meteorology

Month	Isolation, kWh/m^2/day	Clearness Index	Temperature (^{o}C)	Average Sunhours (Hours)	Wind Speed, m/s	Wet Days,d
January	5.93	0.67	23.62	10.4	4.35	0.1
February	6.49	0.68	25.55	10.6	4.23	0.2
March	6.66	0.65	28.02	10.8	4.69	1.4
April	6.20	0.59	27.62	10.9	4.77	6.5
May	5.99	0.58	26.38	10.5	4.51	11.2
June	5.77	0.56	24.79	9.4	3.81	15.0
July	5.34	0.52	23.70	8.0	3.62	19.8
August	5.02	0.49	23.60	6.8	3.45	19.3

September	5.48	0.54	24.24	8.4	3.18	15.3
October	5.84	0.60	25.03	9.9	3.45	4.1
November	6.00	0.67	25.60	10.5	3.99	0.1
December	5.74	0.67	24.19	10.4	4.48	0.1

Source: (http://www.gaisma.com/en/location/jos.html.Retrieved 26th July, 2021).

3.4 Solar PV Design

In the design of the Solar PV Mini Grid for the University of Jos the following steps were taken

i. **Data Collection**

The short term ANFIS-PSO load forecast for the next 24 hours of 36,832.60 kW was used.

ii. **Percentage of Power required from the Solar PV**

With the continues monthly surge in the electricity bills being paid by the University, the design is expected to produce 24 hours power supply to the 11 kV dedicated feeder. With continues development and expansion the surge in billing will continue unabated if no other alternative source of power is available.

iii. **Availability of Sunlight**

The meteorological data for solar radiation is shown in table 1. From the table the average solar radiation for Jos is 5.87kWh/m^2/day and the average clearness index is 0.60.

iv. **Solar Panels to use**

For the design we will be using the Sunpower Maxeon 3 , 400W solar panel that has an efficiency of 22.6% and a size dimension of 0.98m X 1.65m. The amount of power offset is considered to be between 25% to 100%. We also assume that the PV controller is equipped with a maximum power point tracker.

v. **Inverter Size**

Since solar panels are sized to meet daily energy load, to meet the need for this design in which peak load is of paramount importance an inverter which converts the DC from the solar panels to Ac is required. The inverter rating is also expected to handle surge loads anytime such occur.

vi. **Battery Bank Size**

The availability of sunlight will on the average be 11 hours in which the solar panels could be used to generate electricity the remaining 13 hours will require storage and in this the Battery bank would be used.

PV Sizing

PV power (W_P) is usually calculated to meet the required 24 hours load energy (E_L) of the dedicated feeder and the total daily solar energy (G) in kW/m^2/day.

For optimum system opereation some of the parameters to be considered are;

(i) PV Module effecienccy (η_{WP})

(ii) PV Module Temperature coefficient (T_C)

(iii) The efficiencies of (a) Charge controller (η_C), (b) DC-AC inverter (η_{Inv}) and Storage battery (η_B)

The total area required for the installation of the PV array can be calculated by using the equation below.

$Q_{PV} = E_{L/} G \times T_C \times \eta_{PV} \times \eta_{Inv} \times \eta_C \times \eta_B$

Using the solar the average solar irradiation (H_{SC}) for Jos as 5.87kWh/m^2/day, the PV array peak power can be calculated as below;

$W_P = G_{PV} \times H_{SC} \times \eta_{PV}$

Using a Sunpower Maxeon 3, 400W ,22.6% efficiency with panel size of 0.98m x 1.65m

W_P = 2.145kWh/day

For 24 hours

Wp = 89.375W

To generate 36,832.60 kW

Number of modules required is approximately 412 of Sunpower Maxeon 3.

Sizing of Storage Capacity

The role of the battery is to store electric energy for the night hour when there is no sunlight.

The storage capacity can be calculated as below in Wh

���������(���h) = ���������������� /������ . ���/ ������D

Where: -

���������������� is the daily average load demand

- ������ is the battery bus voltage

- ��� are the number of days (one in our case)

- ���������� is the depth of discharge (80% in our case)

The battery voltage of the system is 24V. Also, highest battery capacities per unit will be selected to reduce the number of battery strings in parallel for a better charging balance. Normally, the recommended maximum number of strings in parallel is 4.(Bello,2017)

For our dedicated feeder the storage capacity is calculated as approximately 1,918 kWh.

If we decide to go for a 48 V as DC voltage bus we shall have a storage capacity of approximately 959,182 kWh.

Sizing the Charge Controller

The charge controller is used to improve the life of the storage batteries. The batteries are protected against overcharging by the charge controller. A 24V/20A charge controller will directly connected between the PV array and the batteries to withstand the maximum charging current of the PV system.

Sizing of the DC-AC Inverter

The DC-AC inverter is used to feed the Ac loads with the required electrical energy, so it is usually set to at least 10-25 % higher than the maximum AC power of our load.

The inverter to be selected in our case would be rated 40,000kW

Economic Analysis

Load Profile:

Total Transformer Capacity	12.5MW
Total Generator Capacity	5.6MW
Capacity off Peak	0.9MW
Capacity “Peak” Period	1.5MW
Projected load at 40%	2.0MW

Cost of Energy per source

JEDC Energy Tariff	₦57.53
Diesel Cost per litre	₦ 245.00
Solar Energy Tariff	₦ 30.00

Other Costs

Cost of 2MW solar plant ₦ 1,067B

Average Cost of power per Month ₦ 23M

CONCLUSION

The design of a Solar PV Plant was carried out and the economic analysis also explored. It can be seen that the cost of building a 2MW solar plant would cost approximately ₦1, 067B which would have a lifespan of over 25 years. On the other hand, continues consumption of power from JEDC which averages at ₦25M every month will increase exponentially with increase in tariff and expansion by the institution. Spending money to build a solar PV plant would be more economical on the long run. The cost of running generating sets will also continue to increase as cost of diesel will also continue an exponential increase especially with the deregulation of the oil sector. The cost of building a Solar Plant would just be the bill paid to JEDC for about 46 months (₦1,15b), which will be a very good investment by the proprietor of the University.

REFERENCES

Adejuyigbe, S.B., Bolaji B.O., Olanipekun,M.U and Adu,M.R (2013) Development of a Solar Photovltaic power System to Generate Electricity for Office Aplliances. Engineering Journal Vol.17 Issue 1. Pp.29-39.

Agboneye, O and Odiase, O F(2017) Optimal Design of a Stand Alone Photovoltaic Mini-Grid. Annual Conference of the School of Engineering and Engineering Technology, Akure, Nigeria, 11-13 July. pp.886-908

Attia, H.A., Getu, B.N and Hamad, N.A (2016) A Stable DC Power Supply for Photo Voltaic systems. International Journal of Thermal Environmental Engineering. Vol. 12,No.1 pp 67-71.

Bello, E.R (2017) Design of a PV System with Batteries for grid Connected Building. Masters Degree Thesis. Faculty of Engineering and Sustainable Development, University of Gavle.

El-houari, H., Allaouhi, A., Shafiqur.R., Buker, M.S., Kousksu.T., Jamil, A and Amrani, B (2019) Design, Simulation and Economic Optimization of an off-Grid Photovoltaic System for Rural Electrification. Energies. Vol 12.pp1-16

El-shenawy, E.T., Hegazy, A.H and Abdellatef, M (2017) Design and Optimization of Stand0Alone PV System for Egyptian Rural Communities. International Journal of Applied Engineering Research. Vol 12.No.20.pp 10433-10446.

Gwaivangmin, B.I (2021) Electrical Power Supply Consumption in Education Sector and Energy Audit: Case Study of University of Jos. Nigerian Journal of Technology. Vol.40.No.2.pp321-328.

Hessanmi,M (2018) Designing a Hybrid Wind and Solar Energy System for a Rural Residential Building. International Journal of Low Carbon Technologies.pp.112-126. https://academic.oup/ijlct/article/1/2/112/660894

Johnson, D.O and Ogunseye, A.A (2017) Grid Connected Photovoltaic System Design for Local Government Offices in Nigeria. Nigerian Journal of Technology. Vol.35.No.2.pp571-581

Khamisani,A.A (2018) Design Methodology of Off-Grid PV Solar Powered System (A Case Study of Solar Powered Bus Shelter). Retrieved fromwww.eiu.edu/energy/Design methodology of off-grid solar powered syste_5_1.pp1-23

NREL (2014) Distributed Solar PV for Electricity System Resiliency. U.S Department of Energy. National renewable Energy Laboratory 15013 Denver West Parkway,Golden Co.80401.www.nrel.gov.

Oghogho,T., Sulaimon,O Adebayo,B.A.,Egbune,D and Kenechi,A.V (2014) Solar Energy Potential and its Development for Sustainable Energy Generation in Nigeria: A Road map to Achieving this Feat. International Journal of Engineering and management sciences.Vol.5 No,2. pp.61-67

Oni, J.O and Bolaji, B.O (2011) Development of a Universal DC Power Supply Using Solar Photovoltaic, Utility and Battery Power Sources, Journal of Energy in Southern Africa.Vol.22, No.1 pp12-17.

DESIGN AND ANALYSIS OF PHOTOVOLTAIC SYSTEM AS ALTERNATIVE POWER SOLAR FOR CASE STUDY OF THE FLIGHT HANGAR OF THE NIGERIAN COLLEGE OF AVIATION TECHNOLOGY ZARIA, NIGERIA

A.A. Sadiq; A.D. Usman; K.A. Abubilal
Department of Electronics and Telecommunications Engineering
Ahmadu Bello University, Zaria
aasadiq@abu.edu.ng; adusman@abu.edu.ng; kb.ahmad74@gmail.com

ABSTRACT

The goal of the project is to study the benefits and implementation of solar PV system and cost of the solar energy in NCAT Flight hangar. Solar energy provides an alternative, yet sustainable, energy resource to the increasing demand of energy in NCAT and its surroundings. The research intends to provide a proactive measure to resolve the potential energy issue in the near future by leveraging renewable energy technology. To achieve the project goal, the following tasks have been accomplished: (1) collect and analyze data to estimate the average sunny days, daytime hours, and temperature profiles in NCAT and its surrounding areas; (2) develop financial model to estimate the cost per unit watt given the current solar technology; (3) provide constructive roadmap toward the implementation of solar energy for both the energy investors and the consumers for next twenty-five years. Our research found that the implementation of solar energy in NCAT is geographically and climatically feasible. Meanwhile, the daytime is extremely long in the summer time from 7:00am to 6:00pm. Even in the winter, the daytime still spans from 7:00am to 6:00pm especially solar cells, in the US and around the world. Finally, the use of solar technology also opens ample opportunities for local engineering students from ABU Zaria who are interested in further exploring the innovative energy technology and making local communities greener and cleaner.

Keywords: Solar Energy, Flight hanger, NCAT.

I. INTRODUCTION

Photovoltaic, also called solar cells are electronic devices that convert sunlight directly into electricity. The modern form of the solar cell was invented in 1954 at Bell Telephone Laboratories. Today, PV is one of the fastest growing renewable energy technologies and it is expected that it will play a major role in the future global electricity generation mix. Solar PV systems are also one of the most "democratic" renewable technologies, in that their modular size means that they are within the reach of individuals, co-operatives and small-businesses who want to access their own generation and lock-in electricity prices. PV technology offers a number of significant benefits, including:

1. Solar power is a renewable resource that is available everywhere in the world.
2. Solar PV technologies are small and highly modular and can be used virtually anywhere, unlike many other electricity generation technologies.
3. Unlike conventional power plants using coal, nuclear, oil and gas; solar PV has no fuel costs and relatively low operation and maintenance (O&M) costs. PV can therefore offer a price hedge against volatile fossil fuel prices.
4. PV, although variable, has a high coincidence with peak electricity demand driven by cooling in summer and year round in hot countries. (*Gielen,2012*).

Converting solar energy into electrical energy by PV installations is the most recognized way to use solar energy. Since solar photovoltaic cells are semiconductor devices, they have a lot in common with processing and production techniques of other semiconductor as computer and memory chips. As it is well known, the requirements for purity and quality control of semiconductor devices are quite large. With today's production, which reached a large scale, the whole industry production of solar cells has been developed and, due to low production cost, it is mostly located in the far east. Photovoltaic cells produced by the majority today's largest producers are mainly made of crystalline silicon as semiconductor material. Solar photovoltaic modules, which are a result of combination of photovoltaic cells to increase their power, are highly reliable, durable and low noise devices to produce electricity. The fuel for the photovoltaic cell is free. The sun is the only resources that are required for the operation of photovoltaic systems, and its energy is almost inexhaustible. *(Gielen, 2012*).

A typical photovoltaic cell efficiency is about 15%, which means it can convert 1/6 of solar energy into electricity. Photovoltaic systems produce no noise, there are no moving parts and they do not emit pollutants into the environment. Taking into account the energy consumed in the production of photovoltaic cell, they produce several tens of times less carbon dioxide per unit in relation to the energy produced from fossil fuel technologies. Photovoltaic cell has a lifetime of more than thirty years and is one of the most reliable semiconductor products. Most solar cells are produced from silicon, which is not toxic and is found in abundance in the earth's crust. Photovoltaic systems (cell, module, and network) require minimal maintenance. At the end of the life cycle, photovoltaic modules can almost be completely recycled. (*Suresh Thanakodi 2009).*

Photovoltaic modules bring electricity to rural areas where there is no power grid, and thus increases the life value of these areas. *(Suresh Thanakodi 2009).* Photovoltaic systems will continue the future development in a direction to become a key factor in the production of electricity for households and buildings in general. The systems are installed on existing roofs and/or are integrated into the facade. These systems contribute to reducing energy consumption in buildings. By the introduction of incentives for the energy produce by renewable sources in all developed countries, photovoltaic systems have become very affordable, and timely return of investment in photovoltaic systems has become short and constantly decreasing. *(Lakpini Caspar Sokowoncin, 2002).*

In recent years, this industry is growing at a rate of 40% per year and the photovoltaic technology creates thousands of jobs at the local level. *(Lakpini Caspar Sokowoncin, 2002)*

This research is aimed at analyzing the alternative solar means of powering flight hanger at NCAT Zaria. The objectives were to:

1. find the total daily energy average demand of the hanger; and
2. determine the advantage of solar sources of energy over others sources of energy.

The case study of this project is the flight hanger in Nigerian college of aviation technology (NCAT) Zaria, Kaduna state. By virtue of the location and demographic factors in the place, the economic and commercial activity potential which has been hampered by lack of power supply. *(Lakpini Caspar Sokowoncin 2002).*

The electricity demand of the flight hanger is 436.169KWhr from the research we have conducted. This load was initially attempted to be met by PHCN some years ago but failed due to reasons ranging from inefficiency, in capacity and constant failure as at the present moment the single. The current situation we found ourselves concerning constant fluctuation of electricity power supply by power holding company of Nigeria (PHCN) have led to many electricity users to look for alternative and reliable sources of power supply in order to satisfy their customers' needs. the electricity demand by the academy is sometimes met by 250KVA generator with a daily fuel consumption of 270litres. *(Lakpini Caspar Sokowoncin 2002).*

The power received by the PHCN is epileptic and so the academy does not rely on it whenever there's work in progress. So a diesel generator is considered an alternative supply because if there is power failure in the hanger during work, can cause some damages. *(Lakpini Caspar Sokowoncin 2002).*

In view of this solar energy remained the most available solution of this problem, of course the demand for electricity is everyday increasing hence, reliable and available sources of power supply must be employed in order to solve the problem to provide constant electricity to power the flight hanger *(Lakpini Caspar Sokowoncin 2002).*

The following methods were followed in other to achieve this project.

1. Collection of data: An energy audit was conducted on NCAT flight hanger in order to know the total loads and their rating with the time usage of every appliance
2. The longitude and latitude of Zaria was obtained in order to determine the solar radiation of the station.
3. The geometric area of the station's roof was obtained in order to know if the number of solar panels can be completely placed on the roof, which was found to be possible.
4. System sizing: This involves calculation of solar modules, number of batteries, inverter and charge controller.

2. METHOD AND MATERIALS

To design a solar system, the energy conservation principles should be strictly observed when estimating the required average energy demand in watt-hour per day. This is usually estimated by listing all the loads and their corresponding daily hours of use. Hours for which a particular load is not put to use must be excluded. Loads are the power consuming units of the PV system. There are two types of loads (ac and dc) depending on the type of electrical power that they require for their operation. For the purpose of this design, electrical loads may be broadly classified as either resistive or inductive. Resistive loads do not have any significant inrush of current when energized. Examples of resistive loads include light bulbs and electric heaters. Inductive loads on the other hand, pull a large amount of current (inrush) when first energized and examples include transformers, electric motors and coils. Therefore, a load profile is needed in order to know the total consumption of the building, in doing those two points need to be carefully considered;

i. Total energy consumption: is the number of kilowatt-hours consumed in given period of time.

ii. Maximum or Peak energy consumption: is the maximum amount of electrical power used at a given certain time, e.g peak hour of the day, peak day of the week, peak week of the month and peak month of the year

Main objectives of the load profile are as follows:

1. To know the total power consumption of the NCAT flight hangar per day.
2. To know the peak consumption of the hangar.
3. To determine the time of the day when the peak consumption occurs.
4. To determine the average daily power consumption of the hangar.
5. To know the essential loads and non-essential load of the hangar.
6. To determine the power consumed during the sunshine period (day).
7. To determine the total power consumed when no sunshine period (night).
8. To know the total daily average energy used.

Load profile for this system are classified into on three categories

A. Ring Main Circuit.

B. Power Source.

C. Lamps and Ceiling fans.

3. RESULTS

3.1 Load profile analysis of NCAT Hangar

As discussed so far, the total load profile of the hangar per-hour is 36.922KW. This load is shared among the total appliances connected to this load in hangar which is divided in the Ring Main Circuit, Power Source and Lightening and Ceiling Fan. The load profile connected is generated using MATLAB shown in Figures 1 to 3.

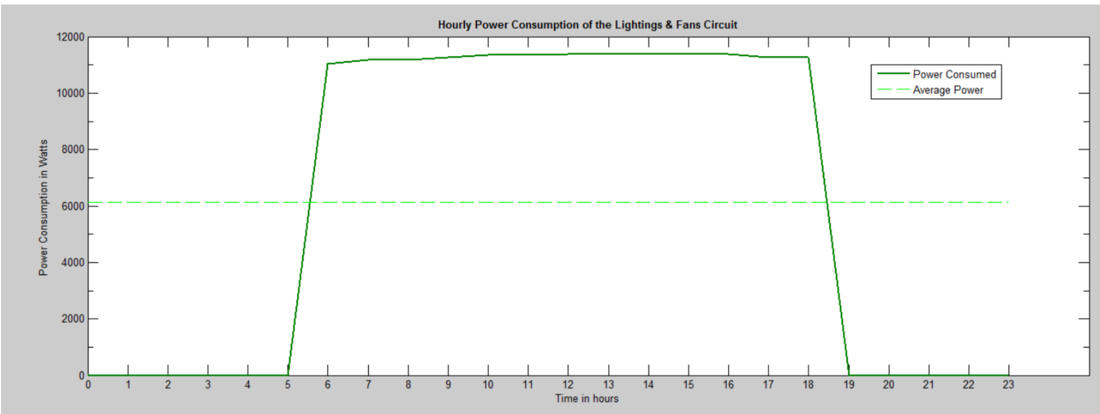


Figure 1.Load Profile of Lightening and Ceiling fans

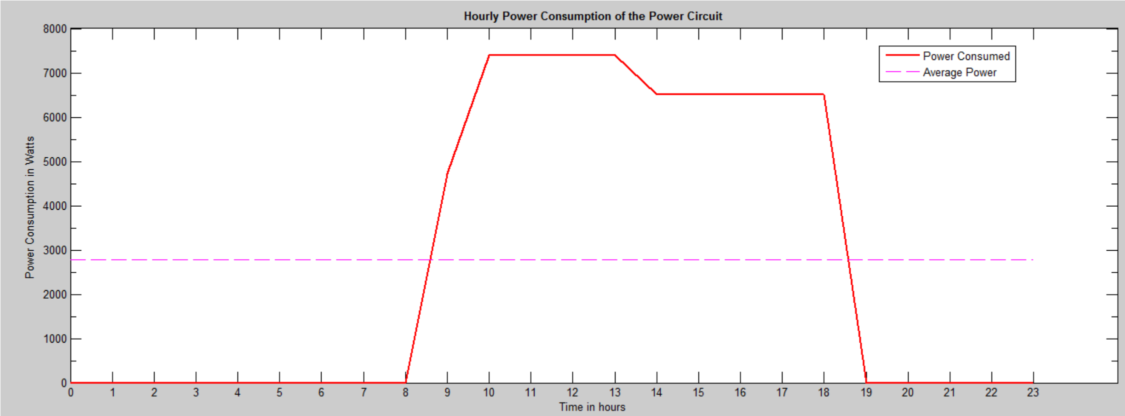


Figure 2. Load Profile of Power Circuit

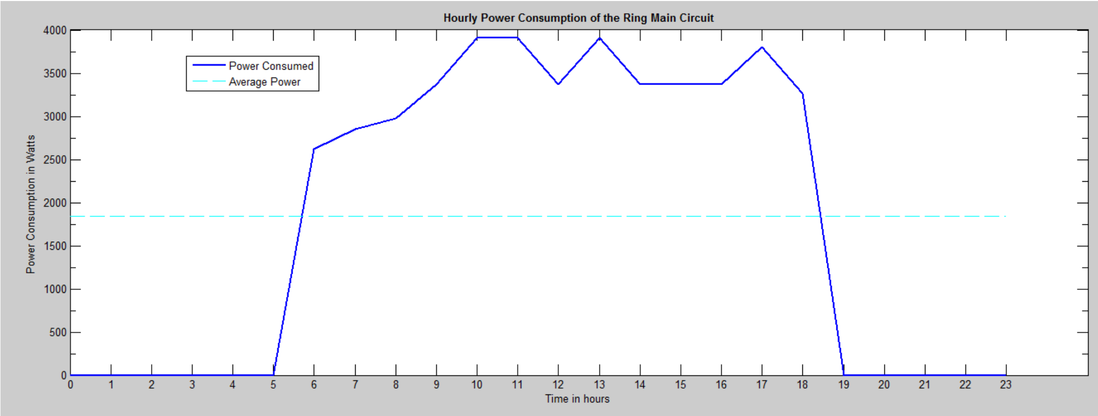


Figure 3. Load Profile of Ring Main Circuits

From the above load profile diagrams, it shows that majority of the appliances are being used for 13hours a day and the lightening and ceiling fans are mostly used.

3.2 Limitations

This is a list of limitation in the design, which should be avoided

1. Data collection may not be 100% accurate.
2. The solar radiation of the station may vary over a long period of time due to climatic change that may occur over a given period of time.
3. Future expansion in the hangar might exceed the allowable expansion for the system size.
4. Cost of installation.
5. An advance software can ease the sizing of the PV system.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

With respect to our result analysis for the design of PV solar system for NCAT flight hangar, where the total energy needed by the hangar were recorded from the total number of appliances used in the hangar, the PV system was designed base on the readings obtained as shown in chapter, the PV panel, battery, inverter and also charge controller was sized and their respective cost where calculated also. Cost and payback period are also calculated to know how economical the system is and to motivate people to also try it out, and finally the result were simulated using MATLAB simulation software to test the design.

In summary, the PV system can be seen as a very good source of power, despite the fact that it is expensive to install but it is very cheap on the-run compared to the diesel/fuel generators and the cost of electricity from the main grid, it is also environmentally friendly too.

4.2 Recommendation

Base on the experience obtained during this project, few recommendations are highlighted below for end users of this technology: -

1. Manufacturing industries shall be installed to promote local production of solar cells, solar modules and solar panels.
2. There should be a public orientation on the needs to use the solar system.
3. The federal government should also divert their attention also to the use of renewable energy (Solar System).
4. Students should be encouraged to do projects on the solar system which can also make them independent after graduation.

REFERENCES

[1] D. Gielen, Renewable energy technologies: cost analysis series (Solar Photovoltaic's). June 2012.

[2] Rijeka, photovoltaic systems. January 2012.

[3] R. Prakash1, Sandeep Singh, Designing and Modelling of Solar Photovoltaic Cell and Array. April 2016.

[4] J.I. Zalika, M.Nasiri, S.E.Sabriand and R.Ishak, A sizing Tool for Standalone System. December, 2015.

[5] Murphy and G. Devlin, A Feasibility Analysis of Photovoltaic Solar Power for Small Communities in Ireland. 2011.

[5] A. Umar. Solar Electric System Design, Operation and Installation, an Overview for Builders in the U.S. Pacific Northwest Washington State University Extension Energy Program. October 2019.

[6] Arno H.M. S meets René A.C.M. M.vanS.M.Zeman. Delft University of Technology Solar Energy Fundamentals,

Technology, and Systems Klaus JägerOlindo Isabella. 2014.

[7] C.H.Rachel, Center Solar Power for Your Home A Consumer's Guide. 2015.

[8] Business Plan for Solar Energy System Installations and Energy Efficiency Retrofits. Renewable energy technologies: cost analysis series Solar Photovoltaic's. June 2012.

[9] T.D. Jin, Principal Investigator Department of Mathematics and Physical Sciences, Sponsor: A.R. Sanchez, Jr. School of Business, TAMIU Texas A&M International University (TAMIU), Laredo, Texas, USA SOLAR ENERGY PAINTS LAREDO GREEN Project Duration: June 1, 2018 to August 31, 2018.

ANALYSIS OF THE HYDROPOWER POTENTIAL OF OTAMIRI RIVER IN IMO

Andy Obinna Ibeje
engineeribeje@gmail.com, Department of Civil Engineering, Imo State University,
P.M.B. 2000, Owerri, Nigeria.

ABSTRACT

The Flow duration curve (FDC) is widely used in hydrology to assess the flow regime of a river. This paper presents the derivation of FDCs for Otamiri catchments in Imo State, Nigeria. FDCs were constructed from 1979-1989 mean monthly flow data, ranked from largest to smallest value, with each corresponding percentage of months for which the flow value was equaled or exceeded. The flow duration curve was obtained by plotting Q vs. exceedance frequency, F_m The derived flow duration curve was used to characterize the flow in the range from 10% to 90% of time flow is equalled or exceeded. This maximum flow and average flow were determined as 9.22rn^3/s and 7.2 1m^3/s respectively while. The power potential and installed capacity were computed as 175.38kw and 224. 28kw respectively. The dependable power and average annual energy generated were estimated as 102.41kW and1,536, 357.27 kwh respectively. The reliability of hydropower generation in Otamiri catchment can be assessed based on the lowest monthly flow which was estimated for Otamiri as 7.21m^3/s. This study has demonstrated that FDC is useful in water resource assessments of river catchments.

.

Keywords: *catchment, Flow duration curve, hydropower, Otamiri*

1. INTRODUCTION

The flow duration curve (FDC)is a graphical representation of the frequency distribution of the complete flow regime (Pumo et al., 2014). A FDC is defined by Serinaldi (2011)as a function which gives flow, q, as a function of probability, p, i.e. q = q(p), where p is the probability that the specified flow is exceeded. Empirical FDCs are graphs, or alternatively tables, constructed from a set of flow measurements, q_i, made over a given interval of time, ranked from largest to smallest value, with each corresponding p giving the percentage of days for which the flow value was equaled or exceeded.FDC is a cumulative-frequency curve which defines the relationship between magnitude of stream-flows of a certain time resolution (hourly, daily or monthly) and frequency of occurrence in any basin by translating the percentage of time for which a certain magnitude of flow equals or exceeds a certain flow value (Vogel &Fennessey 1995). This type of information is commonly used for resource assessments including hydropower design schemes, water supply and water quality assessment and the evaluation of river habitats. The flow duration curve (FDC) provides a probabilistic description of stream flow at a given location. Flow duration curves show the percentage of time that certain values of discharge weekly, monthly or yearly were equalled or exceeded in the available number of years of record. The selection of the time interval depends on the purpose of the study. While daily flow rates of small storms are useful for the pondage studies in a runoff river power development plant, monthly flow rates for a number of years are useful in power development plants from a large storage reservoir (Cigizoglu, 1971).A better understanding of the pattern of streamflow is obtained by a monthly analysis, which has the capability of illustrating the months that contain high flows, low flows or average flows. The shape of the FDC in its upper and lower regions, which has a particular importance in evaluating the stream and basin characteristics is masked by the averaging at the annual time scale while it becomes clear when monthly streamflow data are considered. The flow duration curve is actually a river discharge frequency curve and longer the period of record, more accurate is the indication of the long term yield of a stream. A flow duration plotted on a log-log paper provides a qualitative description of runoff variability in the stream (Atieh et al., 2015).A flat curve indicates a river with a few floods with large groundwater contribution, while a steep curve indicates frequent floods and dry periods with little groundwater contribution (Boscarello et al., 2016). Since the area under the curve represents the volume of flow, the storage will affect the flow duration curve reducing the extreme flows and increasing the very low flows. Since drought is often defined in terms of a fixed period of time with less than some minimum amount of rainfall, the flow duration curves are useful for determining the duration of floods or droughts, the latter being of prime importance in the semi-arid regions (Muller et al., 2014) . Duration curves for long periods of runoff are also useful for deciding the flow rates to be used for particular purposes, say, for power development (Zhang et al., 2015).In the flow duration curve the shape at the upper and lower regions are the most important parts in evaluating the characteristics of a river(Muller and Thompson, 2016). The upper-flow region indicates that the basin is likely to have flooded, whereas, the lower-flow region characterizes the ability of the basin to sustain low flows during dry seasons. Due to the extensive use of FDC in hydrology, different methodologies for the derivation of FDCs at individual gauging stations or at a regional-scale have been studied. Singh (1971); Dingman (1978) and Singh et al. (2001) proposed regression equations incorporating the drainage area and elevation of the hydrological basin as input variables to establish FDC models. The soft computational techniques such as the artificial neural networks, gene expression programming and geostatistical methods were applied by Pugliese et al. (2016) and Atieh et al. (2017) in modeling FDC. Castellarin et al. (2013) reviewed the currently used procedures for deriving FDCs in data-scarce basins, with a particular focus on the reliability of such methods in different climatic contexts. Yokoo and Sivapalan (2011) disaggregated the FDCs into two components, i.e. slow FDCs and fast FDCs to develop a conceptual model to reconstruct FDCs, similar to the earlier work of Muneepeerakul et al. (2010) and Botter et al. (2007). Empirical FDCs are often represented by a parametric function which is usually a probability distribution such as the generalized Pareto distribution with three parameters (Fennessey 1994), the Gumbel distribution (Kottegoda & Rosso 1997), the normal distribution (Singh et al. 2001) and the two- or three-parameter log-normal distribution (Fennessey & Vogel 1990; Claps & Fiorentino1997). However, in the past different non-probabilistic analytical forms were made popular by Müller et al. (2014). In more recent times, other distributions have been used, such as, the Kappa by Castellarin et al. (2007),the Eta Beta by Iacobellis (2008) and the Burr type XII by Ganora and Laio(2015). The choice of the distribution is guided by the ability to adapt to the observed data and the possibility to estimate parameters of the distribution satisfactorily. Pumo et al. (2016) used basin characteristics such as morphologic, climatic and basin-scale features to evaluate parameters of these probability distributions in ungauged basin. This study is focused on the derivation of FDC for River Otamiri catchment in Imo State, Nigeria.

2. METHODOLOGY/ MATERIALS AND METHOD/ PROCEDURES

The little available record was only the 1986-1995 discharge data of Otamiri River (at Nekede gauging station) as the gauging equipment was reportedly faulty. The data was obtained from the Anambra-Imo River basin in Imo state of Nigeria, which is one of the twelve river basin development authorities, (RBDAs) in Nigeria.

2.1 Study Area

The Otamiri River itself starts as a first-order stream at its source at Egbu, Owerri North L.G.A. and captures Nworie river and flows for about 30 km to confluence with the Oramiriukwa River at Emeabiam, Owerri West L.G.A. in Imo State, Nigeria. The catchment area measures about 100 square kilometer. The source of the river is located on latitude 05`26`N and on longitude 07`02`E (Ibe et al., 2003). Akajiaku et al. (2014) reported that the Otamiri River has maximum average flow of 10.7 m^3/s in the rainy season (September - October) and a minimum average flow of about 3.4 m^3/s in the dry season (November - February). The total annual discharge of the Otamiri is about 1.7×10^8 m^3, and 22 percent of this (3.74×10^7 m^3) comes from direct runoff from rainwater and constitutes the safe yield of the river.

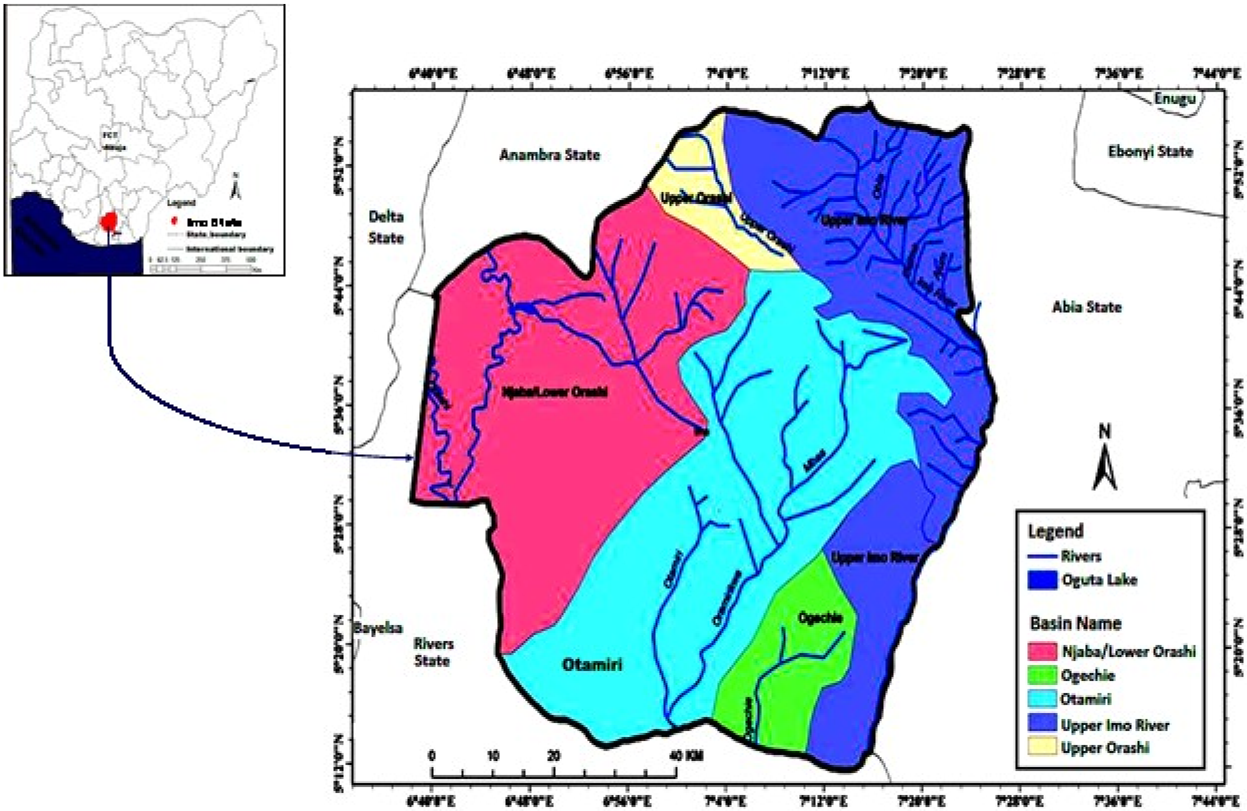


Figure 1: Otamiri sub-basin (within the five major sub-basins in Imo State) showing the location of River Otamiri (modified from Amangabara, 2015)

Table 1: 10-Year Daily Average Discharge Data of Otamiri River

YEAR	DAY	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
	10	3.90	3.70	3.60	3.60	3.89	4.29	7.57	7.12	6.16	4.87	4.30	3.11
1978/79	20	3.85	3.64	3.73	3.73	4.02	5.79	7.17	6.42	6.04	4.58	4.07	2.48
	30	3.8	3.60	3.96	3.96	4.35	5.96	7.67	6.19	5.24	4.50	3.80	2.27
	10	5.48	5.10	4.59	4.51	5.33	7.55	9.84	8.16	7.11	6.22	4.96	3.88
1979/80	20	5.27	4.91	4.84	4.49	5.08	8.54	10.31	7.83	6.91	6.38	4.61	3.76
	30	5.337	4.90	5.19	5.05	6.38	9.29	10.15	7.61	6.62	5.78	4.17	3.68
	10	2.68	2.31	2.41	3.67	4.03	5.14	6.06	5.96	5.85	5.80	4.80	4.41
1980/81	20	2.49	2.27	3.25	3.76	4.23	5.29	6.13	6.42	5.68	5.55	4.63	4.41
	30	2.3	2.13	3.99	4.08	4.70	5.92	6.23	6.05	5.56	5.33	4.54	4.65

	10	4.18	4.22	4.27	4.74	5.44	7.44	8.95	8.02	7.28	7.35	7.34	6.82
1981/82	20	4.23	4.23	4.57	4.88	6.26	8.62	8.67	7.67	7.24	7.43	7.09	6.92
	30	4.11	4.23	4.92	5.27	6.26	8.54	8.25	7.25	7.33	7.38	7.04	6.91
	10	6.68	6.65	7.15	6.69	6.72	7.08	7.68	7.95	8.72	8.26	7.00	7.41
1982/83	20	6.66	6.86	6.73	743	6.85	6.86	8.26	8.56	8.68	7.54	7.09	7.23
	30	6.67	7.36	6.92	6.91	7.30	7.13	8.03	8.56	8.64	7.26	7.26	7.35
	10	7.53	7.86	10.17	9.98	3.70	10.46	11.57	11.41	11.20	11.20	10.57	10.14
1983/84	20	7.36	7.75	10.18	9.97	9.83	11.50	11.74	11.36	11.18	11.17	10.35	9.04
	30	7.09	10.63	10.13	10.52	10.88	11.53	13.39	13.39	12.21	12.21	9.06	9.74
	10	5.97	6.20	6.57	7.19	7.34	7.87	7.70	8.27	8.68	8.02	7.57	7.70
1984/85	20	6.03	6.43	6.87	7.39	8.11	7.36	8.32	8.61	8.53	7.81	7.21	7.73
	30	6.188	6.40	6.98	7.41	8.15	7.41	8.27	8.71	8.26	7.64	7.66	8.01
	10	7.45	7.20	7.16	7.38	8.55	9.72	9.36	8.33	7.99	7.924	7.728	7.58
1985/86	20	7.44	7.12	7.15	7.99	8.99	9.18	9.04	8.16	7.99	8.036	7.74	7.75
	30	7.11	7.11	7.40	7.78	9.07	8.84	9.21	7.98	7.88	7.79	7.64	7.87
	10	7.95	8.26	8.90	7.62	8.33	8.55	9.31	9.25	9.13	9.10	8.76	8.60
1986/87	20	7.68	8.50	7.98	7.66	7.83	8.75	9.20	9.24	9.16	8.64	8.64	9.56
	30	7.88	9.49	7.68	8.68	8.07	8.69	9.18	9.14	9.10	9.05	8.65	8.74
	10	8.67	8.81	8.86	8.86	8.88	9.30	9.30	9.30	8.90	8.55	8.19	8.4
1987/88	20	8.60	8.82	8.65	8.71	8.30	9.43	9.05	9.32	8.82	8.41	8.078	7.90
	30	8.54	8.81	8.58	8.49	8.69	8.69	9.11	9.21	8.68	8.34	7.98	7.47

The 10-day average discharge data used in the evaluation of the empirical FDC of Otamiri River is shown in Table 1. Initially, the total range of discharge values (2-13m^3/s) were divided into 12 classes of 1m^3/s and suitable class intervals selected. The data was then scanned and the number of occurrences of each discharge value was entered into appropriate class interval and recorded and these values were then arranged in ascending order of magnitude. The number of time and the percent of time each class interval flow value has been equalled or exceeded in the period of the record were obtained by the cumulative addition of the value beginning from the last value and upwards, then the percent of time the value of the class interval is equalled or exceeded was computed as the percent of the total number of occurrences (*m*) of the particular flow interval out of the 120 (= 10 yr × 12 = *n*) mean monthly called the exceedance frequency through the Weibull plotting position:

$$F_m = \frac{m}{n} \times 100 \qquad (1)$$

where m is the index of the sorted value and n the total number of observations in the year of interest. The lower value of each class interval as (y-axis,), was plotted against the percentage of time exceeded by flow as (x-axis) to obtain the flow duration curve FDC. The availability of flow is the percentage of time that flow is available for use in a year. The availability of flow therefore corresponds to their percentage exceedence. The amount of work involved in preparing a flow duration curve can be reduced by dividing the flow data into class intervals instead of handling each individual observation. In computing the design flow, various flow values corresponding to different percentage exceedence Q_{15}, Q_{20}, Q_{30}, Q_{50}, Q_{60}, Q_{70}, Q_{80} and Q_{90} were read off the FDC to obtain the flow values. These flow and availability values were then substituted in the power potential equation to obtain various power potentials. The *median flow* (Q_{50}) is the discharge which is equalled or exceeded 50% of the time. The part of the curve with flows below the median flow represented low-flow conditions. Baseflow was interpreted to be significant if this part of the curve had a low slope, as this reflected continuous discharge into the stream. A steep slope suggested relatively small contributions from natural storages like groundwater to the streamflow. The ratio of the discharge which was equalled or exceeded 90% of the time, to that of 50% of the time (Q_{90}/Q_{50}) was used to indicate the proportion of streamflow contributed from groundwater storage according to the method by Nathan and McMahon (1990). Other low-flow indices include: One- or *n*-day discharges that were exceeded at defined percentages of time, say 75, 90 or 95 % represented by Q_{75}, Q_{75}, Q_{95}.; the percentage of time the stream was at zero-flow conditions; the longest recorded period of consecutive zero-flow days.

2.2 Estimation of Power potentials

These power potentials were then substituted in the energy equation to obtain the corresponding annual energy generated.

Power Potential: The power potential P, is an indication of the average hydropower production capability of a river and was computed from the power equation,

$$P = 7\, Q_{av} H \qquad (2)$$

where H=3.475m fixed by the maximum head achievable at the culvert location of Otamiri River

Q_{av}, = average flow or the mean monthly discharge data obtained by dividing the total annual discharge with the total number of years of data

Installed Capacity: The installed capacity, P_{IC}, for this river at the site was estimated on the basis of maximum flow Q_{15}, flow available 15% of the time by substituting Q_{15} for Q_{av} in Equation (2) as:

$$P_{ic} = 7 Q_{15} H \tag{3}$$

Firm or Dependable Power: The firm or dependable power P_F, was estimated on the basis of Q_{90}, which is the flow available 90% the time by substituting Q_{90} for Q_{av} in Equation (2) as:

$$P_f = 7 Q_{90} H \tag{4}$$

Energy Generation: The average annual energy generated, E, from a proposed power plant was computed from the energy equation,

$$E = 7 Q_{av} H P_{ic} \tag{5}$$

RESULTS AND DISCUSSION

Table 2 shows the division of the total range of discharge values (2-13m^3/s) into 12 classes of 1m^3/s and the recording of the number of occurrences of each discharge value in the appropriate class interval. The number of times and the percentages of time that the flow of each class interval has been equalled or exceeded in the period of the record is presented in Table 3.

Table 2: Arrangement of Flow into Class Intervals

Year	**2-2.99**	**3-3.99**	**4-4.99**	**5-5.99**	**6-6.99**	**7-7.99**	**8-8.99**	**9-99**	**10-10.99**	**11-11.99**	**12-12.99**	**13-13.99**	**Total**
1978/79	0	15	4	8	5	4	0	0	0	0	0	0	36
1979/80	0	3	9	9	5	4	2	2	2	0	0	0	36
1980/81	7	4	1	10	5	0	0	0	0	0	0	0	36
1981/82	0	0	0	2	5	12	6	0	0	0	0	0	36
1982/83	0	0	11	0	12	16	8	0	0	0	0	0	36
1983/84	0	0	0	0	0	5	0	0	10	0	2	2	36
1984/85	0	0	0	1	8	15	12	70	0	0	0	0	36
1985/86	0	0	0	0	0	24	6	6	0	0	0	0	36
1986/87	0	0	0	0	0	8	15	13	0	0	0	0	36
1987/88	0	0	0	0	0	3	25	8	0	0	0	0	36
	7	22	34	30	40	91	74	36	12	10	2	2	360

3.1 Otamiri Flow Duration Curve

The median-flows (Q_{50}) which is equal to flow that occurred 50% of time, was obtained by dividing the FDC into two equal parts the central portion of the graph. The median-flows help to identify the base-flow contribution of the river. The median flow was obtained from Figure 2 as 7.5 m^3/s. Thus, the part of the curve which is below the median (Q_{50}%) represented low-flow condition. As it is shown on the flow duration curve for Otamiri River plotted in Figure 2, the two extreme ends have steep slope bending upward in the case of upper-flow region and bending downward in case of lower-flow.

The effect of storage is to raise the flow duration curve on the dry weather portion and lower it on the high flow portion and thus tends to equalize the flow at different times of the year, as indicated in Figure 2. If the mean weekly flow data were used instead of the monthly flow data, the flow duration curve would lie below the curve obtained from monthly flows for about 75% of the time towards the drier part of the year and above it for the rest of the year. In fact the flow duration curve obtained from daily flow data gives the details more accurately (particularly near the ends) than the curves obtained from weekly or monthly flow data but the latter provide smooth curves because of their averaged out values.

Table 3: Flow Duration Analysis of 10-Daily Average Monthly Flow Data for Otamiri

S/No	10 Daily Average Monthly Flow Class Interval (C. I.)	No. Of occurrences in 10yr period (n)	No. of Timeequalled or exceeded (m)	Percent of Time Lower value of C.I equalled or exceeded (m/n x 100%)
1	2-2.99	7	360	100
2	3-3.99	22	353	98.05
3	4-4.99	34	331	91.94
4	5-5.99	30	297	82.5
5	6-6.99	40	267	74.16
6	7-7.99	91	227	63.05
7	8-8.99	74	136	37.78
8	9-9.99	36	62	17.22

9	10-10.99	12	26	7.22
10	11-11.99	10	14	3.88
11	12-12.99	2	4	1.11
12	13-13.99	2	2	0.55

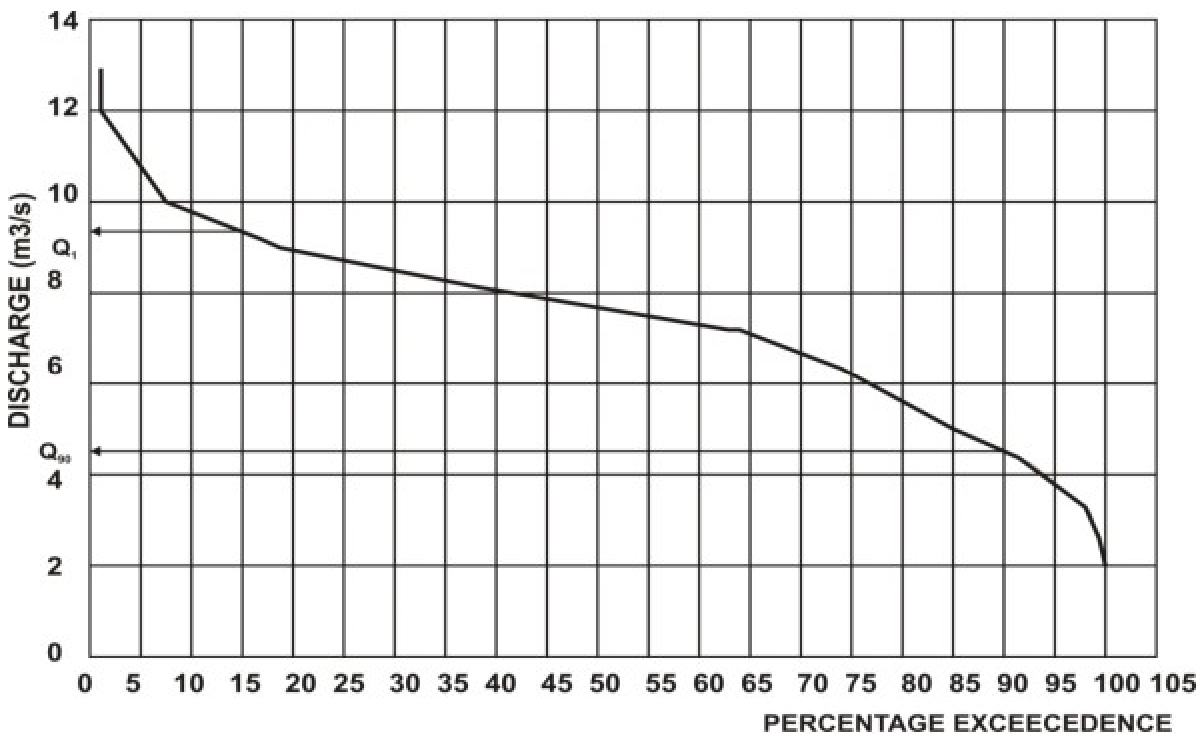


Figure 2: Flow Duration Curve of Otamiri River

3.2 Estimated Power Potential of Otamiri River

This maximum flow $Q_{15}$was determined by reading off the flow corresponding to Q_{15} from the flow duration curve i.e. $Q_{15} = 9.22rn^3/s$**.** The average flow, Q_{av}, was computed from the mean monthly discharge data by dividing the total annual discharge by the total number of years of data, Q_{av} = 7.2 1m^3/s. The minimum dependable flow, Q_{90}, was obtained from the FDC (Figure 2) as 7.21m^3/s. The power potential P was computed as175.38kw. The installed capacity, P_{IC}, for this river at the site was estimated as 224. 28kw. The firm or dependable power P_F, was estimated as 102.41kW. The average annual energy generated, E, from a power plant was computed as 1,536, 357.27 kwh. The availability of each flow value was determined by selecting the percentage exceedence for that flow as shown in Table 3. The flow that gave the maximum energy generation was the design flow Q_d.

4. CONCLUSION AND RECOMMENDATION

Flow duration curve and minimum flows for Otamiri at Nkede gauging station were successfully analyzed. Various flow values corresponding to different percentage exceedence Q_{15}, Q_{20}, Q_{30}, Q_{50}, Q_{60}, Q_{70}, Q_{80} and Q_{90} were read off the FDC. This maximum flow and average flow were determined as 9.22rn^3/s and 7.2 1m^3/s . respectively while. The power potential and installed capacity were computed as 175.38kw and 224. 28kw respectively. The dependable power and average annual energy generated were estimated as 102.41kW and1,536, 357.27 kwh respectively. From the estimated flow duration curve for Otamiri River, the monthly flow which is equalled or exceeded 90% of time Q_{90} is 7.2m^3/s. This flow which is known as the lowest flow for Otamiri River can be considered in assessing the reliability of Otamiri River for hydropower generation as well as environmental flow requirement in the river catchment.

REFERENCES

Akajiaku, C., Chukwuocha, J. & Igbokwe,I., 2014. Delineation and characterization of sub-catchments of Owerri, south-east Nigeria, using GIS. *American Journal of Geographic Information System*, https:/doi.org/10.5923/j.ajgis.20140301.01 .

Amangabara, G.T. (2015) Drainage Morphology of Imo Basin in the Anambra – Imo River Basin Area, of Imo State, Southern Nigeria. *Journal of Geography, Environment and Earth Science International,* 3(1), 1-11.

Atieh, M., Gharabaghi, B.& Rudra, R. (2015) Entropy-based neural networks model for flow duration curves at ungauged sites. *J. Hydrol.,* 529, 1007–1020.

Atieh, M., Taylor, G., Sattar, A.M.A. & Gharabaghi, B. (2017). Prediction of flow duration curves for ungauged basins. *J. Hydrol.*, 545, 383–394.

Boscarello, L., Ravazzani, G., Cislaghi, A. & Mancini, M. (2016). Regionalization of flow-duration curves through catchment classification with streamflow signatures and physiographic–climate indices. *J. Hydrol. Eng.*, 21, 05015027.

Botter, G., Zanardo, S., Porporato, A., Rodriguez-Iturbe, I. & Rinaldo, A. (2008). Ecohydrological model of flow duration curves and annual minima. *Water Resour. Res*. 44:W08418. doi:10.1029/2008WR006814

Castellarin, A., Botter, G.,Hughes, D.A.,Liu, S. , Ouard, M.J.,Parajka, J., Post ,D., Sivapalan, M., Spence, C., Viglione, A. & Vogel, R. (2013). Prediction of flow duration curves in ungauged basins. In: Blöschl, G., Sivapalan, M.,Wagener, T.,Viglione, A. & Savenije H. (Eds). *Runoff Prediction in Ungauged Basins: Synthesis across Processes, Places and Scales*. (pp.135–162), Cambridge, UK: Cambridge University Press.

Castellarin, A., Camorani, G. & Brath, A. (2007). Predicting annual and long-term flow-duration curves in ungauged basins. *Adv Water Resour.* 30(4), 937–953.

Cigizoglu, H.K.(2000). A method based on taking the average of probabilities to compute the flow duration curve. *Hydrol. Res.*, 31, 187–206.

Claps, P. & Fiorentino, M. (1997). Probabilistic flow duration curves for use in environmental planning and management. In: Harmancioglu N.B., Alpaslan, M.N., Ozkul, S.D., Singh, V.P. (Eds). *Integrated approach to environmental data management systems*, (pp.255–2), NATOASIser., Dordrecht: Kluwer

Dingman, S.L. (1978). Synthesis of flow duration curves for unregulated streams in New Hampshire. *Water Resour.* Bull. Am. Water Resour. Assoc., 14, 1481–1502.

Fennessey, N.M. (1994). *A hydro-climatological model of daily streamflows for the northeast United States* [Ph.D. dissertation].Medford (MA): Tufts University

Fennessey, N.M. & Vogel, R.M. (1990). Regional flow-duration curves for ungauged sites in Massachusetts. *J. Water Resour. Plan Manage* ASCE.116, 530–549.

Ganora, D. & Laio, F. (2015). Hydrological applications of the burr distribution: a practical method for the parameter estimation. *J. Hydrol. Eng.* doi:10.1061/(ASCE)HE.1943-5584.0001203

Iacobellis, V. (2008). Probabilistic model for the estimation of T year flow duration curves. *Water Resour. Res.* 44: W02413. doi:10.1029/2006WR005400

Ibe K.M., Nwankwor, G.I. & Onyekuru, S.O., (2003). Groundwater pollution vulnerability and groundwater protection strategy for the Owerri Area, south-eastern Nigeria. In Proc. *Symposium on Water resources systems-water availability and global change*, (pp. 184-194), Sapporo, IAHS.

Kottegoda, N.T. & Rosso, R. (1997). *Statistics, probability, and reliability for civil and environmental engineers*. New York: McGraw-Hill.

Müller, M. F., Dralle, D.N. & Thompson, S.E. (2014). Analytical model for flow duration curves in seasonally dry climates.*Water Resour. Res.* 50:5510–5531. doi:10.1002/2014WR 015301

Muller, M.F., Dralle, D.N. & Thompson, S.E. (2014). Analytical model for flow duration curves in seasonally dry climates. *Water Resour. Res.*, 50, 5510–5531.

Muller, M.F. & Thompson, S.E. (2016). Comparing statistical and process-based flow duration curve models in ungauged basins and changing rain regimes. *Hydrol. Earth Syst. Sci*., 20, 669–683.

Muneepeerakul, R., Azaele, S., Botter, G., Rinaldo, A.& Rodriguez-Iturbe, I. (2010). Daily streamflow analysis based on a two. scaled gamma pulse model. *Water Resour Res.* 46: W11546.doi:10.1029/2010WR009286

Nathan, R.J. & McMahon, T.A. (1990), Identification of Homogeneous Regions for the Purposes of Regionalization, *Journal of Hydrology*, 121, 217-238,

Pugliese, A., Farmer, W.H., Castellarin, A., Arcfield, S.A. & Vogel, R.M. (2016). Regional flow duration curves: Geostatistical techniques versus multivariate regression. *Adv. Water Res*., 96, 11–22.

Pumo, D., Caracciolo, D., Viola, F. & Noto, L.V. (2016). Climate change effects on the hydrological regime of small non-perennial river basins. *Sci. Total Environ.* 542(Part A):76– 92.doi: 10.1016/j.scitoten.2015.10.109

Pumo, D.,Viola, F., LaLoggia, G. & Noto, L.V. (2014).Annual flow duration curves assessment in ephemeral small basins. *J.Hydrol.* 519: 258–270.doi:10.1016/j.jhydrol.2014.07.024

Serinaldi, F. (2011). Analytical confidence intervals for index flow duration curves. *Water Resour Res*. 47:W02542. doi:10.1029/2010WR009408

Singh, K.P. (1971). Model flow duration and streamflow variability. *Water Resour. Res*., 7, 1031–1036

Singh, R.D., Mishra, S.K. & Chowdhary, H. (2001). Regional flow duration models for large number of ungauged Himalayan catchments for planning Micro hydro Projects. *J. Hydrol. Eng.,* 6, 310–316.

Vogel, R.M. & Fennessey, N.M. (1995). Flow duration curves II: a review of applications in water resources planning. *Water Resour. Bull.* 31 (6):1029–1039.

Yokoo, Y. & Sivapalan, M. (2011).Towards reconstruction of the flow duration curve: development of a conceptual framework with a physical basis. *Hydrol Earth Syst.*

*Sci.*15:2805–2819. doi:10.5194/hess-15-2805-2011

Zhang, Y., Vaze, J., Chiew, F.H.S. & Li, M. (2015). Comparing flow duration curve and rainfall–runoff modelling for predicting daily runoff in ungauged catchments. *J. Hydrol.,* 525, 72–86.

THEME FOCUS:

ENERGY MIX RESEARCH AND ITS APPLICATIONS TO ADDRESS CURRENT ENERGY CRISIS

ADOPTION OF ENERGY MIX RESEARCH AND ITS APPLICATIONS FOR ADDRESSING CURRENT ENERGY CRISIS IN NIGERIA

Oluwadare Joshua Oyebode
Civil and Environmental Engineering Department
Afe Babalola University, Ado-Ekiti
Ekiti State, Nigeria
oyebodedare@yahoo.com

ABSTRACT

Application of outputs from energy mix research is the way forward for national economic growth and sustainable energy in Nigeria. This paper examines applications of energy mix research as a special tool for addressing present energy crisis in Nigeria. Methodology used includes secondary data, opinion from experts, personal observations and previous records. Issues linked present system, appraisal of benefits and strategies for way forward were highlighted. The demand for energy is far more than supply of energy in Nigeria. Findings reveal that there is need for strategic synergy between industries and academia to solve current energy crisis in Nigeria. Multidisciplinary research on energy mix with adequate collaboration from industries and academic has not been fully adopted and integrated into energy sector. It has been concluded that current energy crisis can be tackled through energy mix research and its applications. This will bring industrialization, job creation, wealth to the nation, employment opportunities and capacity building in energy sector. Recommendations include periodic training for engineers in energy sector, adequate financing, entrepreneurial training, support initiatives, proper implementation of strategies and regulations.

Keywords: *Energy Mix Research, Applications, Economic Growth, technological Innovations, Energy Crisis*

1. INTRODUCTION

Energy mix research and its applications must be adopted for addressing current energy crisis in Nigeria. Industrial productivities and technological advancement of our nation Nigeria has been grossly affected by severe energy crisis for decades. This has affected its economic, social and political developments traceable to continuously evolving energy situation in Nigeria, and the recent progress in renewable energy technologies.

There are copious benefits of energy mix. The right amount of energy can promote a healthy and sustainable lifestyle for the masses, install a secure energy vision in the minds of the masses, enhance limited possibilities of waste in energy export and import, reduce conflict of environmental and social interests in energy and reframe energy transactions models and create new carbon mitigation policies. Sustainable energy transition is generally understood as a concept of developing robust, effective and efficient energy sectors in a particular country or region without compromising the present and future socio-environmental security. Nigeria is one of the highest emitters of greenhouse gases in

Africa. The practice of flaring gas by the oil companies operating in Nigeria has been a major means through which greenhouse gases are released into the atmosphere.

Energy mix refers to all direct uses of energy, such as transportation and housing, so it is not be confused with power generation mix, which refers only to generation of electricity. Energy mix is the range of energy sources of a region. It refers to the combination of the various primary energy. Sources used to meet energy needs in a given geographic region for generating power and other activities. China is the largest consumer of primary energy in the world, using some 145.46 exajoules in 2020. This is far more than was consumed by the United States, which ranks second. The majority of primary energy fuels is still derived from fossil fuels such as oil and coal. The energy mix reflects the fact that it has a strong economy and so needs a variety of energy sources for industrial production, electrical production, transport, and domestic use.Figure 1 described basic benefits from energy mix in terms of policy, security, access and environment.

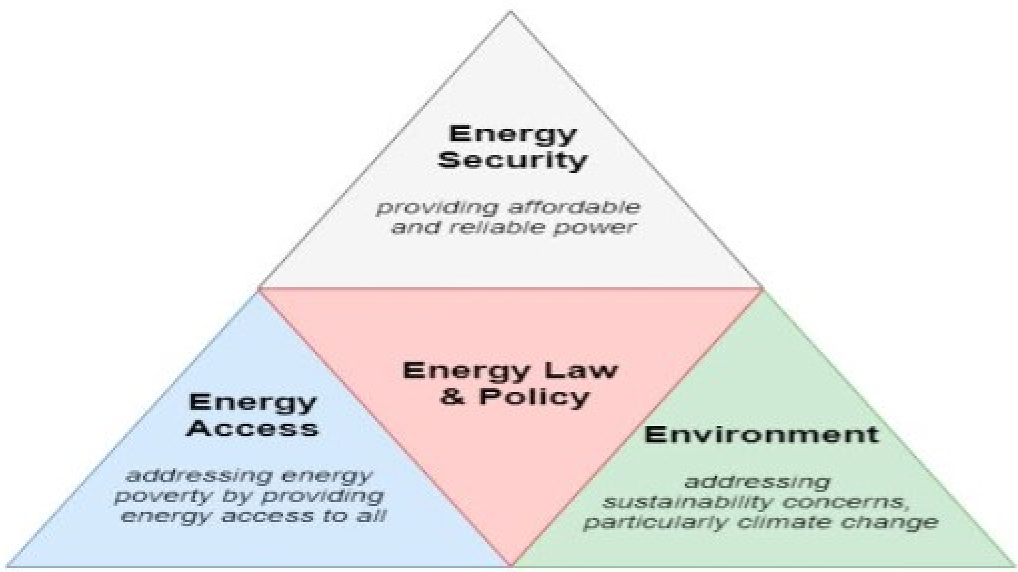


Figure 1: Benefits from energy mix in terms of policy, security, access and environment

Nigeria receives abundant solar energy that can be usefully harnessed with an annual average daily solar radiation of about 5.25 kW h/m^2/day. This varies between 3.5 kW h/m^2/day at the coastal areas and 7 kW h/m^2/day at the northern boundary. The average amount of sunshine hours all over the country is estimated to be about 6.5 h. This gives an average annual solar energy intensity of 1,934.5 kW h/m^2/year; thus, over the course of a year, an average of 6,372,613 PJ/year (approximately 1,770 TW h/year) of solar energy falls on the entire land area of Nigeria. This is about 120,000times the total annual average electrical energy generated by the Power Holding Company of Nigeria (PHCN). With a 10% conservative conversion efficiency, the available solar energy resource is about 23 times the Energy Commission of Nigeria's (ECN) projection of the total final energy demand for Nigeria in the year 2030. To enhance the developmental trend in the country, there is every need to support the existing unreliable energy sector with a sustainable source of power supply through solar energy.

The inefficiency as well as the inadequate facilities to boost electricity supply also have been major causes of the increasing gap between the demand and the supply of electricity. This could be due to the fact that there are only 14 generating stations in Nigeria (3 hydro and 11 thermal stations). Out of the approximated 8,039 MW of installed capacity in Nigeria, not more than 4,500 MW is ever produced. This is due to poor maintenance, fluctuation in water levels powering the hydro plants, and the loss of electricity in transmission. Figure 2 presented the map of Nigeria showing energy resources distribution and socio-economic zones while Figure 3 gave Sustainable development goals at a glance.

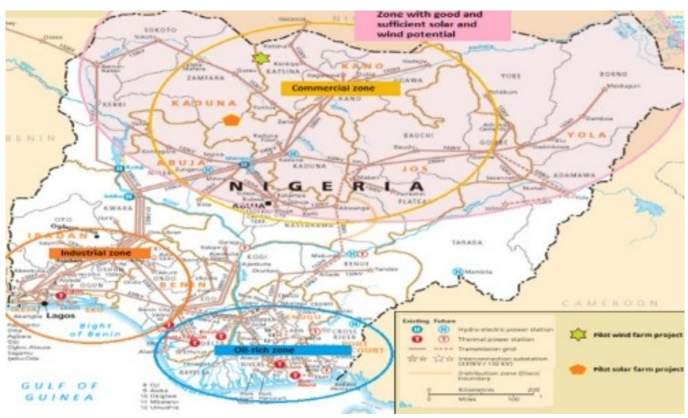


Figure 2: Map of Nigeria showing energy resources distribution and socio-economic zones

It would be difficult for Nigeria to realize any of the numerous objectives of the Sustainable Development Goals (SDGs) (Fig. 3) significant improvement in the availability of electricity to the populace' an expert in the power industry.

Figure 3: Sustainable development goals at a glance

These goals all direct to the need for investment for future survival. The investment in infrastructure and innovation are crucial drivers of economic growth and development. With over half the world population now living in cities, mass transport and renewable energy are becoming ever more important, as are the growth of new industries and information and communication technologies.

2. LITERATURE REVIEW

Factors such as epileptic power supply delayed and overpriced hydropower projects, outdated and insufficient energy infrastructure, transmission and distribution losses, energy theft, and deficient energy management, lack of energy conservation, and low efficiency of equipment, unsustainable energy pricing strategies and unsatisfying energy market regulations. Other essential factors worsening the energy crisis can be attributed to specific geographical and geopolitical problems, the strong dependence on energy imports, and inadequate exploitation of the vast amounts of renewable energy resources (Poudyal et al., 2019).

Nigeria is faced with chronic electricity crisis that has resulted in the crippling of most sectors of the economy. It is estimated that only 40% of Nigerians are connected to the national grid and the connected population are exposed to frequent power outages. Nigeria's electricity grid is mainly powered by large hydropower and depleting hydrocarbon resources. Fossil-based electricity generation contributes not only to increase in carbon footprints, but also exposes the country to changes in price of petroleum resources and political instability from the oil producing region of the country (Aliyu et al., 2015).

Nigeria is located on the west coast of Africa. It is the continent's most populated country in Africa, with over 150 million people. According to the Nigerian Energy Policy report from 2003, it is estimated that the population connected to the grid system is short of power supply over 60% of the time. Additionally, less than 40% of the population is even connected to the grid on a fundamental level, there is simply not enough electricity generated to support the entire population. Due to the lack of reliable electricity, many people and companies supplement the electricity provided by the grid system with their own generators. In fact, most everyone who can afford a generator owns one. According to one approximation, well over 90% businesses have generators. The energy industry in Nigeria has severe environmental ramifications, mostly in the form of both pollution and deforestation (Kenedy et al., 2008).

The success of sustainable development in Africa lies in addressing the imminent energy crisis in the continent. Africa has all the potentials to solve its energy problems if appropriate infrastructural support can be provided for harnessing the abundant renewable resources in the continent, and if skills are pooled together and experiences shared in addressing the key issues (Bugaje, 2006).

Access to clean modern energy services is an enormous challenge facing the African continent because energy is fundamental for socioeconomic development and poverty eradication. Today, 60% to 70% of the Nigerian population does not have access to electricity (Oyedepo, 2012).

Sustainable building is the practice of increasing the efficiency with which buildings and their sites use energy, water, and materials, and also reducing building impacts on human health and the environment, through better siting, design, construction, operation, maintenance, and demolition; the complete building life cycle. Sustainable or "green building" design and construction gives the opportunity to use our resources more efficiently while creating healthier and more energy-efficient homes. These buildings leave a lighter footprint on the environment through conservation of resources, while at the same time balancing energy-efficient, cost-effective, low-maintenance products for our construction needs (Oyebode, 2018).

Sustainable engineering is the process of designing or operating systems such that they use energy and resources sustainably, in other words, at a rate that does not compromise the natural environment, or the ability of future generations to meet their own needs. Eco-effective strategies pursue absolute objectives in terms of reducing environmental pollution, as achieved through the use of renewable energy sources, recirculation of products, by-products and materials into product lifecycles or natural systems, as well as the limitation of environmental pollutants (Oyebode, 2019).

Nigeria is endowed with abundant energy resources, both conventional and renewable, which can potentially provide the country with a sufficient capacity to meet the ambitions of both urban and rural Nigerians of a full, nationwide electrification level. Yet, Nigeria has one of the lowest consumption rates of electricity per capita in Africa. Dissemination of decentralized renewable energy resources will not only improve the wellbeing of rural Nigerian communities, but also enhance Nigeria's energy and economic prospects for potential global investment (Shaaban and Petinrin, 2014).

We are facing a global energy crisis caused by world population growth, an escalating increase in demand, and continued dependence on fossil-based fuels for generation. It is widely accepted that increases in greenhouse gas concentration levels, if not reversed, will result in major changes to world climate with consequential effects on our society and economy (Coyle and Simmons, 2014).

There is great need to overcome barriers to the development of the technologies, such as the lack of understanding of solar thermal systems, lack of incentives for renewable technologies and previous experience of solar photovoltaic systems failure that is making people doubt the viability of renewable electricity. Other barriers that were considered are lack of technical expertise, high technology cost and lack of project funding, including a lack of enabling policies to drive the technologies. Widespread application of these clean energy technologies can help mitigate climate change (Akinyele et al., 2019).

The National Energy Policy (NEP) was developed by ECN and approved by the government in 2003. The document launched in 2005 is the origin of the various master plans, such as Renewable Energy Master Plan (REMP), and National Energy Master Plan (NEMP) in 2007 drafted thereafter. The NEMP contains action plans that guide its implementation to ensure the development of nation’s energy resources with diversified energy resources option for enhanced achievement of national energy security (Sambo, 2009).

3. METHODOLOGY

Methodology used includes secondary data, opinion from experts, personal observations and previous records. Issues linked present system, appraisal of benefits and strategies for way forward were highlighted. Table 1 presented various sources of energy with utilization characterization while figure 4 indicates Nigeria power generation plant and their utilization capacity.

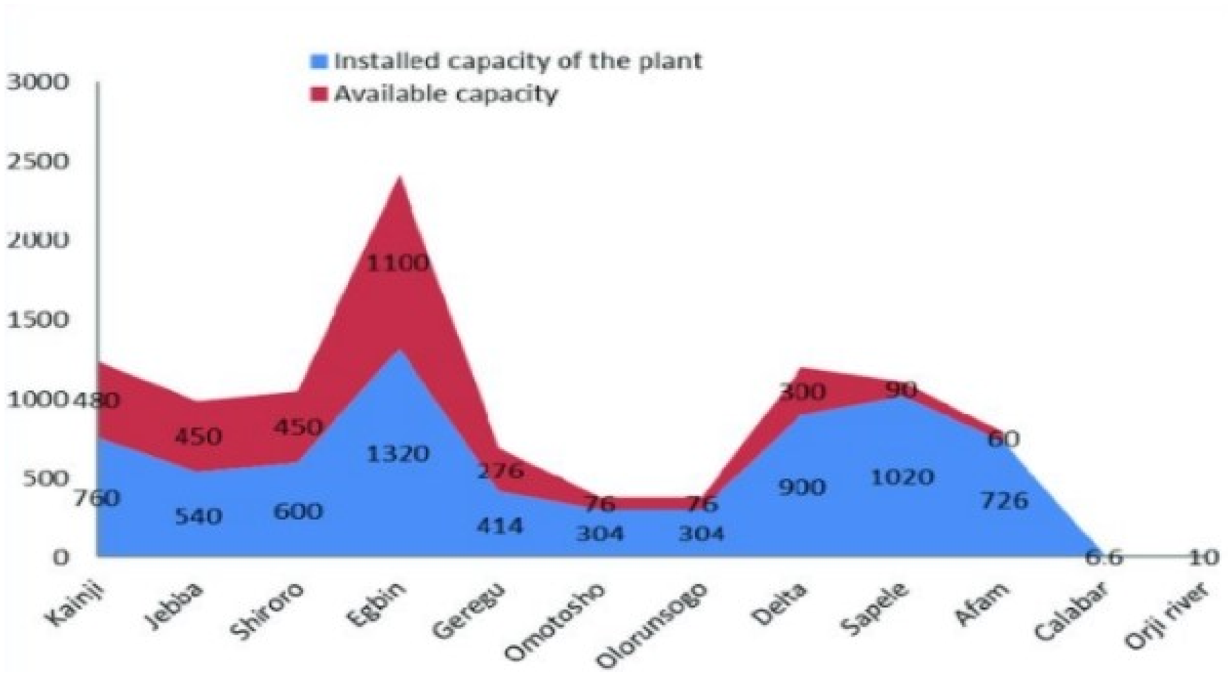


Figure 4: Nigeria Power Generation Plant and their Utilization Capacity
Source: (Olatunji *et al*., 2020)

Table 1: Various Sources of Energy with Utilization Characterization

Resources	Quantification	Utilization characterization
Crude oil	37.062 billion barrels	22% utilization of refineries
Natural gas	182.3 trillion standard cubic foot	18% indiscriminately flared
Coal and lignite	2.7 billion tonnes	7% contribution to net GDP
Tar sands	31 billion barrels of oil equivalent	Negligible usage
Large Hydro	11,250 MW	1938 MW (17% utilized)
Small Hydro	3,500 MW	64 MW (2% utilized)
Solar	3.5-7.0 kWh/m_2/day	27% capacity factor; negligible utilization
Wind	2.0-4.0 m/s at 10 m height	Negligible utilization
Fuel wood	11 million hectares of forest	43.4 million tonnes/yr of consumption
Municipal waste	30 million tonnes/year	0.5kg/capita/day
Animal waste	1.05 tonnes/ day	Negligible utilization
Agricultural residues	91.4 million tonnes/yr. produced	Negligible utilization
Energy crop	28.2 million hectares of arable land	8.5% cultivated

Source: (Oyedepo, 2012).

Recognizing that gas will play a role at least in the near foreseeable future (Zou et al., 2016), especially in developing countries such as Nigeria, where adoption of renewable energy is very sluggish (Maji, 2015; Roche, et al., 2020), energy efficiency is critical to mitigating emissions, and promoting sustainability in Nigeria energy sector. Two major pillars of the present energy transition are energy-efficiency and renewable energy. Five critical factors that affect the success or cost-competitiveness of Nigeria's businesses are inadequate access to funding, macroeconomic situations and economic volatility, poor electricity supply, political instability and high operating overheads. Nigeria exports most of the petroleum products it produced. However, domestic consumption is on the increase. The increase in domestic production is related to population growth, urbanization and economic growth (Okafor et al., 2021).

Figure 5 gave vivid conceptualization of the integration of economic diversification, scaled-up Renewable Energy and energy-efficiency. Table 2 also presented renewable energy potential and their current utilization in Nigeria.

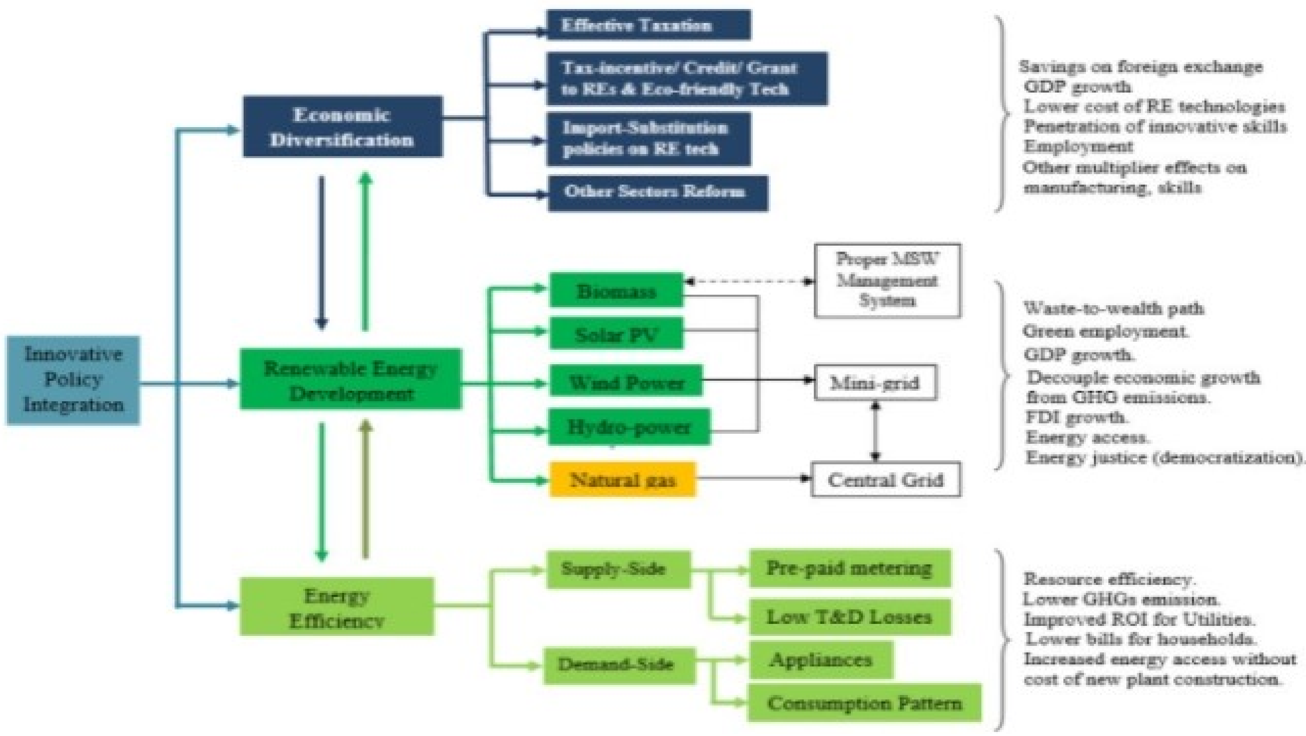


Figure 4: Integration of Economy, RE and Energy-efficiency

Source: (Okafor et al., 2021)

Table 2: Renewable energy potential and their current utilization in Nigeria

Resources	Amount	Current Use
Large hydropower	11,250 MW	1930 MW (17.1%) used
Small hydropower	3,500 MW	64.2 MW (1.83%) used
Solar	4.0–6.5 kWh/m^2/day	27% Capacity Factor (Negligible)
Wind:	2–4 m/s @ 10 m hub height	
- Onshore wind	1,600 MW	Negligible use
- Offshore wind	800 MW	Negligible use
Geothermal	500 MW	Negligible use
Biomass (Non-fossil fuel):		
Municipal waste	30 million tonnes/year	0.5 kg/capita/day
Fuel wood	11 million hectares of forest	43.4 million/tonnes/yr consumed
Animal waste	1.05 tonnes/day	Negligible use
Agricultural residues	91.4 million tonnes/yr produced	Negligible use
Energy crops	28.2 million hectares of arable land	8.5% cultivated

Source: (Adewuyi et al., 2020)

The major challenges confronting energy mix and power generation in Nigeria are:

i. Lack of clear government policies.

ii. Inadequate legal instrument for renewable energy development.

iii. Effective funding of energy mix related projects and researches in all geo-political zones.

iv. Poor plant maintenance, aged/obsolete equipment and gas pipe line vandalism and many others.

4. STRATEGIES FOR ENERGY MIX RESEARCH AND ITS APPLICATIONS FOR ADDRESSING CURRENT ENERGY CRISIS IN NIGERIA

Strategies for Energy Mix Research and its Applications for Addressing Current Energy Crisis In Nigeria include the following:

i. Full exploitation and promotion of renewable energy resources, energy efficiency practices, as well as the application of energy conservation measures in various sectors such as in the construction of industrial, residential, and office buildings, in transportation.

ii. Government has to intensify the further implementation of renewable energy and energy efficiency programs in order to ensure the sustainability of energy supply and subsequently the sustainable economic development of the country.

iii. Instead of flaring gas in Nigeria, the gases can be converted to methanol and used as a fuel for both domestic and industrial use. With good energy efficiency practices and products, the burning of fossil fuel for energy will be greatly minimized.

iv. Introduction of principles of environmental sustainability within these processes of re-use, recycling and disposal of e-waste globally and in Nigeria. These principles must be accompanied by state policies and regulatory frameworks that promote sustainable processes.

v. Development of policies on energy efficiency and integrate them into the current energy policies. A comprehensive and coherent energy policy is essential in guiding the citizens towards an efficient usage of its energy resources.

vi. Promotion of energy-efficient products and appropriate practices at the side of the end users and energy generation.

vii. Human resource development, critical knowledge, and know-how transfer should be the focus for project development, project management, monitoring, and evaluation. The preparation of standards and codes of practices, maintenance manuals, life cycle costing, and cost-benefit analysis tools should be undertaken on urgent priority.

5. CONCLUSIONS

Current energy crisis can be tackled through energy mix research and its applications. This will bring industrialization, job creation, wealth to the nation, employment opportunities and capacity building in energy sector. Governments and all stakeholders have important roles to play in promoting energy efficiency and conservation. Efficiency standards for appliances, equipment and automobiles have proved to be extremely cost-effective in many developed countries and are often relatively easy to implement compared to other policies, particularly if they can be harmonized with the standards adopted in other large markets. Despite their availability in reasonable quantities, renewable energy resources are grossly underutilized in Nigeria. Energy efficiency can be especially important in rapidly industrializing countries as a way to manage rapid demand growth, improve system reliability, ease supply constraints and allow energy the production and distribution infrastructure to 'catch up. Adoption of energy mix research and its applications is a veritable tool for addressing current energy crisis in Nigeria**.** There is no doubt that the present power crisis afflicting Nigeria will persist unless the government diversifies the energy sources in domestic, commercial, and industrial sectors and adopts new available technologies to reduce energy wastages and to save cost.

6. RECOMMENDATIONS

Periodic training should be organized for engineers in energy sector, adequate financing, entrepreneurial training, support initiatives, proper implementation of strategies and regulations. Government, engineering family and energy experts should work on strategies for deployment of technological innovations in the promotion renewable energy systems.

To ensure long term development of renewable energy and energy efficiency, there must be human resource development at high level and manufacturing capacity building. Critical knowledge and technical know-how transfer should be the focus for project development and management. Energy Commission of Nigeria (ECN) should continuously monitor and evaluate the performance of these centers in terms of quality research outputs from them. The government should be more serious to take a pragmatic step towards realizing the targets set by the ECN for the renewable energy contribution to electricity generation in Nigeria. Efficient energy use and conservation of energy through energy saving bulbs, improved fuel wood stoves, efficient electrical appliances, etc, should be promoted by relevant government agencies and non-governmental organizations, to reduce the energy demand. In addition to these, the existing research and development centers and technology development institutions should be adequately strengthened to support the shift towards an increased use of renewable energy.

There is great need for multi-sectorial cooperation to scale up and deepen the scope of Renewable Energy and energy efficiency in Nigeria. This will assist diversification of our economy and all relevant ministries, agencies, professionals, financial institutions, universities, Research and development institutions, entrepreneurs, government, non-governmental organization and other stakeholders must be involved.

To secure additional benefits and ensure that manufacturers continue to innovate, other policies and incentives are needed to generate a demand for products that perform above the minimum standards.

ACKNOWLEDGEMENTS

I thank and acknowledge the President, members of executives, technical committee, reviewers and members of Nigerian Society of Engineers (NSE) for the opportunity given to me to contribute my paper to this conference.

REFERENCES

Adewuyi OB, Kiptoo MK, Afolayan AF, et al. (2020) Challenges and prospects of Nigeria's sustainable energy transition. *Energy Rep* 6: 993-1009. doi: 10.1016/j.egyr.2020.04.022

Ajayi O.O. and O. O. Ajayi, "Nigeria's energy policy: Inferences, analysis and legal ethics toward RE development," Energy Policy, vol. 60, pp. 61-67, 2013.

Akinyele, D., Babatunde, O., Monyei, C., Olatomiwa, L., Okediji, A., Ighravwe, D., ... & Temikotan, K. (2019). Possibility of solar thermal power generation technologies in Nigeria: Challenges and policy directions. *Renewable Energy Focus*, *29*, 24-41.

Akorede, M. F., Ibrahim, O., Amuda, S. A., Otuoze, A. O., & Olufeagba, B. J. (2017). Current status and outlook of renewable energy development in Nigeria. *Nigerian Journal of Technology*, *36*(1), 196-212.

Aliyu, A. S., Dada, J. O., & Adam, I. K. (2015). Current status and future prospects of renewable energy in Nigeria. *Renewable and sustainable energy reviews*, *48*, 336-346.

Bugaje, I. M. (2006). Renewable energy for sustainable development in Africa: a review. *Renewable and sustainable energy reviews*, *10*(6), 603-612.

Coyle, E. D., & Simmons, R. A. (2014). *Understanding the global energy crisis*. Purdue University Press.

Kennedy-Darling, J., Hoyt, N., Murao, K., & Ross, A. (2008). The energy crisis of Nigeria: an overview and implications for the future. *The University of Chicago, Chicago*, 775-784.

Maji IK (2015) Does clean energy contribute to economic growth? Evidence from Nigeria. *Energy Rep* 1: 145-150. doi: 10.1016/j.egyr.2015.06.001

Okafor, C., Madu, C., Ajaero, C., Ibekwe, J., Bebenimibo, H., & Nzekwe, C. (2021). Moving beyond fossil fuel in an oil-exporting and emerging economy: Paradigm shift. *AIMS Energy*, *9*(2), 379-413.

Olatunji, O., Akinlabi, S., Oluseyi, A., Abioye, A., Ishola, F., Peter, M., & Madushele, N. (2018, September). Electric power crisis in Nigeria: A strategic call for change of focus to renewable sources. In *IOP Conference Series: Materials Science and Engineering* (Vol. 413, No. 1, p. 012053). IOP Publishing.

Oyebode, O. J. (2018). Evaluation of municipal solid waste management for improved public health and environment in Nigeria. *European Journal of Advances in*

Engineering and Technology, *5*(8), 525-534.

Oyebode, O. J. (2019). Impacts of Civil Engineering Infrastructures In the Sustainability of the Environment. In *paper published in the conference proceedings of 17th International Conference and AGM tagged "PEACE 2019" of Nigerian Institution of Civil Engineers (NICE)*.

Oyebode, O. J. Green Building: Imperative Panacea for Environmental Sustainability and Life Cycle Construction in Nigeria. *World Journal of Research and Review*, *7*(3), 262584.

Oyedepo, S. O. (2012). Energy and sustainable development in Nigeria: the way forward. *Energy, Sustainability and Society*, *2*(1), 1-17.

Poudyal, R., Loskot, P., Nepal, R., Parajuli, R., & Khadka, S. K. (2019). Mitigating the current energy crisis in Nepal with renewable energy sources. *Renewable and Sustainable Energy Reviews*, *116*, 109388.

Roche MY, Verolme H, Agbaegbu C, et al. (2020) Achieving sustainable development goals in Nigeria's power sector: Assessment of transition pathways. *Clim Policy* 20: 846-865. doi: 10.1080/14693062.2019.1661818

Sambo, A. S. "The Challenges of Sustainable Energy Development in Nigeria " presented at the paper presented at the Nigerian Society of Engineers Forum, ShehuYar'AduaCentre, Abuja, Nigeria, 2009.

Shaaban, M., & Petinrin, J. O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and sustainable energy reviews*, *29*, 72-84.

Zou C, Zhao Q, Zhang G, et al. (2016) Energy revolution: From a fossil fuel energy era to a new energy era. *Nat Gas Ind B* 3: 1-11. doi: 10.1016/j.ngib.2016.02.001

EFFECT OF CASSAVA PEEL ASH AND EGG SHELL POWDER ON MECHANICAL PERFORMANCE OF CONCRETE

Ahmed, A[1]. and Uche, O. A. U.[2]
[1]civil Engineering Department, Federal Polytechnic Bida, Niger State, Nigeria.
[2]civil Engineering Department, Bayero University Kano, Nigeria.
E-mail addresses: [1]aaahmed007@yahoo.com, [2]okoauche@yahoo.co.uk
+2348065460813

ABSTRACT

The research focuses on the mechanical performance of concrete with the agricultural waste materials, such as cassava peel ash (CPA) and egg shell powder (ESP) as partial replacement of cement. The cassava peel (CP) used was sourced from a local industries while the egg shell (ES) used was sourced from bakeries and restaurants. The CP was sun dried, burnt and sieved through a 75µm sieve and the ES was washed, sun dried, grind and sieved through a 75µm sieve, and both materials were characterized by X-Ray Fluorescence (XRF) analytical method. The Compressive, splitting tensile and flexural strengths of these concrete with CPA and ESP of 0, 5, 10, 20, 30 and 40% respectively by weight of cement were investigated in accordance with standard procedures. CPA and ESP were mixed in a proportion of 10:90, 20:80, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80 and 10:90 respectively for the partial replacement of 0, 5, 10, 20, 30 and 40% by weight of cement. Cubes, Cylinder and beams of hardened concrete were tested for compressive splitting tensile and flexural strengths at 3, 7, 28, 56 and 90 days of curing in accordance with standard procedures. The results of the investigations showed that CPA was predominantly of Silicon oxide (56.73%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 66.75%; and the result of the investigations showed that ESP was predominantly of Calcium oxide (49.29%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 3.86%. The addition of CPA and ESP in concrete production showed slight increase in compressive, split cylinder tensile and flexural strengths with increase in CPA/ESP additive up to 10% and decrease in compressive splitting tensile and flexural strengths with further increase in CPA/ESP content. The 28 days compressive strength of concrete with 10% CPA/ESP content was 6.4 % more than normal, while that of concrete with 20% CPA/ESP content was 14.9 % less than normal.

Keywords: Concrete, Cassava peel ash, Egg shell powder, Compressive strength, splitting tensile strength, flexural strength.

1. INTRODUCTION

The over dependent on the utilization of industrially manufactured binding materials (cement) have kept the cost of construction financially high, and this has up till now prevented developing countries like Nigeria in providing cheap housing for its citizen particularly rural dwellers that are mostly agriculturally dependent (Agbede and Joel, 2011). The use of waste materials as a partial or full replacement of cement in mortar and concrete can be an important step towards sustainability in the construction industry worldwide, since cement is used as their main binder, (Krammart and Tangtermsirikut, 2004). The use of alternative binders that are less pollutant and/or the use of residues could impact the construction industry towards the production of concrete with less environmental impact. According to Ramezanianpour, *et al*. (2009) the cost of cement production is expected to decline when Portland cement is partially replaced by rice husk ash, a pozzolana from agro-waste product. In the other hand, a modern life style alongside the advancement of technology has led to an increase in the amount and types of waste being generated, leading to waste disposal crisis, (Sunusi, 2015). This research tries to tackle problem of the waste that is generated from cassava peels and egg shell. Cassava peel is a by-product of cassava processing, either for domestic consumption or industrial uses. According to Adesanya *et al.* (2008) cassava peel constitutes between 20 – 35% of the weight of tuber, especially in the case of hand peeling. Based on 20% estimate, about 6.8 million tons of cassava peel is generated annually and 12 million tones are expected to be produced in the year 2020. Indiscriminate disposal of cassava peels due to gross underutilization, as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem. Thus, there is need to search for alternative methods to recycle cassava peels.

Salau and Olonade (2011) studied the pozzolanic potential of cassava peel ash (CPA) and their results showed that cassava peel ash possesses pozzolanic reactivity when it is calcined at 700°C for 90 minutes. At these conditions, CPA contained more than 70 per cent of combined silica, alumina and ferric oxide, but has low calcium oxide (CaO) which is the source of binding.

Egg shell consist of several growing layers of Calcium Carbonate ($CaCO_3$) and it is a poultry waste with chemical composting nearly same as that of limestone (Kumar et. al. 2017). Use of egg shell waste to replace cement can have benefits like minimizing use of cement, conserves natural lime and utilizing waste materials, majority of egg shell wastes are deposited in landfill and it attracts vermin and causes human health and environmental problems, (Raji and Samuel, 2015).

Okonkwo et al., (2012) concluded in their research that Egg Shell powder (ESP) can be used as an alternate for cement which resulted in higher compressive strength of concrete. Ultimately, they found that soil-cement-egg shell mixture can be used for road pavements. Arash et al., (2012) carried out the experiment on the effect of eggshell powder on plasticity index in clay and expansive soils and reported that plasticity index of the soil can be improved by adding egg shell wastes with the clay soil and can be used in construction projects including earth canals and earth dams.

The dominant oxide in ESP and CPA are CaO and SiO_2 respectively. CaO is the main source of binding and hardening compound in cement, when reacted with water (hydration reaction), which is very high in ESP and low in CPA. But, the SiO_2 in CPA reacts with $Ca(OH)_2$ (by product of cement hydration) to produce more binding property (Pozzolanic reaction). The advantage of reduction in the consumption of cement leading to reduction in the greenhouse effects caused by cement usage is being exploited by the use of pozzolana in concrete and mortar production.

2. MATERIALS AND METHODS

2.1 Materials

The sand was obtained from a River in Bida, Niger State, Nigeria; and the particle size distribution curve of the sand is shown in Figure 1. The coarse aggregate is crushed granite of nominal size of 20 mm obtained from local vendors. The physical properties of the materials are shown in Table 1. Dangote brand of ordinary Portland cement of Grade 42.5N (3X) was used for this research, which complied with BS EN 197-1 (2009). The oxide composition of the cement is shown in Table 2. Cassava peel and Egg shell were sourced from a local Garri Industries and Bakeries in Bida, Niger State, Nigeria. The Cassava peel and Egg shell were sundried. The cassava peel ash (CPA) was obtained by burning the cassava peel to ash and under a controlled temperature of about 600ºc in a kiln and controlling the firing at that temperature for about two (2) hours and the ash was allowed to cool. After cooling, the resultant CPA grounded and sieved using BS sieve No.200 (75µm) sieves. The egg shells powder was obtained by cleaning and removing the remains from the shells The resultant egg shells were dried naturally and subsequently grounded in to a powder form, and the powder was sieved using BS sieve No.200 (75µm) sieves. Chemical composition analysis of the CPA and ESP was conducted using X-Ray Fluorescence (XRF) analytical method and the results are shown in Table 2.

2.2 Methods

Sieve analysis was used to find the particle size distribution of fine and coarse aggregates, in accordance with standard BS EN 12620 (2013). The result is shown in Figure 1. The specific gravity test was conducted on cement, CPA, ESP, sand and crushed granite in accordance with standard. The result is shown in Table 1; while the oxide composition of cement, CPA and ESP was conducted based on standard at the Centre for Energy Research and Training (CERT) Zaria, Kaduna State. The results from this analysis is presented in Table 2. Compressive strength test was conducted on the concrete samples using different percentage of CPA and ESP (0, 5, 10, 20, 30 and 40%). Cube mould of sizes 150mm×150mm×150mm was used to cast a total of 810 cubes for testing the effect of CPA and ESP on the compressive strength of concrete, for a proportion of 10:90, 20:80, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80 and 10:90 respectively for the partial replacement of 0, 5, 10, 20, 30 and 40% respectively by weight of cement. The cubes were cured for 3, 7, 28, 60 and 90 days and crushed to determine their compressive strength in accordance with BS EN 12390- 3 (2009). The behavior of the effect of CPA and ESP on concrete strength was determined and average recorded.

3. DISCUSSION OF RESULTS

3.1 Physical Properties of Concrete Constituent Materials

The physical properties of the constituent materials are shown in Table 1, whereas the particle size distribution curves are shown in Figure 1. The particle size distribution curve indicates that the sand used was classified as zone 2 based on British Standard classification BS 882, Part 2, (1992) grading limits for fine aggregates and was well graded.

Table 1: Physical properties of Ordinary Portland Cement (3X Dangote Brand)

Property	Value		
	OPC	**CPA**	**ESP**
Specific gravity	3.14	2.23	1.29
Fineness (% passing 90µm sieve)	94	100	100
Loss on Ignition	1.3	5.84	----
Colour	Dark grey	Brownish grey	Whitish

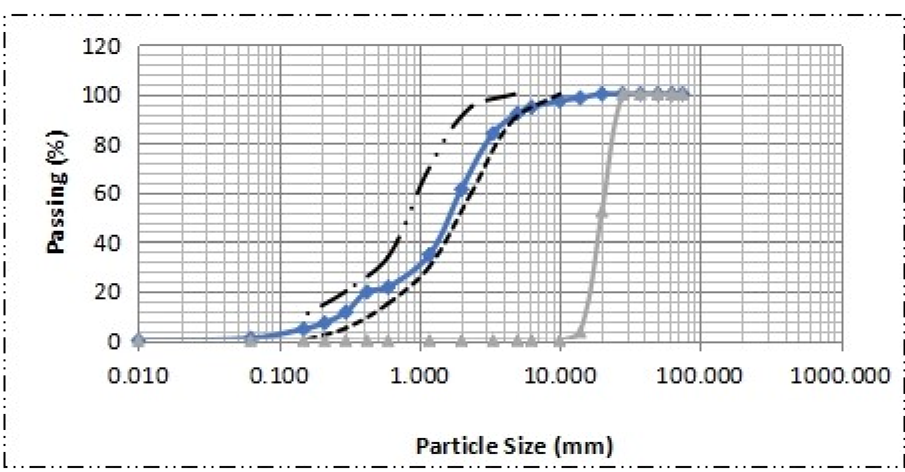


Figure 1: Particle Size Distribution of Fine and Coarse Aggregate

3.2 Chemical Properties of Cement, CPA and ESP

The oxide composition of cassava peel ash (CPA) is presented in Table 2and it indicated that the predominant oxide is Silicon oxide (56.73%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 66.75%; The oxide composition of egg shell powder (ESP) is presented in Table 2 and it indicated that the predominant oxide is of Calcium oxide (52.75%) and a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 0.22%. This shows that ESP is cementitious and may combined with CPA containing high silicon, iron and aluminium oxide in a hydrated mix and due to pozzolanic reactions yield final products that are similar to those obtained from cement hydration process. The SO_3 content was found, which according to ASTM C618 (1993) should not be more than 5.0%. Nurudeen (2012) reported that, the SO_3 content affect the strength of mortar and concrete specimens to some degree. The higher the SO_3 content, the higher the resultant strength.

Table 2: Oxide Composition of OPC (Dangote brand) CPA and ESP

	Oxide Value (%)										
	SiO_2	**Fe_2O_3**	**Al_2O_3**	**CaO**	**K_2O**	**SO_3**	**MgO**	**Na_2O**	**MnO**	**ZnO**	**LOI**
Cement	18.1	4.82	3.10	68.37	0.35	1.82	1.48	0.32	0.03	0.00	1.27
CPA	56.73	2.78	7.24	8.65	3.93	1.30	2.58	0.41	0.78	0.05	7.842
ESP	0.09	0.06	0.07	52.75	0.31	1.54	0.73	0.00	0.00	0.00	--

3.3 Consistency of CPA and ESP–Cement Pastes

The consistency of CPA and ESP - Cement Paste is shown in figure 2 and it was observed that water requirement increases with increase in CPA content. This shows that CPA absorbs more water than the ESP. The normal consistency of cement paste was 31.0% while those of CPA and ESP - Cement Pastes ranged 31.2 – 39.6%, depending on CPA and ESP content. The increase in water requirement with increase in CPA and ESP content may be due to high porosity as well as high of LOI of CPA (Jaturapitakkul and Roongreung, 2003). In addition, a less specific gravity of both CPA and ESP compare to OPC, will give rise to a large volume of water to be required to properly wet excess volume of CPA and ESP added to the mix to produce CPA and ESP-cement gel and this could lead to increase in consistency of the CPA and ESP -cement paste, this is in line with the statement by Ettu et al, (2013).

It was observed that the higher the contents of CPA and ESP in the cement paste, the faster the setting of the cement, for all the percentage replacement of CPA and ESP with OPC. These values were all within the permissible limits as per BS 12 (1991). The behavior of setting time due to the addition of reaction activity of CPA and ESP, as the silica and alumina react with calcium hydroxide (by product from hydration) to form additional calcium silicate and calcium aluminate, this may result in quick setting. This is in line with the statement by Mtallib and Rabiu (2009) and Ujin et al., (2017). The high quantity of CaO in ESA paste provides additional C-S-H for the rapid consumption of C_3S in the OPC which resulted in the acceleration of hydration of the OPC.

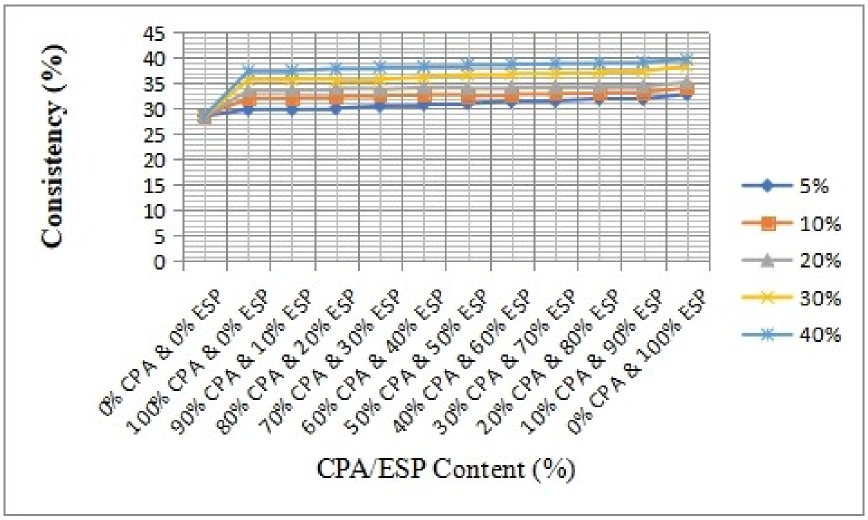


Figure 2: Consistency of CPA and ESP- Cement Paste

3.4 Compressive strength of CPA and ESP – Concrete

Figure 3 shows change in compressive strengths for CPA/ESP with age. From Figure 3a to Figure 3e, it can be observed that the strength increased with the curing age and deceased with increase in content of CPA/ESP content for all the concretes. Control concrete gained 28% at 3 days and 52% after 7 days of curing against its 28 days compressive strength. The compressive strength of control samples were less than that of samples of up to 10% ternary blend CPA/ESP but higher than the 20% binary blend of CPA/ESP at all ages. It was observed that the 28days compressive strength of concrete with up to 20% CPA/ESP content exceeded the design characteristics strength, and basically meet the minimum standard in BS 1881: Part 116: (1983) which recommend that compressive strength for 28 days to be 20N/mm^2 to 34N/mm^2 for normal weight concrete. Based upon the chemical composition, SiO_2 rich CPA is reactive when in contact with CaO, to give more strength; ESP has significant amount of CaO, which reactive SiO_2 from CPA to consume the excessive CaO from it, resulting in enhancement in the strength of concrete.

The decrease in compressive strength of concrete with increase in CPA/ESP content would be due to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of slow in the pozzolanic reaction of CPA and ESP. This is in line with the conclusion by Salau (2012) report on CPA and Oyekan and Kamiyo (2011) reports on RHA.

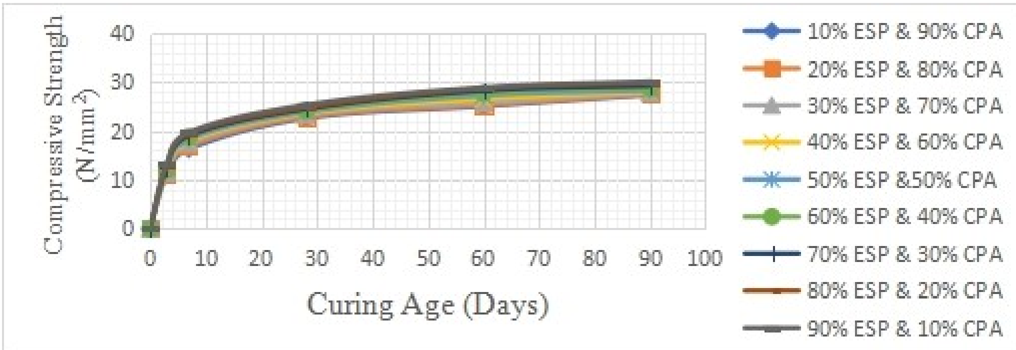


Figure 3a: Compressive Strength of CPA/ESP – Concrete (5% Replacement)

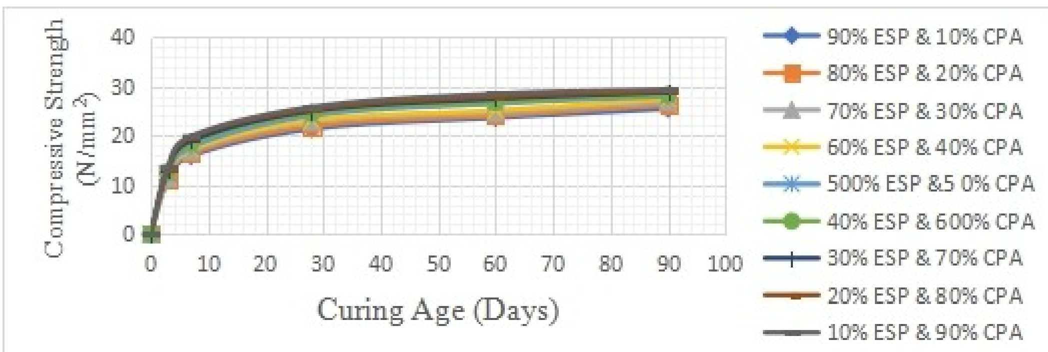


Figure 3b: Compressive Strength of CPA/ESP – Concrete (10% Replacement)

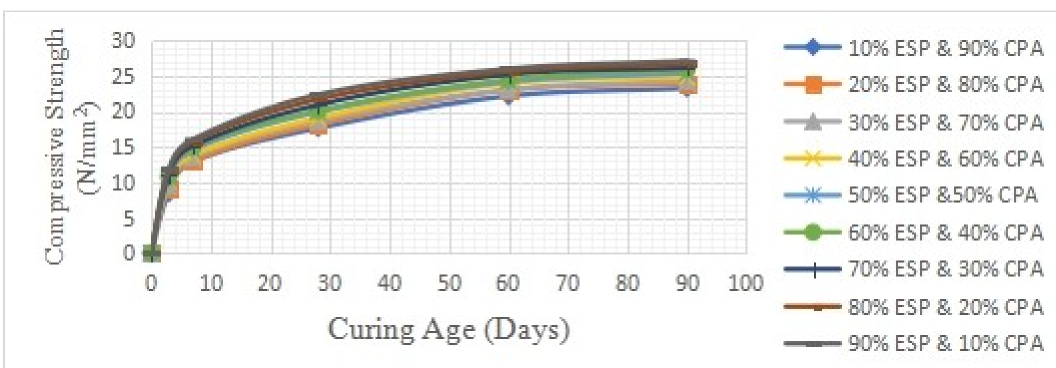


Figure 3c: Compressive Strength of CPA/ESP – Concrete (20% Replacement)

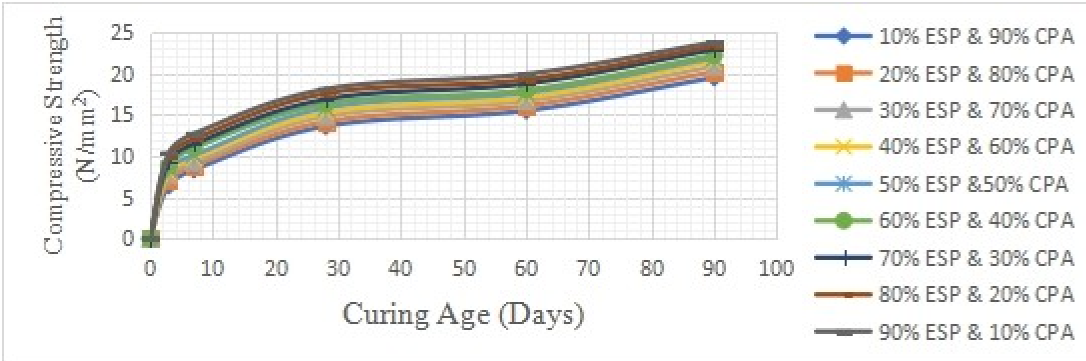


Figure 3d: Compressive Strength of CPA/ESP – Concrete (30% Replacement)

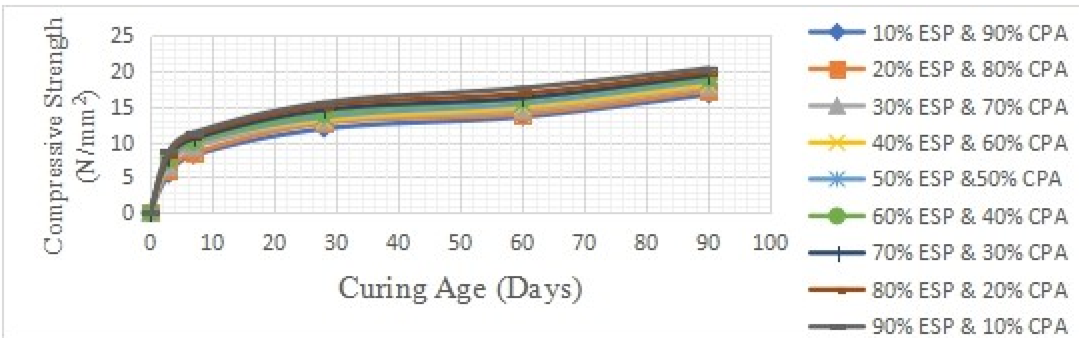


Figure 3e: Compressive Strength of CPA/ESP – Concrete (40% Replacement)

3.5 Flexural Strength of CPA/ESP – Concrete

The results of flexural strength of CPA and ESP-Concrete are shown in Figures 4a to 4e and it was observed that the flexural strength increased with curing age but decreased with increase in CPA and ESP content. It was revealed that the flexural strength of CPA and ESP concrete at 10% replacement was higher than that of control samples. The results also showed that increase in ESP percentage in the blended concrete mixes enhanced the flexural strength of concrete over that of CPA blended concrete.

The decrease in flexural strength with increase in CPA and ESP blend is attributed to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of pozzolanic reaction of CPA and ESP (Pransanphan et al, 2010; Oyekan and Kamiyo, 2011). The improvement in flexural strength of blended RSP mix when compared to CPA may be attributed to increased pozzolanic reaction and the packing ability of the fine particles of ESP. This suggests that a disproportionate blending of the two pozzolans should be in favor of CPA for early strength optimization of OPC-CPA-ESP blended cement concrete.

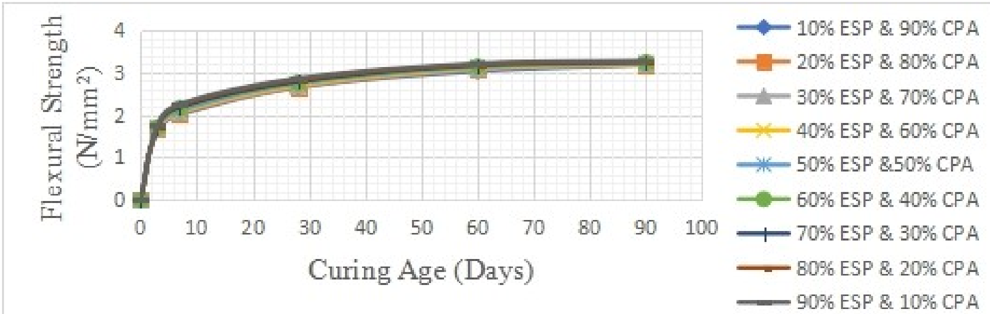


Figure 4a: Flexural Strength of CPA/ESP – Concrete (5% Replacement)

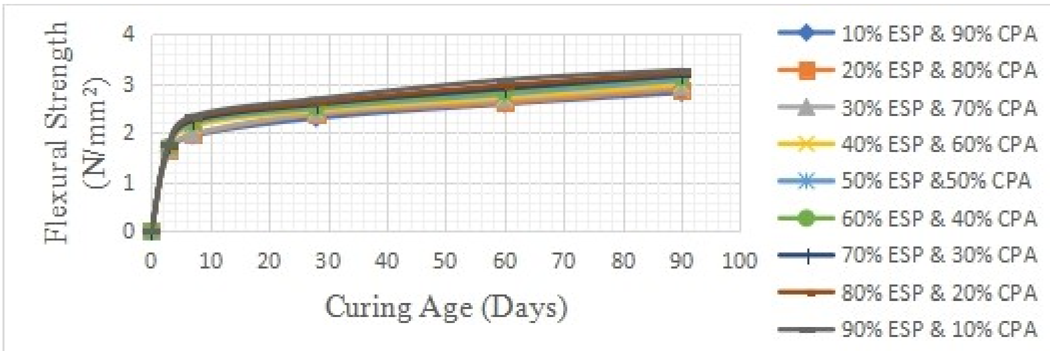


Figure 4b: Flexural Strength of CPA/ESP – Concrete (10% Replacement)

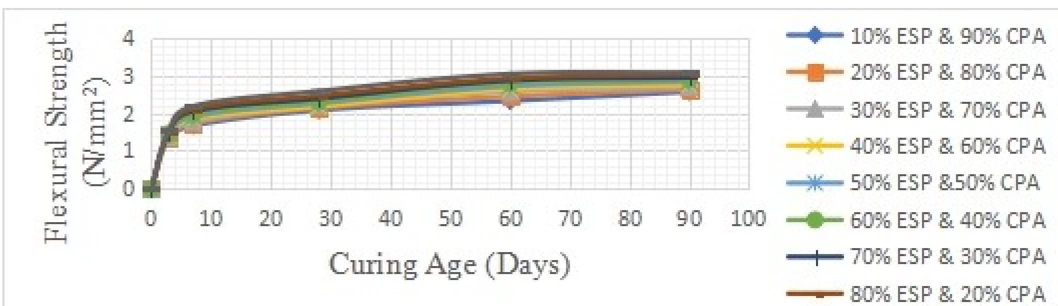


Figure 4c: Flexural Strength of CPA/ESP – Concrete (20% Replacement)

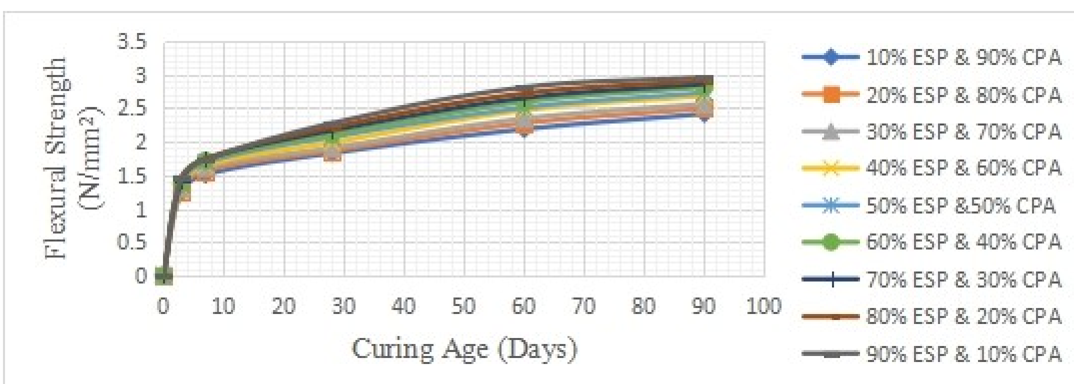


Figure 4d: Flexural Strength of CPA/ESP – Concrete (30% Replacement)

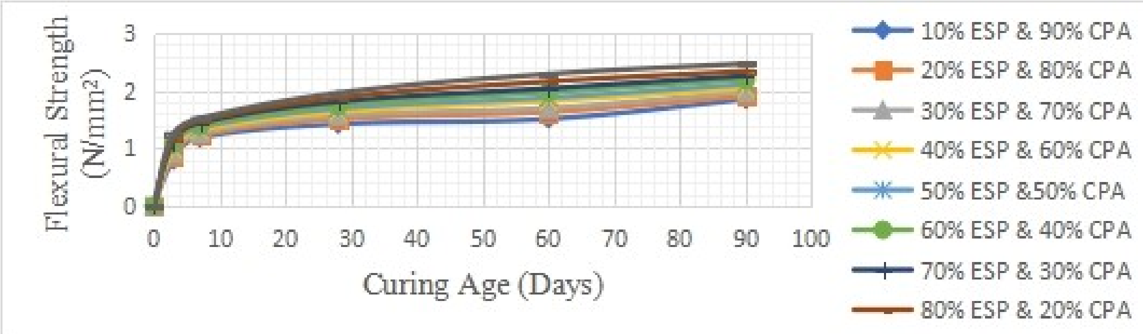


Figure 4e: Flexural Strength of CPA/ESP – Concrete (40% Replacement)

3.5 Split tensile strength

Split tensile strength of all the concretes is shown in Figure 5a to Figure 5e. All the concretes failed to show enough resistance against split tensile strength at 3 day. However, the result of splitting tensile strength of CPA/ESP blend -Concrete are shows that there was an increase in tensile strength with curing age but decrease with increase in percentage of combined CPA and ESP in the blend concrete, though up to 10% replacement was higher than control at curing age of 28 days and above.

The decrease in splitting tensile strength with more than 20% increase in CPA and ESP blend content is attributed to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of pozzolanic reaction of CPA and ESP (Prasanphan et al, 2010; Oyekan and Kamiyo, 2011). However, the enhancement in tensile strength at low level of CPA and ESP substitution may be due to increased pozzolanic reaction and the packing ability of the fine particles of ESP (Zhang et al, 1996; Rodriguez de Sensale, 2006; Sakr, 2006; Habeeb and Fayyadh, 2009). The strength value of OPC-CPA-ESP blended cement concrete consistently lies in-between the values of OPC-CPA and OPC-ESP blended cement concretes for all percentage replacements and curing ages.

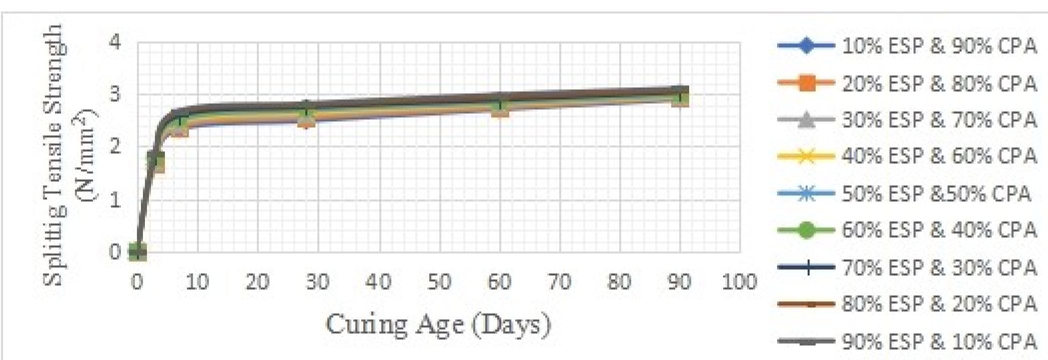


Figure 5a: Splitting Tensile Strength of CPA/ESP – Concrete (5% Replacement)

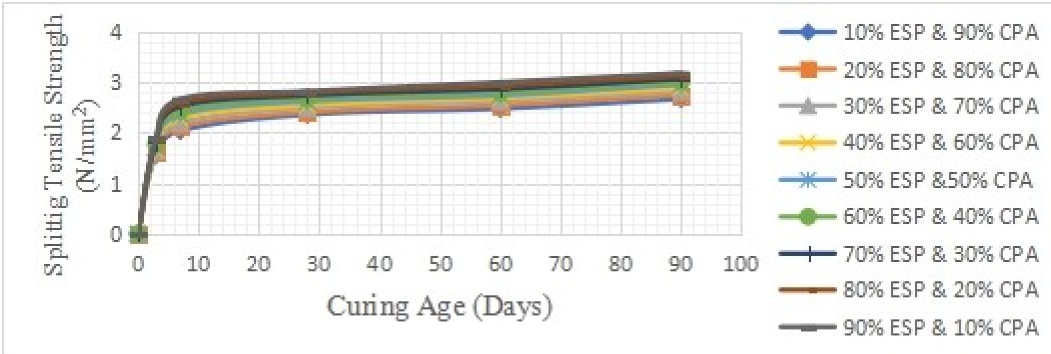


Figure 5b: Splitting Tensile Strength of CPA/ESP – Concrete (10% Replacement)

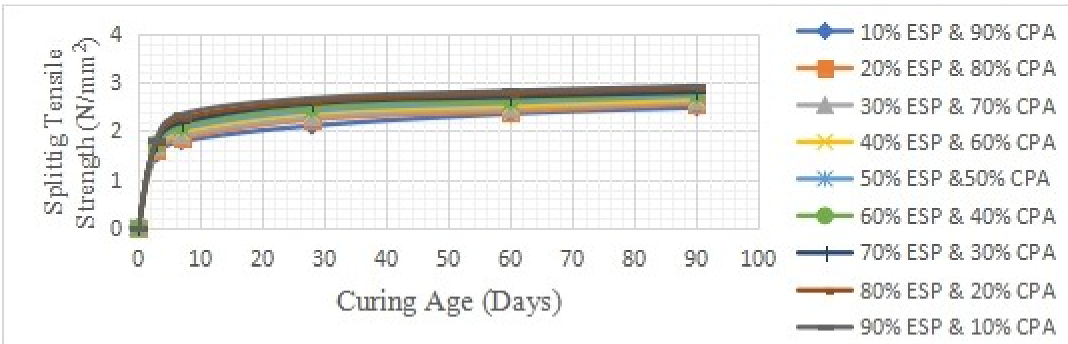


Figure 5c: Splitting Tensile Strength of CPA/ESP – Concrete (20% Replacement)

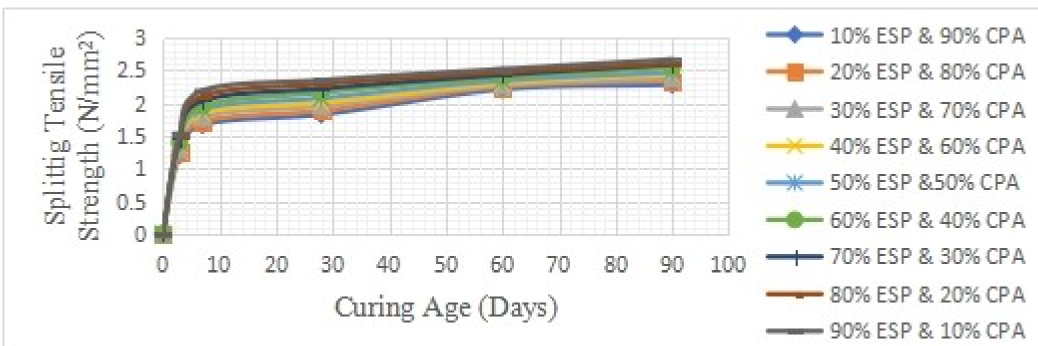


Figure 5d: Splitting Tensile Strength of CPA/ESP – Concrete (30% Replacement)

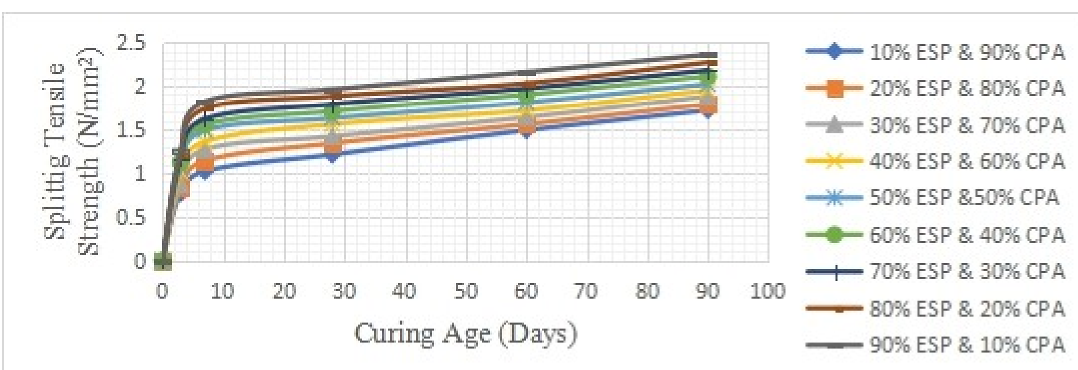


Figure 5e: Splitting Tensile Strength of CPA/ESP – Concrete (40% Replacement)

4. CONCLUSIONS

Based on the study conducted CPA/ESP Concrete, the following conclusions can be drawn. The use of CPA/ESP Concrete

i. With the increase in the percentage of CPA/ESP, the compressive, flexural and splitting tensile strength of concrete increases up to an optimized value and beyond that value, the strength start reducing. Though, with increase in the percentage of CPA over the ESP, the strength decreases.
ii. By replacing with CPA/ESP above 10%, reduction in compressive, flexural and splitting tensile strength was high at the age of 28 days, especially when the percentage of CPA is higher than that of ESP,

REFERENCES

Adesanya, O.A, Oluyemi, K.A., Josiah, S.J., Adesanya, R.A., Shittu, L.A.J., Ofusori, D.A., Bankole, M.A. and Babalola, G.B. (2008). "Ethanol Production by Saccharomyces Cereviasiae from cassava peel hydrolysate", The Internet Journal of Microbiology, Vol.5 No. 1. pp. 25-35.

Agbede, I.O. and Joel, M. (2011): Effect of Rice Husk Ash on the Properties of Ibaji Burnt Clay Bricks. American Journal of Scientific and Industrial Research. Pp. 674-677.

Arash B., Hamidreza S., Mehdi G. and Moustafa Y. R.,(2012,) "Laboratory Investigation of the Effect of Eggshell powder on Plasticity Index in Clay and Expansive Soils ", European Journal of Experimental Biology, 2012, 2 (6):2378-2384.

ASTM C618 (2008). Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete. West Conshohocken, PA: ASTM

British Standard Institutions (BSI) 812: Part 2. Testing Aggregates: Methods of Determination of Density, British Standards Institute, 1995.

British Standard Institutions (BSI) 8500: Part 2 (2000) Specification for Constituent Materials and Concrete

British Standard Institutions (2013): Aggregate for Concrete. London: BS EN 12620: 2013 BSI

British Standard Institutions (2009): Cement Composition, Specification and Conformity Criteria for Common Cements. London: BS EN 197 - 1: (2009) BSI.

British Standard Institutions (1992). BS 882: Specification for Aggregate from Natural Sources for Concrete. British Standard Institution, London

British standard institution (2009). Testing hardened Concrete. Making and curing specimens for strength tests. London: BS EN 12390 - 2 - BSI.

Ettu, L. O., Nwachukwu, K. C. and Arimanwa, J. I., (2013): Strength of Ternary Blended Cement Concrete Containing Cassava Waste Ash and Coconut Husk Ash. Research Inventy: International Journal Of Engineering And Science Vol.2, Issue 12 (May 2013), Pp10-15

Habeeb, G. A., and Fayyadh, M. M. (2009). Saw dust ash Concrete: the Effect of SDA

Jaturapilakkul, C. and Roongreung, B. (2003): Cementing Material from Calcium Carbide Residue-Rice Husk Ash. Journal of Materials in Civil Engineering @ ASCE/Sept/Oct, Vol. 15, no. 5, pp. 470-475

Krammart, P., and Tangtermsirikul, (2004) "properties of ceemnt made by partially replacing cement replace cement raw material with municipal solid waste ashes and calium carbide waste." Conotr. Build. Maters, 18(8), 579 – 583.

Kumar, R. R., Mahendran, R., Gokul N. S., Sathya, D. and Thamaraikannan K. (2017) "An Experimental Study on Concrete Using Coconut Shell Ash and Egg Shell Powder" South Asian Journal of Engineering and Technology Vol.3, No.7 (2017) Pp151-161

Mtallib M. O. A., Rabiu A., (2009), "Effect of Eggshells Ash on the Setting Time of Cement", Nigerian Journal of Technology, Volume 28, Issue 2, PP 29-38.

Nurudeen M.M. (2012): Effect of Neem Seed Husk Ash in Concrete. An Unpublished PhD Dissertation in Civil Engineering submitted to the Postgraduate School, Ahmadu Bello University, Zaria – Nigeria.

Okonkwo U. N., Odiong I.C., and Akpabio, E. E. (2012), Effects of egg shell ash on strength properties of cement-stabilized lateritic, International Journal of Sustainable Construction Engineering & Technology Vol. 3(1): 18 –25

Oyekan, G. L. and Kamiyo, O. M. (2011): "A study on the engineering properties of sandcrete blocks produced with rice husk ash blended cement". Journal of Engineering and Technology Research, 3(3): 88-98.

Prasanphan, S; Sanguanpak, S; Wansom, S. and Panyathanmaporn, T. (2010): Effect of ash content and curing time on compressive strength of cement paste with rice husk ash. Suranaee Journal of Science and Technology, vol. 17, no. 3, pp. 293-302.

Raji, S.A. and Samuel, A. T. (2015): "Egg Shell as a Fine Aggregate in Concrete for Sustainable Construction". International Journal of Scientific and Technology Research Volume 4, Issue 09, September 2015: 8 – 13

Ramezanianpour, A. A., Mahdi-khani, M. and Ahmadibeni Gh., (2009): "The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes". International Journal of Civil Engineerng. Vol. 7, No. 2, June 2009: 83 – 91.

Rodriguez de Sensale, G. (2006): Strength development of concrete with rice husk ash. Cement and Concrete Composites, vol. 28, pp. 158-160

Sakr, K., (2006). Effects of silica fume and rice husk ash on the properties of heavy weight concrete. J. Mater. Civil Eng., 18(3): 367-376.

Salau M.A. and Olonade, K.A. (2011). Pozzolanic Potentials of Cassava Peel Ash. Journal of Engineering Research, Vol. 16. No. 1 pp. 10-21

Salau M.A., Ikponmwosa, E.E. and Olonade, K.A. (2012); "Structural Strength Characteristics of CementCassava Peel Ash Blended Concrete", Civil and Environmental Research, 2(2) 2012, 68-77.

Sunusi A. Y. (2015); "Investigation in to the Use of Calcium Carbide Waste as a Partial Replacement of Cement in Concrete" IJEMR Journal Vol. 2015, Pp: 675-680

Ujin, F., Ali, K. S. and Harith, Z. Y. H. (2017): "The Effect of Eggshells Ash on the Compressive Strength of Concrete." Key Engineering Materials, Vol. 728, (2017): 402- 407. Doi: 10.4028/www.scientific.net/kem.728.402

Zhang, M.H., R. Lastra and V.M. Malhotra, (1996): "Rice husk ash paste and concrete: Some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste". Cem. Concr. Res., 26(6): 963-977.

EFFECT OF SCREEN SIZE, FERMENTATION PERIOD AND BAG TYPE ON THE PERFORMANCE OF MELON SEED WASHING MACHINE

Adebayo, A. A. [1] and Olaoye, J. O. [2]
[1]Department of Agricultural and Bioenvironmental Engineering Technology,
Auchi Polytechnic, Auchi, P.M.B. 13 Auchi, Edo State, Nigeria.
[2]Department of Agricultural and Biosystems Engineering,
University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria.
ajibolaadebayo975@yahoomail.com[1] ; jolanoye@unilorin.edu.ng[2]

ABSTRACT.

A multi-powered centrifugal melon seed washing machine was designed and developed for washing fresh melon pods that had been fermented for short period (i.e. 2-6 days). The aim was to develop a new melon processing technique with short period fermentation with the view to conserve energy and power utilization. One of the objectives of this study was to reduce the long fermentation period, reduce power requirements during washing and other limitations associated with the traditional method of washing melon seeds. The washing machine has four major components; the washing basket, impeller disk, impeller shaft and electric motor/gasoline engine. In this study, investigation was carried out to determine the effects of screen size, fermentation period and bag type on the washing performance index (WPI) of the melon seed washing machine. The developed melon seed washing machine was evaluated at fermentation and washing stages. During evaluation three operational factors were varied; screen size (S) at four levels (15, 20, 25 and 30 mm), fermentation period (F) at three levels (2, 4 and 6 days) and bag type (B) at three levels (jute, black and transparent polyethylene bags). The statistical design was 4x3x3x3 factorial experimental design replicated thrice and 108 experimental runs were made. Statistical software SPSS 18 was used to carry out statistical analysis of variance (ANOVA) and Duncan's New Multiple Range Test (DNMRT) on the evaluation data of the melon washing machine. The statistical results of the (ANOVA) and (DNMRT) of the melon washing machine showed that only the fermentation period and its interactions with bag type has a significant effect on the washing performance index (WPI) of the machine at 95 % confidence level. Also, the evaluation experimental data of the machine were subjected to further statistical analysis using SPSS to plot graphs that showed the interactions between the operational factors and the parameters. The graphs revealed that the washing performance index (WPI) increases from 77 % to 98 % as the fermentation period progresses from 2, 4 and 6 days. The washing capacity (CS) of the melon washing machine was measured to be 51.84 kg/h. Again, evaluation results showed that melon samples in black and white polyethylene bags fermented faster (i.e. 2nd and 4th days) and easier to wash with the washing machine than the samples in jute bags which fermented lately (i.e. 6th days). Therefore, using polyethylene bags for fermentation produces better results than jute bags. Hence, the new melon processing technique for extracting and washing melon seeds from its pods is a faster and more efficient technique with adequate conservation of energy requirement for washing.

***Keywords**:* melon basket, melon materials, rinsing chamber, bag type.

1. INTRODUCTION

Melon (*Citrullus colocynthis lanatus*) is among the indigenous crops originated from Africa and migrated to Asian countries and other parts of the World. Melon plant was believed to have originated from the western Kalahari region of Namibia and Botswana in Africa (Vander vossen *et al.,* 2004; Akubuo and Odigboh, 1999). There are two major types of melon fruits; a smaller type with white bitter pulp called *bara* in Nigeria and the other big type with red sweeter pulp called water-melon. Melon seed from *bara* is widely produced and consumed in Nigeria and all over Africa countries (FAO, 2002). Also, large amounts of melon seed oil worth billions of US Dollars were exported to Africa communities in North America and European countries (Vander vossen *et al.,* 2004). Melon seed is cultivated because it is rich in oil, protein, carbohydrate, vitamins, minerals, fatty acids, crude fiber, ash and other nutrients that are required for healthy growth of human beings (Essien and Eduok, 2013). Its condiments have been used as a substitute for meat among the large population in rural areas in Nigeria and most African countries. In some areas, the melon seeds are roasted, pounded, wrapped in leaves and boiled to produce sweeteners called *igbalo, tasali* and *ogiri* in Sudan, Egypt and Nigeria respectively (Vander-vossen *et al.,* 2004). Also, melon oilseed is used for cosmetic purposes and it is of great interest to the pharmaceutical industries. In addition, melon oilseed is classified as a good energy source; for it has some fuel quality parameters that make it economical for biodiesel production (Ogunwa *et al.,* 2015, Giwa *et al.*, 2010, Giwa and Akanbi, 2020).

Despite the huge economic importance of melon seeds, its production and processing is yet to be effectively mechanized. Most of the existing melon depodding machines were not designed to wash after depodding the seeds (Oloko and Agbetoye, 2006; Nwakuba, 2016; Orhorhoro *et al.* 2018; and Osasumwen, 2020). Apart from the prototype of Agbetoye *et al.* (2013) that was designed to depod and wash at the same time, other existing depodding machines were not designed to wash melon seeds after it had been depodded, they all wash melon seeds using traditional methods. The traditional melon washing technique was characterized with a long period of fermentation, seed losses and rigor. There is a need for developing a separate melon seed washing machine that would wash the seeds after they have been fermented for short period of 2-6 days. Therefore, developing an efficient melon seed washing machine for medium and large scale remains a serious challenge.

2. MATERIALS AND METHOD

2.1 Equipment Description

The developed motorized melon washing machine comprises of power compartment, washing basket, washing and rinsing chambers as shown in Figures 1 and 2. The washing machine was designed and developed to wash, clean and separate the melon seeds from the melon materials.

2.2 Experimental Procedure

The performance evaluation of the fresh melon washing machine was carried out in the fabrication laboratory of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria. After the fresh melon pods were depodded using the developed melon depodding machine, the depodded melon materials (5 kg) were packaged into different bags (i.e. jute, transparent and black polyethylene bags), prepared for short period fermentation (i.e. 2, 4 and 6 days) in the order of experimental design. After the expiration of the fermentation period, the fermented melon materials in different bags were fed into the washing basket of the running washing machine. After 60 seconds of rigorous washing of the melon seeds with the agitated water in the washing chamber, the washing basket with the washed seeds were moved to the rinsing chamber for better washing of the melon seeds for another 60 seconds. The clean seeds were later moved out of the washing basket and spread out for sun dried for 2 to 3 days.

Figure 1: Pictorial front view of a melon washing machine

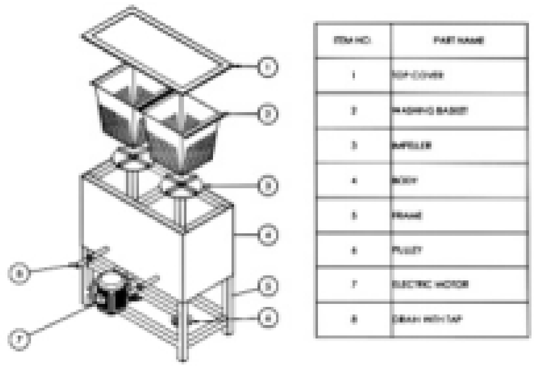


Figure 2: Exploded View of the Melon Washing Machine

2.4 Performance Evaluation Equations for the Washing Machine

The equations used for evaluating the performance of the melon seed washing machine were derived and stated as follows in Equations (1) to (4):

The Ratio of Extractable Seeds from the Fresh Melon Pods (i)

This is defined as the ratio of mass of extractable melon seeds to that of mass of certain quantity (i.e. 5 kg) of melon pods from which the seeds were extracted. Percentage of extractable seeds (i) from a certain mass (i.e. 5 kg) of melon pods was derived by Oloko and Agbetoye, (2006) and was used for estimating the extractable seeds (i) as shown in Equation (1).

$$i = \frac{M_e}{M_p} \times 100\ \% \quad (1)$$

Where, M_e is the mass of the seeds depodded from certain mass of fresh melon pods (kg)

M_p is the mass of 5 kg of fresh melon pods fed into the machine (kg)

Washing Performance Index (WPI)

This is the ratio of the mass of the washed melon seeds to the percentage of mass of extractable melon seeds. The washing performance index (WPI) was derived by Adebayo (2019) and was used for estimating the melon washing performance index (WPI) as shown in Equation (2).

$$(WPI) = \frac{M_w}{M_1 \times i} \times 100\% \quad (2)$$

Where, M_w is the mass of seeds that was washed and retained in the washing basket (kg)

M_1 is the mass of fresh melon pods fed into the machine (kg)

$(M_1 \times i)$ is the percentage of mass of extractable melon seeds (kg)

Percentage of Seed Losses (S_L)

This is the ratio of the mass of melon seeds that *escaped out of the washing basket to the percentage of mass of extractable melon seeds. The* (S_L) *was derived by Adebayo (2019) and was used for estimating the melon percentage of seed losses* (S_L) *as shown in Equation (3).*

$$(S_L) = \frac{M_{sL}}{..} \times 100\% \quad (3)$$

Where, M_{sL} *is the mass of seeds that escaped out of the washing basket during washing operation.*

2.4.4 Washing Throughput, $C_S\ (kg/hr)$

The Melon Washing Throughput (C_S) was derived by Olaoye and Aturu (2018) and was used for estimating the melon percentage of seed losses (S_L) as shown in Equation (4).

$$C_S = \frac{M_w}{T}(\text{kg/hr})$$

Where, M_w is the mass of washed melon seeds retained in the washing basket (kg)

T is the time taken for the machine to wash the depodded melon materials (kg)

2.5 Statistical Analysis

The three operational factors used in evaluation of the melon seed washing machine were screen size (S) at four levels (i.e. 15, 17, 23 and 30 mm), fermentation period (F) at three levels (i.e. 2, 4 and 6 days) and three bag type (B) at three levels (i.e. jute, black and white polyethylene bags) and the three factors were replicated thrice. The experimental design was 4 x 3 x 3 x 3 factorial design and the total experimental runs were 108 runs. The performance data were generated with their replicates and results were recorded and tabulated as shown in Table 1. The statistical analysis of variance (ANOVA) was determined and used for investigating the effects of the operational factors on the performance parameters of the melon seed washing machine at 95 % confidence level. Also, additional statistical results were obtained by using Duncan's New Multiple Range Tests (DNMRT) to compare the percentage mean values among different levels of the experimental factors. Table 2 showed the statistical results of (ANOVA) and Tables 3 and 5 showed the statistical results of (DNMRT).

3. RESULTS AND DISCUSSION

Tables 1 showed the performance evaluation results of the effects of the operational factors on the performance parameters of the melon washing machine and the effects were described in section 3.1.

Table 1: Effects of Operating Factors on the Melon Washing Performance Parameters (Replicated Thrice)

Experimental Runs	Washing Performance Index (WPI) (%)	Seed Washing Capacity C_S (kg/hr)
$S_1F_1B_1$	76.88±1.47	51.84
$S_1F_1B_2$	77.34±1.08	51.84
$S_1F_1B_3$	78.52±3.24	51.84
$S_1F_2B_1$	86.07±1.63	51.84
$S_1F_2B_2$	91.42±2.83	51.84
$S_1F_2B_3$	91.49±2.85	51.84
$S_1F_3B_1$	99.04±0.71	51.84
$S_1F_3B_2$	99.04±0.00	51.84
$S_1F_3B_3$	98.33±1.22	51.84
$S_2F_1B_1$	76.41±1.42	51.84
$S_2F_1B_2$	77.35±2.16	51.84
$S_2F_1B_3$	78.80±1.47	51.84
$S_2F_2B_1$	88.90±2.49	51.84
$S_2F_2B_2$	90.08±1.64	51.84
$S_2F_2B_3$	91.96±0.71	51.84
$S_2F_3B_1$	99.28±0.82	51.84
$S_2F_3B_2$	99.51±0.41	51.84
$S_2F_3B_3$	97.62±1.23	51.84
$S_3F_1B_1$	80.17±0.81	51.84

$S_3F_1B_2$	77.11±1.22	51.84
$S_3F_1B_3$	78.53±3.67	51.84
$S_3F_2B_1$	88.59±5.24	51.84
$S_3F_2B_2$	88.66±1.78	51.84
$S_3F_2B_3$	89.61±0.82	51.84
$S_3F_3B_1$	99.51±0.41	51.84
$S_3F_3B_2$	99.05 ±0.71	51.84
$S_3F_3B_3$	98.10 ±1.47	51.84
$S_4F_1B_1$	78.77±2.13	51.84
$S_4F_1B_2$	78.52±2.55	51.84
$S_4F_1B_3$	76.87±0.41	51.84
$S_4F_2B_1$	88.19±0.81	51.84
$S_4F_2B_2$	91.50±0.41	51.84
$S_4F_2B_3$	91.49±0.81	51.84
$S_4F_3B_1$	99.28±0.82	51.84
$S_4F_3B_2$	99.23±0.41	51.84
$S_4F_3B_3$	98.08±1.08	51.84

*S is the concave Screen Size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm
*F is the Fermentation Period; F_1= 2 Days, F_2= 4 Days, F_3= 6 Days
*Bag Type; B_1= Black polyethylene bag, B_2= Transparent polyethylene bag, B_3= Jute bag

*Mean of three replicates of each parameter ± standard deviation

3.1 Effects of Operational Factors on the Washing Performance Index (WPI)

The statistical analysis of variance (ANOVA) results in Table 2 showed that fermentation period and its interaction with bag type have significant effects on the Washing Performance Index (WPI) at $P \leq 0.05$, while screen size and its interactions were not significant on (WPI) at $P \leq 0.05$. In addition, Duncan's New Multiple Range Tests (DNMRT) results in Tables 3 agreed with the (ANOVA) results in Table 2 that only the fermentation period and its interaction with the bag type showed some levels of significant difference at $P \leq 0.05$. Again, the (DNMRT) results in Table 5 showed that screen size has no significant effect on the (WPI) of the washing machine at $P \leq 0.05$. Therefore, since the range of screen sizes used were of no significant value, it means difference in size reduction of the melon materials has no significant effect on the observed fermentation periods. However, (DNMRT) results in Table 4 showed that bag type has slight significant effect on the (WPI) of the washing machine at $P \leq 0.05$. This implies that fermented melon seeds in the transparent and black polyethylene bags produced slightly higher (WPI) than the fermented seeds in jute bags. Also, the slight higher temperature difference combined with anaerobic fermentation that took place in the polyethylene bags accounted for fermentation aiding properties of the polyethylene bags (Adebayo, 2019) and this agreed with the findings of Peter-Ikechukwu *et al.* (2014 and 2016) and GLBRC (2011).

Table 2: Analysis of Variance (ANOVA) for the Effects of Screen Size, Fermentation Period and Bag Type on the Melon Washing Performance Index (WPI)

Source	**Type III Sum of Squares**	Degree of freedom	Mean Square	F	Significance
Corrected Model	7989.567[a]	35	228.273	69.121	.000*
Intercept	854378.987	1	854378.987	2.587E5	.000*
Screen Size	5.776	3	1.925	.583	.628[NS]
Fermentation Period	7833.483	2	3916.742	1.186E3	.000*
Bag Type	14.978	2	7.489	2.268	.111[NS]
Screen Size * Fermentation Period	13.088	6	2.181	.660	.682[NS]
Screen Size * Bag Type	29.534	6	4.922	1.490	.194[NS]
Fermentation Period * Bag Type	64.406	4	16.102	4.876	.002*
Screen Size * Fermentation Period * Bag Type	28.302	12	2.359	.714	.733[NS]
Error	237.781	72	3.303		
Total	862606.334	108			
Corrected Total	8227.348	107			

a. R Squared = 0.971 (Adjusted R Squared = 0.957)

* Significant at $P \leq 0.05$

Table 3: DNMRT of the Effect of Fermentation Period on the WPI, ε_w (%)

Experimental Factors	Washing Performance Index (WPI) ε_w (%)
F_1	78.10^a
F_2	89.83^b
F_3	98.90^c

*S is the concave Screen Size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm
*F is the Fermentation Period; F_1= 2 Days, F_2= 4 Days, F_3= 6 Days
*Bag Type; B_1= Black polyethylene bag, B_2= Transparent polyethylene bag, B_3= Jute bag
* Means in each column with the same letters are not significantly different at $P \leq 0.05$, but Means with different letters are significantly different at $P \leq 0.05$

Table 4: DNMRT of the Effect of Bagging Type on the WPI, ε_w (%)

Experimental Factors	Washing Performance Index (WPI) ε_w (%)
B_1	89.28^a
B_2	89.13^a
B_3	88.12^b

*S is the concave Screen Size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm
*F is the Fermentation Period; F_1= 2 Days, F_2= 4 Days, F_3= 6 Days
*Bag Type; B_1= Black polyethylene bag, B_2= Transparent polyethylene bag, B_3= Jute bag
* Means in each column with the same letters are not significantly different at $P \leq 0.05$, but Means with different letters are significantly different at $P > 0.05$

Table 5: DNMRT of the Effect of Screen Size on the WPI, ε_w (%)

Experimental Factors	Washing Performance Index (WPI) ε_w (%)
S_1	88.68^a
S_2	88.81^a
S_3	88.97^a
S_4	89.30^a

*S is the concave Screen Size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm

*F is the Fermentation Period; F_1= 2 Days, F_2= 4 Days, F_3= 6 Days
*Bag Type; B_1= Black polyethylene bag, B_2= Transparent polyethylene bag, B_3= Jute bag
* Means in each column with the same letters are not significantly different at $P \leq 0.05$,
but Means with different letters are significantly different at $P > 0.05$

Also, the evaluation experimental data of the machine were subjected to further statistical analysis using SPSS to plot graphs that showed the interactions between the operational factors and the parameters of the melon washing machine. The graphs in Figure 3 further revealed that screen size has little or no significant effects on (WPI) of the melon washing machine; for the three graphs appeared almost flat at different screen sizes. Therefore, graphs in Figure 3 showed fermentation period and bag type have significant effects on (WPI) of the washing machine; for it showed a gradual increment in (WPI) (i.e. 77 %, 91 % and 98 %) as the fermentation periods progresses from 2nd, 4th and 6th days respectively. Although, the available evaluation result of the only melon washing machine fabricated by Agbetoye *et al.* (2013) reported only the depodding result and was silence on the washing evaluation result of the machine. Hence, there was no basis for comparative analysis of the results of this research work.

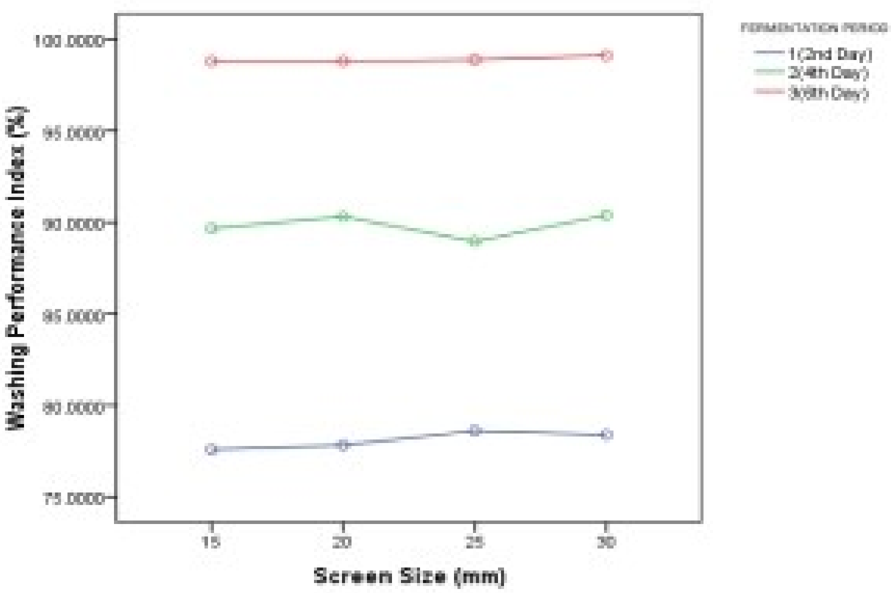


Figure 3: Effects of Screen Size and Fermentation Period on Washing Performance Index

In addition, evaluation results showed that melon samples in black and transparent polyethylene bags fermented faster (i.e. 2nd and 4th days) and easier to wash with the washing machine than the samples in jute bags which fermented lately (i.e. 6th days) and darker as shown in Figure 4.

Also, Figures 5 to 7 show samples of washed melon seeds fermented in different bags (i.e. jute, transparent and black polyethylene bags respectively). This agreed with the findings of Peter-Ikechukwu *et al.* (2014); for black and transparent polyethylene when used as wrappers also produced better fermented mashed melon seeds than other wrapping materials (i.e. aluminum-foil, fresh-leaf, blanched-leaf and dried-leaf) (Peter-Ikechukwu *et al.,* 2014; GLBRC, 2011). Again, evaluation results revealed there was no significant mechanical damage or seed loss recorded during washing operation, but about 1.3 % of melon seed were shelled/peeled during depodding operation with the melon depodding machine (Adebayo, 2019).

Figure 4: Effect of bagging materials on depodded melon materials after fermentation

Figure 5: Samples of Melon Seeds Fermented in Jute Bags

Figure 6: Samples of Melon Seeds in white Polyethylene Bags

Figure 7: Samples of Melon Seeds in Black Polyethylene Bags

4. CONCLUSION

The performance evaluation results of the melon seed washing machine revealed that fermentation period and its interaction with bag type has significant effect on the washing performance index (WPI) of the melon seed washing machine at 95 % confidence level. However, (WPI) of the washing machine was observed to increase from 77 to 98 % as the fermentation period progresses from 2 to 6 days. In addition, the fermented melon seeds in black and white polyethylene bags were observed to produce slightly higher percentage mean values of (WPI) because the polyethylene bags produces better fermented melon seeds than the jute bags. Therefore, using polyethylene bags (whether black or white bags) for fermentation produces melon samples that are easier to wash than melon samples from jute bags. This is because the new melon processing technique exposes more of surface areas of the depodded melon materials to microbial activities in polyethylene bags and makes fermentation period shorter (i.e. 2-4 days). Also, the throughput of the developed melon washing machine was evaluated to be 51.84 kg/h of melon seeds. Hence, the new melon processing technique for extracting and washing melon seeds from its pod is faster and more efficient, the device has effectively let to sustainable management of energy requirements in melon seeds processing.

REFERENCES

Adebayo, A. A. (2019). Development of Depodding Cum Washing Machines for Fresh Egusi Melon Pods. Ph.D. Dissertation. Ilorin, Nigeria: University of Ilorin, Department of Agricultural and Biosystems Engineering.

Agbetoye, L. A. S., Owoyemi, G. O. and Oloko, S. A. (2013) Design Modification and Performance Evaluation of Melon (Citrulluslanatus) Depodding Machine. *Global Research Analysis (GRA)*, 2(7),61-65.

Akubuo, C. O. and Odigboh, E. U. (1999) Egusi Coring Machine. *Journal of Agricultural Engineering Research,* 74,121-126.

Essien, A. E. and Eduok, U. M. (2013) Chemical Analysis of Citrullus Lanatus Seed Oil. *Elixir International Journal, Nigeria*, 54,12700-12703.

FAO (2002) Agricultural Services. Bulletin No. 124. Rome.

Giwa, S. O. and Akanbi, T. A. (2020). A Review on Food uses and Prospect of egusi melon for Biodiesel Production. *Bio-Energy Resources,* 10.

Giwa, S. O., Abdullah, L. C. and Adam, N. M. (2010). Investigating Egusi Seed Oil as Potential Biodiesel Feedstock. *Energies*, 3(4), 607-618.

GLBRC (2011) Fermentation in Bags. *United State of America Department of Energy.*

Nwakuba, N. R. (2016) Performance Testing of a Locally Developed Melon Depodding Machine. *International Journal of Agriculture, Environment and Bioresearch,* 1(1),7-25.

Ogunwa, I. K. Ofodile, S. and Achugasim, O. (2015) Feasibility Study of Melon Seed Oil as a Source of Biodiesel. *Journal of Power and Energy Engineering,* 3,24-27.

Oloko, S. A. and Agbetoye, L. A. S. (2006) Development and Performance Evaluation of a Melon Depodding Machine. *Agricultural Engineering International: the CIGRE Journal,8.*

Orhorhoro, E. K., Oyejide, J. O. and Salisu, S. (2018) Design and Simulation of Continuous Melon Fruit Depodding Machine. *Nigeria Journal of Technological Research,*13(2),51-57.

Peter-Ikechukwu, I. A., Olawuni, I., Kabuo, O. N., Omire, C. G., Bede, N. E., Osobie, C. C. and Osuigwe, C. (2014) Effect of Wrapping Material on Proximate and Sensory Qualities of Ogiri, a Fermented Melon Seed (*Citrullus vulgaris L. series)* Product. Natural Products An Indian Journal (NPAIJ), 10(5),136-141.

Peter-Ikechukwu, I. A., Kabuo, O. N., Alagbaoso, S. O., Njoku, C. N., Eluchie, N. C. and Momoh, W. O. (2016) Effect of Wrapping Materials on Physio-chemical and Microbiological Qualities of Fermented Melon Seed used as Condiment. *American Journal of Food Science and Technology,* 4 (1),14 - 19.

Olaoye, J. O. and Aturu, O. B. (2018) Design and Fabrication of a Mechanized Centrifugal Melon Shelling and Cleaning Machine. *International Journal of Agricultural Technology,* 14(6), 881-896.

Osasumwen, G. O., Aniekan, E. I. and Lucky, E. C. (2020). Design and Fabrication of a Modular Melon Depodding Machine for Optimum Performance in Nigeria Agricultural Sector. European Mechanical Science, 4(3),103-112.

Vander vossen, H. A. M., Denton, O. A. and El Tahir, I. M. (2004) Citrullus Lanatus (Thumb) Matsum and Nakai Vegetables. *Plant Resources of Tropical Africa (PROTA).* Foudation/Backhuyl Publishers/CTA Wageningen, Netherlands, 1,185-191.

ENERGY AND TIME EFFICIENCY OF A NOVEL SUPERHEATED STEAM DRYER DURING THE DRYING OF RADISH AND TOMATO IN SLICE-FORM

Akpan, Mfrekemfon G.[1] ; Ikrang, Elijah G. [1] & Ting Fang [2]

[1] Department of Agricultural/ Food Engineering, Faculty of Engineering, University of Uyo, PMB 1017, Uyo, Akwa Ibom State, Nigeria.

[2] College of Food Science, Fujian Agriculture and Forestry University, Fuzhou, China.

ABSTRACT

This study was carried out to determine the energy efficiency of a novel two staged dryer running concurrently. The two stages were a self-generated superheated steam dryer at the first stage and a vacuum dryer at the second stage using tomato and radish in slice-form. Three drying regimes were developed and ran for a cycle of an hour against the commercial hot air drying which also lasted for an hour. The regimes included three different operating conditions at the first stage and a common second stage to go with them. Results showed that the novel dryer was more energy and time efficient.

1. INTRODUCTION

Energy and time are important when considering the performance of any process and equipment ecause these determine the economic value of any system. Drying is an energy intensive process. Most drying systems currently in use in the food industry are still conventional with very low energy efficiency and high energy demands corresponding to about 20 % of the energy consumption and 90% of the overall cost (Menon et al., 2020). Non- conventional drying methods have been researched into with the hope of getting answers to energy problems, amongst them are superheated steam and vacuum drying. Superheated steam drying has received much attention lately because of its ability to reduce the drying time, high energy efficiency, high quality output and less effects on the environment since it doesn't emit dangerous gas into the atmosphere (Sa-adchom et al., 2011). Vacuum drying also produces high quality products due to its ability to cause moisture evaporation at temperatures lower than its boiling point which consequently is energy efficient.

Multistage drying is also one of the ways to increase the energy efficiency and the quality of the drying products (Somjai et al., 2009). Longan without stone was dried using a two stage comprising of superheated steam and hot air drying (Somjai et al., 2009), chicken meat dried using two multi-drying stages namely : superheated steam/ heat pump and superheated steam/ hot air (Nathakaranakule et al., 2007). Multistage drying has the advantage of using different drying methods for each of the constant and falling stages of dying as opposed to only superheated steam throughout the drying.

Tomato has been dried in various forms and methods in the literature (Bennamoun et al., 2015; Hawlader et al., 1991) but the aim of this study is to use it as a model for high moisture product to check the efficiency of the design and built equipment in terms of energy and time. Radish was included also as a representative of the root vegetable with high moisture. Radish drying has also been reported in the literature (Lee et al., 2020), carried out a study to investigate the drying kinetics of white radish undergoing hot air drying at 40-60 °C range of temperature. Another dehydration study on radish is the osmotic dehydration of radish in sodium solution (Herman-Lara et al., 2013).

The aim of this study was to use radish and tomato as model high moisture food product in the category of root and fruit vegetables respectively to test the time and energy efficiency performance of a novel superheated steam dryer compared to the conventional hot air dryer.

3. MATERIAL AND METHOD

The materials used in this experiment were tomato fruits and white radish roots. Ripe but firm tomato fruits and blemish free white radish were bought from a local vendor in Fuzhou city about the east gate of Fujian Agriculture and Forestry University, 26°5′16″N**119°14′6″E**. They were washed and dapped dry using tap water and a clean lint-free towel. The tomatoes were sliced horizontally when placed with the tip facing down. Only the mid portion of the fruits was used since they contained more moisture at the mid-section. Fruits were discarded if there were empty space in them. The slices were about 5 mm thick with the peels intact. A batch was 2500g and was evenly distributed in single layers on 4 stainless steel mesh trays just before the commencement of drying.

For the radish roots, the mid-section was sliced into thickness of about 4.5 mm thick and 44.3 mm in diameter manually using a slicer and a stainless-steel round cutter. This section was used because of its extremely high moisture nature. A batch was 1500g and was evenly distributed in single layers on 4 stainless steel mesh trays just before the commencement of drying.

The quantity used for a batch in each of the process was a result of preliminary experiments to determine the right quantity of material for the process having in mind the amount moisture diffusing during the drying process, the structural properties of material and the amount of thermal energy available for the superheating.

Initial moisture content of the part used for both tomato and white radish, was carried out in an electric hot air oven at 105 °C for 24 hours with a known weight. Then the moisture content was determined by gravimetric method.

The drying equipment

The drying equipment used for this experiment the equipment described by (Jia et al., 2018) with the following accessories: The vacuum was between 0-0.005 MPa by the vacuum pump (SHZ-95A, Yuhua Instruments Co. Ltd), the surface pump was an electric hand pump (JY-017 of the Huang yanJinyue electromechanical company, Tai Zhou, China.

Drying operation

The drying operation started out initially with the warming up operation and thereafter the drying cycle. After the commencement of the drying cycle, it became a continuous process with no need for the warming up process. Figure 1 shows the state of both drying chambers during the concurrent drying operation.

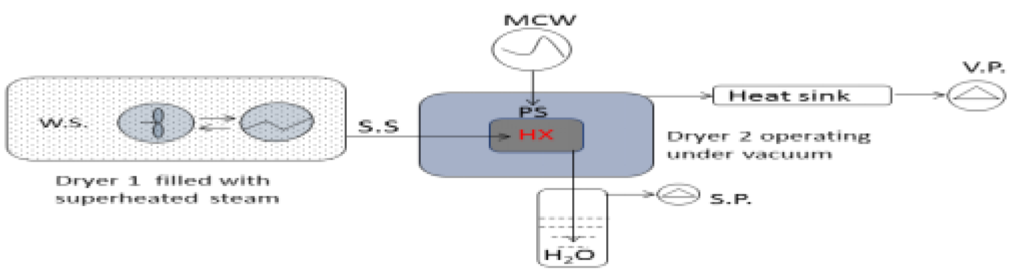


Figure 1: The state of the drying chambers of the drying equipment during the concurrent drying operation of the process generated superheated steam drying.

W.S: A batch of prepared wet sample; S.S: Exhaust superheated steam continuously feeding the heat exchangers; HX: Heat exchangers; P.S: A batch of pre-dried sample; H_2O: condensed water in the condensed water cylinder; MCW: microwave generator; V.P: Vacuum pump; S.P: surface pump.

a) Warming up

During the warming up operation, the first dryer was turned on to run empty for about 10 minutes for thermal stability; after which the first batch of the prepared wet material (W.S) was loaded into it. This was to simultaneously dry and generate steam for both the first chamber and to warm up the second chamber. This was allowed for an hour. The end product of the warming up is the pre-dried sample, PS (Figure 1).

b) Cycle operation

A cycle was used to describe the full load of the equipment running for an hour i.e. the pre-dried sample loaded in the second chamber and the fresh batch of prepared wet sample (WS) loaded into the first dryer. The operating conditions of the equipment depended on the regime in use

(Table 1). After the warming up, the drying operation went on depending on the regime in use for a cycle (see also Figure 1): A fresh batch of prepared wet sample (WS) was loaded into the first dryer after it had run empty for 5 minutes to attain preset temperature. The vacuum pump (V.P) and surface pump (S.P) were turned on simultaneously. The microwave generator was turned on intermittently depending on the regime in use. The 0.5 intermittency ratio (50 % power level) was achieved by alternatively switching on the magnetron for 10 minutes and switching off for 10 minutes. The exhaust superheated steam was continuously fed into the heat exchanger in the second chamber throughout the cycle (1hr). The vacuum was between 0-0.005 MPa by the vacuum pump (SHZ-95A, Yuhua Instruments Co. Ltd), the surface pump was an electric hand pump (JY-017 of the Huang yanJinyue electromechanical company, Tai Zhou, China). The microwave generator was operated at 0.5 intermittency for the duration as defined by the regime. Table 1 has a list of the regimes used in this study.

Commercial hot air-drying operation

Commercial hot air drying was carried out as a control experiment with both tomato and radish root slices. This was done using a cabinet dryer DHG 9123A, Jinghong, China. The weight of sample remained the same as with the concurrent two stage drying. Air flow rate was 2.7 m^3hr^{-1} as measured by LUGB-2303-PT, a flow meter (Henan Pu FeiTe Instruments Co. Ltd, China). The drying was done for one hour at 78 °C in both cases. The prepared materials were used in the same quantities as at when drying with the superheated steam dryer. Each experiment was done in triplicate and the mean value used for further analysis

Each regime was run in 3 cycles (2 replicates) randomly and the average readings of both energy and time were used for further analysis.

Table 1: The regimes of the two-stage concurrent drying in process generated superheated steam used in this study

Regime	**First Chamber (stage1)**	**Second chamber (stage 2)**
A	130°C constantly for 60 minutes	Constant steam through heat exchangers, constant (0-0.04 MPa) vacuum, microwave (585 W) at 0.5 intermittency ratio (10 minutes interval)

B	130 °C: In process Heat penetration was allowed for 18 minutes where the pump wasn't turned on, thereafter turned on for the rest of the 60 mins	Steam through the heat exchangers as allowed by the first dryer, constant (0-0.04 MPa) vacuum and microwave (585 W) at 0.5 intermittency ratio (10 minutes interval)
C	Intermittent drying: 130°C for 20 minutes, 121 °C for 30 minutes and 109 °C for 10 minutes.	Constant steam through heat exchangers, constant (0-0.04 MPa) vacuum, microwave (585 W) at 0.5 intermittency ratio (10 minutes interval)

Temperature measurement

The temperature of the first drying chamber and the product surface temperature were measured during all the drying regimes and during the commercial hot air drying were logged into the computer by a temperature data logger, USB-2408-2A0 of the measurement computing corporation, Norton USA using the T-type thermocouple. Therefore, the temperature of the drying chamber reported was as measured by this data logger during the process.

Energy consumption

The energy consumed during a cycle of each regime was recorded by an energy meter in kWh. The initial reading was subtracted from the final reading to have the energy consumed per regime per cycle.

Specific energy consumption

The specific energy consumption in this study was determined as (Sharma & Prasad, 2006) but with some modifications as shown in Equation 1

$$H = \frac{E_c}{W_l} \quad (1)$$

where H= energy efficiency ($kWhg^{-1}$)

E_c = Energy consumed per cycle (kWh)

W_L = Moisture loss (g).

Specific Time Consumption

This was calculated using Equation 2 to examine the efficient use of time by each regime

$$T_s = \frac{t}{w_l} \quad (2)$$

where, T_s= specific Time consumption (sg^{-1})

t = time (s)

W_L= Weight loss (g)

The specific energy consumption

Energy efficiency was calculated in terms of Specific energy consumption (SEC). This was calculated using Equation 1 and result shown on Table 2 and Table 3 for radish and tomato respectively. Again, the two dried products had similar results on specific energy consumption. The most energy efficient regime was Regime “C” with the least SEC. These results are similar to that reported by Kowalski et al., 2014; Kowalski & Pawłowski, 2011. The more energy saving product was tomato slices. It saved 48.63 % of energy over the hot air drying. Radish slices saved about half of that saved by tomato. This may have been as a result of the structure, being able to release moisture at a faster rate than radish exposed to the same conditions for the same duration. Generally, the superheated steam drying saved more energy than the hot air drying because of the mechanism of operation of the hot air drying. During hot air drying, the air is always drawn fresh from its surroundings, mixed with the part of the air in the chamber and reheated to desired temperature each time, while the moisture laden air within the chamber is exhausted, causing more energy to be consumed. This is in contrast to the superheated steam drying where the steam is recycled and may need just a little heat to be superheated for the moisture pick-up operation. And better in this drying equipment where this reheating is done within the same chamber and used for drying, the latent heat of the exhaust steam is exploited at the second drying stage and used for the drying operation. This equipment generally is expected to save more energy due to this arrangement. The three drying conditions used (regimes A, B and C) therefore outperformed the hot air drying due to these reasons (Table 2 and 3). Specific time consumption of these equipment (novel superheated steam dryer and hot air dryer) was done to examine the effective use of the allocated time for the cycle and for each module. Each cycle lasted for an hour as indicated above and the hot air drying was done for the same duration. The calculations were done using Equation 2 and results shown on Table 4 and 5 for radish and tomato slices respectively. Time is a precious resource and needs to be accounted for in any process to ascertain its efficiency. Some processes take unnecessarily long, therefore time efficiency becomes a necessity. Drying tomato slices saved more time than radish slices because it had lost more moisture than radish at the allotted time. Regime “A” saved the highest time for both products (Table 4 and 5). Hot air drying was done in one duration cycle whereas all the regimes of the concurrent drying operation during the drying of both tomatoes and radish slices were dried at two stages running concurrently, causing the save in time. Therefore, the drying in the concurrent drying was broken into two and ran at the same time due to the equipment design which made the second drying operation dependent on the first. This has significantly saved time in all regimes and with both products. The authors (Nathakaranakule et al., 2007) carried out a comparative study on the drying of chicken using hybrid drying methods involving superheated steam drying.

Table 2: Energy efficiency analysis for the drying of radish slices per regime

Regime	H ($kWhg^{-1}$) (Specific Energy Consumed)	Energy saved compared to HAD (%)
A	0.00186	20.07
B	0.00202	13.14
C	0.00169	27.57
HA	0.00233	-

Table 3: Energy efficiency analysis for the drying of tomato slices per regime

Regime	**H ($kWhg^{-1}$)** (Specific Energy Consumed)	**Energy saved compared to HA Drying (%)**
A	0.00125	46.14
B	0.00136	41.36
C	0.00119	48.63
HA	0.00232	-

The hybrid drying methods compared were superheated steam drying/ hot air drying and superheated steam drying/ heat pump drying. The superheated steam/ heat pump combination dried significantly faster than the superheated steam/ hot air-drying combination but the time saved off the superheated steam/hot air combination was not quantified. The authors attributed the time savings to the low humidity caused by the heat pump drying during the superheated steam/heat pump drying.

Table 4: Specific time consumption and energy saved by the two staged concurrent drying in process generated superheated steam per regime per cycle during radish drying.

Regime	T_s (sg^{-1}) (Specific time consumed)	Time saved compared to HAD (%)
A	0.281	55.52
B	0.297	52.85
C	0.304	51.83
HA	0.630	-

Table 5: Specific time consumption and time saved by the two staged concurrent drying in process generated superheated steam drying per regime per cycle during tomato slices drying.

Regime	T_s (sg^{-1}) (Specific Time Consumed)	Time saved compared to HAD (%)
A	0.17429	68.49
B	0.18068	67.25
C	0.18617	66.31
HA	0.55001	-

CONCLUSION

The two dried products had similar results on specific energy consumption. The most energy efficient regime was Regime "C" with the least SEC. The more energy saving product was tomato slices. It saved 48.63 % of energy over the hot air drying. Radish slices saved about half of that saved by tomato. Drying tomato slices saved more time than radish slices because it had lost more moisture than radish at the allotted time, having saved up to 55.55 % of time while drying radish and above 68 % while drying tomato. This savings was observed in Regime "A" for both products.

REFERENCES

Bennamoun, L., Khama, R., & Léonard, A. (2015). Convective drying of a single cherry tomato: Modeling and experimental study. *Food and Bioproducts Processing*, *94*, 114–123.

Hawlader, M. N. A., Uddin, M. S., Ho, J. C., & Teng, A. B. W. (1991). Drying characteristics of tomatoes. *Journal of Food Engineering*, *14*(4), 259–268.

Herman-Lara, E., Martínez-Sánchez, C. E., Pacheco-Angulo, H., Carmona-García, R., Ruiz-Espinosa, H., & Ruiz-López, I. I. (2013). Mass transfer modeling of equilibrium and dynamic periods during osmotic dehydration of radish in NaCl solutions. *Food and Bioproducts Processing*, *91*(3), 216–224.

Jia, Z., Liu, B., Li, C., Fang, T., & Chen, J. (2018). Newly designed superheated steam dryer bearing heat recovery unit: Analysis of energy efficiency and kinetics of Kelp drying. *Drying Technology*, *36*(13), 1619–1630.

Kowalski, S. J., & Pawłowski, A. (2011). Intermittent drying of initially saturated porous materials. *Chemical Engineering Science*, *66*(9), 1893–1905.

Kowalski, S. J., Rybicki, A., & Rajewska, K. (2014). Intensification of drying processes due to optimal operations. *Chemical Engineering and Processing: Process Intensification*, *86*, 22–29.

Lee, D., Lohumi, S., Cho, B.-K., Lee, S. H., & Jung, H. (2020). Determination of Drying Patterns of Radish Slabs under Different Drying Methods Using Hyperspectral Imaging Coupled with Multivariate Analysis. *Foods*, *9*(4), 484.

Menon, A., Stojceska, V., & Tassou, S. A. (2020). A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies. *Trends in Food Science & Technology*, *100*, 67–76. https://doi.org/10.1016/j.tifs.2020.03.014

Nathakaranakule, A., Kraiwanichkul, W., & Soponronnarit, S. (2007). Comparative study of different combined superheated-steam drying techniques for chicken meat. *Journal of Food Engineering*, *80*(4), 1023–1030. https://doi.org/10.1016/j.jfoodeng.2006.04.067

Sa-adchom, P., Swasdisevi, T., Nathakaranakule, A., & Soponronnarit, S. (2011). Mathematical model of pork slice drying using superheated steam. *Journal of Food Engineering*, *104*(4), 499–507. https://doi.org/10.1016/j.jfoodeng.2010.12.025

Sharma, G. P., & Prasad, S. (2006). Specific energy consumption in microwave drying of garlic cloves. *Energy*, *31*(12), 1921–1926.

Somjai, T., Achariyaviriya, S., Achariyaviriya, A., & Namsanguan, K. (2009). Strategy for longan drying in two-stage superheated steam and hot air. *Journal of Food Engineering*, *95*(2), 313–321. https://doi.org/10.1016/j.jfoodeng.2009.05.005

BIOGAS AS AN ALTERNATIVE SOURCE OF ENERGY IN NIGERIA: PROSPECTS AND CHALLENGES

[1]Ndubuisi Christian Ohakwe, [2]Etoamaihe Julius, [3]Amadi Amadi Oko, [1]Okolo Ejima,

[1]Agricultural and Bio-environmental Engineering Department,
Federal Polytechnic Nekede Owerri
[2]Agricultural and Bio-resources Engineering Dept.,
Michael Okpara University of Agriculture Umudike
[3]Computer Engineering Department, Akanu Ibiam Federal Polytechnic Uwana, Ebonyi State
E-mail: Chrisdavid4ndubuisi@gmail.com. Ondubuisi@fpno.edu.ng

ABSTRACT

The negative impact of fossil fuel on the environment and public health has necessitated the need for an alternative source of energy that is cheap and renewable. Presently the high demand on oil and natural gas caused by high consumption levels is one of the current major problems faced by the world population. There is need for a new energy generation that could challenge the present energy system which is highly dependent on fossil fuel across the globe. The economic and environmental concerns have resulted in research on renewable source of energy to replace the present fossil fuel. Burning fossil fuel such as coal and oil release carbon dioxide (CO2), which is a major cause of global warming. It is expected that not a single source of energy but a combination of various energy sources and carriers will contribute to the energy system of the future. Hence, Biogas which is the anaerobic digestion of organic wastes to produce primarily methane a colourless hydrocarbon and carbon dioxide which can be used for heating, drying, lightening and other farm operations. Biogas offers one of the best alternative energy sources as it presents a viable option for improving sustainable development through energy security, poverty reduction and low emission of greenhouse gases. This paper highlights the potential benefits of biogas generation as a renewable source of energy using livestock waste (cow dung), poultry waste, human waste, crop residue and solid waste at dump sites. It equally elucidates the importance of Biogas utilization as a means of solving problem of power generation, climate change, rural-urban migration, poverty reduction as well as decrease in environmental pollution caused by emission of fumes from cars, motorcycles, industrial activities and burning of woods, kerosene and charcoals for cooking.

Keywords: *Biogas, renewable energy, anaerobic digestion, livestock waste, Bio-digester, sustainable development*

1. INTRODUCTION

Nigeria generates about 542.5 million tons of organic waste such as livestock wastes (cattle excreta, sheep and goat excreta, pig excreta poultry excreta and abattoir waste, human excreta, crop residue and municipal solid waste per annum (Ani, 2017). This in turn has the potential of producing about 25.53 billion cubic metre of biogas (about 169 541.66 MWh of electricity) and 88.19 million tons of bio-fertilizer per annum (Ani, 2017). Abubakar 1990 noted that over the centuries various sources of energy have been used by man in order to meet his basic life essentials. Man has utilized energy in modifying and manipulating land, water, plant and animals to obtain food, clothing and shelter. Nigeria is endowed with huge resources of conventional energy resources (crude oil, natural gas and coal) as well as reasonable amount of renewable energy resources example hydro, solar, wind and biomass (Adaramola and Oyewola, 2011).

The Organization of Petroleum Exporting Countries (OPEC) annual statistical bulletin 2009 revealed that Nigeria proven crude oil reserve and natural gas are 37.2 billion barrels and 5292 million standard cubic metres respectively. In addition, the estimated reserve of tar sands and proven reserves of coals are about 30 billion barrels of oil equivalent and 639 million tons respectively. Most of the developing nations are facing serious shortage of fuels, the most commonly used fuel being wood fuel. The social statistics presented by the Nigeria Bureau of Statistics (NBS) revealed that Nigeria as at 2006 had a total of about 28 900 492 households. 79.6% of these households still depend on wood fuel for cooking as at 2008 (NBS, 2009). In some states like Adamawa, Nassarawa, Zamfara, Sokoto States in Nigeria, the percentage of household depending on wood fuel for cooking is over 90 (NBS, 2009). Even though sizeable proportions of urban and semi-urban dwellers use fuel wood, the majority of users of this fuel are rural dwellers, who constitute between 65-70 % of the population in Nigeria (Ahmadu, 2009). With the recent hike in the pumping price of kerosene in Nigeria, the dependence on wood for domestic cooking has significantly increased. The main challenge of the present world is to harness the energy source which is environmentally friendly and ecologically balanced. This need has forced African countries to search for alternative source of energy. But unfortunately, the new alternative energy sources like solar, hydro, wind, nuclear and so on require huge economic investment and technical know-how to operate, which seem to be very difficult for the developing nations like African countries.

Kerosene and other oil-based sources of fuel are scarce and costly to be easily available for small marginal and medium farmers residing in rural areas. Furthermore, frequent alarming hike in prices of imported fuel has serious economic threat to the poor rural dwellers. The World Energy Council (WEC, 2000) estimated that 1.6 billion of the world’s populations do not have access to commercial energy. Many of these are in Africa, and they are located primarily in the rural areas. It is expected that policy makers and implementers will be able to promote the use of biogas as an alternative source of energy.

1.1 What is Biogas Technology

Biogas refers to the mixture of different gases produced by the breakdown of organic matter in the absence of oxygen. Biogas can be produced from raw materials such as agricultural waste, animal waste, municipal waste, plant materials, sewage, green waste or food waste (Wikipedia).

Ani 2017 defined biogas technology as an alternative energy source which utilizes various organic wastes in order to produce biogas, mineralized water and organic fertilizers. While Buysman 2009, revealed that Biogas is produced under anaerobic conditions; the process is denominated as anaerobic digestion. Also Ngumah et al 2013, described biogas technology as the use of biological processes in the absence of oxygen for the breakdown of organic matter as the stabilization of this material by conversion to biogas and nearly stable residue (digestate) (Marchaim, 1992). They went further to explain that biogas is a mixture of methane (45-75%) and carbon dioxide (25-55%), the actual proportion depending on the feedstock (substrate) used and processes employed. Ani 2017 opined that biogas technology is the use of biological process in the absence of oxygen for the breakdown of organic matter into biogas and a high quality fertilizer. He further noted that biogas technology is a 'carbon neutral process', meaning it neither adds nor removes carbon dioxide from the atmosphere.

1.2. Biogas Production

When organic wastes decompose, it does so in the presence or absence of air and is referred to as aerobic or anaerobic decomposition respectively. Thus decomposition could be natural occurring or maybe artificially induced under controlled conditions. One of the end-products of anaerobic decomposition is biogas which produced naturally from decomposition under water or in the guts of animals and artificially in air tight digesters. Biogas is a kind of gas produced by the biological breakdown of organic matter in the absence of oxygen (Deublein and Steinhauser, 2008).

Stanley 2008 stated that Biogas is generated when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. While Ani 2017, elucidated that biogas is produced from anaerobic decay (decay that occurs without oxygen).

1.3 Biogas Composition

The composition of biogas varies depending upon the substrate as well as the conditions within the anaerobic reactor (temperature, pH and substrate concentration) (Buysman, 2009). Biogas is primarily composed of 50-75% Methane (CH4) and 30-40% Carbon dioxide (CO2) with smaller amounts of Hydrogen Sulphide (H_2S) and ammonia (NH^3). Trace amounts of hydrogen (H_2)

Nitrogen (N_2) Carbon monoxide (CO) and Oxygen are present in the biogas (Monnet, 2003).

1.4 Biogas System

A biogas plant converts biodegradable waste to useable gas under anaerobic conditions. This gas consists mainly of methane and carbon dioxide as well as other traces elements (Ani, 2014). Organic material is added to the digester where under anaerobic conditions bacteria convert the material to two products which are biogas and slurry. The system consists of a digester which provides an area for the material to be digested by bacteria in an environment devoid of oxygen. Material is added to the system via an inlet tube and the digested material is then removed from a separate opening (Ochwieja, 2010).

1.5 Classification of Biogas Plants

Monnet 2003 listed that there is a wide range of facility types which differ in location, size of feedstock and process employed. The characteristics of the facility have to be carefully chosen in each specific case. Ahmadu, 2009 noted a typical biogas plant consists of two main parts; a digester (where fermentation occurs) and a gas holder (where the gas produced is stored). Other parts include an inlet mixing tank and an outlet tank. Various kinds of biogas plants, e.g. the Indian, Chinese, Taiwanese and Philippine plants are in used. He further opined that the classification of biogas plants is based on several criteria such as method of feeding the digester, orientation, geometry as well as the gas storage system.

1.6 Types of Biogas Technology

There are two major types of Biogas Technology for the production of Biogas. They are briefly highlighted as;

1. Fixed Dome type

This consists of an airtight container or fixed non-movable gas space constructed of brick, stone or concrete, the top and bottom being hemispherical. Sealing is achieved by building up several layers of mortar on the digesters inner surface of brick is used for construction. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. It is relatively cheaper to construct the fixed dome digester than the floating gasholder type. It has longer life; there is no problem of corrosion or rusting. However, the amount of biogas present cannot be known, problem of gas leakage is there; gas production is lesser and requires skilled labour (Sanjay et al, 2012).

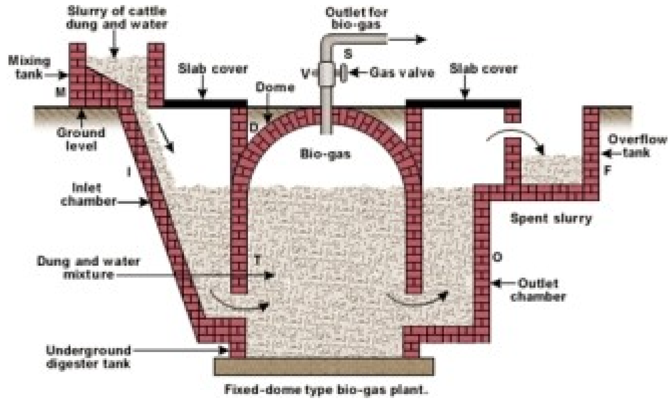


Fig1: Fixed Dome Biogas Type
Source: Goggle On line pictures on Biogas

2. FLOATING GAS-HOLDER TYPE

The design of this type consists of a dome shaped gas holder made of steel for collecting biogas. The dome shaped gas holder is not fixed but is moveable and floats over the slurry present in the digester tank. Due to this reason the biogas plant is called Floating gas holder type biogas plant. The cover is usually constructed of mild steel. The level of biogas present inside the gas plant can be known, it runs at constant gas pressure, No gas leakage problem due high pressure and high gas production. Though, it is expensive due to steel gas holder, corrosion or rusting of gas holder may lead to leakage of the gas, also maintenance cost is higher and the cover have been the main problem of this design (Sanjay et al 2012). However, the mild steel cover is gradually being replaced by plastic gas holder (Ani, 2014).

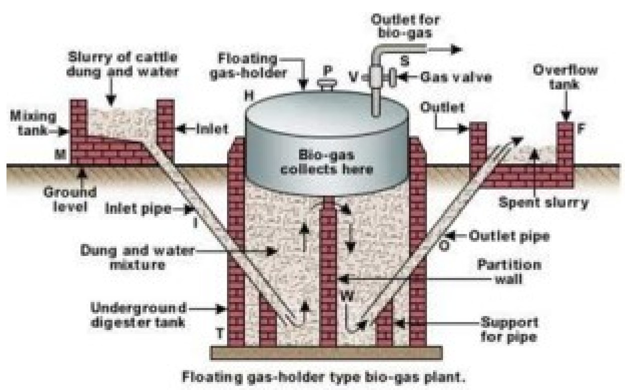


Fig 2: Floating Gas Holder Type
Source: Goggle On line Pictures on Biogas

3. GLOBAL PRODUCTION AND UTILIZATION OF BIOGAS

Biogas has provided an economically viable and sustainable means of meeting the thermal energy needs in China (7.5 million), India (3 million) and Nepal, where over 37000 biogas digesters were installed from 1992 to 1998 (Doelle, 1998). Also, 900 small scale digesters in Germany, 10 000 000 in China, 5 000 000 in India, 40 000 in Cambodia, 5000 in Vietnam and 500 in Costa Rica (Ani, 2017). Their use is not limited to these countries, but extends throughout the developing world. More recently, developed countries have been making increasing use of gas generated from both wastewater and landfill sites (Agbogu and Mbaeyi, 2006). He fuel produced may be used for direct firing of boilers or to fue1 a CHP (combined heat and power) plant. Alternatively, the gas can be upgraded by extracting the trace gases and carbon dioxide to produce a vehicle-grade fue1 (Harris, 2006).

According to Deublein and Steinhauser (2008), France, in 1987 the streets lamps of Exeter started running on biogas produced from wastewater. Germany, agricultural products were used to produce biogas in 1945.

Today, China is credited as having the largest biogas programme in the world with over 20 million biogas plants installed (Tatlidil et al., 2009).

Ducellier and Isman started building simple biogas machine in Algeria to supply farmhouses with energy. The most recent Anaerobic Digestion plant in Belgium can handle 58000 tons of waste per year. A plant in Freiburg in Germany processes 36000 tons of waste per year producing 3 million cubic meters of gas and 15000 tons of compost (Harris, 2006).

3.1 Benefits of Biogas

i. Biogas is Eco- Friendly
ii. Biogas Generation Reduces Soil and Water Pollution
iii. It’s a Simple and Low-Cost Technology That Encourages a Circular Economy
iv. Biogas Generation Produces Organic Fertilizer
v. Healthy Cooking Alternative for Developing Areas

A. Benefits to the Energy Sector

i.Source of renewable (green) energy, which leads to a lesser dependency on the finite fossil fuels.
ii.The use of the digestive decreases the use of fossil fuels in the manufacturing of synthetic fertilizer.
iii.It is carbon dioxide neutral.

B. Benefits to Agricultural Sector

i. Transformation of organic waste to very high quality fertilizer.
ii. Improved utilization of nitrogen (by plants) from animal manure.
iii. Balanced phosphorus / potassium ratio in digestate.
iv. Homogenous and light fluid slurry.

C. Benefits to the Environment

i. Reduces emission of greenhouse gas

ii. Reduces nitrogen leaching into ground and surface waters

iii. Improves hygiene through the reduction of pathogens, worm eggs and flies.

iv. Reduces odour by 80%

v. Controlled recycling/ reduction of waste.

vi. Reduces deforestation by providing renewable alternative to wood fuel and char coal.

D. Benefits to the Economy

i. Provides cheaper energy and fertilizer.

ii. Provides additional income to farmers.

iii. Creates job opportunities.

iv. Decentralizes energy generation and environmental protection.

Fig 3: Biogas used as Gas Cooker
Source: Goggle on line Picture on Biogas

4. PROSPECTS AND CHALLENGES

Nigeria is Africa's energy giant. It is the continent's most prolific oil producing country, which along with Libya, accounts for two-thirds of Africa's crude oil reserves (Oyedepo, 2012). Nigeria has warm, stable climate and easy availability of plant material and animal wastes (cow dung, poultry droppings, and pig excreta among others) is at an advantageous position for adopting and popularizing biogas. At present much of the dung producing about millions of herds of cattle in Nigeria is either wasting or burnt among as wasteful cooking fuel. Assuming an average production of 10kg of dung per animal per day and a collection rate of 60 per cent, the amount of dung available in the country in a year may work suit to about 300 million tons which can generate a staggering millions of tons of humus-rich manure. As it is 30 million m3 of biogas equals 20 million tons of kerosene oil, nearly three times the animal consumption of the commodity in the country (Anon, 2003).

Biogas is not popular in Nigeria as well as most countries in Africa. Most of the materials available on biogas in Nigeria are reports of scientific researches into the technical aspects and basic factors of biogas production, especially on raw materials (Garba and Ojukwu, 1998, Ezeonu et al, 2002).

Presently biogas production is beginning to catch attention in Nigeria. At Ibadan a local NGO and a community-based organization has joined with Technology Innovators from Thailand, to build a sustainable Ibadan project in Nigeria to Install a biogas plant that will run on abattoir effluents to create a source of domestic energy, abate pollution and mitigate gas emissions.

Also, another abattoir biogas project in Enugu with a proposed plant capacity of $8500m^3$ 2000 number of cows slaughtered daily, quantity of solid organic waste, 120 tons parlay, volumes of waste water generation, with electricity generation of 1.9 MWL per day at 35 percent generation efficiency, savory application of solid organic fertilizer production (Ani, 2014). Another project which needs of biogas production is a Toilet/ Kitchen waste linked biogas (Urine reactor) plant located in Abuja with a plant capacity of 10m3, biogas production of 6m3 with biogas application for cooking gas and electricity 1.5kw biogas gen (Ani, 2014).

Another biogas plant uses cassava and cow dung as feed stock for Biogas and solar food dryer in project location in Oyo state with capacity of $20m^3$ (Ani, 2014).

The biogas plant if implemented through Public-Private Partnership, in addition to the production of a cheap source of domestic cooking gas and organic fertilizer is expected to generate employment.

It is a known fact that health is wealth and the synergy between poverty and ill wealth has long been established. Biogas utilization will turn environmental and human health hazards into valuation energy resource and revenue source. A supply piped gas for cooking will reduce deforestation and the daily drudgery of collecting firewood.

The introduction of biogas stoves will reduce or eliminate health hazards like respiratory disorders associated with wood fires. The hygienic state of settlements will also improve when sewages, channeling slaughter house wastes, a major sources of local water pollution and greenhouse gas emission into biogas production, clean burning domestic gas for urban poor families and cheap organic fertilizers to low-income farmers. Biogas production and utilization will eliminate methane, the highly destructive greenhouse gas, so it does not go into the environment and contribute to global warming. Environmentally, biogas has some advantages over fossil fuels such as coal and petroleum. Growing plants for use as biomass fuel helps to keep global warming in check Biogas production and utilization will also boost livestock keeping in Africa and helps to meet the ever-growing demand for meat in Africa. The result would be more income for families.

However, there are problems. There is always a strong inertia against change in every human society. The following are some of the challenges;

1. Planning and Construction:
2. Lack of financial capabilities:
3. Lack of public support
4. Lack of effective and clear policies
5. Technical challenges:

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the study it is evident that biogas can serve as an alternative source of energy not only in Nigeria but in all African countries, since what is required in its production are readily available ranging from animal wastes (cow dung), organic waste solid waste which could be converted to renewable energy through the use of bio digesters biogas can replace fossil fuels as well as reduce disposed waste volume to dump sites. Hence it generates high quality renewable fuel proven to be useful in a number of end-user applications. Also it can create employment and can produce organic fertilizer and many more environmental benefits.

5.2 RECOMMENDATIONS

The following are recommended for biogas production as an alternative source of energy in African countries;

a. An immediate shift in government policies to encourage the adoption and promotion of biogas energy in Nigeria.

b. Provision of subsidies to individuals and companies that would want to build and run biogas production plants.

c. Training and deployment of extension officer or trained personnel that would provide the technical know- how on building and managing biogas plants.

d. Introduction of a biogas programme that would lead to the evolution of inexpensive and locally adaptable technology.

e. Reprogramming the agricultural sector to produce daily cow wastes, poultry wastes as well as regular production of fodder grass.

REFERENCES

Adaramola, S. and Oyewola, K. (2011): Refining Biogas Produced from Biomass; An Alternative to cooking Gas.

Agbogu, V.N and Mbaenyi, I.E.(2006): Biogas Production; Family Economic Empowerment opportunities. A Paper Presented at 7th Annual National Conference of the Home Economics Research Association of Nigeria, (HERAN) UNN; Nigeria.

Ahmadu T.O. (2009): Comparative Performance of Cow Dung and Chicken Droppings for Biogas Production, M.Sc. Thesis Submitted to the Department of Mechanical Engineering Ahmadu Bellow University, Zaria.

Ani, Chioma N. (2014): Evaluation of Some Nigeria Corn Varieties for Fuel Ethanol Production.

Ani, Chioma N. (2017): Biogas as a Sustainable Solution Energy and Waste Management Challenges in Nigeria

Anonymous (2003): Biogas Plants Available at: File://A/. biogas – htm

Buysman, M. (2009): Biogas Design and Operational Manual, Institute for Agricultural Engineering.

Deublien, D. and Steinhauser, A. (2008): Biogas from Waste and Renewable Resources. Wiley-VCH Verlag GmbH & Co. KGaA.

Doelle,H.W. (1998): Socio-Ecological Biotechnology Concept. Biotechnology Volume Vii. Fundamental in Biotechnology.

Ezeonu, F.C., Udedi, F.C., Okaka, A.N.C. and Okonkwo, C.J. (2002): Studies on Brewers Spent Grains (BSG) Biomethanation. I-Optimal Conditions for Digestion, Nigeria Journal of Renewable Energy 10 (1 &2). Pp 53-57.

Garba, B. and Ojukwu, U. P. (1998): Biodegradation of Water Hyacinth (Eichhornia Crassipas) as an Alternative Source of Fuel. A Review Nigeria Journal of Renewable Energy 6 (1&2) Pp. 12-15.

Harris, K. (2006): Effect of Temperature on Biogas Production in Anaerobic Treatment of Domestic Wastewater.

Hullu, M. (2008): Engines for Biogas, Early Approaches towards Electricity Generation from Biogas.

Kolumbus, S. (2007): Anaerobic Biotechnology for Bioenergy Production; Principles and Applications. Wiley-Blackwell Ames.

Monnet, F. (2003): An Introduction to Anaerobic Digestion of organic Waste, Final Report.

Marchaim, U. (1992): Biogas Processes for Sustainable Development, FAO.

Nigeria Bureau of Statistic, (2009): The Energy Sector – an Overview with a Special Emphasis on Renewable Energy.

Ngumah, C.C. Ogbulic, J.N. Orji, J.C. and Amadi, E.S. (2013): Biogas Potential of Organic Waste in Nigeria, Journal of Urban and Environmental Engineering Vol. 7 No. 1, Page 110-116.

Ocwieja, S.M. (2010): Life Cycle Thinking Assessment Applied to Three biogas Projects in Central Uganda, A Master of Science Thesis, in Environmental Engineering Michigan Technological University Report, Available at http://www.cee.mtu.edu/peacecorps/studentfiles/ocwieja-uganda.pdf Retrieved 17/05/2011.

Oyedepo, Sunday Olaiyinka (2012): Energy and Sustainable Development in Nigeria.

http//energysustainsoc.biomedcentral.com/article, Retrieved on 19/09/2018.

Sanjay, K.,Vishal, K. and Ram, K.S (2012):Biogas Production Technology; Fundamental of Agricultural Engineering. Kalyani Publishers.

Sasse, A. (1998): Renewable Energy, Optimizing Low Temperature Biogas production from Biomass.

Stanley, M. (2008): A Biogas from Waste and Renewable Engineering, Foundation School of Engineering, Colombia University.

Tatlidil, F., Bayramogu, Z. and Akturk, D. (2009): Animal Manure as One of the Main Biogas Production Resources, Case of Turkey. Journal of Animal and Veterinary Science.

www.Home Biogas.com/blog/advantage and disadvantage of biogas, Retrieved 9/17/2018.

www.Wikipedia-Biogas. Retrieved 20/11/2019

World Energy Council (2000): The Challenge of Rural Energy Poverty in Developing Countries, World Energy Council, London.

USING AQUACROP TO ESTIMATE CROP BIOMASS PRODUCTION- GREEN ENERGY

[1]Alli, A.A., [2]Omofunmi, O.E and [3]Oladipo, A.S

[1 & 3]Department of Agricultural & Bio-environmental Engineering, Yaba College of Technology Yaba Lagos Nigeria
[2]Department of Agricultural and Bioresources Engineering, Federal University Oye - Ekiti, Nigeria
Corresponding Author. alidek002@yahoo.com; +2348056450609

ABSTRACT

The objective of this paper was to simulate biomass production. Biomass is a biophysical parameter contained in agricultural materials that is responsible for the generation of green energy or electricity through thermal conversion. Biomass emits lesser carbon than fossil fuels making it significant in pollution control. The research location is at Epe in Lagos state, Nigeria which lies on the latitude and longitude of 6^0*. 58' N and* 3^0*. 96' E. Climatic data required include rainfall (mm), radiation (MJ/M*^{2}*), maximum and minimum temperature (*^{o} *C), wind speed (m/sec), mean relative humidity (%) and Carbon dioxide concentration ranging from 1982 to 2018 daily obtained from the website of National Aeronautics and Space Administration. Aqua crop used was of version 6.1 Food and Agriculture Organization and crop chosen was tomato. The results show that total biomass generated was 470 g/m*^{2} *while growing degree, canopy cover, and harvest index are 1940 mm, 5420 mm, and 2640 respectively.*

Keywords : Biomass, Aquacrop, Fossil, Simulation, Energy and Environment

1. INTRODUCTION

In the quest for clean energy to make our environment and atmosphere carbon free, attention has been shifted to biofuels as an alternative source of energy. In renewable energy mix, biofuel is generated from biomass- a biophysical parameter contained in agricultural materials that is responsible for the generation of green energy or electricity through thermal conversion. Fossil fuels, not only its prospecting, exploration and refining process are becoming more capital intensive (Adegoke *et al* 2014); areas where fossil fuels (crude oil, petroleum and natural gases) are found are always crises prone (Emordi *et al* 2012); and finally the products are confronted with depleted reserves with growing demand due to the rapid growth of users' population and industrial revolution (Adegoke *et al.,* 2014; and Dutta *et al.,* 2013). The effects of fossil fuels on environment and human health have called for concerted efforts to develop alternative energy mix such as briquettes production from biomass, use of hydro, tides, solar, wind etc which are largely available in Nigeria (Dutta *et al.,* 2013; Ladapo et al., 2020; Akhator *et al.,* 2017 and Akinrinola *et al.,* 2014).

Biomass, reported to account for over 70 % of renewable energy used globally (FAOSTAT, 2019), can be estimated using various methods ranging from field measurement techniques which is energy sapping , time consuming and unsuitable for large scale spatial and temporal measurement (Li *et al*., 2015); remote sensing technology- preferably for estimating crop biomass at the regional or global scale (Haboudane et al., 2004; and Tilly et al., 2014); use of traditional optical remote sensing data (Becker-Reshet et al., 2010; Gao et al., 2013; Li *et al*., 2015; and Liu et al., 2010); and hyperspectral sensor which has capacity to generate sufficient information on biochemical and biophysical composition of vegetation canopy (Delegido et al., 2010; Gilmore et al., 2008; Hladik et al; 2013; and Koetz et al., 2007). Among previous authors reviewed, no one used Aquacrop to estimate biomass production, hence the objective of this paper is to use crop growth model- aquacrop to simulate the estimation of biomass production.

2. MATERIALS AND METHODS

2..1 Research Location

The research location is at Epe in Lagos state, Nigeria which lies on the latitude and longitude of 6^0. 58' N and 3^0. 96' E with elevation of 3.98 meters above the sea level. Epe is located at the bank of the North side of Lekki Lagoon.

2.2 Aqua crop Data Source and Process

Data were processed into Aqua crop format and saved in Micro soft Excel with csv or text file for compatibility in the directory of aqua crop after removing voids and non numeric elements. Aquacrop data needed were sourced from the archive of National Aeronautics and Space Administration ranging from 1982 to 2018 (37 years) on daily basis as stated thus:

i. Reference evapo-transpiration (ETo) - ETo determines the evaporative demand of the atmosphere, and the rate of the crop transpiration and soil evaporation.
ii. Minimum (T min) and maximum (T max) air temperature (^{o} C): T min and T max are required to calculate evapotranspiration (ETo) which is to handle heat transfer and heat loss around the crops; growing degree days which determines crop development and phenology; adjustments in crop transpiration during cold periods; and determination of heat and cold stresses as affect pollination.
iii. Rainfall data (mm): Rainfall is required to bring the soil water up to field capacity; update the soil water balance and to calculate soil water stresses affecting crop growth and production processes.
iv. Mean annual atmospheric CO_2 concentration (CO_2): Aqua crop has some CO_2 adopted from different scenario like Manualloa.CO_2 which is universal and capable to test the crop response for climate change scenarios.

The MaunaLoa.CO_2' file contains observed mean annual [CO_2] for the period 1902 till today with projected atmospheric composition for the future.

v. Air humidity is required to calculate ETo: The difference between the saturation (es) and actual (ea) vapour pressure, called

vi. Radiation data is required to calculate ETo which is the amount of energy available to make water to be vaporized. It can also be estimated from the actual duration of sunshine. In absence of any measurement, solar radiation (Rs) can be estimated from the difference between maximum and minimum temperature.

2.3 Biomass Components of Aquacrop

Simulation of biomass is based on the following four steps which are regarded as components constituting biomass production with their definitions and calculations appropriately;

1. **Development of Green Canopy Cover (CC):** Green canopy cover represents the foliage development in aquacrop which is the fraction of the soil surface covered by the canopy ranging from 0 % - 100% of the soil surface canopy coverage (i.e from sowing to maturity). Various stresses are monitored by adjusting the soil water content daily in the soil profile, and soil water stress might affect the leaf and hence canopy expansion and if severe might trigger early canopy senescence;

2. **Crop Transpiration (Tr):** For well watered conditions, Tr is calculated by multiplying the reference evapotranspiration (ETo) with a crop coefficient (KcTr). The crop coefficient is proportional to CC and hence varies throughout the life cycle of the crop in correspondence with the simulated canopy cover.

$$Tr = Ks\,(KSTr,x\,.\,Kc\,Tro)\,ETo\text{ ---------------}$$

Where Tr- Crop transpiration; Ks- water stress; KSTr,x- Cold water stress; KcTro- Crop transpiration Coefficient, while crop transpiration coefficient KcTro is derived thus;

$$KcTr = KcTr{,}X\ .\ CC^{*}\text{---2}$$

Where CC* - the canopy cover adjusted for micro- advective effects which is ranged from 1.05 to 1.20 for most crop; KcTr,x- Crop coefficient for maximum crop transpiration and this is determined by the canopy cover with reference to grass characteristics of the crop.

3. **Above-ground biomass (B):** The above ground biomass produced is proportional to the cumulative amount of crop transpiration (ΣTr). The proportional factor is the biomass water productivity (WP) which is valid for diverse locations, seasons, and CO2 concentrations as represented in the equation 3 below;

$$B = WP^{*}\sum\left(\frac{Tri}{EToi}\right)\text{ --------------------}$$

Where B- Biomass; Σ − Summation; WP*- Biomass water productivity normalized for climate; Tri- Daily amount of water transpired with the reference to evapotranspiration (EToi) for that day.

4. **Crop yield (Y): B**iomass (B) exploits all photosynthetic products such harvest index, actual harvest index and reference harvest index to produce crop yields. Final crop yield (Y) is simulated by multiplying B with a harvest index (HI) which expresses the mass of the harvested product as a percentage of the total above-ground biomass as expressed below;

$$Y = HI * B$$ −−−−−−−−−−−−−−−−−−−−

Where B- biomass; HI- harvest index and Y- final crop yield

Flow Chart for Aquacrop Simulation

Aqua Crop, as shown in Figure 1 below is a crop model used to stimulate yields response to water. It describes the relationship that exist among plant, water, soil and climate. Aquacrop has capacity to handle relatively large data, and missing data is accounted for by computing it with minus number nine hundred and ninety nine (-999).

The flow chart shows the procedures in carrying out simulation using aquacrop. Climate data required mainly for simulation included rainfall saved as PLU, minimum and maximum temperature, evapotranspiration (ETo) generated from humidity and minimum and maximum temperature using ETo calculator, and carbon dioxide (CO_2) Mouna- Loa Special report on emission scenario (SRES A2) while crop used for simulation was tomato with crop cycle of November 9, 2017 to February 22, 2018 under drip irrigation management.

Meanwhile, ground water was not considered for the simulation because the effective root zone of tomato is 1 m which is regarded as shallow crop, and Epe soil is sandy loam while all necessary titles were assigned to project details for crosschecking before striking the run button and all the out put data were saved in Ms Excel for data analysis.

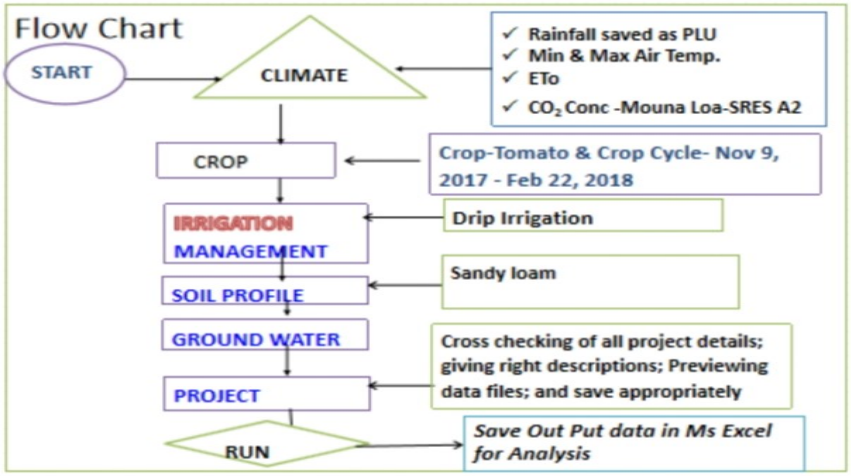


Figure 1. Aquacrop Simulation chart

4. RESULTS AND DISCUSSION

4.1 Global Statistics on Gross Energy Consumption

Tables 1- 3 show the global final energy consumption, total global energy supply of renewable and the descriptive statistics of biomass components. Table 1 shows that only 13 %, 12.3 %, 12.6 %, 13.6 % , 14.6 % and 13.9 % of renewable energy were used out of the total global energy consumption of 420 EJ, 481 EJ, 539 EJ, 572 EJ, 576 EJ and 585 EJ for years 2000, 2005, 2010, 2015, 2016 and 2017 respectively. This shows that the use of renewable energy is still comparably low, while global use of nuclear energy is the lowest. Globally, concentration on the use of carbon generated energy is still very high with its attendant implication on our atmosphere.

Table 2 shows that biomass alone accounted for over 70 % of renewable energy use. The total global primary energy supply of renewable for years 2000, 2005, 2010, 2015, 2016 and 2017 are 54.7 EJ, 59.4 EJ, 68.2 EJ, 77.7 EJ, 80.5 EJ and 81.1 EJ of which biomass accounted for 42.8 EJ, 45.9 EJ, 51.2 EJ, 55.1 EJ, 56.5 EJ and 55.6 EJ respectively. The use of tidal energy is still abysmally low globally while the use of solar and wind energies are trending far behind the use of hydro energy. In year 2017 only, global primary energy supply of renewable showed that biomass, hydro, solar, wind, geothermal and tide are 56.5 EJ, 14.6 EJ, 2.60 EJ, 3.45 EJ, 3.37 EJ and 0.004 EJ respectively.

Table 3 shows the descriptive statistics of biomass components generated from the aquacrop simulation for the crop cycle of 109 days of tomato ranging from nursery to plant recovery to vegetative to flowering and to fruit formation and yield. The sum of growing degree (GD), canopy cover (CC), Biomass water productivity normalized for climate (WP), Biomass and harvest index (HI) are 1930.90 mm, 5418.70 mm, 1837 mm, 469.72 g/m^2, and 2273.70 respectively.

Figures 2 -5 show the graphs of day after planting versus biomass, canopy cover, growing degree and harvest index respectively. Figure 2 shows the graph of day after planting versus biomass which demonstrated how biomass progresses as crop grows. Biomass production is almost zero at nursery and plant recovery stages. At vegetative stage, biomass started growing until it reaches yield. Biomass is at climax at yield formation and ripening stage.

Table 1. Gross Final Energy Consumption Globally

Year	Total	Coal	Oil	Natural Gas	Nuclear	Renewable	% of Renewable
2000	420	97	153	86.8	28.3	54.7	13.0
2005	481	125	168	98.8	30.2	59.4	12.3
2010	539	153	173	115	30.1	68.2	12.6
2015	572	161	182	123	28.1	77.8	13.6
2016	576	156	184	127	28.5	80.6	14.6
2017	585	158	186	130	28.8	81.1	13.9

Unit: In EJ (IAE, 2019)

Table 2. Total Global Primary Energy Supply of Renewable

Year	Total	Biomass	Hydro	Solar	Wind	Geothermal	Tide etc
2000	54.7	42.8	9.43	0.21	0.11	2.19	0.002
2005	59.4	45.9	10.6	0.31	0.37	2.25	0.002
2010	68.2	51.2	12.4	0.77	1.23	2.61	0.002
2015	77.7	55.1	14.1	2.27	3.02	3.24	0.004
2016	80.5	56.5	14.6	2.60	3.45	3.37	0.004
2017	81.1	55.6	14.7	3.07	4.06	3.59	0.004

Unit: In EJ (IAE, 2019)

Table 3. Descriptive Statistics of Biomass Components

Descriptive Statistics	GD	CC	WP	Biomass	HI
Mean	17.55	49.26	16.70	4.26	20.67
Standard Error	0.13	2.87	0.00	0.37	2.73
Standard Deviation	1.34	30.08	0.00	3.90	28.66

Kurtosis	-0.90	-1.32	-2.04	-1.28	-1.50
Skewness	-0.61	-0.71	-1.01	0.42	0.32
Minimum	14.30	0.00	16.70	0.00	-9.90
Maximum	19.40	75.00	16.70	11.52	63.00
Sum	1930.90	5418.70	1837.00	469.73	2273.70

Figure 3 shows four stages involved in canopy development of tomato such as emergence or transplant recovery, vegetative, flowering and yield formation and ripening stages. Emergence and transplant recovery stage started from DAP 1 to DAP 5, and canopy development was in rapid form during vegetative which covered DAP 5 to DAP 37. Flowering stage started DAP 37 to DAP 77 and thereafter yield formation and ripening set in. Canopy started declining after ripening stage. The longest stage in canopy development is flowering stage. Canopy development grows with biomass production.

Figure 4 shows that growing degree was at peak during yield formation and ripening stage, and decline during flowering stage. Probably, this shows that series of activities are involved at flowering stage such as insects attack, more demand for water etc.

Figure 5 shows that harvest index remains zero from DAP 1 to DAP 37. It was at flowering stage , harvest index started progressing until it got to full yield formation and ripening before it becomes stabilized.

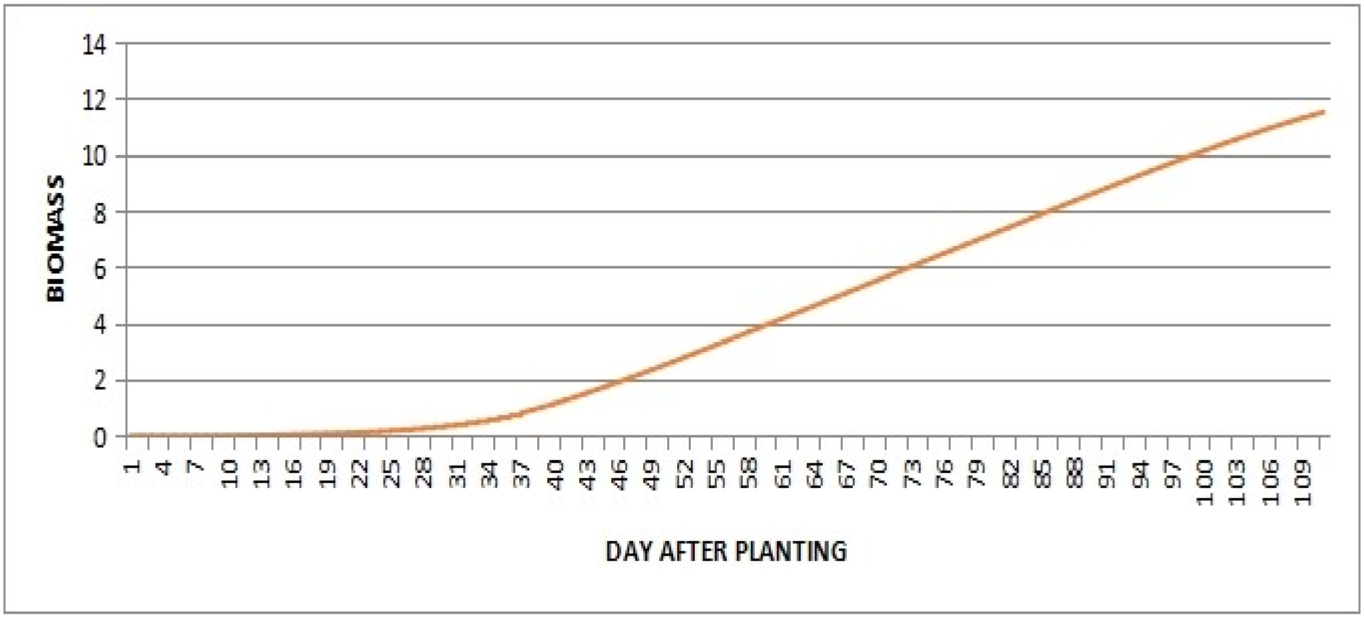


Figure 2. Graph of Biomass Versus Day after Planting

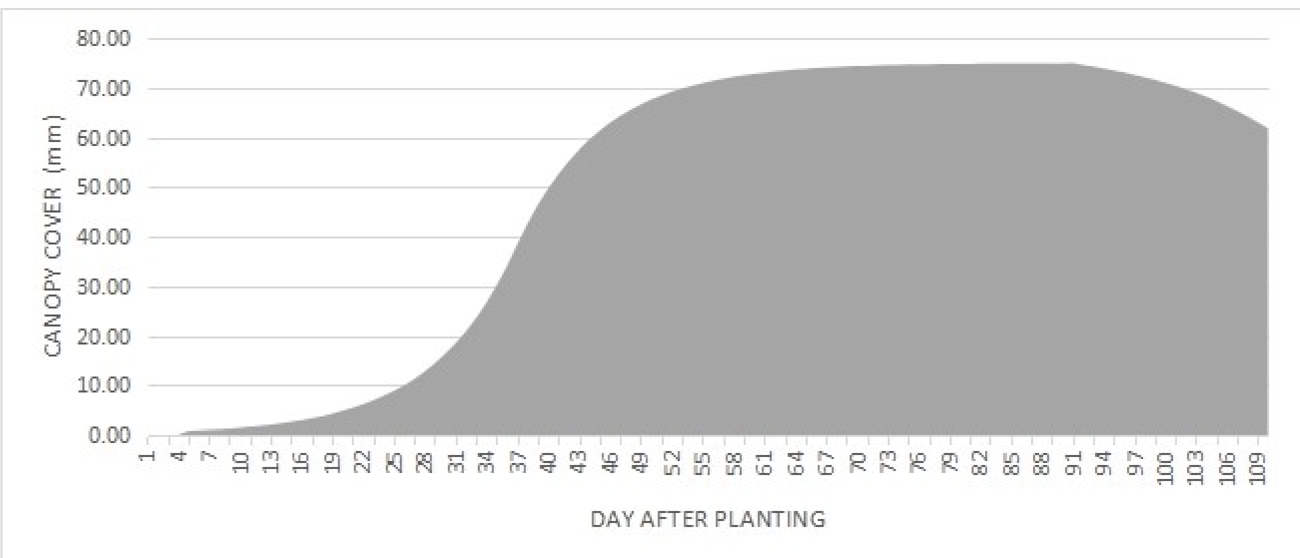


Figure 3. Graph of Canopy Cover Versus Day after Planting

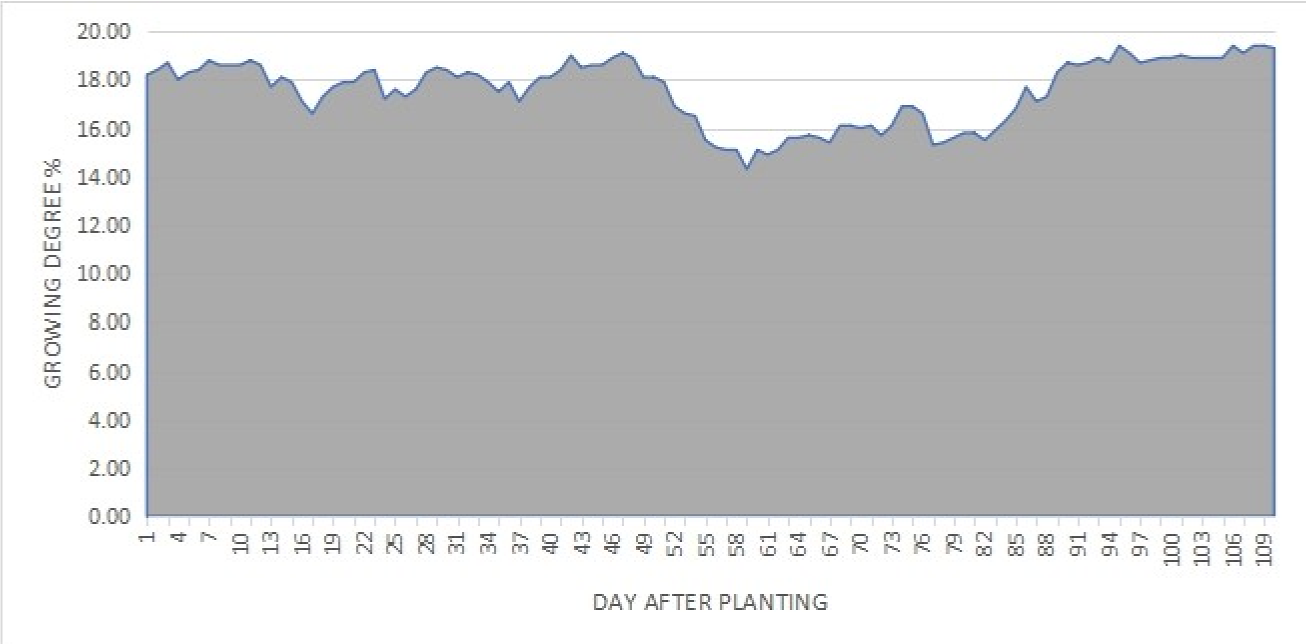


Figure 4. Graph of Growing Versus Day after Planting

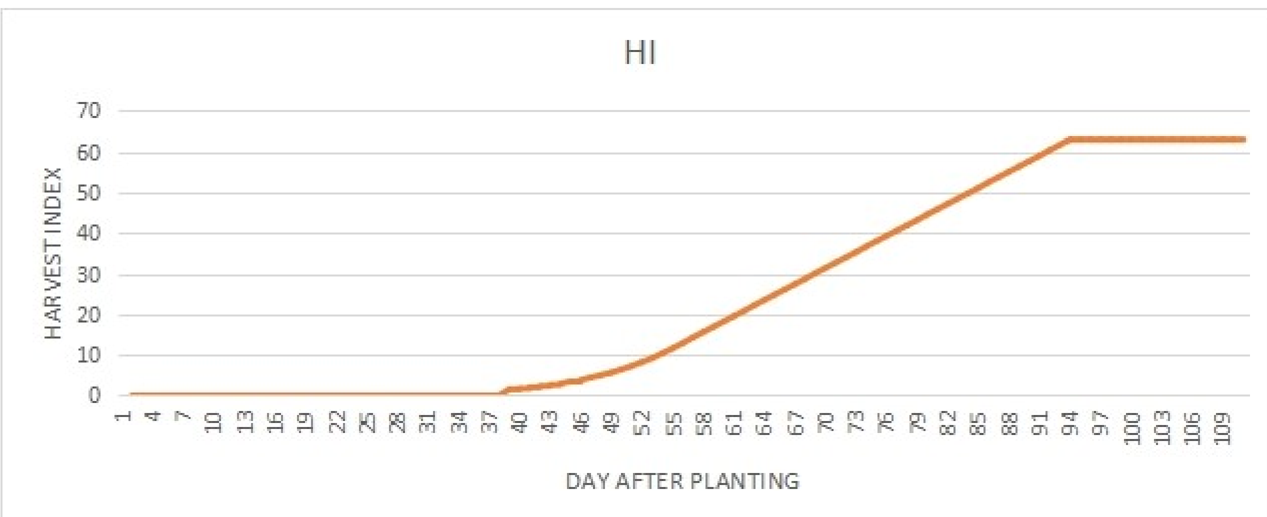


Figure 5. Graph of Harvest Index Versus Day after Planting

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Among the global primary energy supply for renewable, Nigeria as a country is blessed with abundance of them all (Akinrinola et al 2014). Biomass, as it accounts for over 70 % of primary energy supply for renewable energy, remains untapped gold of energy mix production in Nigeria and the entire world. Biomass is generated from various agricultural and wood products with insignificantly different energy properties. Ladapo et al (2020) reported that briquettes produced from both maize and sawmill residues are good source of domestic energy as their energy properties are not significantly different. One of the advantages of biomass resource is that it can stay for a longer period of time without any significantly depletion (Akhator *et al.,* 2017; Enweremadu et al 2004).

Aquacrop proves effective in the simulation of biomass production and responses of water to crop growth as it accounts for green canopy development which represents the foliage development ranging from 0 % - 100% of the soil surface canopy coverage (i.e from sowing to maturity), while various stresses are monitored by adjusting the soil water content daily in the soil profile which will invariably trigger early canopy senescence if not well managed; crop transpiration ; above-ground biomass which is proportional to the cumulative amount of crop transpiration (ΣTr); and crop yield which exploits all photosynthetic products such harvest index, actual harvest index and reference harvest index to produce crop yields.

Some examples of materials that make up biomass fuels are scrap lumber, forest debris, certain crops manure and some types of waste residues.

Biomass or green energy will continue indefinitely because man has not found alternative to agriculture; Waste residues will continue to exist; forest resources will continue to generate forest derived biomass; urbanization and industrialization will continue to exist and generate waste residues; and climate change will force man to look in the direction of biomass or alternative energy use.

Importance of Biomass or alternative energy use are its carbon neutrality; emission of lesser carbon than that of fossil fuel; is renewable, cheaper in production and environment friendly.

This paper contributes to the body of knowledge as follows; It promotes the use of alternative energy; contributes to pollution control measures and climate change mitigation and adaptation strategies; enhances simulation technology and promotes climate smart agriculture.

4.2 RECOMMENDATION

Aquacrop simulation was carried out at the peak of dry season to generate 470 g/m^2 of biomass under drip irrigation management, and the result might be different if it were carried out during rainy season under rainfed. It is therefore recommended that simulation be carried during rainy season under rainfed condition.

REFERENCES

Adegoke, O. A., Fuwape, J. A., and Fabiyi, J. S. (2014). Combustion Properties of Some Tropical Wood Species and Their Pyrolytic Products Characterization. *Journal of Energy and Power.* 4(3): 54-57.

Akhator, E. P., Obanor, A. I., and Ugege, A. O. (2017). Physico-Chemical Properties and Energy Potential of Wood Wastes from Sawmills in Benin Metropolis, Nigeria. *Nigerian Journal of Technology,* 36 (2): 452 – 456

Akinrinola, F.S., Darvell L.I., Jones, J.M., Williams, A., and Fuwape, J.A. (2014). Characterisation of Selected Nigerian Biomass for Combustion and Pyrolysis Applications. Journal of *Energy and Fuels*. 28 (6): 3821-3832.

Becker-Reshef, I., Vermote, E., Lindeman, M., and Justice, C. (2010). A Generalized Regression-Based Model for Forecasting Winter Wheat Yields in Kansas and Ukraine using MODIS data. *Journal of Remote Sensing and Environment,*114: 1312–1323.

Delegido, J., Alonso, L., González, G., and Moreno, J. (2010). Estimating Chlorophyll Content of Crops from Hyperspectral Data using a Normalized Area over Reflflectance Curve (NAOC). *International Journal of Applied Earth Observatory and Geo Informatics*, 12, 165–174.

Dutta, P.P., Pandey, V., Sen, S., Das, A. R., Nath, A., and D.C. Baruah (2013) Fuel characteristics of Some Indigenous Plants. *International Journal of Emerging Technology and Advanced Engineering.* 3(3): 570-576

Enweremadu, C. C., Ojediran, J. O., Oladeji, J.T. and Afolabi, I.O. (2004). Evaluation of Energy Potential of Husks from Soy-Beans and Cowpea. *Journal of Science Focus*, 8: 18-23.

FAOSTAT (2019). Food and Agriculture Organization Global Bioenergy Statistics.Assessed 12th July 2021 through http://www.fao.org/faostat/en/?#home,

Gao, S., Niu, Z., Huang, N., and Hou, X (2013). Estimating the Leaf Area Index, Height and Biomass of Maize using HJ-1 and RADARSAT-2. *International Journal of Applied Earth Observatory and Geo Informatic*s, 24, 1–8.

Gilmore, M.S., Wilson, E.H., Barrett, N., Civco, D.L., Prisloe, S., Hurd, J.D., Chadwick, C. (2008). Integrating Multi-Temporal Spectral and Structural Information to Map Wetland Vegetation in a Lower Connecticut River Tidal Marsh. *Journal of Remote Sensing and Environment,* 112: 4048–4060.

Haboudane, D., Miller, J.R., Pattey, E., Zarco-Tejada, P.J., and Strachan, I.B. (2004). Hyperspectral Vegetation Indices and Novel Algorithms for Predicting Green LAI of Crop Canopies: Modeling and Validation in the Context of Precision Agriculture. *Journal of Remote Sensing and Environment,* 90, 337–352.

Hladik, C., Schalles, J., and Alber, M. (2013). Salt Marsh Elevation and Habitat Mapping using Hyperspectral and LiDAR Data. *Journal of Remote Sensing and Environment,* 139, 318–330.

IAEA, 2019. International Atomic Energy Agency Report on Global Energy Use 2019, World Bioenergy Association, 54-57

Koetz, B., Sun, G., Morsdorf, F., Ranson, K.J., and Itten, K., and Allgoewer, B. (2007). Fusion of Imaging Spectrometer and Lidar Data over Combined Radiative Transfer Models for Forest Canopy Characterization. *Journal of Remote Sensing and Environment, 106:* 449–459.

Ladapo, H.L., Alli, A.A., and Dickson, P.O (2020). Evaluation of Energy Potentials of Briquettes Produced from Maize and Sawmill Residues. *Journal of Research in Forestry, Wildlife and Environment,* 12(3): 192-197.

Li, W., Niu, Z.H., Huang, N., Wang, C., Gao, S., and Wu, C.(2015). Airborne Lidar Technique for Estimating Biomass Components of Maize: A Case Study in Zhangye City, Northwest, China. *Journal of Ecology Indices.* 57, 486–496.

Liu, J., Pattey, E., Miller, J.R., and Smith, A., and Hu, B. (2010). Estimating Crop Stresses, Above Ground Dry Biomass and Yield of Corn using Multi-Temporal Optical Data combined with a Radiation use effificiency model. *Journal of Remote Sensing and Environment,* 114*:* 167–177.

Tilly, N., Hoffmeister, D., Cao, Q., Huang, S., Lenz-Wiedemann, V., and Bareth, G. (2014). Multi- Temporal Crop Surface Models: Accurate Plant Height Measurement and Biomass Estimation with Terrestrial Laser Scanning in Paddy rice. *Journal of Applied Remote Sensing*, 8: 10-15.

LEVERAGING ON ENERGY MIX FOR TRANSITION FROM CURRENT ENERGY SITUATION TO CLEAN ENERGY ENVIRONMENT IN NIGERIA

Oluwadare Joshua Oyebode
Civil and Environmental Engineering Department
Afe Babalola University, Ado-Ekiti
Ekiti State, Nigeria
oyebodedare@yahoo.com

ABSTRACT

Clean Energy Environment is vital for health, wealth, industrial output and economic growth. This paper x-rays possibilities of leveraging on energy mix to transit from current state to Clean Energy Environment in Nigeria. Current energy situation were carefully checked and mitigation strategies identified. Findings revealed that there are a lot of pollution of our environment due to energy deficit, inadequate utilization of renewable energy, lack of strategic management skills, decadence in energy sector and lack of adequate attention to energy mix. It was concluded that there is dire need to leverage on energy mix for cleaner environment, better productivity and sustainable energy system in Nigeria. The rising cost of electricity has motivated the search for energy mix and this has placed a demand on the realization of cleaner environment. Global interest in climate change and demand for efficient energy has necessitated reduction in environmental pollution and increase in renewable energy. Investment in clean energy will create employment and enhanced opportunities for engineers. Mitigation strategies include implementation of energy efficiency programme, adoption of low emission technologies, periodic energy audit and capacity building in energy sector. Policy and management strategies that can increase energy mix improvement require adequate attention by government and other regulatory bodies in energy sector. It is recommended that government, Nigerian Society of Engineers (NSE), Council for the regulation of engineering in Nigeria (COREN) and all stakeholders should give adequate priority and attention to energy mix for clean energy environment, sustainable industrial growth and economic growth in Nigeria.

Keywords: Sustainable Energy Mix, Clean Energy, Economic Growth, Environment, Leveraging, industrial output

1. INTRODUCTION

Clean energy works by producing power without having negative environmental impacts, such as the release of greenhouse gases like carbon dioxide. A lot of clean energy is also renewable, including wind power, some hydro resources and solar powered energy generation. Renewable energy, often referred to as clean energy, comes from natural sources or processes that are constantly replenished.

Power sector emissions cause numerous health problems such as asthma and heart attacks and premature deaths. All energy sources have some impact on our environment. Fossil fuels—coal, oil, and natural gas—do substantially more harm than renewable energy sources by most measures, including air and water pollution, damage to public health, wildlife and habitat loss, water use, land use, and global warming emissions. However, renewable sources such as wind, solar, geothermal, biomass, and hydropower **also** have environmental impacts, some of which are significant. Despite these environmental impacts, renewable energy technologies compare extremely favorably to fossil fuels, and remain a core part of the solution to climate change.

There is great need for development of robust, effective and efficient energy sectors in a particular country or region without compromising the present and future socio-environmental security. Sustainable development and economic growth can be achieved through the rational development and exploitation of energy resources. For a country, it is imperative to secure stable supplies of energy in order to achieve and maintain progress in economic activity. Global competition for acquiring energy and mineral resources remains difficult, posing a challenge to countries in obtaining stable and affordable energy.

Energy is the power derived from utilization of physical and chemical resources, especially to provide light and heat or to work machines. Energy Mix is the group of different primary energy sources from which secondary energy for direct use such as electricity is produced. Energy Mix Transition is the change in composition or structure of primary energy supply or the gradual shift from specific pattern of energy provision into a new state of an energy system Clean Energy Environment is an environment influenced by works through the production of power without having any negative environmental impact, such as the release of greenhouse gases such as carbon dioxide.

2. LITERATURE REVIEW

Nigeria is yet to begin its journey of energy transition from fossil fuels to renewable energy in real terms despite ambitious targets and projections. It links it to structural gaps, policy discordance, non-conducive investment climate, questionable commitment of stakeholders to transit to renewable energy and inability to attract robust private investments (Nwozor et al., 2021).

Sustainable development was defined, adequately, as any action that helps to satisfy the present needs, across all the regions of the world, without compromising the future of our globe. Sustainable development is a multi-dimensional way of thinking about the interdependencies among natural, social, and economic systems in our world. It represents a process in which economics, finance, trade, energy, agriculture, industry, and all other policies are implemented in a way to bring about development that is economically, socially, and environmentally sustainable (Ozturk and Yuksel, 2016).

Without compromising the need for environmental sustainability, the development and economic growth of most developing countries will need to be built on clean-burning alternative fuel sources such as natural gas and agricultural wastes. The continent of Africa, as of now, has the least financial and technical ability, as well as, market incentive for renewable energy investment. Adequate financing of the renewable energy project in Africa may be one of the key limitations to achieving the United Nations SDGs within the stipulated period (Schwerhoff and Sy, 2017).

Due to the huge energy imbalance and social infrastructure deprivation in SSA, most homes and businesses are either run using small diesel or gasoline generators or by direct/unhealthy bio-energy conversion for cooking and heating purposes. The negative impacts on the immediate environment and health are enormous (Avila et al., 2017); this is against the Kyoto 1997 protocol and Paris 2015 agreement which are centered on the need for global greenhouse gas emission mitigation (Waren et al., 2018).

Nigeria has made pledges at various international for a to mainstream renewable energy in its energy mix. Techno-economic feasibility and environmental significance of solar power and bioenergy for Nigeria's sustainable development is site-specific and subject to factors such as incentives and financing, research and development, public enlightenment, government's policies, and private investments (Giwa et al., 2017).

The provision of energy infrastructure is essential for economic growth, social cohesion, and environmental sustainability (Edomah et al., 2016).

The government of Nigeria and the Energy Commission of Nigeria should set up policies and agencies to help enlighten the public on the negative effects of the activities of the common Nigerian man, with respect to energy consumption and saving, water efficiency, waste management, recycling, and non-destructive construction practices. A legal, administrative, and financing infrastructure should be established to facilitate planning and application of renewable energy projects (Oyebode, 2018).

There is great demand for drastic transformation of oil and gas sector for optimal delivery, environmental safety, and economic growth in Nigeria (Oyebode, 2021).

The immediate call for all-green energy may be another form of energy injustice or unfairness to the African continent due to the huge financial implication and insufficient energy structure in the region. Energy justice deals with the agreements and decisions on who bears the costs and the inevitable burdens of energy transition or integration of new energy facilities (Oludamilare et al., 2020).

The acute electricity supply hinders the country's development and not only restricts socio-economic activities to basic human needs; it adversely affects quality of life. Nigeria's unreliability of supply and decline in traditional fossil fuel production, combined with very grave environmental matters and continued uncharted economic and population growth makes it imperative to search for alternative forms of energy. Whilst proceed with increasing the generation capacity, transmission and distribution of existing traditional energy sources through the development of energy systems and policies that enhance social, economic and environmental performance; it is appropriate to focus on alternative to the traditional energy sources which among other things is capital intensive, and the technology required becomes obsolete with a short space of time thereby requiring intensive overhauling of the machineries or better still a complete replacement of the existing technology with a newer innovation leading to colossal waste of fund. However, the answer to the present imbroglio may be found in renewable and sustainable energy forms both for rural and urban areas of the country.

Energy is central to sustainable development and poverty reduction efforts. It affects all aspects of development-social, economic, and environmental-including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender related issues. None of the Millennium Development Goals (MDGs) can be met without major improvements in the quality and quantity of energy services in developing countries. Energy is intrinsically linked with sustainable development at the local, national, and regional levels. At the local level, modern energy is required to improved the overall quality of life (especially, that of the poor) by enhancing productive activities and enterprise, which will result in increased incomes. At national and regional levels, adequate modern energy leads to stable economic development, promotion of trade, and enhancement of participation in global markets, besides the added benefits of better social and economic linkages.

The Federal capital territory is Abuja; and the country shares boundaries with Benin (773 km) to the west, Cameroon (1690 km) to the east; and

Niger (1497 km) and Chad (87 km) to the North Oludamilare et al, (2020).

The impacts of climate change caused by enhanced global warming have been well established by the fifth assessment report of the Intergovernmental Panel on Climate Change. thermal expansion of the earth's surface waters and melting of glaciers on land that has in turn caused sea level rise, flooding and land loss; destruction of crop lands; acidification of water bodies due to emission of excess carbon dioxide (CO_2) as well as salt intrusion into inland freshwaters amongst others (Pachauri et al., 2014).

Energy resource management involves putting the available energy resources into best uses. Most times, these available energy bearers are overlooked and allowed to waste and often constitute environmental nuisances. Nigeria is majorly reliant on its non-renewable sources to meet its energy needs. In pursuit of its commitment to transit to alternative clean energy, Nigeria developed the biofuels policy document in 2007. The major aspiration of the policy is to harness the country's biomass potentials and deploy same to meeting Nigeria's energy needs.

3. METHODOLOGY

This study examined leveraging on energy mix transformation from current energy situation to clean energy environment in Nigeria. The overview of Nigeria: demography, energy sector activities and socio-economic implications with an estimated population of close to 200 million people, as of late 2018, Nigeria remains the most populated African country. Located in West Africa sub-region along Latitudes 4◦N and 14◦N, and Longitudes spanning from 3◦E to 8◦E as shown on Fig. 3, Nigeria covers about 923,768 km2 of the world area.

The southern coast opens directly to the Gulf of Guinea in the Atlantic Ocean; which makes it a strategic location for international trade (Adewuyi, 2020). The population density is 204.28 per km2 with a GDP of 375.77 Billion US dollars and per capita GDP of 2412.41 US dollars as at 2017. Nigeria is considered relatively wealthy judging by the value of the national income and financial/economic output but the minimal purchasing ability when it comes to international trading is among the lowest (Adewuyi, 2020).

The weak economy is reflected directly in the nations' human development index (HDI), where Nigeria ranked as 157 out of 189 countries; with HDI value for 2017 being 0.5320 (Adewuyi, 2020). The potential of Nigeria as the most promising economy and the most viable market in the sub-Saharan African region is well-recognized all over the world going by its location and population advantage. The most significant impediment to the maximization of Nigeria's potentials for adequate socio-economic growth is the poor condition of the power sector;

according to the Transmission Company of Nigeria, the grid generating potential currently stands at 12,522 MW. For many years now, Nigeria has been facing an extreme electricity shortage. This deficiency is multi-faceted, with causes that are financial, structural, and sociopolitical, none of which are mutually exclusive. (Kennedy-Darling et al., 2015; NERC (2017). However, the consequences of ineffective operational management, poor maintenance, coupled with the irregular supply of primary fuels, have kept the country's average daily available generation to below 4,000 MW, as reflected on the operational status of each existing generation station.

The existing Nigerian power system is highly unreliable both in content and in essence; the generation and transmission capacity is grossly insufficient, and the distribution network is outdated and inefficient. Figure 1 gave percent Contribution to global warming by countries.

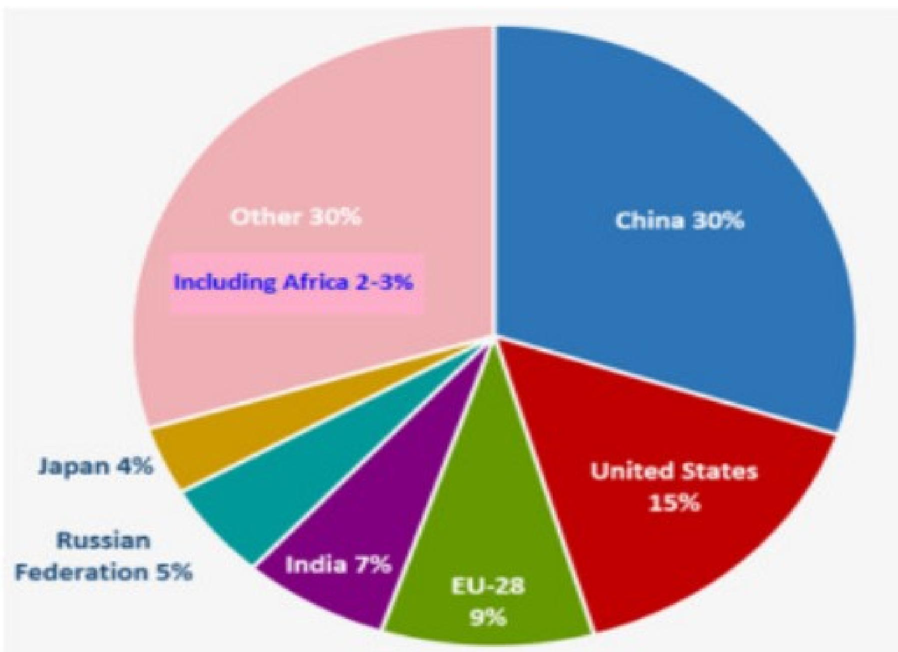


Figure 1. Percent Contribution to global warming by countries
Source: (Edenhofer et al., 2014)

4. DISCUSSIONS OF FINDINGS

Nigeria's energy transition has been influenced by a long history of trading relations, external interference in domestic decision-making, discovery of energy resources, and technology development. Plate 1 presented environmental sustainability areas and enablers, plate 2 gave circular industrial economy for cleaner energy and plate 3 presented Resource shift to Resource circularity as a better energy strategies.

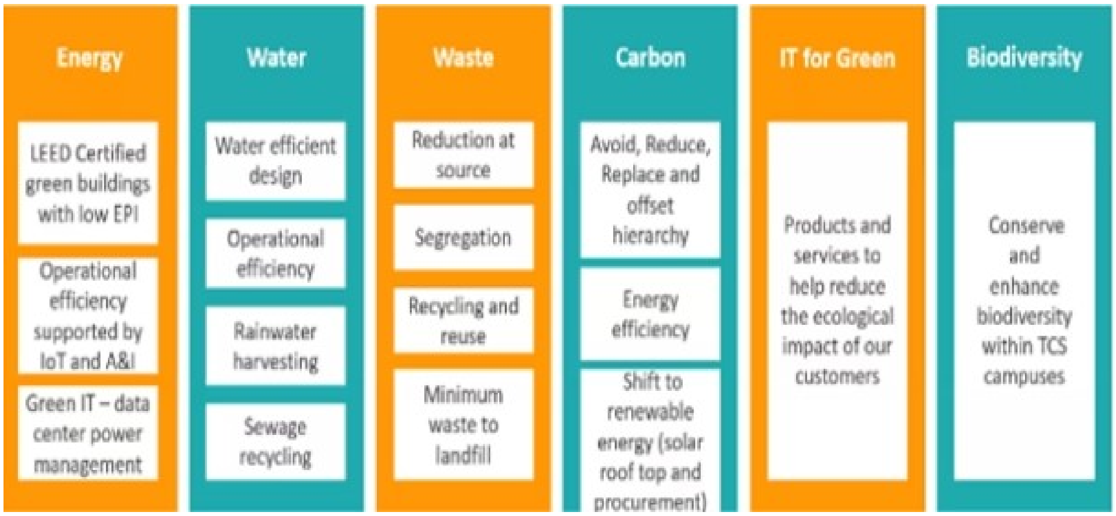


Plate 1: Environmental sustainability areas and enablers

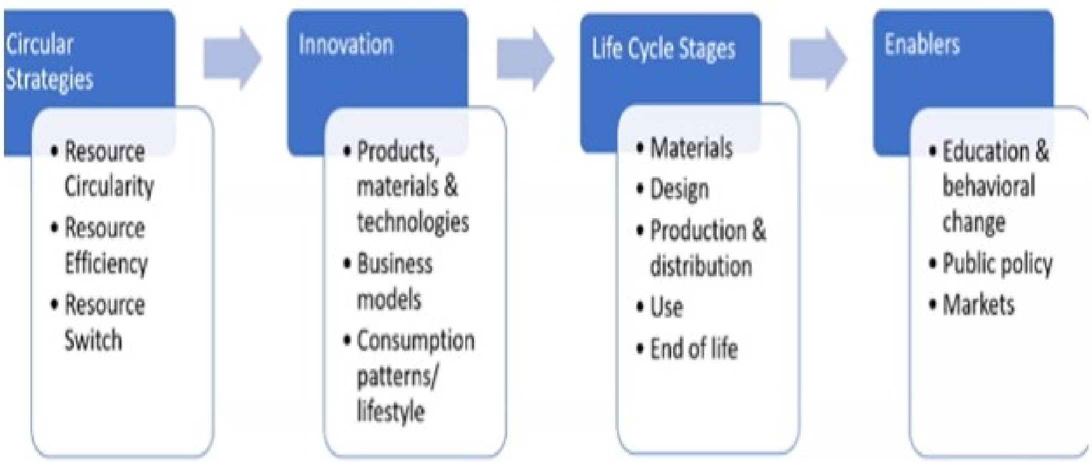


Plate 2: Circular industrial economy for cleaner energy

Resource Efficient and Cleaner Production (RECP) is the continuous application of an integrated preventive environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment. Plate 4 presented robust relationship among mini-grids, business models and industrial applications. This initiate is built on three pillars of sustainability, governance and finance which bring together countries, financiers and developers of clean energy projects to align interests and combine scale and speed to fast track financing from the private sector for deployment of clean energy in Africa.

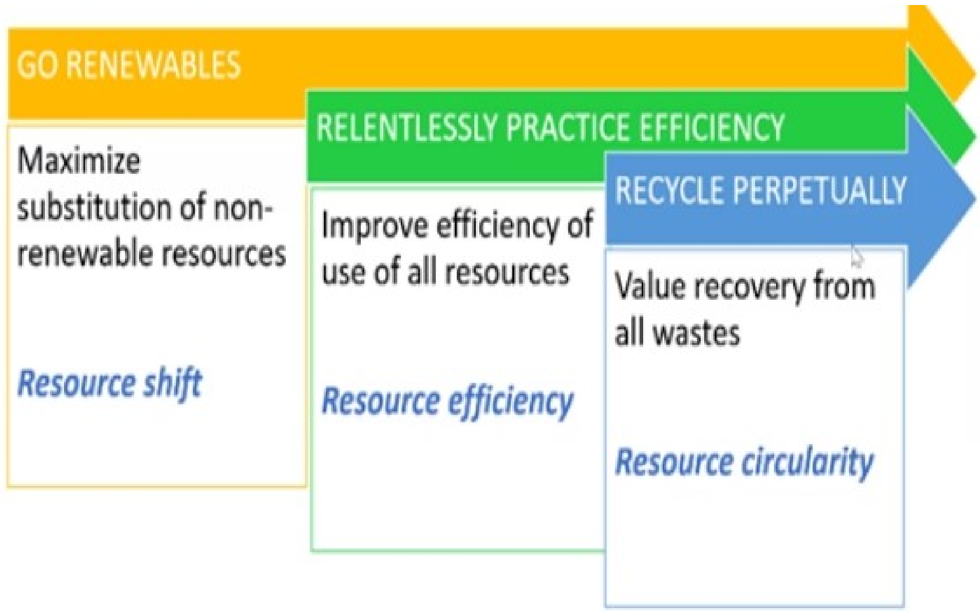


Plate 3: from Resource shift to Resource circularity: Better energy Strategies

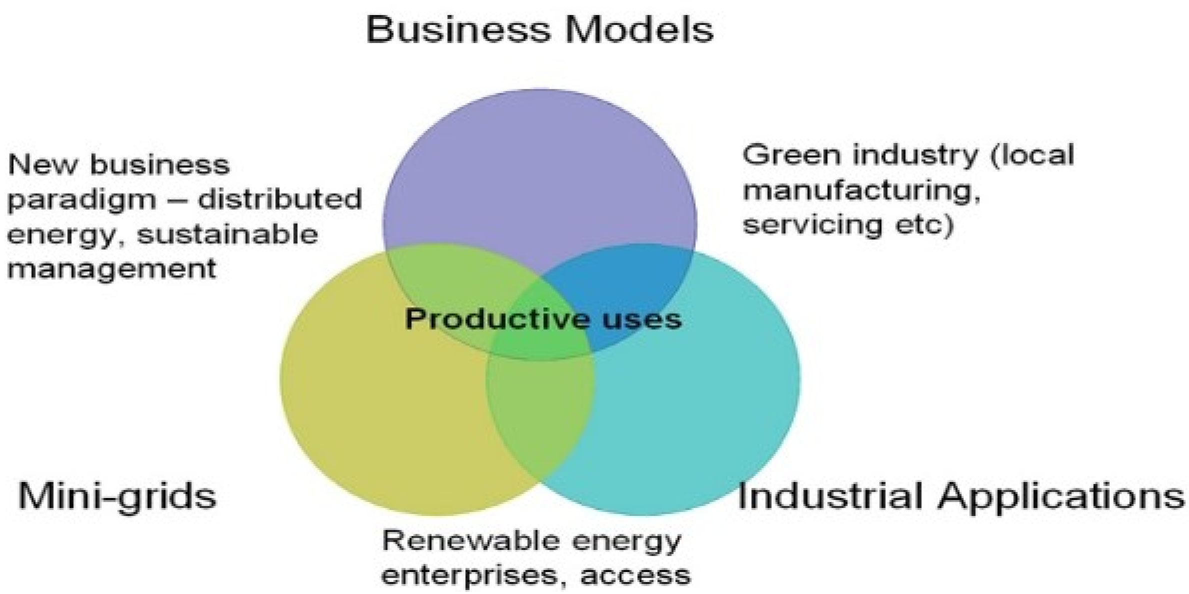


Plate 4: Relationship among mini-grids, business models and industrial applications

A simple concept based on system dynamic principles was developed. The concept is a system mapping that shows the stock and flow of the interlinking of energy resources, the environment and economy as presented in figure 2 and plate 6 presented the leveraging advantage through sustainable, governance, finance.

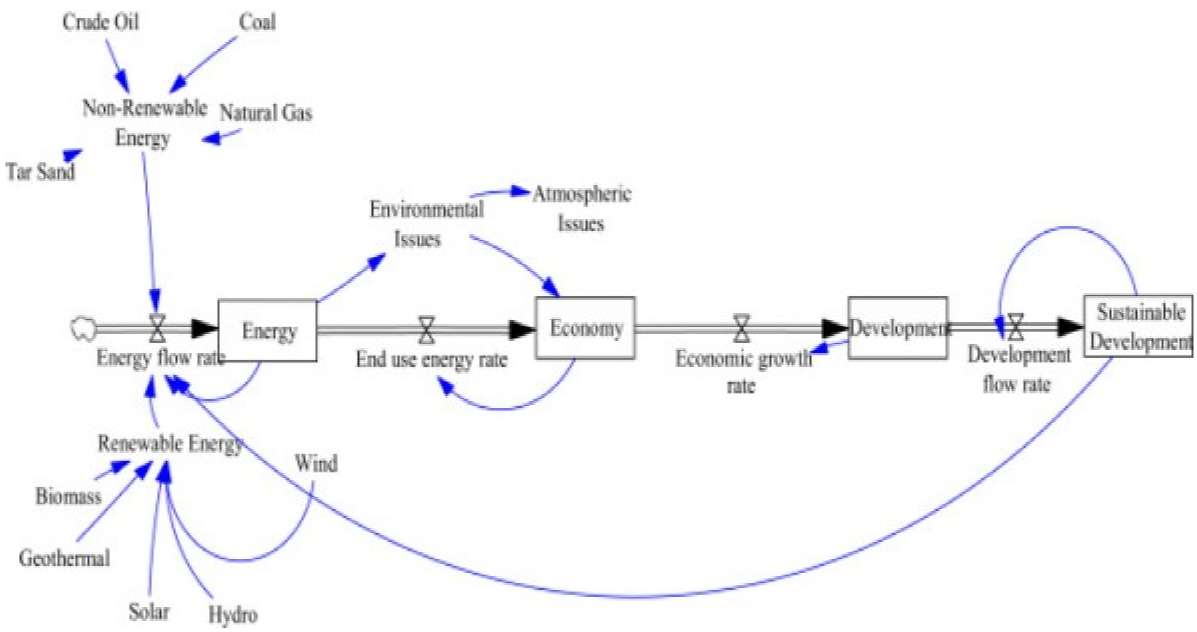


Figure 2: System mapping of sustainable development and renewable energy

There is the need for all African counties to compute their Energy Development Indices so as to know the effectiveness of the energy development strategies and thereby to effect appropriate amendments for future improvements. Renewable energy sources provide an opportunity for developing countries and countries with economies in transition to embrace a low carbon pathway powered by innovative, smart and locally relevant energy solutions.

Plate 6: Leveraging through Sustainable, Governance, finance

Importantly, institutions have played a vital role in the provision of energy infrastructure and in Nigeria's energy transition. The establishment of the various institutions within each energy era was geared towards providing the needed infrastructure to support industrialization, to improve and ease mobility, to improve trading activities through the development of ports and harbours, and to support economic development. A sustainable means for achieving environment-friendly and economical energy framework is regarded as the core element for the secure and time-efficient drive of an all-inclusive economy in Nigeria and other African countries. There are a lot of pollution of our environment due to energy deficit, inadequate utilization of renewable energy, lack of strategic management skills, decadence in energy sector and lack of adequate attention to energy mix.

5. CONCLUSIONS AND RECOMMENDATION

5.1 CONCLUSION

There are great need for the nation to leverage on energy mix for cleaner environment, better productivity and sustainable energy system in the country. The rising cost of electricity has motivated the search for energy mix and this has placed a demand on the realization of cleaner environment. Global interest in climate change and demand for efficient energy has necessitated reduction in environmental pollution and increase in renewable energy. Investment in clean will create employment and enhanced opportunities for engineers. Mitigation strategies include implementation of energy efficiency programme, adoption of low emission technologies, periodic energy audit and capacity building in energy sector. Policy and management strategies that can increase energy mix improvement require adequate attention by government and other regulatory bodies in energy sector.

5.2. RECOMMENDATIONS

The following recommendations are as follows:

i. Nigerian Society of Engineers (NSE), Council for the regulation of engineering in Nigeria (COREN) and all stakeholders should spearhead a paradigm shift and support government and expert contributions towards energy mix for transition from current energy situation to clean energy environment in Nigeria
ii. Nigerian government should respect the national and international commitments on sustainable development and climate change, including commitments made under the Paris Agreement and the sustainable development goals (SDG).
iii. The government should halt any plans to open up or further develop any fossil fuel-related projects or large hydro plants and instead promote substantial investments in solar, wind and geothermal energy projects that will contribute to achieving SDG 7.
iv. Establish an agency to promote the use of energy-efficient products and ensure the appropriate practices.

v. Develop and imbibe energy efficiency technologies and creation of awareness on renewable energy and energy efficiency.

vi. Training, continuous learning and professional development are crucial for effective management, excellence professional practice, energy mix implementation strategies and sustainable policy will strengthened our energy sector.

vii. Government should provide a clear policy framework for a just energy transition, which priorities investments in renewable energy that promote local participation and ownership of distributed renewable energy initiatives.

viii. Implementation strategies, adequate priority and attention should be given to energy mix for clean energy environment, sustainable industrial growth and economic growth in Nigeria.

ix. Government should set up proper transparency, monitoring and compliance mechanisms to critically monitor all investments in the energy sector. Governmental bodies should adhere to the highest standards of transparency.

ACKNOWLEDGEMENTS

I thank and acknowledge the President, members of executives, technical committee, reviewers and members of Nigerian Society of Engineers (NSE) for the opportunity given to me to contribute my paper to this conference. Special appreciation to all participants of 2021 National Engineering Conference, Council for the Regulation of Engineering in Nigeria (COREN) and all professional bodies that I belong to such as World Safety Organization (WSO), Nigerian Institution of Civil Engineers (NICE), American Society of Civil Engineers (ASCE), Nigerian Institution of Water Engineers (NIWE), Society of Petroleum Engineers (SPE), Institute of Professional Managers and Administrators of Nigeria (IPMA) and Institute of Policy Management Development (FIPMD).

REFERENCES

Adewuyi, O. B., Kiptoo, M. K., Afolayan, A. F., Amara, T., Alawode, O. I., and Senjyu, T. (2020). Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences. *Energy Reports*, *6*, 993-1009.

Avila, N., Carvallo, J. P., Shaw, B., and Kammen, D. M. (2017). The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers.

Generating Energy for Sustainable and Equitable Development, Part, *1*, 1-79.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Kadner, S., Minx, J. C., Brunner, S., ... and Zwickel, T. (2014). Technical summary.

Edomah, N., Foulds, C., and Jones, A. (2016). Energy transitions in Nigeria: The evolution of energy infrastructure provision (1800–2015). *Energies*, *9*(7), 484.

Giwa, A., Alabi, A., Yusuf, A., and Olukan, T. (2017). A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. *Renewable and Sustainable Energy Reviews*, *69*, 620-641.

Nwozor, A., Oshewolo, S., Owoeye, G., and Okidu, O. (2021). Nigeria's quest for alternative clean energy development: A cobweb of opportunities, pitfalls and multiple dilemmas. *Energy Policy*, *149*, 112070.

Oludamilare B. A, Mark K. K, Ayodeji F.A, Theophilus A, Oluwatobi I. A, Tomonobu S. **(2020)** Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences **Energy Reports 6 (993–1009).**

Oyebode, O. J. (2018): Green Building: Imperative Panacea for Environmental Sustainability and Life Cycle Construction in Nigeria. *World Journal of Research and Review*, *7*(3), 262584.

Oyebode, O. J. (2021). Strategies for Transforming Oil and Gas Sector for Economic Growth and Environmental Sustainability in Nigeria. *Journal of Alternate Energy Sources and Technologies*, *12*(2), 40-45p.

Ozturk, M., and Yuksel, Y. E. (2016). Energy structure of Turkey for sustainable development. *Renewable and Sustainable Energy Reviews*, *53*, 1259-1272.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... and van Ypserle, J. P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). Ipcc.

Warren, R., Price, J., VanDerWal, J., Cornelius, S., and Sohl, H. (2018). The implications of the United Nations Paris Agreement on climate change for globally significant biodiversity areas. *Climatic change*, *147*(3), 395-409.

Schwerhoff G., Sy M. (2017). **Financing renewable energy in Afric key challenge of the sustainable development goals.** Renew. Sustain. Energy Rev., 75 (2017), pp. 393-401, 10.1016/j.rser.2016.11.004

http://www.sciencedirect.com/science/article/pii/S136403211630778X

NERC (2017). **Power Generation in Nigeria.** Nigerian Electricity Regulatory Commission (2017)

https://www.nercng.org/index.php/home/nesi/403-generation

Kennedy-Darling, J., Hoyt, N., Murao, K., and Ross, A. (2008). The energy crisis of Nigeria: an overview and implications for the future. *The University of Chicago, Chicago*, 775-784.

PHOTOVOLTAIC POWER OUTPUT FORECASTING USING OPTIMIZED MARKOVIAN APPROACH

Victor Eniola[a], Toyin Juliet Alozie[b,*], Yahya Oluwaseun Aroyeun[b], Olatubosun Fasipe[a], Bukola Adisa[c]

[a] Research & Consultancy Department, Energy Commission of Nigeria, Abuja 900211, Nigeria
[b] Maintenance Department, Energy Commission of Nigeria, Abuja 900211, Nigeria
[c] Renewable Energy Department, Energy Commission of Nigeria, Abuja 900211, Nigeria

[*] Corresponding Author; Tel: +234 802 825 2552, Email: alo_babs@yahoo.co.uk

ABSTRACT
It is well known that the variability in photovoltaic (PV) power output is primarily owing to fluctuations in radiation received by the solar panels. Forecasting in the short-term horizon particularly is very crucial to power quality and power schedules such as load drop or gain, and power dispatch planning. This study articulates an innovative method based on ordinary model (Hidden Markov Model, HMM) and HMM optimized with Genetic Algorithm (GA) for hour-ahead forecasting of the power output (P_o) of a 1.2 kW PV system. Solar irradiance (G_s), module temperature (T_m) acquired by mathematical modelling and wind speed (w) were used as initial forecast data. The model testing and validation was built on the computation of normalized root mean square error (nRMSE). The results showed that GA-optimized HMM was able to forecast P_o an hour-ahead with lower nRMSE than HMM under clear sky day (CSD) condition. However, the abnormalities of the forecasting model resulting from instantaneous fluctuations in solar irradiance under cloudy day (CD) condition were decreased with correction factor (ξ). It was deduced that if the average change in the absolute value of solar irradiance $|\overline{\Delta G_s}|$ was more than 128% and 90% in the morning and evening times respectively, the GA-optimized forecasting model with or without ξ presents an average nRMSE of 2.33%. Therefore, HMM+GA gave more accurate P_o forecast for CSDs whereas HMM+GA+ξ presents the best P_o for CDs, supporting the consideration of the proposed forecast model as a good technique for hour-ahead P_o forecasting of PV system.

Keywords: Forecasting, photovoltaic, power, hidden Markov model, genetic algorithm.

5. INTRODUCTION

With respect to climate issues and global warming, various incentives and energy guidelines that can advance the penetration of renewables have been orchestrated in many countries (Al-Hajj et al., 2017). It is possible to operate 100% renewable energy-based electric power grid in 2050 (Alzahrani et al., 2017). Among the renewable resources, solar power is one of the technologies that is being considered recently in view of its benefits such as inexhaustibility and near-zero pollution.

In recent years, the mean growth of Photovoltaic (PV) system is up to 30% annually (H. Wang et al., 2017). PV power is a promising complement for the dwindling fossil fuel-based system (M. Yesilbudak et al., 2016; M. Yesilbudak et al., 2017). Alongside the diminishing prices of PV modules, it is anticipated that the PV power supply to energy systems and modern electric power would grow further. To meet the world's energy needs, PV power is a viable solution. However, the PV technology is confronted still with some difficulties particularly for high supply in which intermittency and discontinuity are pronounced (Omar et al., 2016). PV power plant production capacity depends on meteorological parameters. The variability in PV power output is primarily owing to fluctuations in radiation received by the solar panels. This inherent unpredictability of PV power at higher supply to the grid gives complications relating to conveyable generation, reserve costs, power quality and overall dependability of the grid (Mehmet Yesilbudak et al., 2018). As such, models with high forecast accuracy are essential for various forecast horizons related to law, scheduling, unit commitment and transmission (Lahouar et al., 2017). Forecast horizon can be classified as either short-term, medium-term or long-term. With short-term forecasting, intermittency problem associated with PV based power production as well as power quality issues can be addressed. Particularly, short-term forecasting is very crucial to power schedules such as load drop or gain, and power dispatch planning. It affords improvement in power system control and reliability, increases the penetration of PV power technology, enhances energy planning and management. With short-term forecasting, energy prices can be determined beforehand. Forecast models are characterized into three namely: physical models; statistical techniques and hybrid approaches. Physical methods, such as Numerical Weather Prediction (NWP) model, explains solar energy to electrical power conversion. On daily basis, power production can be predicted with physical methods by utilizing a given day's probable weather conditions. Alternatively, statistical approaches such as Artificial Neural Network (ANN) based on persistent notion or probabilistic time series model, for example, an Autoregressive Integrated Moving Average (ARIMA), classically depends on machine learning processes. With this method, renewable energy-based power prediction can be implemented using historical training dataset, which can be of any size. However, it requires striking a balance between training dataset size and model sensitivity. The larger the training dataset, the better the model accuracy with respect to long-term trend study. When two or more physical and/or statistical methods are integrated, the resulting combination is referred to as a hybrid model. Such amalgamation has the advantage of outweighing the drawbacks associated with standalone approach and finally improves the forecast (Ogliari et al., 2017).

Hidden Markov Model (HMM) is a model in which a sequence of states generates a sequence of observation or emission, though the states sequence the model passed through to produce the emission is not known. The attribute *hidden* signifies the sequence of states the model went through, and not to the model parameters. Even if these parameters are exactly known, the model is still an HMM. The model has determinate internal states that generate a set of external emissions. The changes in the internal states are not observable to an external examiner. A unique Markov property is that the present state is always dependent on the immediately preceding state only. Analysis of HMM seeks to recover the sequence of states from the observed data. This model hinges on the estimation of transition and emission probabilities. Short term hour-ahead prediction of PV power is very crucial to power quality and power schedules such as load drop or gain, and power dispatch planning. In the prediction of varying power supply, ANN has been applied severally with an acceptable level of success. Nevertheless, it requires a more robust training dataset and the selection of HMM is informed by some other considerations such as its adaptability; richness in mathematical structure and ability to describe data more accurately with an optimal increase in the number of discrete states (Liu et al., 2018; Rabiner, 1989).

PV power output forecast has been carried out with several methods such as neural networks (Leva et al., 2017; Sharma et al., 2016; Yang & Dong, 2013), grey theory (Y. Z. Li et al., 2008; Zhong et al., 2017), cloud modelling (Barbieri et al., 2017), random forests (Lahouar et al., 2017), Support Vector Regression (SVR) (Zhang et al., 2017), Gaussian Process Regression (GPR) (Fen et al., 2017) and hybrid approach (De Giorgi et al., 2015; Eseye et al., 2018). PV power output has also been forecasted based on Markov processes (Y. Z. Li et al., 2008). Recently, efforts have been made to predict streamflow for water resource management (Liu et al., 2018), prediction of solar irradiance (J. Li et al., 2016) using HMM. Nevertheless, there is need to improve the forecasting capability of the model.

In this study, therefore, a time series mathematical forecasting model based on ordinary model (HMM) and HMM optimized with Genetic Algorithm (GA); expressed as HMM+GA, is proposed to predict hour-ahead power output of a 1.2 kW PV system. GA makes use of a population whose size is fixed and comprises individual distinct probable solutions to a given problem, which evolve in time. It applies the selection, recombination (crossover) and mutation operators to exclude the poorest solutions and generate new results from the selected current ones. To smoothen abnormalities resulting from abrupt changes in solar irradiance (G_s), the correction factor (ξ) is required to adapt the HMM and HMM+GA models. The key contribution of our study is the comparison of HMM and HMM+GA forecasting models in PV power prediction. The effectiveness of the integration of GA and model adaptation with ξ to improve the forecast accuracy of the model is also discussed.

6. METHODOLOGY

The power output (P_o) of the 1.2 kW thin-film silicon modules is installed at the School of Renewable Energy and Smart Grid Technology (SGtech), Naresuan University, Thailand is forecasted based on historical data of G_s, ambient temperature (T_{amb}) and wind speed (w). Figure 1 presents the flowchart of the PV power output forecast process. First, the data is filtered to 1-hr time resolution followed by data refinement to compensate for missing or negative data points by replacing them with their monthly averages. In order to avoid irrational error values at the validation step, the dataset was preprocessed to eliminate zero-value data occurring at early hours and night times. Subsequently, the dataset is divided into two quotas. About 95% of the dataset was used for training while the remaining was used for forecasting model validation. To consider very short-term forecasting, G_s and module temperature (T_m) were the best parameters to precisely forecast rapid PV energy variations due to cloud cover and T_m significant effect on voltage which invariably affects the P_o of the PV system (Barbieri et al., 2017; Dubey et al., 2013). In the present study, the T_m was determined from T_{amb} using mathematical transformation as expressed in Eq. (1) (Barbieri et al., 2017; Savvakis & Tsoutsos, 2015).

$$T_m = 0.943T_{amb} + 0.028G_s - 1.528w + 4.3 \quad (1)$$

In estimating parameters and model training, the use of HMM necessitates the determination of the likelihood of sequence of observations, predicting the next observation in the sequence of observations and finding the most likely underlying explanation of the sequence of observations. The solutions to these problems require the forward-backward algorithm, Viterbi Algorithm (VA) and the Baum-Welch algorithm (Joshi et al., 2017; Rabiner, 1989). For model development, G_s is categorized into five different states according to the following rules presented in Table 1. The state classification corresponds to very cloudy, cloudy, partial cloud, clear sky and very clear sky. Then again, the observations are also grouped into three levels equivalent to low, moderate and high generations. The latent variables of the HMM are discrete and express to a Markov chain. Supervised training is implemented by equating outputs to states and inputs to observations. The model learned from input-output relationship and makes predictions based on models of observed data.

Table 1. Categorization of G_s

G_s (W/m^2)	≤ 200	≤ 400	≤ 600	≤ 800	> 800
State	1	2	3	4	5
Class	very cloudy	cloudy	partial cloud	clear sky	very clear sky

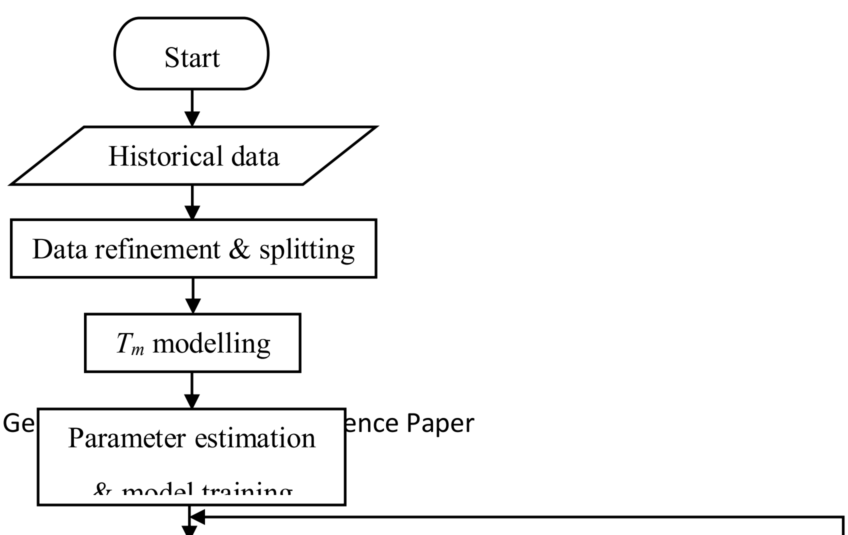


Fig. 1. Flowchart of PV power output forecast process.

To predict with HMM, the training data was sequenced and the transition matrix with other model parameters were estimated. After 500 number of iterations of the Baum-Welch algorithm was specified in training the model, the state transition probability distribution matrix A is as given in Eq. (2). With five discrete states, A is of the order 5×5. Element a_{ij} represents the probability distribution of transitioning from state i to j. Thus, $a_{ij} \geq 0$ and $\sum_1^N a_{ij} = 1$, for $1 \leq i \leq N$. Viterbi decoding gives the highest probable state sequence that is employed to predict the next hour power output. The P_o formula which the model relies upon for prediction is expressed in Eq. (3) (J. Wang et al., 2017). To obtain P_o at time t+1, G_s and T_m at time t were initialized and passed unto the forecast model. The power forecasting has been implemented using HMM toolbox™, as determined in the HMM-based P_o forecasting step.

$$A = \begin{bmatrix} 0.514 & 0 & 0 & 0.470 & 0.016 \\ 0.487 & 0.500 & 0 & 0.013 & 0 \\ 0 & 0.569 & 0.066 & 0 & 0.365 \\ 0 & 0 & 0.504 & 0.402 & 0.094 \\ 0 & 0.038 & 0.024 & 0.376 & 0.562 \end{bmatrix} \quad (2)$$

$$P_o = \eta A_m G_s [1 - \alpha(T_m - 25)] \quad (3)$$

Parameter optimization and model improvement are built on GA. All input parameters are initialized and the fitness function, expressed as the sum of the square of the deviation between actual and fitted values, is created. To optimize this function using GA, a function handle is passed to the fitness function together with the number of variables in the problem. To also ensure that GA scrutinizes the region of relevance, preselected upper and lower bounds are passed as arguments following number of variables. When the fitness value becomes less than the function tolerance, the optimization process is terminated. Optimized parameters are adopted for the modification of the HMM, forming a sort of GA-optimized HMM. At the validation step, abnormalities observed to have resulted from instantaneous changes in solar irradiance are smoothened using ξ. If the average change in the absolute value of solar irradiance $|\overline{\Delta G_s}|$ is more than 128% in the morning, and/or if $|\overline{\Delta G_s}|$ in the evening time exceeds 90%; then the adoption of ξ becomes crucial. However, the GA optimization process is considered non-recursive in the case for which the adoption of ξ is necessary. The computation of ξ is based on interior-point algorithm. This algorithm requires a fitness assignment and a constraint set by error definition, bounds whose upper value is set at the corresponding actual power output (P_{act}) and parameter initialization.

The results of the ordinary model and proposed optimized model are comparatively analyzed in the validation process, using the testing and validation dataset. The study utilized statistical methods involving normalized Root Mean Square Error (nRMSE) and Mean Absolute Percentage Error (MAPE), which are computed as follows:

$$nRMSE = \frac{1}{P_{rated}}\sqrt{\frac{1}{n}\sum_{i}^{n}\left(P_{a,i} - P_{f,i}\right)^2} \qquad (4)$$

$$MAPE = 100 \times \frac{1}{n}\sum_{1}^{n}\frac{|P_{a,i} - P_{f,i}|}{P_{a,i}} \qquad (5)$$

Both methods were measured to compare the forecasted P_o with the P_{act} value. Such computations provide an insight into the degree of reliability of the forecast model. An efficient forecast model is expected to present a low value of nRMSE or MAPE.

7. RESULTS AND DISCUSSION

Figure 2 presents the Gs and Po of the 1.2 kW PV system correlation for clear and cloudy sky. It is well known that the Po increases with increasing Gs. In Fig.2a, it is observed that the Po and Gs profiles are symmetrically distributed over time due to the typical nature of the Clear Sky Day (CSD). The highest Po is about 83% rated power of the PV system (Prated) from 12:00 to 13:00. On the other hand, both the Po and Gs present the instantaneous change along the day (Fig.2b). However, regardless of the sky condition under consideration, Po maintains a profile analogous to that of Gs. This similarity is indicative of the strong correlation between both parameters.

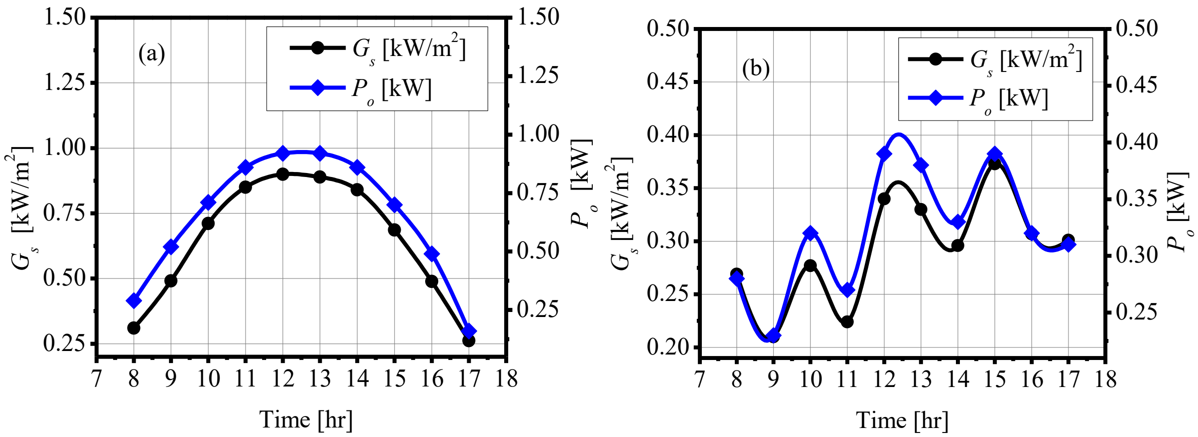


Fig. 2. Time dependence of G_s and P_o correlation for (a) clear and (b) cloudy sky condition.

Figure 3a presents the results of P_o model validation of 09.04.2018 using ordinary model (HMM) and optimized model (HMM+GA). Power output forecasted with HMM (P_{HMM}) is not close to the P_{act}, particularly between 11:00 and 15:00. In order to improve the P_o forecasting close to the P_{act}, the HMM is optimized with GA. So, the power output determined with GA-integrated HMM, expressed as P_{opt}, almost match with the P_{act}. To consider the error of HMM and HMM+GA (Fig.3b), the values of nRMSE$_{opt}$ are almost lower than that of nRMSE$_{HMM}$. The HMM is observed to over-forecast the data points with an ensemble nRMSE of 5.36%, whereas the ensemble nRMSE of GA-integrated HMM is reduced to 2.55%.

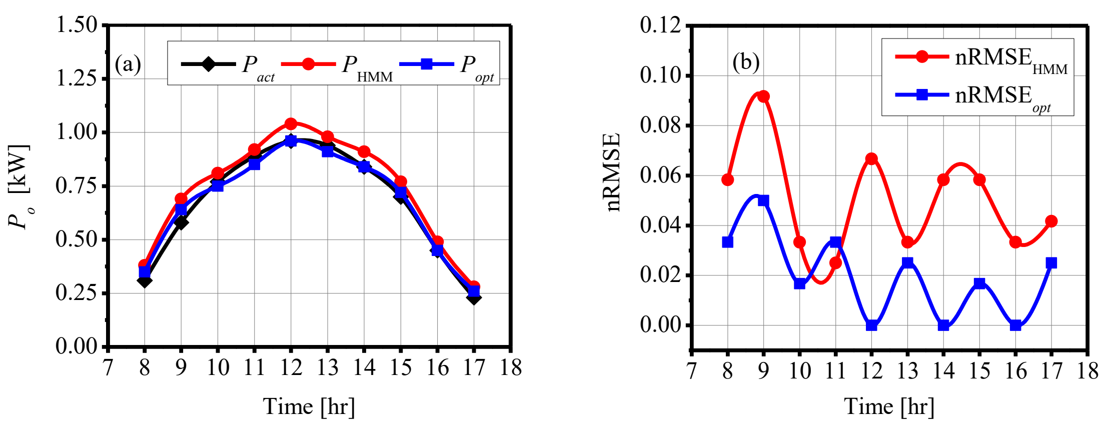


Fig. 3. P_o forecast and nRMSE of models on 09.04.2018 using HMM and HMM+GA.

The HMM and HMM+GA P_o forecast validation on 15.04.2018, is as shown in Fig.4a. The P_o output forecasting using HMM is higher above P_{act}, particularly between 10:00 and 15:00. The over-forecast of the HMM is reduced with the HMM+GA model which forecasts the P_{opt} to match almost with the P_{act}. Error consideration based on nRMSE (Fig.4b) shows that $nRMSE_{opt}$ values are well below those of $nRMSE_{HMM}$. The HMM gives a maximum nRMSE of about 9% between 10:00 and 11:00, whereas the optimized model presents a maximum nRMSE value nearly 3% at around the hours of 12:00 and 16:00. The ensemble $nRMSE_{HMM}$ of 6.27% as against 1.57% for $nRMSE_{opt}$ further explains the overshooting nature of the HMM.

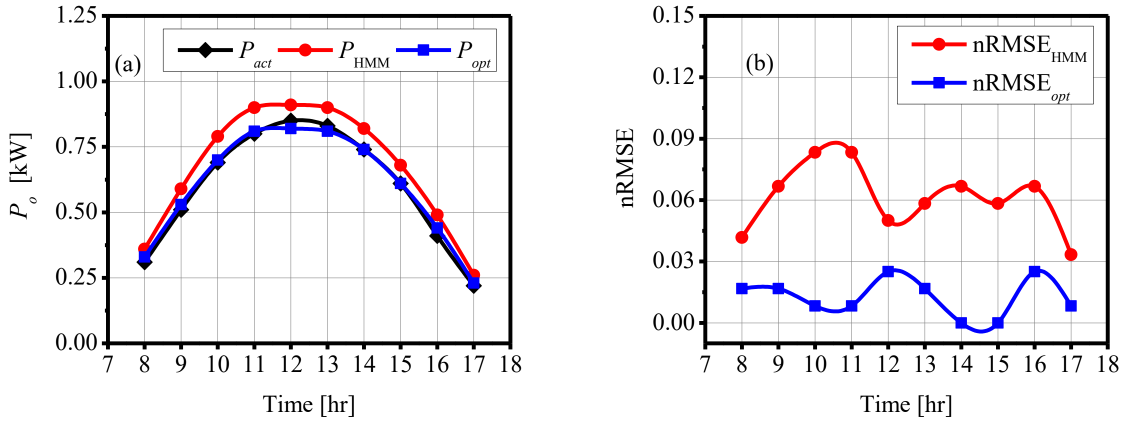


Fig. 4. P_o forecast and nRMSE of models on 15.04.2018 using HMM and HMM+GA.

In a much similar manner, the HMM+GA model predicted more accurately than P_{HMM} for the day 23.04.2018, as shown in Fig.5a. The power overshoot of the P_{HMM} escalated at 13:00 hour, but the predictions with P_{opt} is however overlapping with P_{act} values. The improvement in P_o forecasting is attributable to the integration of GA with HMM. Considering the error of both forecast models, the values of $nRMSE_{opt}$ are lower than those of $nRMSE_{HMM}$, according to Fig.5b. The $nRMSE_{HMM}$ corresponding to the maximum power overshoot is about 9%, whereas the peak of the $nRMSE_{opt}$ is lower than 4%. With P_{opt}, ensemble nRMSE decreased considerably from 6.33% to 1.77%. Computational analysis reveals that the HMM optimized with GA is capable of improving the reliability of the P_o forecasting by 4.56%.

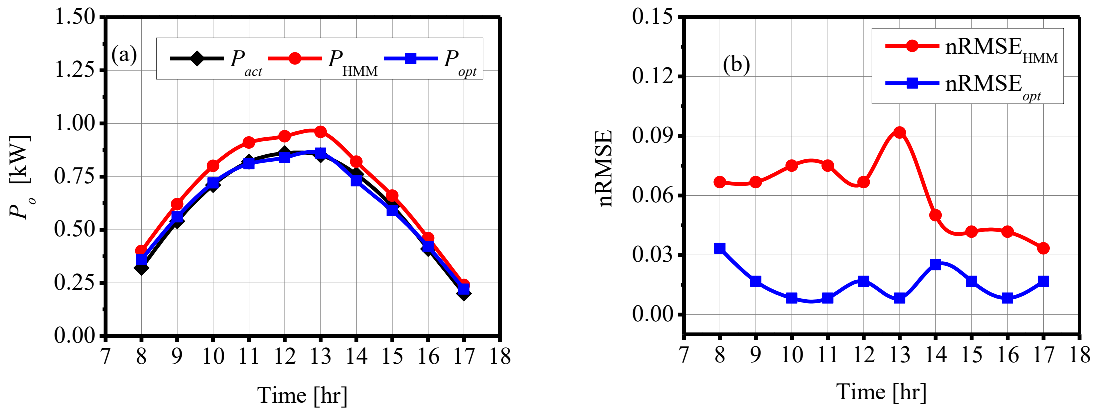


Fig. 5. P_o forecast and nRMSE of models on 23.04.2018 using HMM and HMM+GA.

Figure 6a presents the results of P_o model validation of the day 30.04.2018 based on HMM and HMM+GA. It is observed that the P_{act} fluctuates as a result of the cloudy sky condition. The P_{opt} is closer to P_{act} than P_{HMM} over the entire day. However, P_{HMM} and P_{opt} do not approach P_{act} primarily due to the influence of sudden changes in G_s at 8:00 and 17:00 hours. According to their nRMSE curve (Fig.6b), both nRMSEs present the highest values. Additionally, $nRMSE_{opt}$ and $nRMSE_{HMM}$ have the highest values of about 26-28% and 32-35% respectively. It indicates that HMM and HMM+GA models have a limitation for instantaneous changes in G_s. To rectify abnormality, correction factor (ξ) was adopted based on HMM+ξ and HMM+GA+ξ with the criteria outlined in the methodology section. The ξ plays a crucial role on Cloudy Day (CD) when the $|\overline{\Delta G_S}|$ is more than 128% in the morning, and/or if $|\overline{\Delta G_S}|$ in the evening time exceeds 90%. The computed values of ξ used to smoothen the data at 8:00 and 17:00 hours were 0.40 and 0.24 respectively. Sequel to the use of ξ, both P_{HMM} and P_{opt} present more reasonable P_o curves in Fig.7a. Considering the influence ξ-adapted HMM and ξ-adapted HMM+GA on the nRMSE (Fig.7b), it can be observed that $nRMSE_{HMM}$ and $nRMSE_{opt}$ in the hours of 8:00 and 17:00 reduced close to 3% and zero respectively. The reduced peaks of $nRMSE_{opt}$ and $nRMSE_{HMM}$ coupled with their respective ensemble nRMSE values decreasing to 5.61% and 4.29% further strengthen the correctional strength and significance of ξ. To compare HMM and HMM+GA adapted with and without ξ (Fig.6 and Fig.7), the abnormalities and nRMSE are significantly reduced with the use of ξ and the values of nRMSE of ξ-adapted HMM and HMM+GA are less fluctuating than without the ξ.

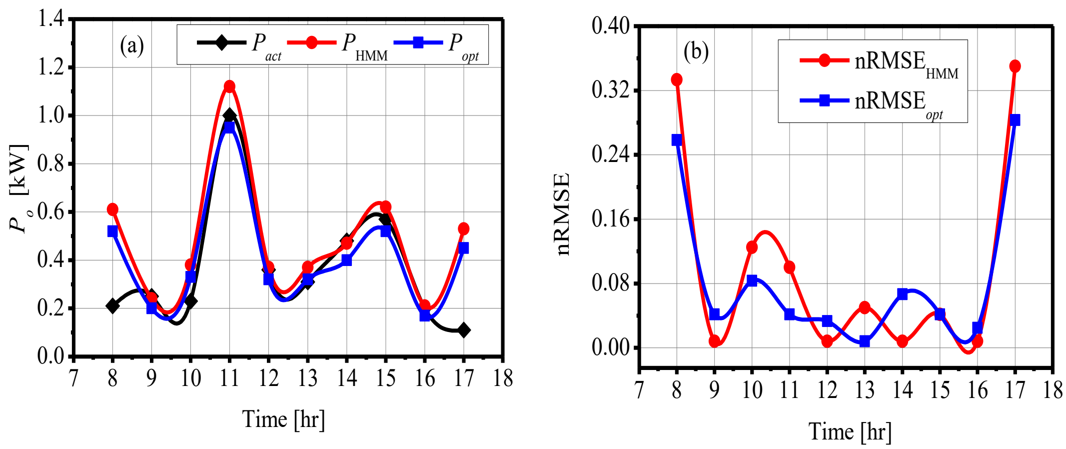


Fig. 6. P_o forecast and nRMSE of models on 30.04.2018 using HMM and HMM+GA.

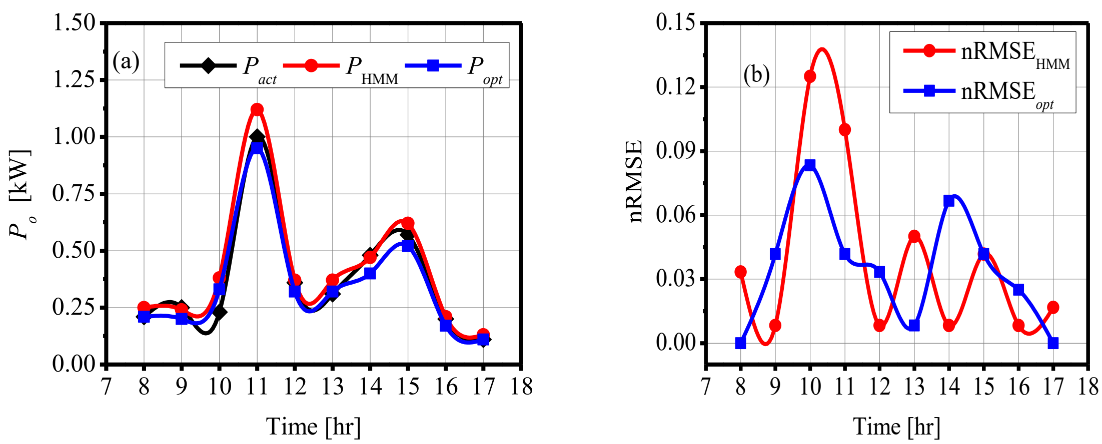


Fig. 7. P_o forecast and nRMSE of models on 30.04.2018 using HMM+ξ and HMM+GA+ξ.

Figure 8a presents the result comparison of P_o forecast models for the day 25.03.2018 using HMM+ξ and HMM+GA+ξ on cloudy sky condition. The computed value of ξ used to adapt the abnormalities occurring at 8.00 and 9.00 is 0.33. P_o forecasted with HMM+ξ presents overshoot noticeably around 11:00 and 14:00. In order to improve the P_o close to the P_{act}, P_{opt} was predicted based on HMM+GA+ξ model; which is perceived to forecast P_o more accurately. To consider the forecast error (Fig.8b), the ensemble $nRMSE_{opt}$ values of 2.42% for the HMM+GA+ξ is lower than the 5.11% $nRMSE_{HMM}$ of the HMM+ξ; especially the value of HMM+GA+ξ relatively maintains a range around 1-4%.

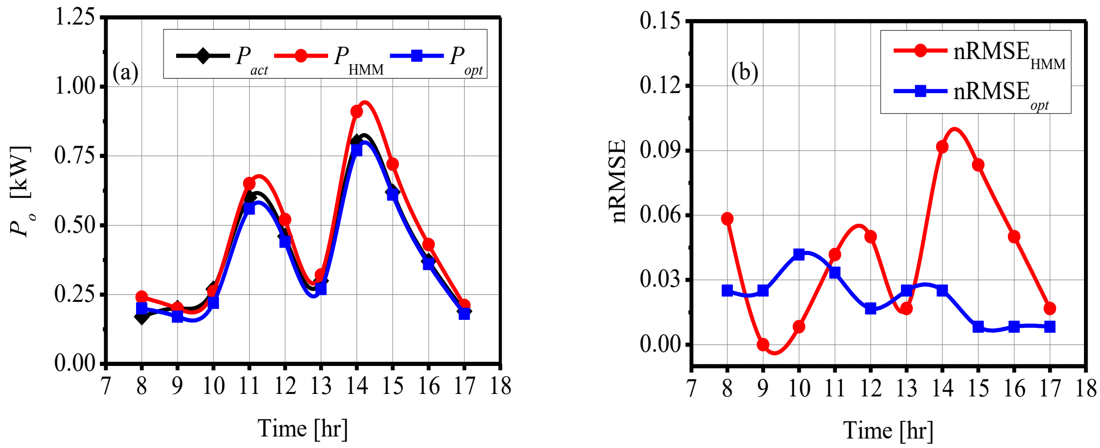


Fig. 8. P_o forecast and nRMSE of models on 25.03.2018 using HMM+ξ and HMM+GA+ξ.

Figure 9a presents the results of P_o forecast for the day 26.06.2018 based on cloudy sky condition using HMM+ξ and HMM+GA+ξ models. The computed value of ξ used to fine-tune the abnormalities occurring at 8:00 is 0.41 and those occurring from 15:00 – 17:00 are adjusted with ξ = 0.35. P_{HMM} and P_{opt} with both models present good agreement with P_{act} along the entire day. The improvement in power output prediction with HMM+GA+ξ can be perceived by considering the nRMSE curves shown in Fig.9b. Fortunately, the curve of $nRMSE_{HMM}$ and $nRMSE_{opt}$ almost exhibit similar trend with low ensemble nRMSE value of 1.51% for the HMM+ξ and 1.42% for HMM+GA+ξ.

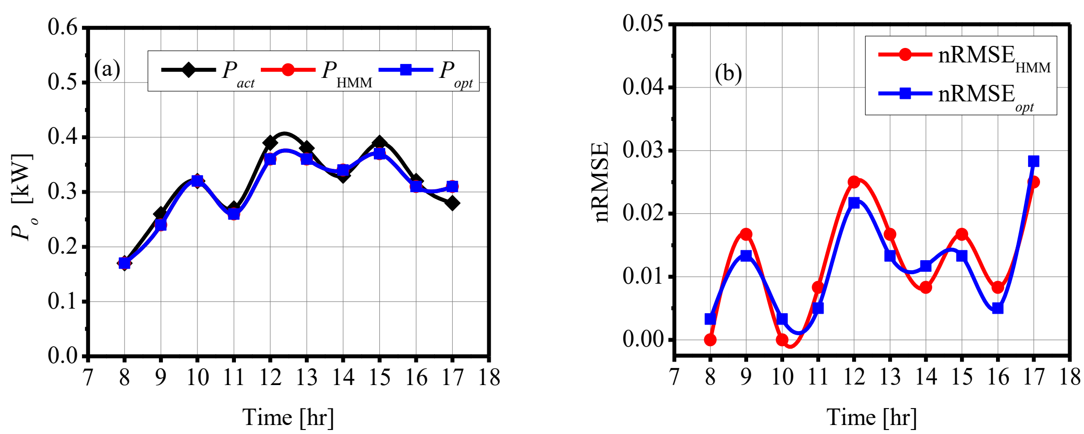


Fig. 9. P_o forecast and nRMSE of models 26.06.2018 using HMM+ξ and HMM+GA+ξ.

Table 2. Forecast model performance from March to June 2018

Date	Class	Models	nRMSE [%]		MAPE [%]	
			P_{HMM}	P_{opt}	P_{HMM}	P_{opt}
09.04.2018	CSD	HMM/HMM+GA	5.36	2.55	11.17	4.94
15.04.2018	CSD	HMM/HMM+GA	6.27	1.51	13.43	3.09
23.04.2018	CSD	HMM/HMM+GA	6.33	1.77	13.40	4.20
30.04.2018	CD	HMM+ξ/HMM+GA+ξ	5.61	4.29	15.64	12.33
25.03.2018	CD	HMM+ξ/HMM+GA+ξ	5.11	2.42	12.95	8.55
26.06.2018	CD	HMM+ξ/HMM+GA+ξ	1.51	1.42	4.63	4.52
Average			5.03	2.33	11.87	6.27

The model performance of the HMM and GA-optimized HMM with or without ξ on the hour-ahead forecasting of P_o of the PV system under different conditions of G_s (CSD or CD) are summarized in Table 2. For the days considered in the validation process, the reliability of the HMM and GA-integrated HMM is indicated by ensemble nRMSE and MAPE. It can be observed that both nRMSE and MAPE reduced when GA is integrated with HMM, corresponding to the class of day under CSD consideration. This reflects PV power forecasting with GA-integrated HMM has a higher P_o prediction capability, as the results of the optimized forecast parameters. In the case of instantaneous G_s on CD consideration, the data analytics stipulated the decision support tool for the application of ξ-adapted HMM and HMM+GA. It was deduced that if $|\overline{\Delta G_s}|$ is more than 128% in the morning, ξ in the range of 0.33 - 0.41 is acceptable. On the other hand, if $|\overline{\Delta G_s}|$ in the evening time exceeds 90%; appropriate ξ is in the range of 0.24 - 0.35. The use of ξ for the days in which fluctuation in G_s is pronounced, further improves the accuracy of forecast as expressed in percentage of nRMSE and MAPE. The HMM with or without ξ presents the average nRMSE and MAPE larger than HMM+GA with or without ξ. In addition, the average nRMSE and MAPE of HMM+GA with or without ξ is 2.33% and 6.27%. Therefore, the integration of GA and ξ into HMM are able to improve the forecasting accuracy of the hour-ahead P_o of the PV system as a result of the optimized forecast parameters.

Comparing with previous studies, (Zhong et al., 2017). presented a short-term day-ahead PV power generation volume based on multivariable Grey theory model improved with Particle Swarm Optimization (PSO); indicating that the model verification with PSO yields Mean Relative Error (MRE) decreasing from 7.14% to 3.53%, which corresponds to about 51% reduction. However, the technique enunciated in this study gives a percentage reduction in nRMSE of about 54%. (Zhang et al., 2017) articulated a 10 minute-ahead PV P_o forecasting using fuzzy clustering analysis with SVR model and reported an average nRMSE of 5.55%. In contrast, our model presents an average nRMSE of 2.33%. (Lahouar et al., 2017) proposed a short-term day-ahead PV P_o forecast based on random forests using bagging algorithm with and without former information on the solar irradiance, and the authors reported a MAPE of 28.97% in the month of April. A multivariate ensemble framework for seasonal one day and week-ahead PV P_o forecast using Autoregressive predicator, Particle Swarm Optimized-Radial Basis Function (PSO-RBF) network predicator and Particle Swarm Optimized-Feed-forward Neural Network (PSO-FNN) predictor presented an nRMSE of 9.55% for CSD and 9.51% for CD in the spring season (Raza et al., 2017). With the model proposed in this study, the maximum MAPE in the month of April is 12.33% and the maximum nRMSEs are 6.33% and 5.61% for CSD and CD, respectively.

In the present study, therefore, GA-optimized HMM with or without ξ has been considered a good model for the hour-ahead P_o forecasting of the PV system. This model can be deployed by power system owners and grid operators, offering them some benefits including power quality, load drop or gain, reduced reserve costs, pricing-ahead of energy, better energy planning and management. In practical application, this forecast model can be suitably applied in locations or areas whose weather pattern is similar to Thailand's. However, in case the nature of meteorological parameters follows a different pattern, the model retraining may be required using at least 6 months of historical data from the PV power plant.

8. CONCLUSION AND RECOMMENDATION

In this study, the hour-ahead P_o forecasting of the PV system based on ordinary model (HMM) and optimized model (HMM+GA) together with or without correction factor (ξ) has been proposed. On the class of the day under CSD consideration, HMM+GA is able to predict the P_o with high forecasting accuracy. In a typical CD consideration, ξ is required to adapt HMM+GA when $|\overline{\Delta G_s}| \geq 128\%$ in the morning and/or $|\overline{\Delta G_s}| \geq 90\%$ in the evening time. The proposed optimized model presents higher accuracy than the ordinary model in all the days considered. With its average nRMSE and MAPE computed to be 2.33% and 6.27% respectively, GA-optimized HMM with or without ξ has been considered a good approach to hour-ahead forecasting of PV power output.

9. ACKNOWLEDGEMENTS

The authors express sincere gratitude to the Thailand International Cooperation Agency (TICA), for funding this research. The kind cooperation of SGtech is also appreciated.

REFERENCES

Al-Hajj, R., Assi, A., & Fouad, M. (2017). A predictive evaluation of global solar radiation using recurrent neural models and weather data. *In Proc.* I*EEE 6th International Conference on Renewable Energy Research and Applications* (ICRERA).

Alzahrani, A., Shamsi, P., Ferdowsi, M., & Dagli, C. (2017). Solar irradiance forecasting using deep recurrent neural networks. *In Proc. IEEE 6th International Conference on Renewable Energy Research and Applications* (ICRERA).

Barbieri, F., Rajakaruna, S., & Ghosh, A. (2017). Very short-term photovoltaic power forecasting with cloud modeling: A review. *Renewable and Sustainable Energy Reviews, 75*(2017), 242-263.

doi: DOI : https://doi.org/10.1016/j.rser.2016.10.068

De Giorgi, M., Congedo, P., Malvoni, M., & Laforgia, D. (2015). Error analysis of hybrid photovoltaic power forecasting models: A case study of mediterranean climate. *Energy Conversion and Management, 100*(2015), 117-130. doi: DOI : https://doi.org/10.1016/j.enconman.2015.04.078

Dubey, S., Sarvaiya, J, & Seshadri, B. (2013). Temperature dependent photovoltaic (PV) efficiency and its effect on PV Production in the World – A review. *Energy Procedia, 33*, 311-321. doi: 10.1016/j.egypro.2013.05.072

Eseye, A, Zhang, J., & Zheng, D. (2018). Short-term photovoltaic solar power forecasting using a hybrid wavelet-PSO-SVM model based on SCADA and meteorological information. *Renewable Energy, 118*(2018), 357-367. doi: DOI : https://doi.org/10.1016/j.renene.2017.11.011

Fen, L., Chunyang, L., Yong, Y., Quanquan, Y., Jinbin, Z., & Lijuan, W. (2017). Short-term photovoltaic power probability forecasting based on OLPP-GPR and modified clearness index. *The Journal of Engineering, 2017*(13), 1625-1628. doi: DOI : 10.1049/joe.2017.0607

Joshi, J., Tankeshwar, K., & Srivastava, S. (2017). Hidden Markov Model for quantitative prediction of snowfall and analysis of hazardous Snowfall events over Indian Himalaya. *Journal of Earth System Science*, 126: 033. doi: 10.1007/s12040-017-0810-6

Lahouar, A., Mejri, A., & Slama, J. (2017). Importance based selection method for day-ahead photovoltaic power forecast using random forests. *In Proc. 2017 International Conference on Green Energy Conversion Systems* (GECS).

Leva, S., Dolara, A., Grimaccia, F., Mussetta, M., & Ogliari, E. (2017). Analysis and validation of 24 hours ahead neural network forecasting of photovoltaic output power. *Mathematics and Computers in Simulation, 131*, 88-100. doi: https://doi.org/10.1016/j.matcom.2015.05.010

Li, J., Ward, J, Tong, J., Collins, L., & Platt, G. (2016). Machine learning for solar irradiance forecasting of photovoltaic system. *Renewable Energy, 90*, 542-553. doi: https://doi.org/10.1016/j.renene.2015.12.069

Li, Y., Luan, R., & Niu, J. (2008). Forecast of power generation for grid-connected photovoltaic system based on grey model and Markov chain. *In Proc. 3rd IEEE Conference on Industrial Electronics and Applications*.

Liu, Y., Ye, L., Qin, H., Hong, X., Ye, J., & Yin, X. (2018). Monthly streamflow forecasting based on hidden Markov model and Gaussian Mixture Regression. *Journal of Hydrology, 561*, 146-159. doi: https://doi.org/10.1016/j.jhydrol.2018.03.057

Ogliari, E., Dolara, A., Manzolini, G., & Leva, S. (2017). Physical and hybrid methods comparison for the day ahead PV output power forecast. *Renewable Energy, 113*, 11-21. doi: https://doi.org/10.1016/j.renene.2017.05.063

Omar, M., Dolara, A., Magistrati, G., Mussetta, M., Ogliari, E., & Viola, F. (2016). Day-ahead forecasting for photovoltaic power using artificial neural networks ensembles. *In Proc. 2016 IEEE International Conference on Renewable Energy Research and Applications* (ICRERA).

Rabiner, L. (1989). A tutorial on hidden Markov models and selected applications in speech recognition.*In Proc. IEEE, 77*(2), 257-286. doi: 10.1109/5.18626

Raza, M., Nadarajah, M., & Ekanayake, C. (2017). A multivariate ensemble framework for short term solar photovoltaic output power forecast. *In Proc. 2017 IEEE Power & Energy Society General Meeting*.

Savvakis, N., & Tsoutsos, T. (2015). Performance assessment of a thin film photovoltaic system under actual Mediterranean climate conditions in the island of Crete. *Energy, 90*, 1435-1455. doi: https://doi.org/10.1016/j.energy.2015.06.098

Sharma, V., Yang, D., Walsh, W., & Reindl, T. (2016). Short term solar irradiance forecasting using a mixed wavelet neural network. *Renewable Energy, 90*(2016), 481-492. doi: DOI : https://doi.org/10.1016/j.renene.2016.01.020

Wang, H., Yi, H., Peng, J., Wang, G., Liu, Y., Jiang, H., & Liu, W. (2017). Deterministic and probabilistic forecasting of photovoltaic power based on deep convolutional neural network. *Energy Conversion and Management, 153*, 409-

422. doi: https://doi.org/10.1016/j.enconman.2017.10.008

Wang, J., Ran, R., & Zhou, Y. (2017). A Short-Term photovoltaic power prediction model based on an FOS-ELM algorithm. *Applied Sciences, 7*, 423. doi: 10.3390/app7040423

Yang, Y., & Dong, L. (2013, 26-27 Aug. 2013). Short-term PV generation system direct power prediction model on wavelet neural network and weather type clustering. *In Proc. 5th International Conference on Intelligent Human-Machine Systems and Cybernetics*.

Yesilbudak, M., Colak, M., & Bayindir, R. (2018). What are the current status and future prospects in solar irradiance and solar power forecasting? *International Journal of Renewable Energy Research, 8*(1), 635-648.

Yesilbudak, M., Çolak, M., & Bayindir, R. (2016). A review of data mining and solar power prediction. *In Proc. 2016 IEEE International Conference on Renewable Energy Research and Applications* (ICRERA).

Yesilbudak, M., Colak, M., Bayindir, R., & Bulbul, H. I. (2017). *Very-short term modeling of global solar radiation and air temperature data using curve fitting methods.* Paper presented at the 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA).

Zhang, W., Zheng, X., Geng, X., Li, Q., & Bao, C. (2017). Short-term photovoltaic output forecasting based on correlation of meteorological data. *In Proc. IEEE Conference on Energy Internet and Energy System Integration* (EI2).

Zhong, Z., Yang, C., Cao, W., & Yan, C. (2017). Short-Term photovoltaic power generation forecasting based on multivariable grey theory model with parameter optimization. *Mathematical Problems in Engineering, 2017*, 1-9. doi: DOI : 10.1155/2017/5812394

NOMENCLATURE

Abbreviation

ANN	artificial neural network
ARIMA	autoregressive integrated moving
ELM	average
CD	extreme learning machine
CSD	cloudy day
FNN	clear sky day
GNN	feedforward neural network
GPR	genetic algorithm
HMM	Gaussian process regression
kW	hidden Markov model
MAPE	kilowatts
MRE	mean absolute percentage error
nRMSE	mean relative error
NWP	normalized root mean square error
PSO	numerical weather prediction
PV	particle swarm optimization
SGtech	photovoltaic
	school of renewable energy and
SVR	smart grid technology
VA	support vector regression
	Viterbi algorithm

Greek symbol

α	temperature coefficient
η	(power)
	module efficiency

Special symbol

$\lvert\bar{\Delta}\rvert$	average percentage change in absolute value
ξ	correction factor
G	irradiance
P	power
T	temperature
w	wind speed

Subscript

a, act	actual
amb	ambient
e	evening
f	forecasted
m	module, morning
o	output
opt	optimized
s	solar

TECHNO-ECONOMIC ANALYSIS OF SELECTED STEAM METHANE REFORMING METHODS FOR HYDROGEN PRODUCTION

Okechukwu, C.C. and Alabi, S.B*

Department of Chemical and Petroleum Engineering, University of Uyo, Uyo, AkwaIbom, Nigeria.
*Corresponding author: Email: sundayalabi@uniuyo.edu.ng; Mobile: 08063043106

ABSTRACT

This study investigates three steam methane reforming (SMR) methods namely SMR and Shift Reactor (SR), SMR and Dry Reforming of Methane (DRM) and SMR with the combination of DRM and SR for the purpose of producing hydrogen and to determine the best process among the selected three, using UNISIM Software Package. This was done on the basis of feedstock rate of 100 kmol/hr of methane which reacted with 250 kmol/hr of steam for 8000 hrs annually, to determine the most favourable method based on CO_2 and CO emissions (COx), hydrogen yield and plant profitability using net profit percentage as the profitability index. The results show that, SMR/SR process has the highest hydrogen yield of 91%, and SMR/DRM has the lowest yield of 72 %. The SMR/SR method has the lowest CO_x emission rate of 87.89 kmol/hr while each of SMR/Shift reactor and SMR/DRM/SR has higher COx emission rate of 100 kmol/hr. The profitability analysis, based on direct cost analysis method, shows that SMR/SR process is the most profitable process with a net profit percentage of 41.3 % while SMR/DRM process is the least profitable process with a net profit percentage of 24.6 %. As SMR/SR process has the highest yield, highest profitability index and lowest COx emission rate, it can therefore be concluded that the most favourable process route, technically and economically, is SMR/SR for the production of hydrogen using methane as feedstock.

Keywords: *Hydrogen, Steam methane reforming, Dry methane reforming, Carbondioxide and Carbon Oxides.*

1. INTRODUCTION

Hydrogen can be produced from a variety of feedstock which include natural gas and coal. There are several methods through which hydrogen can be produced from fossil fuel sources; these include steam methane reforming (SMR), autothermal reforming, partial oxidation and the use of coal using coal gasification. Steam reforming is currently one of the most widespread and is also one of the least expensive processes of hydrogen production through which more than 90 % of the hydrogen is being produced (Palmová and Schöngut, 2004). The most frequently used raw materials are natural gas and lighter hydrocarbons. The first step of the steam methane reforming process involves methane reacting with steam to produce a synthesis gas (syngas), a mixture primarily made up of hydrogen (H_2) and carbon monoxide (CO). In the second step, known as water gas shift (WGS) reaction, the carbon monoxide produced in the first reaction is sent to the water gas shift reactor to produce hydrogen and carbon dioxide (CO_2) before it is sent for purification at the pressure swing adsorption (PSA)unit.

Anthropogenic activities which cause the emission of carbon dioxide (CO_2) include the combustion of fossil fuels and other carbon containing materials, the fermentation of organic compounds such as sugar and the breathing of humans. CO_2 gas has a slightly irritating odour, is colourless and is denser than air. Carbon dioxide accounts for over 84% of the greenhouse gasreleased into the atmosphere and originate almost exclusively from the utilization of fossil fuels (Energy Information Administration (EIA), 1998). The EIA estimates that if current trends continue, worldwide carbon dioxide emissions will increase from 1,559 to 2,237 million metric tons equivalent (1.5% annual change) by the year 2025 (Energy Information Administration, 2003). There is strong scientific evidence of a rapid, persistent and uncontrolled increase in atmospheric carbon dioxide (CO_2) due to humans' activities, largely resulting from the burning of fossil fuels. The breathing of CO_2 is toxic to humans when levels are high with numerous deaths reported based on occupational exposure (Scott et al., 2009). The CO_2 exposure limit for an 8 hour working day has been set at 5,000 ppm (OSHA, 2012).

The issue of climate change is one of the main reasons for introducing hydrogen technology. One of the matured methods for producing hydrogen in bulk is steam methane reforming (SMR) and the two commercial methods of producing hydrogen from SMR are SMR and shift reactor (SR) and SMR and dry methane reforming (DRM). Although SMR and SR method produces high hydrogen yield, unfortunately it produces high quantity of carbon dioxide (CO_2). On the contrary, SMR and DRM method produces low hydrogen yield and favourably low quantity CO_2. As the quantity of CO_2 emitted from SMR and SR is high, the cost of capturing it will increase the total cost of production. Therefore, the objectives of this study were to perform an economic analysis on the plants to determine the process that is most economically favourable and also to investigate the method that can reduce CO_2 and at same time increase the hydrogen yield, considerably. Consequently, a comprehensive study on a selected steam methane reforming methods becomes necessary.

2.0 MATERIALS AND METHODS

2.1 Materials

UNISIM Software Package is a multi-purpose process simulation solution for process design, simulation, safety studies, process optimization and business planning. The software was of great benefit to this work because the pieces of equipment needed for the simulation were incorporated it. Consequently, they facilitated the modeling and simulation of the selected steam methane reforming methods. The components chosen from the Software are reformers and shift reactors, heat exchangers, channel gas mixer, storage tanks, valves, pressure swing adsorption plant, methane, steam and underground gas pipelines. The prices of all the materials used were gotten from Alibaba website (Alibaba, 2018), while the Equation for system specifications and direct cost analysis were obtained from Coulson and Richardson's Chemical Engineering Series, Volume 6.

2.1.1 EQUIPMENT DESIGN AND SPECIFICATION

The shape of the unit operators used in this study is cylindrical with hemispherical end.

The volumetric flow rate and volume of such shape is given as;

$$\frac{MassFlowrate}{hr} \quad X \quad \frac{MolarFlowrate}{kmol}$$

Equation 2.1

It is to noted that $0.5m^3$

This implies that:

$$Vs = \frac{Molar\ Volume\ of\ A\ in\ kmol}{hr} x \frac{0.5\ m^3}{kmol}$$

Equation (2.2)

Equation 2.2 is the volumetric flow rate designated as Vs and Equation 2.3 shows the equation used in calculating the volume of the substances used.

$$volume\ (V_s) = \frac{2\pi D^3}{3}$$

Equation (2.3)

Where V_s is the volumetric flow rate of the stream and D is the diameter of the unit operation vessel. According to design heuristics, 90% of the volume of the column should be filled with the stream as such volume of the column becomes;

$$V = V_s \times 1.1$$

$$D = \sqrt[3]{\frac{3V}{2\pi}}$$

Equation (2.4)

Equation 2.4 was obtained from equation 2.3 by making D the subject formula.

The height of the column is given as;

$$\text{Height of the column (H)} = 3 \times D$$

Equation (2.5)

The length of the column becomes;

$$\text{Length of the column (L)} = H - D$$

Equation (2.6)

2.2 PROCESS ROUTE FOR HYDROGEN PRODUCTION AND PURIFICATION

In this study, three processes were simulated and they were steam methane reforming (SMR) and shift reactor (SR), SMR and dry reforming of methane (DRM) and SMR with the combination of SR and DRM. The feedstock for the production of Hydrogen for each of the processes was methane which reacted with steam with a molar flow rate of 100 kmol/hr for methane and 250 kmol/hr for steam, respectively. The flow rate of methane which is 100 kmol/hr was the value chosen as the basis for the simulation performed on the three processes which was multiplied by the ratio of 2.5:1 to get the inflow of steam which is 250 kmol/hr and the annual operating time used for each of the three processes was 8000 hrs per year which was gotten by multiplying 24 hrs by 365 which gives a total of 8,765 hrs per year. However 765 hrs was set aside for maintenance and shutdown of plants while 8000hrs was used for production.

To obtain a high yield of hydrogen using SMR process in this study, different ratios of steam to methane molar flow ratios like 2:1, 2.5:1, and 3:1 were used for the simulations but the ratio of 2.5:1 was the ratio that obtained high yield of hydrogen among the other three ratios. The operating conditions used in the simulations for the inlet temperature and pressure of the natural gas and steam for this process were 20^{o}C, 520 kPa (for methane) and 180^{o}C, 965 kPa (for steam) respectively, as these were the standard operating conditions for the SMR process (Nikolaidis and Poullikkas, 2017). The procedures that were followed in this study and the operating conditions and stream specifications are shown in Figure 2.1.

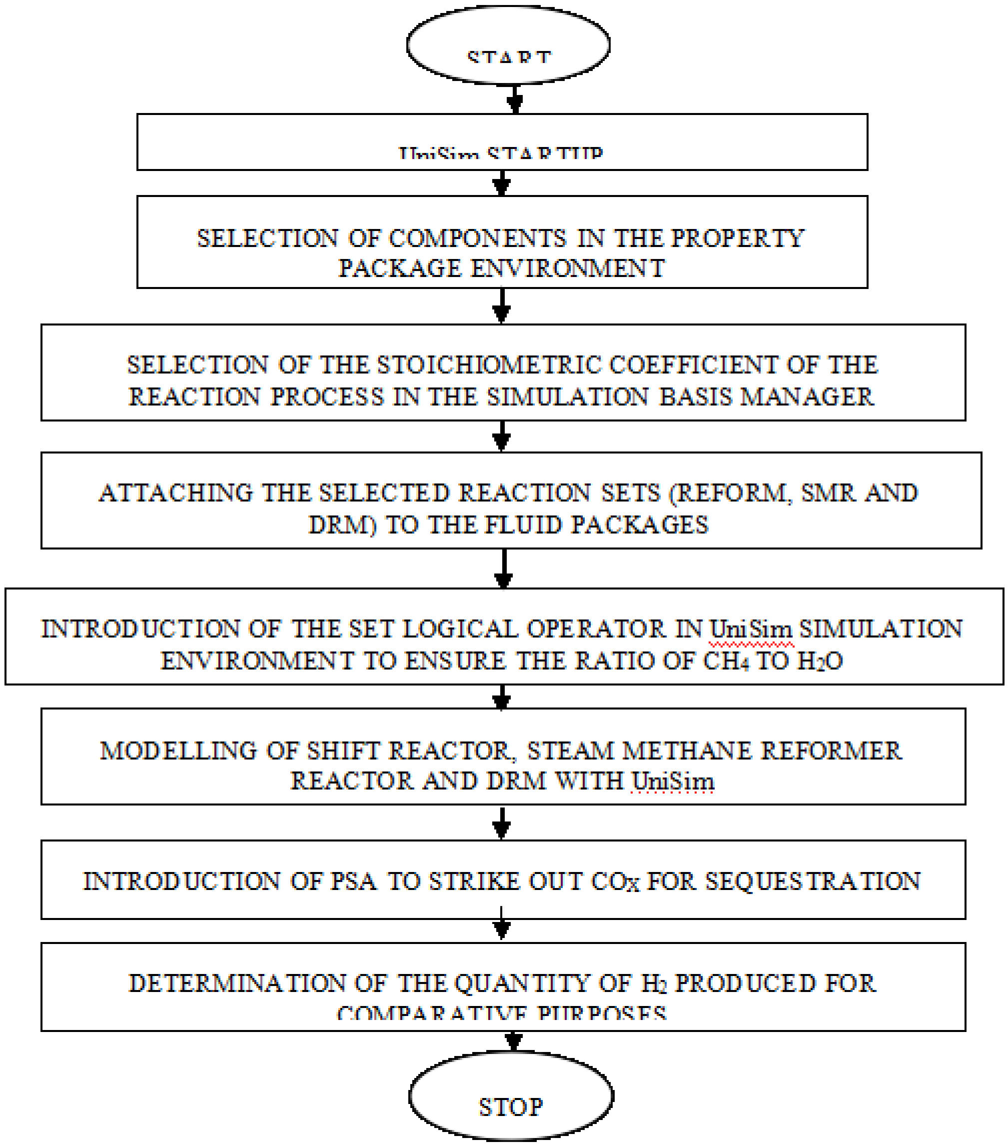


Figure 2.1; Modeling and simulation steam methane reforming processes with UniSIM

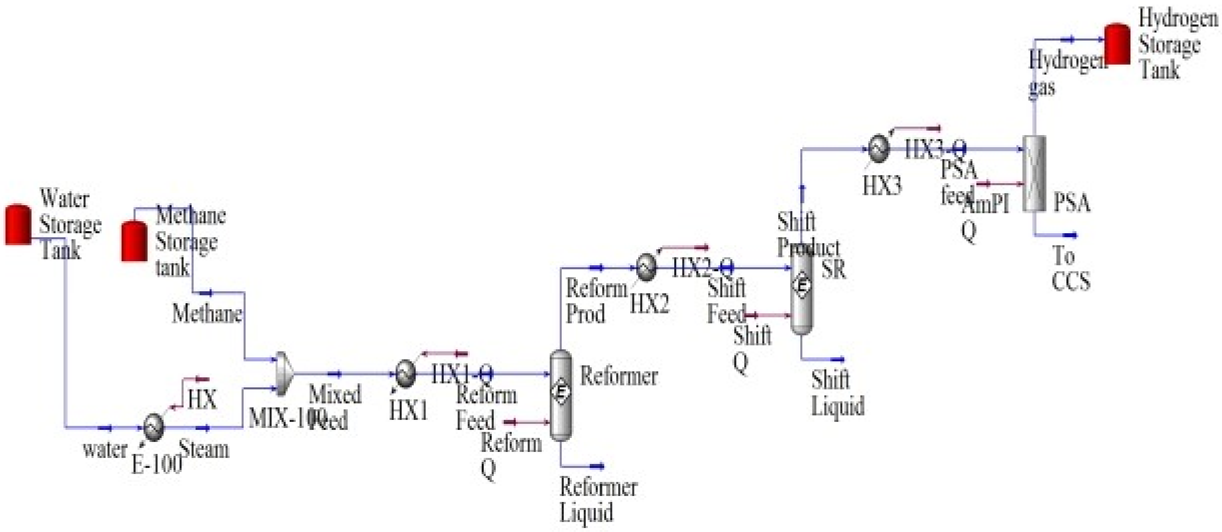


Fig. 2.2: Process Flow Diagram for SMR and SR Process

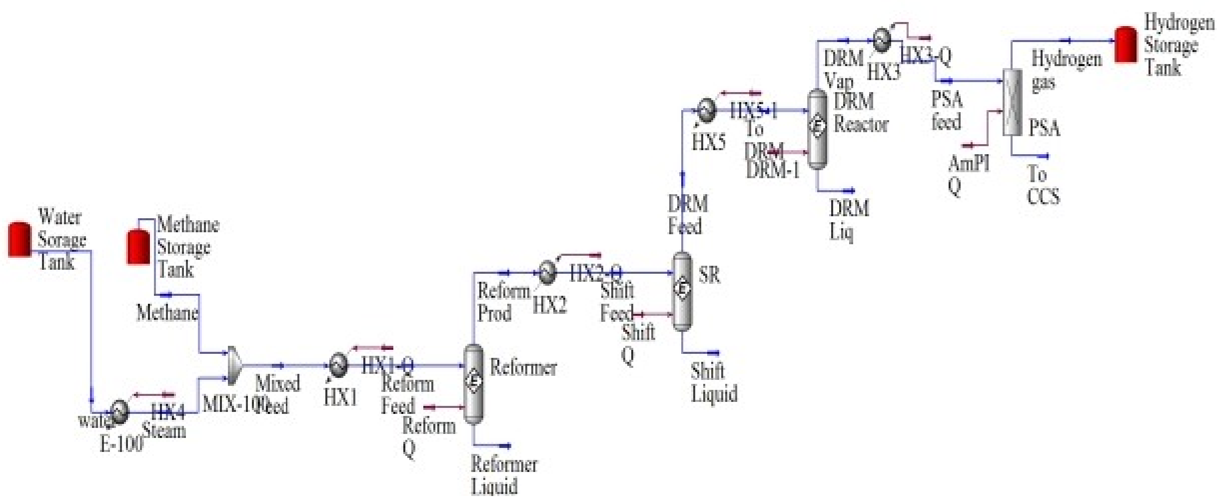


Fig. 2.3: Combination of both Shift reactor and DRM in the SMR process

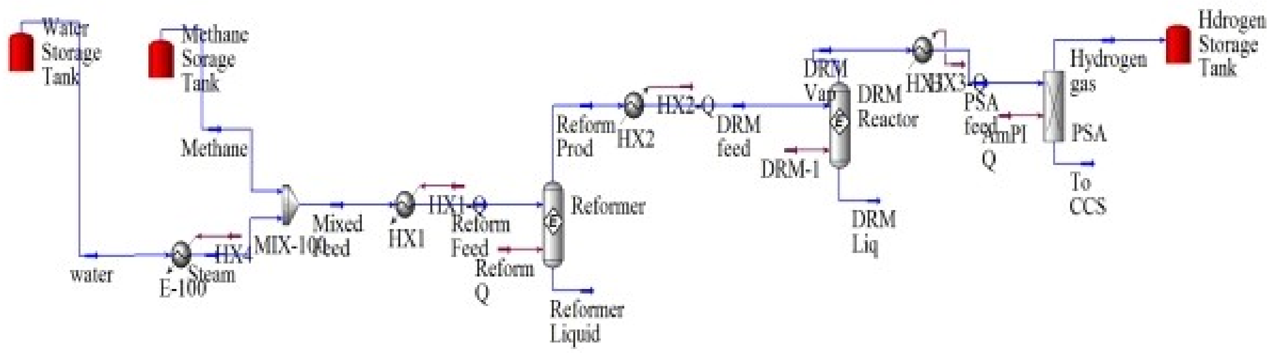


Fig. 2.4: Process flow diagram for SMR and DRM Process

3. RESULTS AND DISCUSSION

The simulation and economic analysis results for the three selected SMR process are as presented in Tables 3.1 through 3.7

Table 3.1 shows the reaction balance of steam methane reforming were methane reacted with steam to produce a syngas as shown in Table 3.1

Table 3.1. Reaction balance for SMR

Component	Inflow(kmol/hr)	Outflow(kmol/hr)
Methane	100	12.11
H_2O	250	131.5
Hydrogen	0	294.3
CO	0	57.25
CO_2	0	30.63
Total	**350**	**525.79**

Table 3.2 is the reaction balance that occurred in SMR/SR process. After the production of the syngas by the reformer, the product was sent to shift reactor where carbon monoxide reacted with steam to produce CO_2 and more hydrogen as shown in table 3.2

Table 3.2: Reaction balance for SMR and Shift Reactor

Component	Inflow(kmol/hr)	Outflow(kmol/hr)
Methane	12.11	12.11
H_2O	131.5	98.40
Hydrogen	294.3	327.4
CO	57.25	24.17
CO_2	30.63	63.72
Total	**525.79**	**525.8**

Table 3.3 is the reaction balance for SMR/SR/DRM process as the eed from SR proc
DRM were methane reacted with carbon dioxide to produce more hydrogen as show

Component	Inflow(kmol/hr)	Outflow(kmol/hr)
Methane	12.11	0
H_2O	98.40	98.40
Hydrogen	327.4	351.6
CO_2	24.17	48.40
CO	63.72	51.60
Total	**525.8**	**550**

Table 3.3: Reaction balance for the SMR/SR/DRM process

Table 3.4 shows reaction balance of SMR/DRM process, after the reaction of methane and steam in the reformer to produce syngas, the product was sent to the DRM where methane reacted with CO_2 to produce hydrogen and carbon monoxide as shown in table 3.4

Table 3.4: Reaction balance for the DRM reactor without shift reaction process

Component	Inflow(kmol/hr)	Outflow(kmol/hr)
Methane	12.11	0
H_2O	131.5	131.5
Hydrogen	294.3	318.5
CO_2	57.25	81.48
CO	30.63	18.52
Total	**525.79**	**550**

Table 3.5 shows the yield percentage of the three processes while table 3.6 shows the quantityof COx produced by each of the process.

Table 3.5: Hydrogen produced in kmol/hr for the Three Processes

Process type	Yield (%)
SMR and Shift Reactor	91
SMR, Shift Reactor and DRM	83
SMR and DRM	72

Table 3.6. The Quantity of Cox (CO and CO2 Produced by each Process)

Process type	CO_x(kmol/hr)
SMR and shift reactor	87.89
SMR, shift reactor and DRM	100
SMR and DRM	100

Table 3.7 is the summary of the economic analysis of the three processes showing their Return on Investment and

Payback time.

Table 3.7: Summary of the economic analysis for the three processes

Process Type	CO_2 Emission (kmol/hr)	CO Emission (kmol/hr)	COx Emission (kmol/hr)	ROI %	Pay Back Time
SMR and shift reactor	63.72	24.17	87.89	52	28 Months
SMR, shift reactor and DRM	51.60	48.40	100	44.2	32 Months
SMR and DRM	18.52	81.48	100	30.8	48 Months

3.1 DISCUSSION

For steam methane reforming(SMR) process, it is observed from Table 3.1 that the quantity of methane and steam that reacted were 87.89 kmol/hr and 118.5 kmol/hr, respectively to produce 294.3 kmol/hr of hydrogen, 57.25 kmol/hr of CO and 30.63 kmol/hr of CO_2 at 87.89 % conversion. It is observed fromTable 3.2 that the addition of shift reactor (SR) increases the quantity of hydrogen produced from SMR from 294.3 kmol/hr to 327.4 kmol/hr and the level of CO is reduced from 57.25 kmol/hr to 24.17 kmol/hr; this is in agreement with the work of Younus (2018). Unfortunately, the level of CO_2 increases from 30.63 kmol/hr to 63.72 kmol/hr with a conversion rate of 57.78 %. Table 3.3 shows that the quantity of CO_2 produced by SMR and SR process is reduced from 63.72 kmol/hr to 51.60 kmol/hr, while the Hydrogen produced in this process is increased from 327.4 kmol/hr to 351.6 kmol/hr after incorporating DRM and SR into the SMR process. The shift reactor (SR) process has higher hydrogen yield than the SMR produced in the first reactor but the introduction of DRM into the process increase the quantity of hydrogen produced because methane had to react again with carbon dioxide to produce additional hydrogen, which means that the combination of SR/DRM into SMR process produces more hydrogen than SMR and SR process, which consequently reduces the quantity of CO_2 but unfortunately leads to an increase in CO.

Table 3.4 shows that SMR and DRM alone produces the least hydrogen compared to the other processes; however, it has the least CO_2 present but has highest CO which means that this process can minimize the quantity CO_2 production but has the capacity to increase the rate of CO generation. Table 3.5 shows that the SMR and SR has the highest yield percentage of 91% while SMR and DRM has the least yield percentage of 72%; this is in agreement with the report by Nikolaidis and Poullikkas (2017). Table 3.6 shows that the combination of SMR and shift reactor has the least CO_X of 87.89 kmol/hr compared to the other two processes which produces CO_x of 100kmol/hr each. Finally, Table 3.7 shows the results of the economic analysis of the three processes with SMR and SR having the highest return on investment of 52% and the shortest payback time of 28 months. From all the results presented, it is obvious that SMR and SR is the most favourable process for the production of hydrogen from methane as feedstock because from an economic point of view, it has the highest profit and also has the least CO_x produced as byproduct.

4.0 CONCLUSION AND RECOMMENDATION

In this study, three steam methane reforming (SMR) methods namely SMR and Shift Reactor (SR), SMR and Dry Reforming of Methane (DRM) and SMR with the combination of DRM and SR were investigated for the purpose of producing hydrogen, using UNISIM Software Package. This was done on the basis of feedstock rate of 100 kmol/hr of methane. SMR/SR process was found to have the highest hydrogen yield of 91%. Moreover, it has the lowest CO_x emission rate of 87.89 kmol/hr and highest net profit percentage of 41.3 %. It is therefore concluded that the most favourable process route, technically and economically, is SMR/SR for the production of hydrogen using methane as feedstock.

CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Alibaba.(2018).*Material super supplier.* https://www.service.alibaba.com/ensupplier/faq_detail/20395666.html(Retrieved on 25thSeptember2019).

EnergyInformationAdministration.(1998). *EmissionsofGreenhouseGasesintheUnitedStates*.http://tonto.eia.doe.gov/FTPROOT/environment/057397.pdf. (Retrieve25thSeptember2019).

Energy Information Administration.(2003).*Annual Energy Outlook.*http://tonto.eia.doe.gov/FTPROOT/forecasting/0383.pdf.(Retrievedon28thSeptember2019).

ErsözA.(2008).Investigationofhydrocarbon reformingprocessesformicro-cogenerationsystems,*International Journal of HydrogenEnergy*, 33(23): 7084-7094.

FxMallam.(2019).*Dollar tonairarateblackmarket.* http://www.fxmallam.com/dollar-to-naira-rate-black-market.(Retrieved on 25thSeptember2019).

Haussinger, B., Kiwi, M. L. and Reneken, A. (2003). Mathematical Modelling of the Unsteadystateoxidation of NickelCatalysts, *Applied catalysisA:General,* 58(21): 234-247.

Levin,D. B.andChahine, R. (2010).Challengesfor renewable hydrogen production frombiomass,*International Journal of Hydrogen Energy*, 35(10):4962-4969.

Muradov, N. Z and Veziroglu, T. N. (2005). From hydro carbon to hydrogen carbon to hydrogeneconomy,*InternationalJournalofHydrogen Energy*, 30(3): 225-237.

Newson,E.andTruong,T.B.(2001).Low-temperatureCatalyticPartialOxidation ofHydrocarbons (C_1–C_{10}) for Hydrogen Production,*International Journal ofHydrogenEnergy*28(12): 1379–1386.

Nikolaidis,P.andPoullikkas,A.(2017).Comparativeoverviewofhydrogenproductionprocesses,*Renewable and SustainableEnergy Reviews*, 67:597-611.

OSHA(OccupationalSafetyandHealthAdministration).(2012).*SamplingandAnalyticalMethods: Carbon Dioxide in Workplace Atmospheres.*http://www.osha.gov/dts/sltc/methods/inorganic/id172/id172.html(Retrieved on7thOctober2019).

Thind, A. (2013). *The effect of carbon emissions on human health*. https://prezi.com/cy3vzyg2axgj/the-effectof-carbon-emissions-on-human-health.(Retrievedon 6th September2020).

USEPA.(2016). *United States Environmental Protection Agency overview on greenhouse gasesemission.*https://www.epa.gov/ghgemissions/overview-greenhouse-gases.(Retrieved on 16thSeptember2020).

THEME FOCUS:

MINI/SMART GRID DEVELOPMENT AND ITS INTEGRATION WITH CLEAN ENERGY FOR MASS ADOPTION

PROMOTION OF ENERGY MIX DEVELOPMENT IN NIGERIA FOR ADVANCEMENT OF CLEAN ENVIRONMENT AND ECONOMIC GROWTH

G. O. Ihekweme and J.O. Mahmud
NASENI Solar Energy Limited Karshi, FCT, Abuja, Nigeria
cgina@aust.edu.ng, ginaagness@yahoo.com (08037207268) and mahmudja@yahoo.com (08059459478)

ABSTRACT

Nigeria population is currently about 206 million people and estimated to sway to 401 million people by the year 2050. The problem of insufficient energy for heating and cooling systems, or fuel for transportation together with greenhouse gas emission challenges are re-occurring decimals with no definite solutions on sight. Energy accounts for two-thirds of total greenhouse gas, thus attempts to reduce emissions and mitigate climate change call for continual discuss in the energy sector. This paper presents the enigma of energy mix; generation and usage in Nigeria and also tables emissions problems, discussing possible factors that can lead to different consequences. Notably, promotions of sustainable development through energy mix utilization directly combats climate change and form integral part of viable solution to power and health situations. Key lessons and tenable interventions suitable for transition to clean environment and national economic growth such as exploitation of renewable energy resources, energy conservation measures and policies implementation are also discussed.

Keywords: Energy Mix, Renewable Energy, Nigeria, Economic Growth, Climate Change, Clean Environment

1. INTRODUCTION

Nigeria has the largest population and economy in sub-Saharan Africa, but limitations in the power sector constrain growth. The country is endowed with large oil, gas, coal, wood, tar sand, hydro and solar resources, and it has the potential to generate 16.4 gigawatts (GW) of electric power from existing installed plants (USAID, 2019). Though as at 2018, the country has the capacity to produce an estimated 7,000 MW of electricity. However, on most days, it is only able to dispatch around 4,000 megawatts (MW), which is insufficient for a country of over 206 million people. The shortfall was attributed to weak infrastructure, gas supply problems and water shortages (Ley et al., 2015). About half this population has no access to energy (Isabelle, 2018). In 2019, only about 3.5 GW capacities was available for a populated nation whose energy demand is tremendous. As at August 2021, power generation fluctuates between 3,567.30 MW to the 4,557.50MW peak generation (AEP, 2021).

The Nigeria’s population is estimated to grow up to 401 million over the next 3 decades (Central Intelligence Agency, 2017), much higher than the growth seen in China’s urban population during the country’s two decade of economic and energy boom (International Energy Agency, 2019). Peak electricity demand is expected to grow to 15 GW by 2025 as more people become electrified and the economy grows. The Nigeria government is targeting a 90% electrification rate by 2030, which will be supplied by an ambitious target of 45 GW of installed capacity in the same year. These profound demographic changes are set to drive economic growth, infrastructure development and, in turn, energy demand.

This paper presents the enigma of energy mix; history, generation and usage in Nigeria and also presents climate change, greenhouse gases and emissions problems, discussing possible factors that can lead to different consequences. Key lessons, challenges and recommendations suitable for transition to clean environment and national economic growth such as exploitation of renewable energy resources, standards and policies implementation are also discussed.

1.1 Energy Mix Development History in Nigeria

To appreciate the term, energy mix, a definition and brief introduction suffices. The term "energy mix" refers to the combination of the various primary energy sources used to meet energy needs in a given geographic region. It includes fossil fuels (oil, natural gas and coal), nuclear energy and the many sources of renewable energy (wood and other bio-energies, hydro, wind, solar and geothermal). These primary energy sources are used, for example, for generating power, providing fuel for transportation, cooking, heating and cooling residential and industrial buildings. The ability of a country to meet its energy needs using the types of energy available to it, in differing proportions is called energy mix. While the figures vary significantly from one country to another, fossil fuels dominate the energy mix at the global level, accounting for over 80% of the total.

Energy mix is sometimes misconstrued as power generation mix or electricity mix (Planet Energies, 2020). The power generation mix describes the breakdown of energy sources used specifically to generate electricity. For this reason, it does not take into account issues surrounding energy use in transportation and large segments of industry and housing. However this paper will discuss both power and energy mixes concurrently.

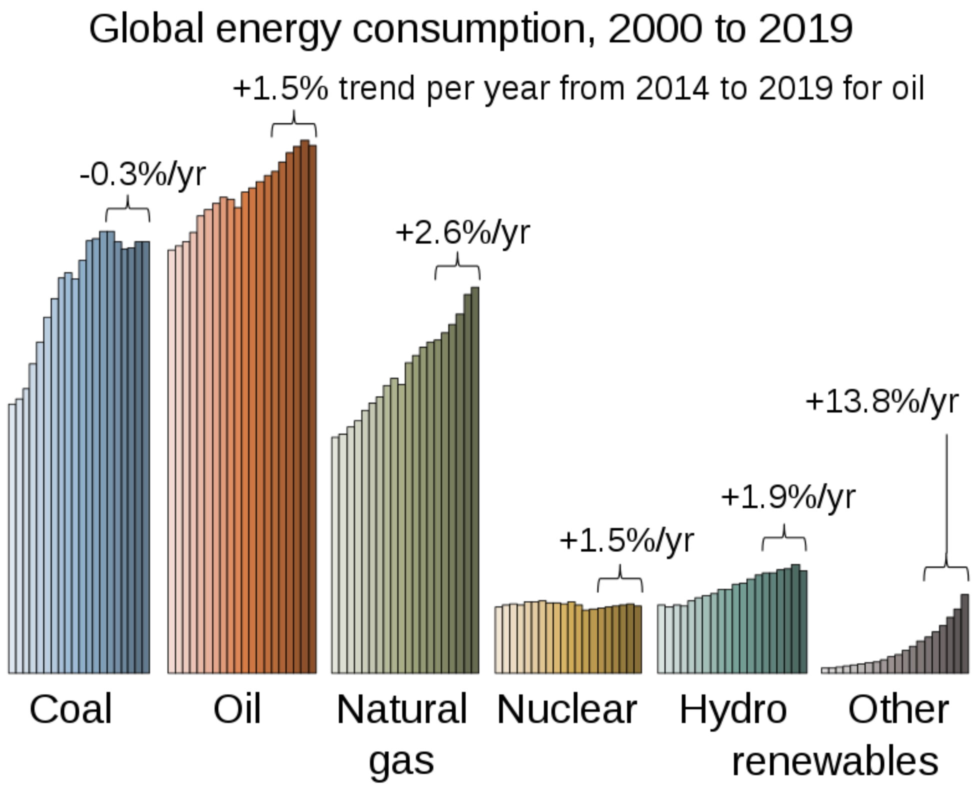


Figure 1: Global Energy Consumption from 2000 to 2019 (Jackson et al., 2019)

Globally, coal, oil, and natural gas remain the primary energy sources even as renewables have begun rapidly increasing (figure 1). From 2014 to 2019, there was a decline of 0.3% in coal usage annually while that of renewable energy increased yearly by 13.8%. This implies that the future of energy utilization lies within the renewable energy segment (Jackson et al., 2019). Historically, power generation in Nigeria dates back to 1886 when two generating sets were installed to serve the then Colony of Lagos (NERC, 2019). Coal was discovered in Nigeria in 1909 and mining started at Enugu in 1916. Estimated reserves of 639 million tonnes are still untapped since the use of coal was stopped decades ago. Crude oil was discovered in 1956 at Oloibiri while natural gas which was also discovered in the Niger Delta has estimated reserve of about 120 trillion (Sambo, 2006). An Act of Parliament in 1951 established the Electricity Corporation of Nigeria (ECN), and in 1962, the Niger Dams Authority (NDA) was also established for the development of hydroelectric power (NERC, 2019). The hydro sources of energy did not come to scene until 1968, when construction of the 590 MW plant at Kainji commenced (Ogunsola, 2016). ECN and NDA were merged in 1972 and this amalgamation resulted in the formation of the National Electric Power Authority (NEPA) which was saddled with the responsibility of generating, transmitting and distributing electricity for the whole country. Nigeria has effortlessly tried to reform and restructure the power sector through privatization. The reform gave birth to Power Holding Company of Nigeria (PHCN) in 2005 which replaced NEPA.

Table 1 presents the list of power generation companies that closed transaction from 2013 till date. It shows that the added capacity generated till date hovers a little bit above 3,000 MW despite the efforts of government, international donors and developmental organizations interventions in this regard. Nonetheless the government is not relentless in investing and supporting upcoming energy projects. The largest upcoming project is the Mambilla Power Station in North-East Nigeria, a $5.79 billion project which is due to be completed in 2024 with most of the financing coming from Chinese lenders (Isabelle, 2018). The project is also estimated to generate 3,050 MW of renewable energy in the rural region with more focus on solar power generation.

The Transmission Company of Nigeria (TCN) operates the transmission grids of Nigeria. Losses are mostly encountered from generation to distribution. For instance, the average capacity evacuated to distribution companies (DISCOs) during the fourth quarter of 2019 was 2,868 MW. Transmission losses (from generation to DISCOs) amounted to 22% (NERC, 2019).

1. CLIMATE CHANGE PROBLEMS AND THE RELEVANCE OF ENERGY MIX

Climate change which includes the rising sea levels, extreme weather, flooding, droughts and storms came to be as a result of large amounts of greenhouse gases and allied emission problems. These gases (water vapour, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs)) are released into the atmosphere from numerous human activities worldwide such as burning fossil fuels for electricity generation, heating and transport. Combustion of fossil fuels also releases air pollutants that harm the environment and human health. The human activities are:

Table 1: Power Africa new MW to date at financial close: 3,043 MW (USAID, 2019)

GENCO	Power Type/ Capacity	Financial Closed Date	Commercial Operation Date
First Independent Power-Afam	Natural Gas (180 MW)	25/09/2013	29/12/2017
First Independent Power-Elema	Natural Gas (75 MW)	25/09/2013	29/12/2017

First Independent Power-Omoka	Natural Gas (25 MW)	25/09/2013	29/12/2017
Kainji Power-Jebba Hydro Power Station	Hydro Power (96.4 MW)	01/11/2013	29/12/2017
Kainji Power-Kainji Hydro Power Station	Hydro Power (540 MW)	01/11/2013	29/12/2017
Olorunsogo	Natural Gas (213.4 MW)	23/12/2013	30/11/2015
Omotosho	Natural Gas (74 MW)	14//08/2014	30/112015
Sapele Power	Naturals Gas (940 MW)	01/11/2013	30/09/2015
Ugheli Power	Natural Gas (220 MW)	01/11/2013	30/09/2015
Azura Edo	Natural Gas (450 MW)	28/12/2015	31/12/2018
Egbin Power	Natural Gas (220 MW)	01/11/2015	29/12/2017

1. Electricity generation: The generation of electricity and heating systems release toxic substances to the environment.
2. Emission of greenhouse gases from vehicles and generators: Some vehicles and fumes from generators emit greenhouse gases such as sulphur dioxide and carbon monoxide from their exhaust.
3. Burning of Hydrocarbon products: The burning of hydrocarbon products releases carbon dioxide and other gases into the atmosphere.
4. Deforestation: This refers to cutting down trees, usually for agriculture. Trees form a protective barrier against the heat from the sun and cutting them down fast racks ozone layer depletion.
5. Industrial emissions: Industrial activities especially from cement and heavy equipment and machineries produce greenhouse gases that are emitted into the atmosphere.

China, United States and the European Union contribute approximately 52% of global fossil CO2 emissions between 2018 and 2019. After stabilizing for four or so years, China's CO2 emissions in 2018 increased 2.3% to 10.1 billion tonnes CO2 and a preliminary 2.6% increase in 2019 (range of +0.7% to 4.4%) to approximately10.3 billion tonnes CO2 (Peters et al., 2019). To support the global climate agenda, the EU has adopted binding climate and energy targets for 2020 and proposed targets for 2030 as part of its overall efforts to move to a low-carbon economy and to cut greenhouse gas emissions by 80-95 % by 2050 (EEA, 2017). The first set of climate and energy targets for 2020 includes a 20 % cut in greenhouse gas emissions (compared with 1990 levels), 20 % of energy consumption coming from renewables and a 20 % improvement in energy efficiency. Whereas Nigeria has a vision of generating 30GW by year

2030 with 30% renewable energy (Nextier, 2016), just to have adequate energy for her growing population and to checkmate climate conditions. EU institutions envisage the next milestone targeting 40 % cut in emissions by 2030, 27 % of energy coming from renewable sources and a 27 % improvement in energy efficiency (or 30 %, as recently proposed by the European Commission) compared with baseline (EEA, 2017).

In Nigeria, total energy consumption arises from natural gas which is fossil based and hydro power generation. The country will always need oil and petrol for transportation and gas to make fertilizers. Moreover, the petro-chemical sector, on which many industries rely (to make plastics, synthetic fibres, polyester, nylon, medicinal drugs such as aspirin) has petroleum origins. These fossil-based activities will continue to impact negatively on the climate and in most cases result in extreme weather conditions. The variations in temperature, rainfall and humidity associated with the science of climate change in Nigeria affect climate-dependent sectors (FutureLearn, 2021). Figure 2 shows a climate change photo arising from two extreme weather conditions i.e, excessive drought area in dry season which is assumed to be flooded in wet season due to the cracks which usually arise from muddy area in wet season. These have far reaching consequences which are discussed below.

Figure 2: Climate change in Nigeria (FutureLearn, 2021)

The consequences of climate change from weather fluctuations are; low crop yield, food shortage, poor livestock production, low income, loss of homes, properties and road networks. The World Health Organisation (WHO) estimates that between 2030 and 2050, climate change is expected to cause approximately 250 000 additional deaths per year globally, from malnutrition, malaria, diarrhea and heat stress alone; this was estimated to translate to direct damage costs to health of between USD 2-4 billion per year (WHO, 2020).

To mitigate climate change induced problems to the barest minimum, energy mix becomes a veritable tool to embrace. However, there is no ideal energy mix in the world today since it does not take sufficient account of climate change issues. The main culprit is the world's over dependence on fossil fuels energy origins which accounts for over 80% of energy generation and utilization. These fossil resources carry two major setbacks. On one hand, they emit large quantities of CO2 when burnt and this is one of the major causes for global warming. On the other, they are not infinitely available. With the growing world's population which is estimated to reach 9 billion inhabitants on Earth alone, much more serious problems are anticipated. Rarefaction of oil already has a serious consequence: its increased price and associate social and economic impact negatively on the poorest households. When the oil finally depletes, more problems are on sight. Therefore, considerations such as these should invite a paradigm shift from the current practiced energy mix to embrace more renewable options such as wind, hydro and solar energy mixes.

3. RENEWABLE ENERGY AND CLEAN ENVIRONMENT

Renewable energy sources are wood and other bio-energies, hydro, wind, solar and geothermal. These energy sources utilize appropriate technologies to provide clean energies. Nigerian then Minister of power, works and housing, Babatunde Fashola said in 2018 when making a speech in London that the government aims to generate 30% of its total energy from renewable sources by 2030 to be able to meet the energy demand of the trajectory population (Isabelle, 2018). The paradigm shift to renewable energy if achieved is an efficient way to bring power to rural communities and help clean up the environment of urban pollution rates, reduce the dependence of the fossil fuel based energy demand and associated emissions problems most especially at Niger Delta region of the country. These renewable energy sources are abundantly available in Nigeria.

Having seen the potentials and attributes of renewable energy, Nigeria envisions generating 30GW by year 2030 with 30% renewable energy (National Council on Power, 2016; Nextier, 2016).

.

Table 2: Renewable energy potential in Nigeria (Energy Commission of Nigeria, 2014)

Renewable Energy Resources	Estimated Reserve
Large Hydropower	11,250 MW
Small Hydropower (<30 MW)	3500 MW
Fuel Wood	11 million hectares of forest and woodland

Municipal Waste	30 million tonnes/year
Animal Wastes	245 million assorted animals in 2001
Energy Crops and Agricultural Residue	72 million hectares of agricultural land
Solar Radiation	3.5-7.0 kW h/m2/day
Wind	2-4 m/s at 10 m height Wind speeds in Nigeria range from a low 1.4 to 3.0m/s in the Southern areas, except for coastal line and 4.0 to 5.1m/s in the North. The Plateau area particularly interesting.

3.1 Investment opportunities in Energy Mix: Panacea to Economic Growth

Nigeria is said to have huge sources of untapped energy available. From renewable sources alone (table 2), numerous opportunities exist of which if efficiently harnessed, it will add to existing fossil fuel based energies. Less energy demand is expected if energy mix is diversified. Steady access to electricity will reduce unemployment, engage the teeming youth and in effect enhance productivity and economic growth.

The Africa Energy Outlook report 2019 by the International Agency (IEA) stated that the performance policy targets 20% (unconditional) to 45% (conditional) reduction in greenhouse gas emissions by 2030 compared to the business-as-usual scenario and increase oil production to 2.5 mb/d and become a net exporter by 2020, and end gas flaring by 2030. While industrial development policy targets the dedication of at least 30% of the federal budget to capital expenditure and achieve GDP growth of 7% and create over 15 million jobs by 2020 and double manufacturing output to 20% of GDP by 2025. The policies and target (figure 3) seem good, if implemented or achieved, it will improve the energy demand, generate cleaner energies thereby reducing greenhouse gas emission and tremendous growth in GDP.

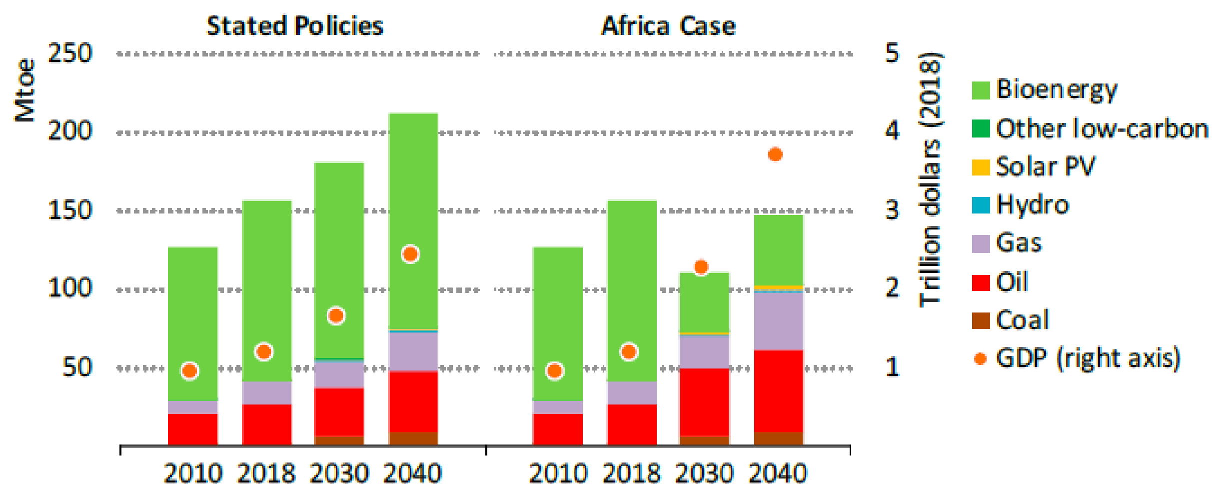


Figure 3: Nigeria primary energy demand and GDP (IEA, 2019).

Policies, strategies, legislative laws, reform acts and standards have always been enacted. Yet, energy efficiency remains in draft form and still need to be developed considering inherent realities associated with the sector. There is however, a gap between the policy framework and their operationalization through the formulation and effective implementation on plans with a clear roadmap (NESP, 2015).

4. CHALLENGES FACING ADEQUATE ENERGY MIX PROMOTION IN NIGERIA

The Nigerian power sector experiences many broad challenges related to electricity policy enforcement, regulatory uncertainty, gas supply, transmission system constraints, and major power sector planning shortfalls that have kept the sector from reaching commercial viability. Some of the challenges facing the energy industries in Nigeria include:

Vandalization, poor maintenance culture, rising theft of power equipment, cables, solar panels and accessories, wind vane, transformer components, pipelines, etc, are increasingly stolen by criminals and scavengers.

Another problem confronting energy mix development and sustainability in Nigeria is the over-dependence on imported end-products and reliance on foreign technologies. In many cases, these sub-standard and less durable products are imported by unscrupulous folks and sold at cheaper prices. This is where the Local Content Act comes into play which unfortunately is not been robustly implemented at the moment (Energypedia, 2020; Ley et al., 2015).

Weak synergies, critical infrastructure deficit and logistic problems such as poor road network, lack of power supply which constraints local industries to operate on generators sometimes upwards of 24 hours daily (Power Sector Watch, 2021). Outrageous interest rate regime said to be in the neighborhood of 23% per annum which restricts access to credit. It's almost impossible for a business to thrive at this Shylock rate. Lack of appropriate legal, regulatory and institutional framework as well as incentives to attract investors.

Other challenges include: poor standardization of products and falsification of records; failure of implementing agencies to accept Negotiable Duty Credit Certificates (NDCC) issued by the Federal Ministry of Finance, frequent policy summersault occasioned by vested interests, sourcing of foreign exchange (FOREX) usually at very high rates mostly from the black market. As at August 2021, naira exchanged officially at the rate of 412 naira to a dollar while the black market fluctuates between 510 to 515 naira to a dollar. Initial investment cost becomes a barrier due to high dependence on imported components, equipment and machineries.

The unprecedented insecurity cum terrorism challenges stifling in almost every geo-political zone in Nigeria are major setbacks in virtually all sector the industry and literally hinder successful economic growth. In August 2021, it was reported that gunmen killed a police officer and six employees of Nigerian oil and gas Services Company Lee Engineering during an attack on a project site in the southeastern state of Imo (African News, 2021). The foregoing is some of the challenges that increase production cost of locally manufactured energy products in Nigeria thereby making them costly and unable to compete against imported products.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Given that the energy sector is arguably the foremost drivers of both local and sophisticated industries, it is pertinent that a proper energy mix with proper load projection and good management system be part of tenable solution to the problems. Government should not relent in giving the sector all the assistances and supports required to sustain and promulgate the sector. Every facet of initiative and implementation would enhance rural infrastructure and stimulate growth and productivity in the country's rural economy. Climate stabilization can be achieved through energy saving culture and replacing fossil fuel use with renewables and other low- and no-carbon approaches and tools.

5.2 Recommendations

1. The Standards Organization of Nigeria (SON), the Manufacturers Association of Nigeria (MAN) and other stakeholders

must synergize and ensure that the Nigerian market is not flooded with sub-standard fossil fuel based and renewable energy products. Strict pre-shipment inspection of goods bound for Nigeria is hereby recommended to the effect that all products for related to energy mix whether produced or imported into Nigeria must meet both local and international certifications.

2. The intention of the Local Content Act or Law and the recent Automotive Policy ought to be managed by the Nigerian Content Development and Monitoring Board are meant to encourage the capacity development of local skills, value addition, technology transfer, use of local manpower, local manufacturing, guide and monitor and to create an enabling environment for Nigerians to get more involved in running the country's economy. The Local Content Law also aims to tackle rampart incidents of capital flight from Nigeria. The government and relevant agencies of government must make sure that this law is not circumvented and does not become a paper-tiger. If they are not in place and implemented, it is high time incentives such as the Export Expansion Grant Scheme, tax reliefs to local industries, exemption of duty on essential raw materials, duty draw back amongst others were re-introduced. Imported energy products should also attract high import duties. This will no doubt make Nigerian exports competitive in the international market.
3. The relevant stakeholder agencies/organizations that are the main national public actors and are responsible for contributing to the nation's energy demand are to be encouraged and given needed support. For instance, the National Agency for Science and Engineering Infrastructure (NASENI) charged with the mandate of establishing and nurturing an appropriate and dynamic Science and Engineering Infrastructure in the area of capital good research, production and reverse engineering including power equipment should access all funds as stated in the Reform Act that established the agency. In the power sector, the agency has contributed immensely by the establishment of an assembly plant for Photovoltaic (PV), NASENI Solar Energy Limited (NSEL) with an annual production capacity of 7.5 MW; the local manufacture of Small Hydropower turbines, wind turbines and pole mounted transformers.
4. Other key actors relevant to the energy sector to be supported are but not limited to; The Federal Ministry of Power (FMP)

who is to formulate and implement power generation, distribution and transmission of electricity amongst other policy nationwide. The National Planning Commission (NPC) is to act as a central agency for monitoring and evaluating development plans, policies and programs. The Nigerian Electricity Regulatory Commission (NERC) has a primary duty among other duties of protecting the interest of electricity consumers and reduction of greenhouse gases to them. The Rural Electrification Agency (REA) is to provide access to reliable electric power supply for rural dwellers irrespective of where they live and what they do, in a way that would allow for reasonable return on investment through appropriate tariff that is economically responsive and supportive of the average rural customer. The Federal Ministry of Water Resources (FMWR) to enact and implement policies that ensures provision of access and sufficient water for environmental and economic demand amongst others which includes that for the energy sector. Standards Organization of Nigeria (SON) to provide and monitor standards of products and services while the Nigerian National Petroleum Corporation (NNPC) is to harness Nigeria's oil and gas reserves for sustainable national development. NNPC is a critical stakeholder in this regard but has not been contributing its expected quota due to non-functioning of its refineries. The National Environmental Standards and Regulations Enforcement Agency (NESREA) is charged with the development of new, and review of existing national environmental laws and regulations which are expected to promote clean environment. These agencies and others including donor and implementing agencies, if adequately supported will contribute seamlessly to the Nation's energy mix development and clean environment in all facet of the energy sector.

5. Tackling the unprecedented insecurity, terrorism and insurgency situation in Nigeria will definitely boost business activities and also attract the much needed foreign direct investment (FDI) in all sectors.
6. The government should intensify economic reforms in the sector by developing indigenous human and manufacturing capacities, invest hugely in research and development, support innovations and commercialization of research results.

REFERENCES

(IEA) International Energy Agency. (2019).

Africa Energy Outlook 2019 - Overview Nigeria. *World Energy Outlook Special Report*, 288. Retrieved from https://www.iea.org/reports/africa-energy-outlook-2019#energy-access%0Ahttps://www.iea.org/reports/africa-energy-outlook-2019#africa-case

AEP, (Africa Energy Portal). (2021). *Nigeria: Power generation falls further by 27% to 3,567MW*. Retrieved from https://www.vanguardngr.com/2021/04/power-generation-falls-further-by-27-to-356

African, N. (OIl and G. (2021). *Gunmen kill seven at Nigerian gas project site*. Retrieved from https://www.energymixreport.com/gunmen-kill-seven-at-nigerian-gas-project-site/

CIA(Central Intelligence Agency). (2017). *The CIA World Factbook 2017*. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/ni.html

ECN (Energy Commission of Nigeria). (2014). *Draft National Energy Master Plan*.

EEA, (European Environment Agency). (2017). *Energy and climate change*. Retrieved from https://www.eea.europa.eu/signals/signals-2017/article

Energypedia. (2020). *Nigeria Energy Situation*. Retrieved from https://energypedia.info/wiki/Nigeria_Energy_Situation

FutureLearn. (2021). What are the impacts of climate change in Nigeria?

G. P. Peters, R. M. Andrew, J. G. Canadell, P. Friedlingstein, R. B. Jackson, J. I. Korsbakken, C. L. Q. & A. P. (2019). Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. *Nature Climate Change Volume 10, Pages3–6 (2020)*, *10*. https://doi.org/https://doi.org/10.1038/s41558-019-0659-6

Isabelle, G. (2018). Oil-rich Nigeria turns to renewable energy as population booms. *Thomas Reuters Foundation*.

Jackson, R. B., Friedlingstein, P., Andrew, R. M., Canadell, J. G., Le Quéré, C., & Peters, G. P. (2019). Persistent fossil fuel growth threatens the Paris Agreement and planetary health. *Environmental Research Letters*, *14*(12). https://doi.org/10.1088/1748-9326/ab57b3

Ley, K., Gaines, J., & Ghatikar, A. (2015). The Nigerian Energy Sector - An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification. *Internationale Zusammenarbeit (GIZ) GmbH*, (June), 168. Retrieved from www.gopa-intec.de

National Council on Power. (2016). *Federal Republic of Nigeria Sustainable Energy for All Action Agenda (Se4All-Aa)*. 12. Retrieved from https://www.seforall.org/sites/default/files/NIGERIA_SE4ALL_ACTION_AGENDA

_FINAL.pdf

NERC, (Nigerian Electricity Regulatory Commission). (2019). Power Generation in Nigeria. Retrieved from https://nerc.gov.ng/index.php/home/nesi/403-generation

NESP, (Nigeria Energy Support Programme). (2015). *The Nigerian Energy Sector - an Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification*.

Nextier, P. (2016). *Nigerian Sustainable Energy for All Action Agenda*. Retrieved from http://nextierlimited.com

Ogunsola, O. I. (2016). *History of Energy Sources and Their-Utilization in Nigeria History of Energy Sources and Their-UtiIization in Nigeria*. *8312*(March). https://doi.org/10.1080/00908319008960198

Planet, E. (2020). *The Energy Mix and Energy Transition*. Retrieved from https://www.planete-energies.com/en/medias/close/what-energy-mix

Power Sector Watch. (2021). *Nigeria ' s Electricity Supply Industry Highlights*. (February), 1–3.

Sambo, A. S. (2006). *Renewable Energy Electricity in Nigeria the way forward, in Proceeding of the Renewable Electricity Policy Conference, Abuja, Nigeria, pp. 1 – 42.*

USAID. (2019). *NIGERIA Power Africa Factsheet*.

WHO, (World Health Organisation). (2020). *Nigeria strengthens capacity to address impact of climate change on health*. Retrieved from https://www.afro.who.int/news/nigeria-strengthens-capacity-address-impact-climate-change-health

SMART GRID DEVELOPMENT IN NIGERIA

Augustine Okechukwu Ezenagu
Bezalel Multi-concept Engineering Services Limited.
petokey1@gmail.com, 07032527285

ABSTRACT

The energy crisis in Nigeria today has led to so many failed attempts in finding a permanent solution to the epileptic power situation ravaging the Nigerian economy. However, research has shown that smart grid development can serve as a permanent solution to the power sector crisis, hence the need to explore and harness its potentials towards the possible application and mass adoption in Nigeria. Most research on smart grids so far has been centered on their application in developed countries that have sophisticated power infrastructure. This paper will instead strive to present a comprehensive review on how reliability, efficiency and revenue collection among others can be the driving factors for the adoption of smart grid technology in Nigeria, where network infrastructure is less advanced. This paper compares the possible motives for smart grid adoption in developing countries with that of developed countries. Following this, the paper moves on to present an overview of smart grids in developing economies and examines its adoption in the Nigeria electricity network.

Keywords: *energy crisis, smart grid, deployment, application, driving factor, adoption.*

1. INTRODUCTION

Nigeria is the most populous African country blessed with an abundant amount of fossil fuel and renewable energy resources, but the energy crisis in Nigeria today has led to so many failed attempts in finding a permanent solution to the epileptic power situation ravaging her economy. According to the World Bank data; only about 50.9% of Nigerians have access to electricity (Emodi, 2019).

The importance of electricity to any nation cannot be over emphasized. The power utility is the bedrock for the growth of the nation because it will enhance every other sector thereby leading to rapid social and economic growth (Amuta, 2018). In Nigeria, electricity is the pillar of her economic growth and development with roles in the nation's production of goods and services in the industrial sector as well as agriculture, health and education (Emodi, 2019).

As the sources of electrical energy include an increasing mix of renewable assets, such as wind and solar, energy providers are driven to find innovative solutions to efficiently manage an increasingly complex and interconnected network or smart grid. This often involves implementing new technologies and equipment to further automate, monitor and control the flow of power based on reliability, economic and environmental considerations (Electrical Power Engineers, 2020).

The reasons for exploiting smart grid in developing countries such as Nigeria is to look into providing power system that is computer, information and technology base. This will take care of the power problem, thereby combating unreliable grid (Amuta, 2018).

Various, slightly altering, definitions have been proposed for the term smart grid. In this article the term smart grid will be used in line with the definition proposed by the International Energy Agency in their report *Technology Roadmap: Smart Grids*, which states that a "smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users (Behaim, 2017).

The idea of smart grid is fast growing in the power industry and the technology can gradually be introduce into the national grid so as to put an end to the increasing struggle for electricity. This will bring about a sustainable development in the country with smarter electricity grids (Amuta, 2018).

One fundamental goal of a smart grid system is to establish the means to economically and dynamically provide power that is reliable and efficient by operating at peak capacity using sustainable methods (Electrical Power Engineers, 2020).

Therefore, to achieve this sustainable development, the power system must move to the emerging smart grid technology. The main aim of smart grid is to increase customer participation and be involved in decision making so as to create the operation system whereby both utilities and consumers can interact. Thus this paper describes an overview of the smart grid technology and its possible mass adoption in the Nigeria electricity network.

2. AN OVERVIEW OF SMART GRIDS IN DEVELOPING ECONOMIES

2.1 Concept of Smart Grid

A smart grid exists wherever the electricity delivery system, from point of generation to point of consumption, which highly integrates the advanced sensing and measurement technologies, information and communication technologies (ICTs), analytical and decision-making technologies, automatic control technologies with energy and power technologies and infrastructure of electricity grids – and where it is delivering enhanced grid operations, better customer services, and positive environmental benefits(International Communication Union, 2020). Some important aspects of what is 'smart' are listed below:

- *Observability*: It enables the status of electricity grid to be observed accurately and timely by using advanced sensing and measuring technologies;

- *Controllability*: It enables the effective control of the power system by observing the status of the electricity grid;
- *Timely analysis and decision-making*: It enables the improvement of intelligent decision-making process;
- *Self-adapting and self-healing*: It prevents power disturbance and breakdown via self-diagnosis and fault location.
- *Renewable energy integration*: It enables the integration of renewable energy such as solar and wind, as well as the electricity from micro-grid and supports efficient and safe energy delivery services for electric vehicle, smart home and others.

2.2 Goals and Objectives of Smart Grid

Efficient and reliable transmission and distribution of electricity is a fundamental requirement for providing societies and economies with essential energy resources. The utilities in the industrialized countries are today in a period of change and agitation. On one hand, large parts of the power grid infrastructure in developed countries are reaching their designed end of life time, since a large portion of the equipment was installed in the 1960s. On the other hand, there is a strong political and regulatory push for more competition and lower energy prices, more energy efficiency and an increased use of renewable energy like solar, wind, biomasses and water. Figure 1 shows a vision for the development of Transmission and Distribution (T&D) networks – moving from passively and centrally controlled arrangements to actively and automated sub-network control under a modern smart grid arrangement(International Communication Union, 2020).

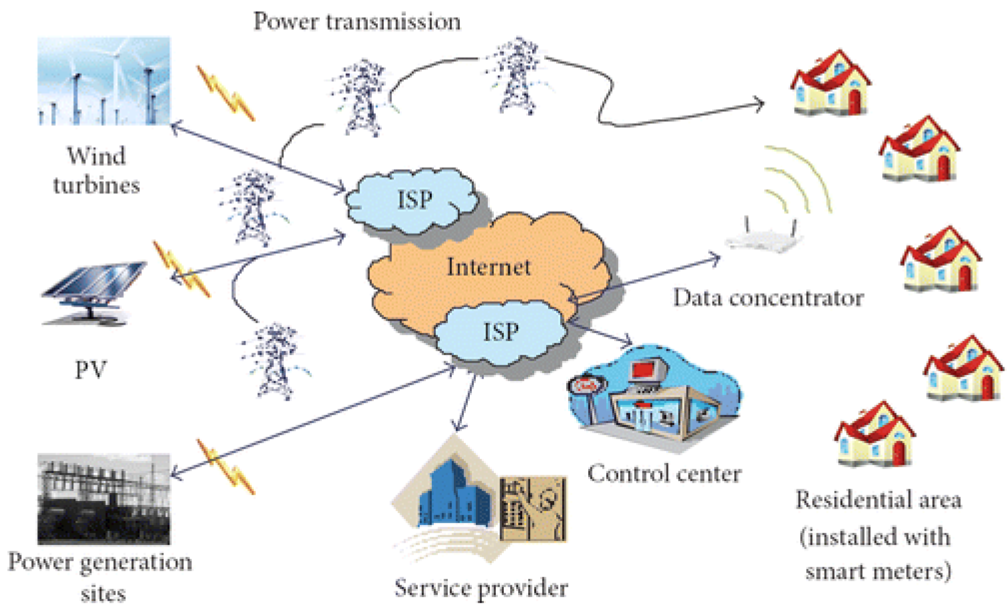


Figure 1: A concept of smart grid system (Ataul, 2019).

In industrialized countries, the load demand has decreased or remained constant in the previous decade, whereas developing countries have shown a rapidly increasing load demand. Aging equipment, dispersed generation as well as load increase might lead to highly utilized equipment during peak load conditions. If the upgrade of the power grid should be reduced to a minimum, new ways of operating power systems need to be found and established(National Institute of Standards and Technology, 2020).

In many countries, regulators and liberalization are forcing utilities to reduce costs for the transmission and distribution of electrical energy. Therefore, new methods (mainly based on the efforts of modern information and communication techniques) to operate power systems are required to guarantee a sustainable, secure and competitive energy supply (International Communication Union, 2020).

The general goals of Smart Grid are to ensure a transparent, sustainable and environmental-friendly system operation that is cost and energy efficient, secure and safe. Objectives of developing the Smart Grid are quite different from country to country for their various demands and start points. However, the common objectives of a Smart Grid are clear and listed below: (Feller, 2018)

- *Robustness*: The Smart Grid shall improve resilience to disruption to provide continuous and stable electricity flows, avoiding wide-area breakout accidents. It shall guarantee the normal and secure run of the electricity grid even under the instance of emergency issues, such as natural disasters, extreme weather and man-made breakage, and provides self-healing abilities;

- *Secured operation*: The Smart Grid shall enhance communication networks and information security of the electricity grid;
- *Compatibility*: The Smart Grid shall support the integration of renewable electricity such as solar and wind, has the capacity of distributed generation access and micro-grids, improve demand response functions, implement the effective two-way communication with consumers and satisfy various electricity demands of consumers;
- *Economical energy usage*: The Smart Grid shall have the capacity of more effective electricity markets and electricity trades, implement optimized configuration of resources, increase efficiency of the electricity grid, and reduce electricity grid wastage;
- *Integrated system*: The Smart Grid shall highly integrate and share information and data of an electricity grid, utilize the uniform platform and model to provide standardized and refined management;
- *Optimization*: The Smart Grid shall optimize assets, reduce costs and operate efficiently;
- *Green energy*: The Smart Grid shall solve problems of energy security, energy saving, carbon dioxide emission and etc.

2.3 Smart Grid Initiative: Opportunities and Challenges

The large interest in smart grids is relatively new, and most of the research and investment on the topic has come from developed countries, mainly in Europe and North America. Smart grid development is currently still tied very closely to the economic development of countries (Behaim, 2017). Furthermore, most smart grid development so far has been focused in countries with high renewable energy targets, as they are starting to face problems with the stability of their power supply due to more intermittent generation (Behaim, 2017). The reasons why different countries invest in smart grids are as varied as their national geographies and political systems are different:

United States – During the Obama years, the American Recovery and Revitalization Act (ARRA) provided for a total of $4.5B for smart grid initiatives. Of that, $3.9B was administered by the US Dept of Energy (DoE) for investment and research and development programs. The remaining $600M was for worker training and interoperability work undertaken by the US National Institute of Standards and Technologies (NIST). During the two Trump years the US

Administration has dropped the ball, doing little in practical terms -- although the words coming from the DOE have been favorably inclined towards smart grid (Feller, 2018).

China - The State Grid Corp of China (SGCC) has been deploying extensive fiber-optic networking throughout China high-voltage substations. This network now totals many millions of kilometers of fiber-optic channels. According to one SGCC spokesperson, there will be "a lot of business opportunities for smart grid relevant industries," such as the firms supplying smart metering systems, power storage devices, telecommunication devices, and software (Feller, 2018).

Australia - The national government announced plans to invest large sums – in one instance committing hundreds of millions of dollars, in partnership with the energy sector, with all of it focused on developing a national energy efficiency initiative. This initiative supported the installation of Australia's first commercial-scale smart grid. The national government, along with some of the key state governments, now has a variety of programs underway – with millions of smart meters rolling out to homes and businesses (Behaim, 2017).

During the 2019 calendar year, some national governments and regional agencies will act in ways that further the smart grid. The hope is that the rest of the world will follow their lead (Feller, 2018). Figure 2 shows the different areas of application for different smart grid technologies through the network.

For most developing countries, renewable energy generation is not a top priority, as they are more concerned with achieving universal energy access. Nevertheless, the potential for applying smart grid technology in developing countries is increasingly being explored (Emodi, 2019). Most case studies published on the topic of smart grids in developing countries so far focused on more emerging economies, such as India, Brazil, and Mexico. As of yet, very little experience has been gathered with smart grid technology in the world's least economically developed nations (National Institute of Standards and Technology, 2020).

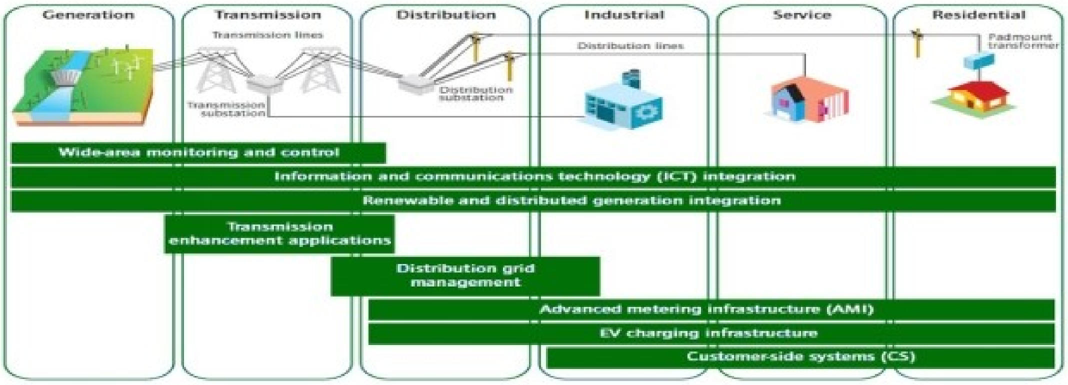


Figure 2: Smart grid technology areas (Amuta, 2018).

However, smart grid technology presents many advantages for improving grid performance and increasing energy access in these less developed economies. Most developing countries still have largely underdeveloped grid networks, giving them the opportunity of leapfrogging in terms of technical development and going straight for a smart grid network when expanding their infrastructure. Especially if the country is planning on expanding its renewable energy capacity, investing in smart grids technology will be advantageous, due to the increased flexibility and grid responsiveness gained (Kempener, 2019).

Nevertheless, smart grid projects in developing economies should be assessed and evaluated carefully, especially on a financial level, to ensure that the limited amount of capital available in these countries is invested wisely. Recovering the costs for smart grid investment might prove to be difficult in developing countries, due to the cap on the amount by which utility tariffs can be raised and still remain affordable for the majority of the population. It should, however, be considered that smart grid technology is often mutually reinforcing, so that while initial investments may be quite high, future projects can easily build upon existing technology, thus reducing their payback time(IEA, 2017). Table 1 summarizes some of the opportunities and challenges which smart grids present for developing countries.

Table 1: Opportunities and challenges for developing countries (Behaim, 2017)

Opportunities	**Challenges**

Early stage grid development allows developing countries to technology 'leapfrog' and directly install smart grid technologies when building up their T&D network.	Utilities in developing countries are often capital-constrained, limiting their ability to invest into smart grid projects, even if they are economically viable.
Potential for innovative energy services such as linking payments to the mobile communications network, installing local charging stations, or using mini/micro grids for rural electrification.	Upper cap on the utility tariffs which can be charged so as still to remain affordable for the users. Therefore, difficult to retrieve O&M for the system.
Reduce technical and power theft losses in the power network. By recording electricity loads across the power lines smart grids can be used to track and reduce these losses.	Lack of detailed data, for example of the systems operation and consumer demographic. This kind of data is not readily available in all developing countries.

Another likely challenge is that regulatory and institutional issues may also limit innovation. For example: regional standards, harmonizing of different power networks, ensuring data privacy (Ataul, 2019).

3. ADOPTION OF SMART GRID TECHNOLOGY IN THE NIGERIA ELECTRICITY NETWORK

3.1 Basic Elements

Smart grid enhances both power distribution and power management by providing distributed intelligence - and enabling a measure of control (Electrical Power Engineers, 2020). The end result is more cost-efficient delivery of power, based on true demand. For a smart grid to work effectively, it requires some key working elements that can be synchronized (Feller, 2018):

- Interoperability across multiple vendors.
- Protection of data & system integrity.
- Support for many types of media.
- Rapid collection and analysis of massive quantities of data.
- Connectivity to and from millions of devices.
- Rapid response to "busty" event–related message data.
- Convergence of multiple existing networks.

The information obtained from adopting a smart grid network can serve multiple stakeholders for multiple purposes. Smart grid information can help providers determine pricing structures, moving from flat rates to usage-based rates, for example. Additionally, a smart grid network can be deployed to allow power consumers the opportunity to monitor their rates and adjust or schedule peak usage accordingly (Electrical Power Engineers, 2020).

Smart grids can vary significantly in terms of their design and layout. The one critical component which sets a smart grid apart from the usual grid is that it includes some form of communication network in addition to the traditional power network (Behaim, 2017). The number of different smart grid technology and appliances available is rapidly increasing. Some of the most commonly implemented smart grid technologies include (Amuta, 2018):

- Advanced Metering Infrastructure (AMI), including smart meters, in home displays, servers, and relay, communications equipment to improve revenue collection, combat electricity theft, and receive outage notification as well as service and maintenance scheduling.
- Advanced electricity pricing, often including more complex tariff structures to influence consumer behavior.
- Demand response, using AMI to target the consumer's control over systems and devices, thus being able to shift peak loads, increase the system flexibility and make use of cheap time-of-use tariffs.
- Distributed automation which uses automated re-closers, switches, capacitors, remote-controlled distributed generation and storage, transformer sensors, as well as wire and cable sensors to allow for an automated control of the grid during various scenarios.
- Renewable resource forecasting, whereby weather forecasting is used to predict the future availability of renewable power on the network.
- Smart inverters which are digital inverters with a programming interface capable of sending and receiving information.
- Distributed energy resources, including power conditioning equipment and communications and control hardware for grid/off-grid power generation technology.
- Distributed storage including power conditioning equipment and communications and control hardware for storage technology or power conversion technologies.
- Transmission enhancement, using superconductors, Flexible Alternating Current Transmission System (FACTS) and High Voltage Direct Current (HVDC) to improve network stability and automated recovery.

3.2 The Benefits of Mass Adoption of Smart Grid

When implemented effectively, and combined with increased renewable energy capacity, smart grids can bring along many benefits in Nigeria, especially in terms of reducing power outages and electrical losses in the system (Kempener, 2019). Table 2 lists the main benefits, as determined by the International Renewable Energy Agency study on smart grid in developing countries. Most of the benefits will be experienced by the utility and by society in general. However, the main benefit which can be expected from the smart grid is a reduction in power outages, which will mostly be of advantage for electricity customers in Nigeria (Olusola, 2019).

Table 2: Benefits of mass adoption of smart grid (Behaim, 2017).

Rank	Benefit	Primary Beneficiary
1	Reduced sustained outages	Costumers
2	Reduced electricity losses	Utility
3	Reduced CO_2 emissions	Society
4	Reduced ancillary service costs	Utility
5	Deferred distribution investments	Utility
6	Reduced SOx NOx and PM10 emissions	Society
7	Reduced equipment failure	Utility

3.3 The Driving Factors for the Adoption of Smart Grid Technology

The smart grid technology will operate in a duplex communication system, encouraging better efficiency and it has been reported as a win-win situation for stakeholders (Amuta, 2018). Consumers will get involved in power management decisions with the aid of household devices which will also profit Utilities in the long run. Initial cost estimates are huge but with returns on better efficiency and improved billing systems alongside many other improvements, will serve as factors that will aid mass adoption in Nigeria (Olusola, 2019). The driving factors for the adoption of smart grid technology include:

- *Reliability improvements:* Smart grid technologies, if deployed in an integrated power grid, can improve the reliability and quality of power supply. With digital technologies increasingly ubiquitous, uninterrupted power supply with consistent voltage, frequency, and related characteristics is increasingly important to individual homes and business operations as well as the productivity of the economy as a whole (William, 2019).

- *System efficiency improvement:* A smart grid helps manage customer loads and system assets in a more coordinated fashion, such that the system can provide more useful energy services from its total asset base (Amuta, 2018). It also reduces system inefficiencies and operating costs. Smart grid designs can resist both physical and cyber attacks. Sensing, surveillance, switching, and intelligent detection, analysis and control software can be built into grid operations to detect and respond to threats. This can make grid systems more resilient, with self-healing technologies that can respond faster and with less impact to human-made and natural incidents (William, 2019).
- *Revenue collection and assurance improvements:* A smart grid can help enable markets that give consumers greater access to competitively provided energy and related services, from unregulated power purchasing to enhanced information, communication, and control features (Amuta, 2018). The smart grid can provide consumers information that helps them modify how they use and purchase electricity. It can provide them choices, incentives, and disincentives in their purchasing patterns and behavior, which in turn can help drive new technologies and markets (Olusola, 2019). Smart grid will be able to curtail time of used energy pricing so that price of energy during high demand periods is comparatively higher than that of low demand periods (William, 2019).
- *Renewable energy standards or targets:* Smart grids can help through automation of control of generation and demand (in addition to other forms of demand response) to ensure balancing of supply and demand in the integration of renewable and distributed energy resources—encompassing large scale at the transmission level, medium scale at the distribution level and small scale on commercial or residential building (Olusola, 2019).
- *Economic advantages:* From The significance of the smart grid potentials and its technologies highlighted, it is crystal clear that the smart grid technology has better potentials to make the Nigeria grid network more cost-effective, energy-efficient and reliable hence providing polished power system with active

consumers participation thereby improving the economy of the country (Amuta, 2018).

- *Generation Adequacy:* The smart grid will absolutely fuse many types of electrical generation and storage systems with an easier interconnection process that is equivalent to a “plug and play” technology of the retail computer industry and accommodate all generation and storage options (Ataul, 2019).

Figure 3 below shows the motivating driving factors for the deployment and adoption of smart grid technology based on priority.

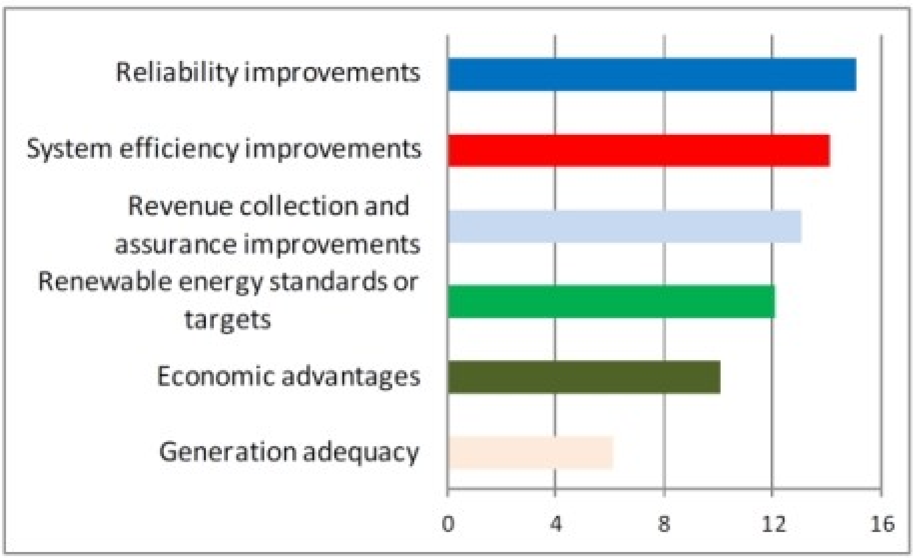


Figure 3: Smart grid technology motivating drivers (United Nation Economic Commission for Europe, 2020).

4. CONCLUSION AND RECOMMENDATION

This brief overview of smart grid technologies in developing countries like Nigeria shows that while there is a potential for smart grid development, projects implemented in Nigeria need to be planned and assessed carefully due to different expectations and requirements from smart grid technologies. It should also be ensured that the roll out of smart grid technologies is tailored to the needs of the electricity network in Nigeria, so as to prevent ineffective investments of already limited capital. The studies reviewed in this article indicate that the main drivers for smart grid adoption and development in Nigeria are reliability, efficiency and revenue collection improvements. The integration of renewable energy generation, as well as opening new markets and increasing customer flexibility are much less of a priority for a place like Nigeria than they are for developed countries.

5. ACKNOWLEDGEMENTS

This paper and research behind it would not have been possible without the exceptional support of my supervisor and mentor, Engr. Lucas Ibrahim. His enthusiasm, wealth of knowledge and exacting attention to detail has been an inspiration towards the final draft of this paper. I am also grateful for the insightful comments and corrections offered by Engr. Kishak Cinfwat after reviewing the manuscript. Finally, I will like to express my profound gratitude to Engr. Pastor. Olakunle Johnson, Engr. Yakubu Ashoms and Engr. Dr. Meshak Alfa, for their support in making this paper a reality.

REFERENCES

Amuta ELizabeth, S. W. (2018). Smart Grid Technology Potentials in Nigeria: An Overview. *13*, 1191-1200.

Ataul Bari, J. J. (2019). Challenges in the Smart Grid Application: An overview.

Behaim, J. V. (2017). *Smart Grid Performance in Developing Countries.* England: Energypedia.

Electrical Power Engineers. (2020). *Smart Grid Development.* Retrieved 2021, from https://www.epeconsulting.com/

Emodi Nnaemeka Vincent, S. D. (2019). Integrating Renewable Energy and Smart Grid Technology into the Nigeria Electricity Grid System. *5*.

Feller, G. (2018). *What Next for Smart GRid Development?* Califonia: T&D World.

IEA. (2017). How2Guide for Smart Grids in Distributed Networks.

International Communication Union. (2020). *Smart Grid Overview.* Geneva: Telecommunication Standardization Sector.

Kempener, R. (2019). Off-Grid Renewable Energy Systems: Status and Methodological Issues.

National Institute of Standards and Technology. (2020). *NIST Framework and Roadmap for Smart Grid Interoperability Standards.*

Olusola Bamisile, H. Q. (2019). Smart Micro Grid: An Immediate Solution to Nigeria's Power Sector Crisis.

United Nation Economic Commission for Europe. (2020). Electricity System Development: A focus on smart grids.

William Prindle, M. K. (2019). Succeeding in the Smart Grid Space by Listening to Customers and Stakeholders.

UPGRADING OF NIGERIAN OILSAND IN THE PRESENCE OF COMMERCIAL FLUID CATALYTIC CRACKING CATALYST

[1,2]P .O Nwosibe,, [1]S. M Shuwa, [1]A .Y Atta, [1]B .Y Jibril
[1]Department of Chemical Engineering, Ahmadu Bello University, Zaria
[2]Department of Chemical Engineering, Federal Polytechnic, Kaduna
Correspondence: patnwosibe@gmail.com., 08037710269

ABSTRACT

Catalytic upgrading of heavy and extra-heavy oil is being explored worldwide as one important in-situ upgrading technology among others. In this study, an equilibrated FCC catalyst (E-CAT) was sourced from a refinery, characterized using XRD, XRF and FT-IR techniques and tested in upgrading heavy crude oil. The FCC (Fluid Catalytic Cracking) equilibrated commercial catalyst, hydrogen and glycerol were added into bitumen (32000cSt measured at 40ºC) in a high-pressure batch reactor at 350ºC for reaction time of two hours, pressure of 10bar and catalyst to bitumen ratio of 0.02. Viscosity reduction after thermal upgrade were 83 and 98% at room temperature and at 40ºC respectively while the reduction after catalyst upgrade were 87.9 and 98.9% under the same conditions. It was found that there was improved API gravity from 11.6 to 26.6 in thermal reaction and 31 in catalytic reaction. Other physiochemical properties of the bitumen investigated also improved significantly towards the production of lighter oil. The structural composition of the bitumen before and after the reaction at 350ºC were investigated using FT-IR and GC-MS. The result shows that the heavy molecular compounds like resins and asphaltene were broken down to lighter compounds.

Keywords: Oilsand, FCC catalyst, heavy oil, catalytic upgrade, bitumen

1. INTRODUCTION

Owing to increasing global demand for crude oil and its allied products and subsequent decline in conventional crude reserves, it becomes imperative to search for alternative sources of crude oil to meet the rising global demand for the next decades (Ado et al. 2018). Heavy oil, extra heavy oil, bitumen and oilsand are some of the alternatives that are attracting attention of researchers. Although, there is a global effort to deviate into renewable energy, fossil fuel and its allied products would continue to play a major role in the global energy demand for the next few decades (Alaei et al. 2017).

Conventional crude oils have high mobility due to their low viscosity, while oilsands and bitumen have limited movement in the underground reservoir because of their excessive viscosity.

Therefore, in comparison to light crudes, oilsands and bitumen are harder to explore and more expensive to recover and upgrade mainly due to their high viscosity, low API gravity, high asphaltenes, heteroatom, and heavy metals (Deniz-Paker and Cinar 2017).

Heavy oil reserves are about 6 trillion barrels worldwide mainly located in Canada, Venezuela, Russia and the USA (Lakhova et al., 2017). Production of these resources in Canada is about 2 million Barrels of Oil Per Day (Yuning *et al*,2017)Venezuelan extra heavy crude hovers around 1 million Barrel of Oil Per Day (Abu *et al*,2010). In order to optimize production, more advanced production approaches need to be undertaken like; Enhanced Oil Recovery and inclusion to production quota of countries where hitherto do not utilize these resources.

Nigeria with proven oilsands bitumen of about 38 billion barrels becomes the sixth largest country in the world (Ogiriki et al. 2018). Unfortunately, this large deposit has remained untapped till date even though it has been established to have similar chemical compositions like Alberta's (Victor-Oji et al. 2017).

Catalysts are required in heavy crude oil/bitumen/oilsand upgrading to provide a pliable route for asphalthene cracking-hydrogenation reactions leading to increased lighter hydrocarbon yield and reduce coke formation. Dual functional metal on oxide support is eminently used as a typical catalyst since the metal-site provide the hydrogenation function while the oxide provides the cracking function which severity depends on the acidity of the oxide.

Consequently, zeolite-based catalysts produce results with greater cracking activity due to their higher acidity. Williams and Chishti (2000) pyrolysed Kark oil shale from the Kohat basin area of northern Pakistan using zeolite ZSM-5 at temperatures between 400 to 550ºC with significant increase in concentrations of single ring aromatic compounds and polycyclic aromatic hydrocarbons like; naphthalene, biphenyl and phenanthrene, attributed to aromatisation reactions of zeolite. On the other hand, Kuznicki et al (2007) successfully reduced the viscosity of North America oilsands alongside metals, nitrogen and sulfur at 400ºC with natural zeolite upgraded with raw high sodium chabazite ore. They compared their results at similar conditions with thermal cracking to attain a viscosity reduction of 88.7% for the latter and 96.7% for the former, a marked 8% difference.

Due to intense pressure on development of renewable energy sources, biomass and bio-oil have tried to replace zeolite from oilsand/bitumen upgrading. Various reviews abound (Fan et al., 2017; Galadima and Muraza 2017; Why et al., 2019; Ahmed et al., 2020; Scarsella et al., 2020) from fast pyrolysis of lignin, liquefaction of algae and bio-oil upgrading, to co-pyrolysis of biomass.

Irrespective of this deviation, researchers have continually explored various methodologies and zeolite combinations i.e., combination of zeolite with metal supports Particularly, Fluid Catalytic Cracking (FCC) unit catalysts in conventional refineries are being explored for heavy crude/ bitumen/ oilsand upgrading into conventional fuels and chemical feedstocks. In this respect, Zhang et al. (2017) converted Canadian oilsand bitumen via integrated cracking and coke gasification in a fluidized bed reactor with FCC and zeolite bifunctional catalysts at 510 ºC. They successfully converted high molecular weight hydrocarbons into gas and coke with 78 wt% liquid yield on both catalysts as the zeolite bifunctional material exhibited heightened coke gasification owing to its developed pore structures. Similarly, Meng et al. (2019) designed a core-shell zeolite catalyst with hierarchical pore network to facilitate FCC processing of VGO heavy oil.

Therefore, in this work we attempt to upgrade Nigerian oilsand for the first time over a commercial equilibrated FCC catalyst (E-CAT) at temperature lower than the visbreaking temperature of bitumen. Successful implementation of this study is expected to prologue investigation into catalytic upgrading of Nigerian oilsand with used FCC catalysts.

2. MATERIALS AND METHODOLOGY

2.1 Materials

The fresh oilsand was sourced from Agbabu in Ondo State, Nigeria. FCC equilibrated catalyst from Kaduna Refinery and Petrochemical Company (KRPC), and hydrogen gas purchased from BOC gas Ltd.

2.2 Catalyst characterization

X-ray diffraction (XRD) was conducted using a Rigaku miniflux II X-ray diffractometer with Cu k radiation. The anode operated at 40Kw and 40 mA X-Ray. E-CAT was scanned in a continuous mode at wavelength Kalpha =1.540562 and Kbeta =1.3922182.0 from 20º to 50º at scanning speed of 12º/min. The pattern was compared to that of commercial zeolite-Y catalyst supplied from Zeolyst.

Also, X-ray Fluorescence was carried out using an XRF thermos scientific Niton analyser with model number XL3t 950. The FTIR analysis of the catalysts was carried out using an Agilent CAIY 630 FTIR machine.

2.3 Upgrading Experiment

A mass of 100 g of fresh oilsand was measured and charged into the high-pressure batch reactor followed by 2 g E-CAT for the catalytic reaction. The set up was pressurized with hydrogen to an initial pressure of 6 bar after which the hydrogen sourced was disconnected. The reactor was then switched on with the stirrer set at 120 rpm and temperature at 350 ºC. The reaction was allowed to proceed for 2 hours after attaining the set temperature before the reactor was turned off and allowed to cool via natural convection.

Thereafter, the reaction product was collected for analysis. For the thermal cracking the experiment was carried out at similar conditions and procedures without catalyst.

2.4 Product Analysis

Changes in functional group of the compounds in the oilsand after upgrading were analysed by FT-IR. GC-MS analysis was carried out using a Varian 3800 gas chromatograph equipped with Agilent MS capillary column (30 m × 0.25 mm i.d.) linked to a Varian 4000 mass spectrometer functioning in the EI mode. The column conditions and temperature program were reported in our previous work.

The quantity of coke produced after upgrading was obtained by dissolving 1.0 g of the resulting crude in 40 ml Dichloromethane. The mixture was stirred for 10 minutes and stored away from sunlight for 24 hours, following separation with a 2 µm filter paper (Onoriode et al. 2019). Likewise, the asphalthene fraction was removed by dissolving 500 mg of crude in 40 ml n-heptane. The solution was stirred and allowed to stand for 24 hours, and then the precipitate was filtered and weighed (Rudzinski et al. 2000).

The viscosity of the upgraded oilsand was measured using the DV-1 digital viscometer machine. Flash point and fire point were analyzed using the SYD-3536 Cleveland Open-Cup Apparatus with a cup, thermometer and bunsen burner, while pour point was determined using the automatic ASTM D5949 Method. Also, the specific gravity was calculated from the API as shown below;

API = 141.5/SG -131.5 where SG is Specific gravity

3. RESULTS AND DISCUSSION

3.1 FCC equilibrated catalyst

Figure 1 shows the X-ray powder diffraction pattern of the E-CAT compared to zeolite Y. The latter has the characteristic peaks of zeolite Y even though the intensity of the peaks assigned to E-CAT is generally lower possibly due to the presence of other components in the catalysts.

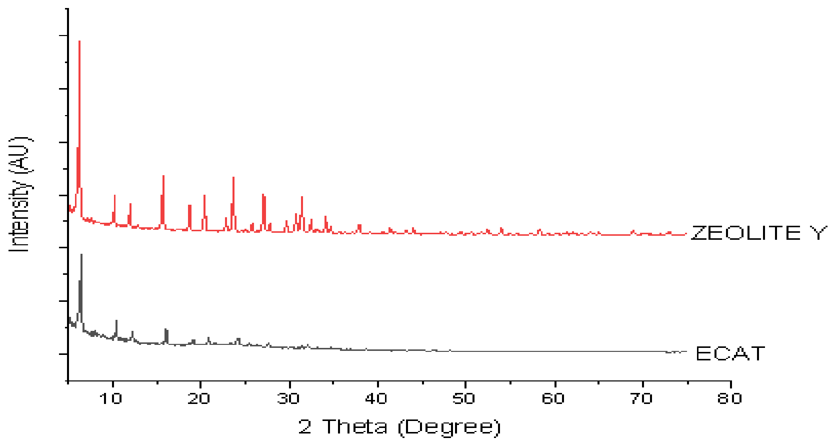


Figure 1: XRD patterns of zeolite Y and E-CAT

The XRF measurements further supplement the crystallography by providing spatial information on the quantification of oxides present in both catalysts. As previously suspected, oxides of phosphorus, chromium, manganese, zinc and strontium present in the E-CAT were the reason for lower intensity compared to zeolite Y as indicated in Table 1. Sequentially, the Si/Al ratio of pure zeolite Y is higher than E-CAT as equally observed by Hollander et al., 2002.

Table 1: Oxide composition of E-CAT and zeolite Y analyzed by XRF

OXIDE	E-CAT (wt %)	ZEOLITE-Y (wt %)
Na_2O	0.20	1.68
MgO	0.38	0.13
Al_2O_3	43.36	21.77
SiO_2	51.55	75.96
P_2O_5	0.49	0.00
SO_3	0.17	0.30
Cl	0.00	0.07
K_2O	0.03	0.02
CaO	0.02	0.02
TiO_2	2.86	0.02

Cr_2O_3	0.09	0.00
Mn_2O_3	0.02	0.00
Fe_2O_3	0.81	0.03
ZnO	0.01	0.00
SrO	0.01	0.00
Si/Al ratio	1.19	3.49

In the same vein, FT-IR analysis of both catalysts showed that zeolite-Y and E-CAT are significantly similar particularly in the region of 900 – 1200 cm^{-1} absorption bands representative of stretching and bending modes of Si-O or Al-O frameworks.

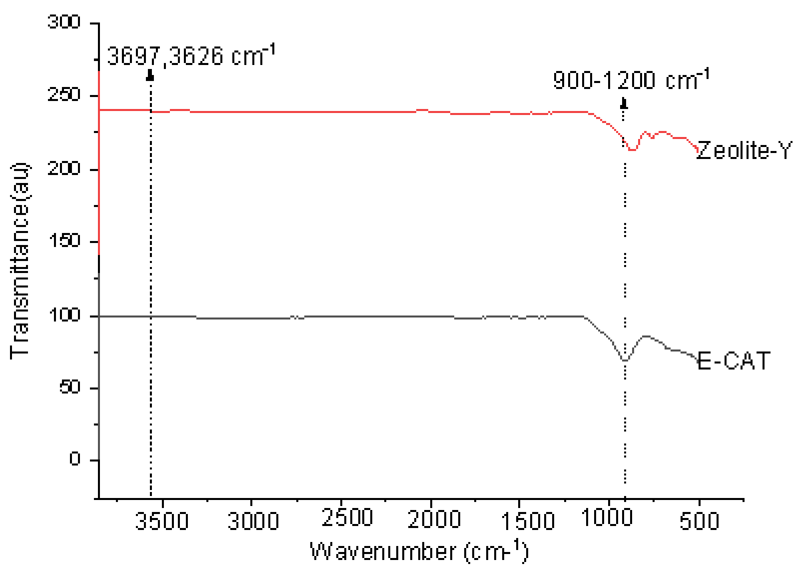


Figure 2: FT-IR spectra of zeolite Y and E-CAT

Subsequently upgrading of Nigerian oilsand with the E-CAT results in 87.9% viscosity reduction as against 83.1% via thermal cracking with API gravity increase from 11.6 for fresh oilsand to 26.6 for thermal cracking and 31 for catalytic.

Table 2: Viscosity of oilsand samples

Samples	Viscosity (cSt)	API gravity
Fresh oilsand	33,000	11.6
Thermal cracking	5561	26.6
Catalytic upgrading	4000	31

Physiochemical analysis which entails flash point, fire point and pour point are relevant in determining the quality of oilsands/bitumen. Flash point could be defined as the lowest temperature at which a liquid will form ignitable vapour in the air near its surface on exposure to open flame; likewise, fire point is the lowest temperature at which the vapour will continue to burn for at least 5 seconds after ignition. Pour point on the other hand is the temperature below which a liquid loses its flow characteristics.

The lowest flow temperature of the catalytic upgraded oilsand was 30 ºC compared to 35 ºC for thermal cracking from 42 ºC for the fresh oilsand which is a direct implication of the viscosity reduction. Likewise, the flash point and fire point temperatures follow similar trend of catalytic < thermal < fresh oilsand corroborating the API gravity increase from fresh to catalytic upgraded oilsand.

Table 3: Physiochemical analysis of the oil samples

Test	Fresh oilsand	Thermal cracking	Catalytic upgrading
Flash point (ºC)	240	200	180
Fire point (ºC)	260	230	210
Pour point (ºC)	42	35	30

Another significant analysis is the coke and asphalthene contents during upgrading. After thermal upgrading 21 wt% coke was formed compared to 10 wt% during catalytic reaction, while the asphalthene was cracked to lighter components from 34 wt% in the fresh oilsand to 14 wt% in thermal upgrading and 10 wt% in during catalytic reactions. These lighter components formed were significant in reducing the flash and fire point temperatures of the upgraded oilsand as well as improving the viscosity and API gravity of the catalytic upgraded oilsand.

Table 4: Coke and asphalthene contents of the oil samples

Samples	Coke (wt %)	Asphalthene (wt%)
Fresh oilsand	-	34
Thermal cracking	21	14
Catalytic upgrading	10	10

FT-IR

The FT-IR spectrum of bitumen before and after upgrading were used to analyse the variation of structures from the view of molecules as shown in Figure 3. The peak 697cm^{-1} assigned to C-S bond in the bitumen was weakened after the upgrading reaction. Notably, the extent to which the C-S bond was broken in the heavy oil after catalytic upgrading reaction was greater than that of heavy oil after thermal upgrade. Besides the peak at 2855.1cm^{-1} and 2922.2cm^{-1} assigned to methylene were weaker in the bitumen after the reaction (Jingling *et al*., 2019). This implies that dealkylation went on during the upgrading process. The peaks 3619.2 cm^{-1} and 3697.2 cm^{-1} assigned to large OH molecular compounds in the raw bitumen were missing in the upgraded ones while lighter compounds have been formed indicating the conversion of the bitumen to light oil. The peak 3399.3 which represents aliphatic amine and 2139.8 and 2072.4 assigned to unsaturates alkenes were also broken down. Notably the peak 1208.7 assigned to sulphur compound has been eliminated which confirms the cracking of resins and asphaltene compounds which accounts for the heaviness in the bitumen.

Finally, the major difference between the thermal and catalytic upgraded bitumen is the compound N=C=S with peak number 2072.4 which is found in the thermally upgraded oil but absent after catalytic upgrade.

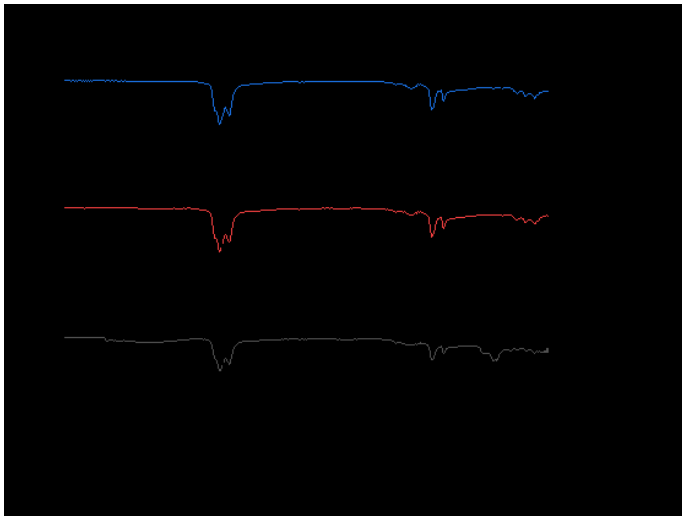


Figure 3: FTIR spectra of fresh and upgraded oilsand

In order to elucidate the extent of upgrading in a bid to analyze the types of components formed during cracking, GC-MS analysis was performed on the fresh oilsand, thermally cracked oilsand and catalytic upgraded oilsand. Results show that the fresh oilsand contains heavy heteroatoms (N and O) and acidic compounds (Smith et al., 2008) with Si from clay particles identical of typical oilsand bitumen. Conversely, after upgrading pure aromatic compounds were formed with combined 12.02 wt% for thermal cracking and 17.8 wt% during catalytic upgrading. It is pertinent to state here that the GC method employed elutes both pure aromatic and polar aromatic compounds up to unsaturated compounds (Onoriode et al., 2020).

Table 5: GC-MS analysis of fresh oilsand

Ret. time	Weight % m	Rel. area %	Nomenclature	Mol. formula
5.01	2.74	4.22	Cyclopentane,1,3-dimethly –cis	C_9H_{14}
6.42	6.43	6.09	Hexane,3-methly-	C_7H_{16}
7.92	0.86	6.60	Acetic acid chloroethyl esther	$C_4H_7ClO_2$
9.34	0.11	7.65	1,4,Bistrimethylsilyl benzene	$C_{12}H_{22}S_{i2}$
10.68	0.88	8.71	Oxirane,hexadecyl	$C_{18}H_{36}O$
11.93	7.68	9.76	n-nexadexanoic acid	$C_{16}H_{32}O_2$
14.26	9.76	14.25	Tetrasiloxane decamethyl	$C_{10}H_{30}O_3S_i$
15.31	21.01	8.41	Oleic acid	$C_{18}H_{32}O_2$

16.26	8.0	8.81	Octadenoic acid	$C_{18}H_{36}O_2$
17.18	3.42	7.65	Cylobabitol	$C_{12}H_{10}N_2O_3$
18.06	1.92	6.33	2-Octantal	$C_8H_{14}O$
18.98	0.93	5.81	4-chlor-2,4dimethylhexane	$C_8H_{17}Cl$
19.72	1.0	4.75	Tetradecanoic acid	$C_{14}H_{28}O_2$
22.0	0.30	0.50	Dedecanoic acid	$C_{12}H_{24}O_2$
28.96	0.30	0.26	Octadecaene	$C_{18}H_{36}$

Table 6: GC-MS analysis of thermally cracked oilsand

Ret. time	Weight % m	Rel. area %	Nomenclature	Mol. formula
4.96	5.77	6.25	Toluene	C_7H_8
6.29	4.41	3.61	Benzene	C_6H_6
7.82	1. 84	1.80	Styrene	C_8H_8
9.31	3.42	1.08	Butanol 2,2 dimethyl	C_6H_{14}
9.70	3.41	1.68	3,5-Dimethoxycinnamic acid	$C_{11}H_{12}O_8$
11.80	3.40	2.89	1-butane 1- phynol	$C_{10}H_{12}O$
11.92	1.99	1.68	1-heptene	C_7H_{14}
14.26	7.11	1.68	Octan- 4-ethyl	$C_{10}H_{42}$
15.24	2.98	2.16	Undecane	$C_{11}H_{24}$
16.61	2.98	2.28	4-Hydroxy-2-methoxycinnamaldehyde	$C_{10}H_{10}O_3$
16.79	2.01	4.89	Pyridine	C_5H_5N
17.11	7.13	3.37	2,5- dimethyl furan	C_6H_8O
17.97	4.27	3.31	Cyclopentanone,2-methyl	$C_6H_{10}O$
19.00	11.57	4.33	Phenol	C_6H_6O
19.96	6.41	5.05	1,2-Benzenedicarboxylic acid	$C_8H_6O_4$

20.32	3.93	8.17	Phenol, 2,3,6-trimethyl-	$C_9H_{12}O$
21.10	0.18	8.89	Aniline	C_6H_7N
21 .98	12.71	12.02	n- Hexadecanoic acid	$C_{16}H_{32}O_2$

Table 7: GC-MS analysis of catalytic upgraded oilsand

Ret. time	Weight % m	Rel. area %	Nomenclature	Mol. formula
5.00	7.77	3.30	Benzene	C_7H_6
6.42	3.02	4.61	Toulene	C_7H_{18}
7.42	1.44	1.02	Styrene	C_8H_8
7.92	2.81	5.22	o-xylene	C_8H_{10}
9.34	2.29	2.29	n-prophyl benzene	C_9H_{14}
9.98	2.76	6.04	1-butanol -1phenol	$C_{10}H_{12}O$
10.26	2.0	1.43	Naphthalene,1,6-dimethyl-	$C_{12}H_{12}$
10.68	7.11	6.61	Phenanthrene	$C_{14}H_{10}$
11.31	0.98	4.19	9,10-dihydroanthracene	$C_{14}H_{12}$
11.98	2.59	7.45	p- cresol	$C_{10}H_50$
12.84	2.01	2.10	1- naphthol	$C_{18}H_{12}$
13.28	7.13	7.34	Chrysene	$C_{10}H_{12}O_2$
13.34	2.11	2.84	Isoeugenol	$C_{10}H_{12}O_2$
14.26	5.96	7.24	Phenol	C_6H_6O
15.30	7.15	6.61	1,2-Benzenedicarboxylic acid	$C_8H_6O_4$
16.32	6.77	6.50	Phenol, 2,3,6-trimethyl-	$C_9H_{12}O$
17.21	7.54	6.08	Aniline	C_6H_7N
18.66	12.90	5.35	n- Hexadecanoic acid	$C_{16}H_{32}O_2$
18.98	4.43	4.51	Diethyl phthalate	$C_{12}H_{14}O_4$
19.74	2.61	3.81	3,5-Dimethoxycinnamic acid	$C_{11}H_{12}O_4$

Consequently; phynol, phenol and 2,5 – dimethyl furan were classified as unsaturated compounds. With this classification, unsaturates formed weighed a combined 26.03 wt% for thermal cracking and 18.08 wt% for catalytic upgrading. This result summarized the effect of the E-CAT in cracking asphalthene to more aromatics and less unsaturated hydrocarbons.

4. CONCLUSION AND RECOMMENDATION

Nigerian oilsand was selectively cracked and obtaining lower viscosity, asphalthene and coke, and higher API gravity as equally manifested in lower flash, fire and pour point. Although, resins were present in significant quantity in the upgraded oilsand, the equilibrated catalyst promotes aromatization and hydrogenation of unsaturated compounds. Meanwhile, in the investigation of biomass, ZSM-5 zeolite and rice husk which was also a source of hydrogen proved to be typical catalysts for oilsand upgrading by reducing the reaction time compared to pyrolysis and application of glycerol and sawdust. Although secondary cracking reaction was severe when rice husk was combined with ZSM-5 zeolite due to higher acidic sites, increased saturates hydrocarbons were formed during pyrolysis and application of rice husk and ZSM-5 zeolite.

.

5. ACKNOWLEDGEMENTS

Special thanks to the management of PTDF laboratory Department of Chemical Engineering Ahmadu Bello University Zaria

REFERENCES

Abu S.M. Junaid, Wei Wang, Christopher Street, Moshfiqur Rahman, Matt Gersbach, Sarah Zhou, William McCaffrey, and Steven M. Kuznicki. Viscosity Reduction and Upgrading of Athabasca Oilsands Bitumen by Natural Zeolite Cracking. World Academy of Science, Engineering and Technology International Journal of Materials and Metallurgical Engineering 4 (9) 2010

A. S. M. Junaid, M. M. Rahman, G. Rocha, W. Wang, T. Kuznicki, W. C. McCaffrey, and S. M. Kuznicki. On the Role of Water in Natural-Zeolite-Catalyzed Cracking of Athabasca Oilsands Bitumen. Energy Fuels 2014, 28, 3367−3376

Ahmad Galadima, Oki Muraza. Hydrothermal liquefaction of algae and bio-oil upgrading into liquid fuels: Role of heterogeneous catalysts. Renewable and Sustainable Energy Reviews 81 (2018) 1037–1048

Bernard A. Goodman. Utilization of waste straw and husks from rice production: A review. Journal of Bioresources and Bioproducts 5 (2020) 143–162

Donald F. Smith, Tanner M. Schaub, Sunghwan Kim, Ryan P. Rodgers, Parviz Rahimi, Alem Teclemariam, Alan G. Marshall. Characterization of Acidic Species in Athabasca Bitumen and Bitumen Heavy Vacuum Gas Oil by Negative-Ion ESI FT−ICR MS with and without Acid−Ion Exchange Resin Prefractionation. Energy Fuels 2008, 22, 4, 2372–2378

Elaine Siew Kuan Why, Hwai Chyuan Ong, Hwei Voon Lee, Yong Yang Gan, Wei-Hsin Chen, Cheng Tung Chong. Renewable aviation fuel by advanced hydroprocessing of biomass: Challenges and perspective. Energy Conversion and Management 199 (2019) 112015

Kharisov, B.I., González, Má.Oliva., Quesada, T.S., de la Fuente, Idalia.Gó., Lonoria, F., Materials and nanomaterials for the removal of heavy oil components. Journal of Petroleum Science and Engineering 156 (2017) 971-982

Liangliang Fan, Yaning Zhang, Shiyu Liu, Nan Zhou, Paul Chen, Yanling Cheng, Min

Addy, Qian Lu, Muhammad Mubashar Omar, Yuhuan Liu, Yunpu Wang, Leilei Dai, Erik Anderson, Peng Peng, Hanwu Lei, Roger Ruan. Bio-oil from fast pyrolysis of lignin: effects of process and upgrading parameters. Bioresource Technology 241 (2017) 1118-1126

M.A. den Hollander, M. Wissink, M. Makkee, J.A. Moulijn. Gasoline conversion: reactivity towards cracking with equilibrated FCC and ZSM-5 catalysts. Applied Catalysis A: General 223 (2002) 85–102

Muhammad Rabiu Ado, Malcolm Greaves, Sean P. Rigby. Effect of pre-ignition heating cycle method, air injection flux, and reservoir viscosity on the THAI heavy oil recovery process. Journal of Petroleum Science and Engineering 166 (2018) 94-103

Mahshad Alaei, Mansour Bazmi, Alimorad Rashidi, Alireza Rahimi. Heavy crude oil upgrading using homogenous nanocatalyst. Journal of Petroleum Science and Engineering 158 (2017) 47–55

Melek Deniz-Paker, Murat Cinar. Investigation of the combustion characteristics of Bati Raman oil with sand. Journal of Petroleum Science and Engineering 157 (2017) 793– 805

Mohamed H.M. Ahmed, Nuno Batalha, Hasan M.D. Mahmudul, Greg Perkins, Muxina Konarova. A review on advanced catalytic co-pyrolysis of biomass and hydrogen-rich feedstock: Insights into synergistic effect, catalyst development and reaction mechanism. Bioresource Technology 310 (2020) 123457

Meng Pan, Jiajun Zheng, Yujian Liu, Weiwei Ning, Huiping Tian, Ruifeng Li. Construction and practical application of a novel zeolite catalyst for hierarchically cracking of heavy oil. Journal of Catalysis 369 (2019) 72–85

Oki Muraza, Ahmad Galadima. Aquathermolysis of heavy oil: A review and perspective on catalyst development. Fuel 157 (2015) 219–231

Onoriode P. Avbenake, Rashid S. Al-Hajri, Baba Y. Jibril. Catalytic upgrading of heavy oil using NiCo/γ-Al_2O_3 catalyst: Effect of initial atmosphere and water-gas shift reaction. Fuel 235 (2019) 736–743

Onoriode P. Avbenake, Rashid S. Al-Hajri, Baba Y. Jibril. Saturates and aromatics characterization in heavy crude oil upgrading using Ni–Co/γ-Al_2O_3 catalysts. PetroleumScienceand Technology. https://doi.org/10.1080/10916466.2020.1779743

Marco Scarsella, Benedetta de Caprariis, Martina Damizia, Paolo De Filippis. Heterogeneous catalysts for hydrothermal liquefaction of lignocellulosic biomass: A review. Biomass and Bioenergy 140 (2020) 105662

Paul T. Williams, Hafeez M. Chishti. Two stage pyrolysis of oil shale using a zeolite catalyst. Journal of Analytical and Applied Pyrolysis 55 (2000) 217–234

Shadrach Olise Ogiriki, Jennifer Oyindamola Adepoju, Adeyinka Sikiru Yusuff, Victor Anochie. Physical Properties of Agbabu and Yegbata Bitumen in Nigeria. Journal of Applied Science & Process Engineering 5 (1) 2018

Steven M. Kuznicki, William C. McCaffrey, Junjie Bian, Espen Wangen, Andree Koenig, Christopher C.H. Lin. Natural zeolite bitumen cracking and upgrading. Microporous and Mesoporous Materials 105 (2007) 268–272

Alfiya Lakhova, Sergey Petrov, Dina Ibragimova, Galina Kayukova, Aliya Safiulina, Alexey Shinkarev, Rachael Okekwe. Aquathermolysis of heavy oil using nano oxides of metals. Journal of Petroleum Science and Engineering 153 (2017) 385-390

Victor-Oji CO, Osuji LC, Onojake MC. Bulk Physiognomies and Sara Constituents of Bituminous Sands from Ondo State, Nigeria. J Pet Environ Biotechnol 2017, 8:4

Walter E. Rudzinski, Tejraj M. Aminabhavi, Steve Sassman, Linette M. Watkins. Isolation and Characterization of the Saturate and Aromatic Fractions of a Maya Crude Oil. Energy & Fuels 2000, 14, 839-844

Yuming Zhang, Lei Huang, Xiaochen Zhang, Guogang Sun, Shiqiu Gao, Shu Zhang. Upgrading of Canadian Oil Sand Bitumen via Cracking and Coke Gasification: Effect of Catalyst and Operating Parameters. Energy Fuels 2017, 31, 7, 7438–7444

Fan Nie, Demin He, Jun Guan, Kaishuai Zhang, Tao Meng, Qiumin Zhang. The influence of abundant calcium oxide addition on oil sand pyrolysis. Fuel Processing Technology 155 (2017) 216-224

Yisong Wang, Tao Du, He Jia, Ziyang Qiu, Yanli Song. Effect of extra-framework cation in ion-exchanged ZSM-5 from rice husk ash on CO_2 adsorption. Solid State Sciences 97 (2019) 105985

POWER QUALITY IMPROVEMENT OF GRID INTEGRATED RENEWABLE ENERGY SOURCE USING MODULAR MULTILEVEL CONVERTERS (MMC) TOPOLOGY

[1*]Orji Kingsley Ikechukwu, [2] B.O. Anyaka, [3] Uche Ogbuefi [4]Nwagbara Donatus

[1,2,3,4] Department of Electrical Engineering, University of Nigeria Nsukka, Enugu State, Nigeria.

[1]engrkingsleyorji@gmail.com [2]boniface.anyaka@unn.edu.ng [3]gladysagu555@gmail.com
[4]engr.donatus@gmail.com

ABSTRACT

Harmonics in renewable energy grid integration with conventional inverters has resulted to deterioration of power quality. This work tends to investigate the reduction of harmonics, using modular multilevel converter. The advancement of modular multilevel converter topology pave path for the realization of integrating renewable energy into the grid, with quality output, performance, high modularity etc. In view of these difficulties, this study offers a half bridge submodule (HBSM) converter based on width band gate (WBG). The switching module is controlled by the phase shifting carrier-based pulse width modulation (PSC-PWM) approach which is advantageous in terms of voltage quality and total harmonic distortion. The WBG switching module has reduced power losses and also has higher power efficiency. This research includes a closed loop control system that uses fast FCS-MPC also called indirect model predictive control this is used in order to maintain load voltage constant for under voltage and over voltage condition. The result obtained from the study shows a total harmonic distortion of 23.9%. This value stands better when compared with values obtain from other type of modulation techniques. Hence the integration of renewable energy in to the system.

Keywords: Modular Multilevel Converter, Power Quality, THD Optimization, Wide Band Gate.

1. INTRODUCTION.

The current utility grid is stressed and aged as a result of increased consumer burden, depletion of fossil fuels, lower generation efficiencies, transmission/distribution losses, and so on. These are causing frequent grid outages, which have become an impediment to a country's economic growth. Furthermore, government regulations for reducing carbon emissions encourage the use of alternative or renewable energy sources (RES). With this goal in mind, many decentralized RES-based microgrids are being formed all over the world through the use of power electronic conversion devices [1, 2, 3, 4, 5, 6]. Microgrids supplement conventional power systems through the philosophy of on-site power generation and also allow for the sale of excess power back to the utility grid. However, the power quality issue raised by intermittent RES and harmonic-prone power electronic inverters is the critical concern that denies the micro grid's fruitfulness [7, 8].A voltage, current, or frequency defect that causes consumer equipment to deteriorate is referred to as a power quality problem [9]. Grid integration with a simple two-level conventional inverter produces a square wave which is adequate for most sophisticated applications. In these cases, a perfect sinusoidal wave is preferred. Furthermore, the rated power of conventional converters is restricted by the rated power of the semiconductor devices utilized and the permissible switching frequency [9]. In renewable energy production systems, conventional inverters based on power-frequency transformers running at 50Hz and AC filters are commonly used to step up the voltage to grid voltage levels of 6-36KV and minimize voltage THD, respectively. Because of its great weight and large size, it necessitates a large investment and installation expense [10]. As new high-power semiconductor devices become accessible, new power converter topologies are being developed to meet the needs of future medium or high-voltage converter systems. Due to its excellent output performance, high modality, simple scalability, low voltage and current rating demand for the power switches, modular multilevel (MMC) converter topologies and circuits have sparked a lot of interest in this field [11, 12, 13]. It is also applicable to a wide range of medium and high voltage systems. [14, 15] provide an excellent overview of multilayer dc-ac power converter topologies. All of these approaches, however necessitate a high switching frequency which increases switching losses [16]. As a result, lowering the switching frequency is also critical for practical implementation [17]. Given the aforementioned challenges in current state of the art practices for obtaining quality power generation in microgrids, this paper proposes the design of a simple “half bridge submodule (HBSM) converter with phase-shifted carrier-based (PSC-PWM) topology” as shown in fig. 1. The major goal of this research is to achieve total harmonic using the suggested inverter architecture, which can improve power quality for microgrid applications which can improve power quality for microgrid applications, while also removing some of the inherent difficulties of conventional multilevel inverter topologies. From the submodule and overall topologies standpoint. Despite its low cost and limited DC fault tolerance [18, 19], the half-bridge submodule (HBSM) is widely used in commercial applications for a variety of two-level and multilevel topologies. In recent years, advanced overall topologies have been reported to suit application-oriented needs. The MMC control methods for output voltage and current regulation [20], submodule balance [21], and circulating current elimination [22] or injection [23] have all been developed and reported. Meanwhile, instead of utilizing a conventional proportional integral (PI) regulator or resonant controller, nonlinear and predictive controls [24] give a solution for improving the MMC dynamic response. On power semiconductors, the modulation techniques used by the power converter [25] have a direct impact on the output value and quality. This study considers a number of experiments that have been conducted to improve modulation approach. The forthcoming WBG technology [26] ushers in a revolution in power electronics, which is foreseen in the MMC application with power losses estimation using various modulation techniques.

2.1 Description of the system.

2.1.1Topology of the modular multilevel converter.

Figure 1a shows the three phase MMC configuration, which includes a DC terminal, an AC terminal and a converting kernel with three phase legs. Each leg/phase has two symmetrical arms, one upper and one lower. Each phase contains two arms. Each arm is made up of $\frac{n}{2}$ series linked submodules (SMs), where n is the number of SMs per phase and LMMC is the arm inductor. The direct current bus (DC-bus) voltage (U_{DC}) is divided evenly among all SMs, being the SM’s DC voltages with Vc equals to:

$$Vc = \frac{\mathrm{UDC}}{n/2} \qquad 1$$

Figure 1b shows the SMs of the MMC utilized in this work, which are half H-bridges. Two switches (IGBT and reverse diode) and a DC storage capacitor are included in each SM. The IGBTs are controlled by two complimentary signals S and S1, which represent the two possible output voltages of the SMs, VSM. When S =1, V_{SM} = Vc. If S = 0, V_{SM} = 0V. Therefore, the converter output voltages can take (n+1) voltage levels. Adding an additional SM to each arm improves the output voltage range by two voltage levels. The most common SM [27] is the half H-bridge topology, while there are alternative SM topologies that provide more output levels at the cost of increasing the number of components such as the full H-bridge, multilevel Neutral Point Clamped (NPC) or Flying Capacitors (FC) cells [28].

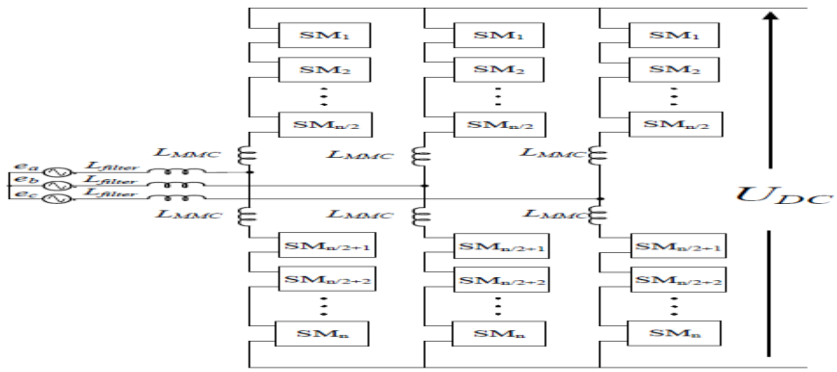


Figure 1a: Diagram of the modular multilevel converter (MMC)

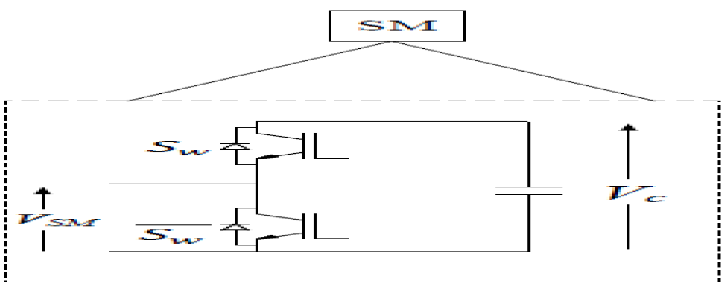


Figure 1b: Half – bridge submodule

2.12 The control strategy of the topology.

MMC's control strategies enable it to achieve great performance while maintaining exceptional safety, reliability and efficiency. As a switching converter, MMC is a nonlinear system with a number of coupled variables. Using linear principles, traditional control methods can be easily implemented in digital controllers. However, in terms of numerous control objectives such as AC current and voltage, leg/arm voltage and circulating currents these systems have a dynamic response limitation. Nonlinear and predictive control systems are interesting solutions for MMC applications to provide simultaneous control and dynamic response. Model predictive control (MPC) is a better choice for power converters as it is a nonlinear control method. The MPC approach can handle various constraints in a single cost function and provides fast dynamic response as well as robustness to parameter fluctuation and external interference. A typical prediction approach used in MMC control is finite control set MPC (FCS-MPC), also known as direct MPC. The computational cost of obtaining the best switching states is one downside of the FSC-MPC, which intensifies with the rising voltage levels. A fast FCS control technique is being investigated as a solution to this problem. Along with predictive control, fast FCS-MPC [29], also known as indirect MPC, remains the submodule balancing approach. The output and circulating currents are controlled using predictive control as the main controller. Meanwhile, the submodule balancing method is utilized as the secondary controller to balance the submodule voltages or SoCs within the arm. The computational effort of the indirect FCS-MPC is reduced to a great amount, as a result of only n+1 switching states must be assessed for the optimal cost function.

2.13 Modulation Techniques.

To generate a desired output voltage for the MMC. Many pulse width modulations (PWM) approaches have been devised. These modulation strategies can be characterized as high switching frequency PWM (HSF-PWM), low switching frequency (LSF-PWM), and fundamental switching frequency (FSF-PWM) modulation situations, depending on the switching frequency [30, 31]. The switching losses in semiconductor increase as the switching frequency rises. As a result, when a limited number of submodules are involved, the high switching frequency approach is commonly utilized, however when a large number of submodules are involved, the low switching frequency and fundamental switching frequency methods are used [32]. Carrier-based PWM is a common HSF-PWM method in which the modulation reference of each phase is compared with various carrier waveforms to provide the gating signals for multilevel converters [33]. As comparable carrier signals, triangular or sawtooth waveforms are commonly used. Phase-shifted carrier-based (PSC-PWM) and level-shifted carrier-based (LSC-PWM) approaches are two types of carrier-based modulation schemes that are based on the arrangement of multiple carriers [34]. The LSF-PWM system encompasses the switching frequency of space vector modulation (SVM). In SVM-PWM, it is desirable to choose the switching vectors and design the switching sequences with greater freedom. In the two-level converter, SVM-PWM has shown good performance with superior harmonic characteristics and DC-link utilization [35]. The SVM-PWM approach, on the other hand is difficult to execute in multilevel modulation due to the greatly increased computing cost and complexity [36]. Another low switching frequency modulation approach referred to sampled average modulation (SAM) has a similar process to SVM-PWM but with less computation complexity and simple implementation to multilevel converters with any number of submodules [37]. The command voltage is generated via SAM-PWM by averaging the two closest voltage levels and avoiding zero vectors in each sampling period. Nearest level modulation (NLM) is a prominent approach for fundamental switching frequency modulation

[38, 39]. The switching states and dwell period are directly obtained from the command voltage in this method which eliminates the need for carrier signals. It's simple to set up and use, especially in the case of MMC with a high number of submodules. Selective harmonic elimination (SHE) is another FSF-PWM technique. SHE-PWM [40] can provide high output voltage performance. However, due to the time-consuming calculation of significant switching angles with multilevel voltages, this strategy is difficult to execute.

2.14 Power Losses, Efficiency, Total Harmonic Distortion and Wide Band Technology

Wideband gap semiconductors based on silicon carbide (Sic) and gallium nitride (GaN) provide offer enhanced energy efficiency, high power density, and superior electrical and thermal conductivities [41, 42]. WBG transistors are predicted to take over a wide range of power conversion applications that have hitherto been dominated by traditional silicon-based power devices. In terms of applications with high power density, power loss calculation is crucial for thermal management and cooling. Conduction and switching losses are the two types of power losses in semiconductors. When compared to silicon-based modules, WBG power devices have a lower on-state resistance, which contributes to lower conduction loss.

The power losses calculation is carried out with the simulation model in MATLAB in order to examine the thermal performance of standard silicon-based semiconductors and WBG switching modules modulated by different modulation techniques for the MMC

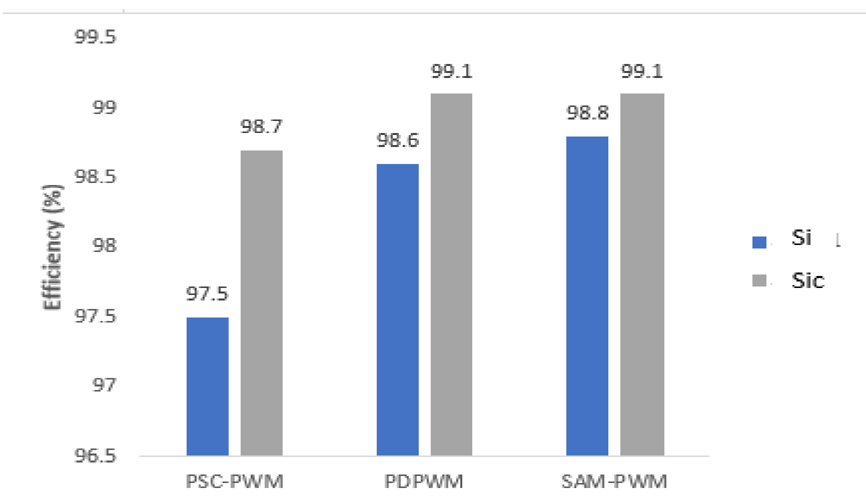


Figure2: Diagram of semiconductor power losses

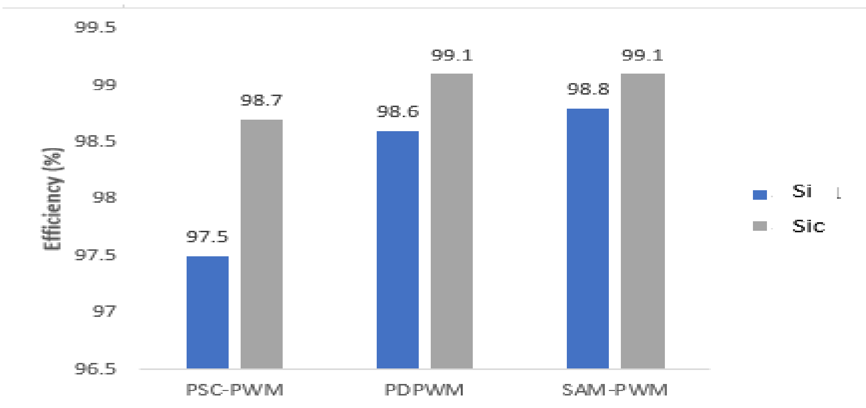


Figure 3: Diagram of MMC efficiency

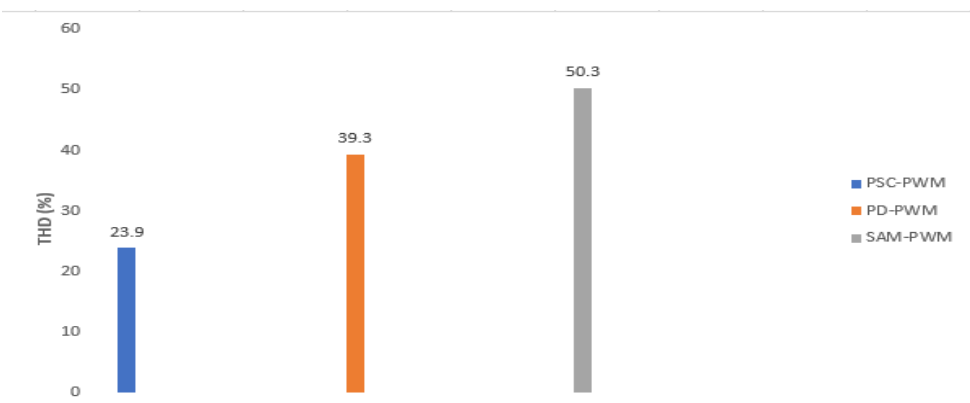


Figure 4: Diagram of output voltage THD

3 CONCLUSION

Figure 2,3 and 4 shows the comparative performance of several modulation schemes based on semiconductor power losses, MMC efficiency and output voltage THD. Figure 2 and 3 show that Sic modules produce lower power losses and higher power efficiency for all three modulation schemes as compared to silicon devices. In figure 2, it is also revealed that the PSC-PWM has higher power losses than the PD-PWM and SAM-PWM for both silicon and Sic switches, resulting in a lower MMC efficiency, as show in figure 3. Despite its inferior performance in terms of power loss and efficiency, figure 4 shows that PSC-PWM is superior to the other two approaches in terms of voltage quality with a THD of 23.9 percent. The disparity in performance implies that changes in the material properties of switching devices resulting in WBG components having greater performance in terms of lower power losses and higher power efficiency. The advantages of WBG power transistor s can further reduce the size of the entire power system conversion while maintaining high reliability. WBG power switches, in conjunction with MMC, are expected to play a significant part in the power conversion application in the near future.

References

[1] G. Venkataramanan and C. Marnay, "A larger role for microgrids," *IEEE Power Energy Mag,* p. 78–82, 2008.

[2] H. Jiayi, J. Chuanwen and X. Rong, "A review on distributed energy resources and microgrid," *Renewable and SustainEnergy Review,* vol. 12, no. 9, p. 2472–2483, 2008.

[3] M. G. JOSEP , . B. FREDE , . Z. TOSHKO , . H. KAS , . M. ERIC , . J. SAMIR , P. C. MARIA , .´. G. RAMO´ and . I. . F. UAN , "Distributed generation toward a new energy paradigm," *IEEE Industrail Magazine ,* vol. 4, no. 1, pp. 52-64, 2010.

[4] . K. Benjamin , . P. Christopher , . D. Richard , T. Holly , . S.˜. Marcelo and . K. S. Pankaj , "Benefits of power electronic interfaces for distributed energy systems," *IEEE Transactions Energy conversion,* vol. 25, no. 3, pp. 901-908, 2010.

[5] . A. Mariano , C. A and K. Mehrdad , "Renewable Energy Alternatives for RemoteCommunities in Northern Ontario, Canada," *IEEE Transaction of Sustainable Energy,* vol. 4, no. 3, pp. 661-670, 2013.

[6] . V. . P. K. Y and . R. Bhimasingu , "Integrating Renewable Energy Sources to an Urban Buildingin India: Challenges, Opportunities, and Techno-EconomicFeasibility Simulation," *Technol Econ Smart Grids Sustain Energy,* vol. 1, no. 1, pp. 1-16, 2015.

[7] . S. Deepak and . L. C. Mariesa , "An Ultracapacitor Integrated Power Conditionerfor Intermittency Smoothing and Improving PowerQuality of Distribution Grid," *IEEE TRANSACTIONS ON SUSTAINABLE ENERGY,* vol. 5, no. 4, pp. 1145-1155, 2014.

[8] . A. Saeed , . E. Ali and . S. Yilmaz , "Efficient Single Phase Harmonics Elimination Method for MicrogridOperations," *IEEE Transactions on Industry Applications,* vol. 51, no. 4, pp. 3394-3403, 2015.

[9] S. Dasgupta, S. Mohan, S. Sahoo and S. Panda, "Application of Four-Switch-Based Three-Phase Grid-Connected Inverter to Connect Renewable Energy Source to a Generalized Unbalanced Microgrid System," *IEEE Trans. Ind. Electron,* vol. 60, no. 3, pp. 1204-1215, 2013.

[10] E. Solas, G. Abad, J. Barrena, S. Aurtenetxea , A. Cárcar and L. Zaja¸c, "Modular Multilevel Converter with Different Submodule Concepts—Part I: Capacitor Voltage Balancing Method," *IEEE Trans. Ind. Electron,* vol. 60, no. 10, pp. 4525-4535, 2013.

[11] X. Shi, B. Liu, Z. Wang, Y. Li, L. Tolbert

and F. Wang, "Modeling, Control Design, and Analysis of a Startup Scheme for ModularMultilevel Converters," *IEEE Trans. Ind. Electron.,* vol. 62, no. 11, pp. 7009-7024, 2015.

[12] S. Debnath and M. Saeedifard, "A New Hybrid Modular Multilevel Converter for Grid Connection of Large Wind Turbines," *IEEE Trans.Sustain.Energy,,* vol. 4, no. 4, pp. 1051-1064, 2013.

[13] R. Li, J. Fletcher, L. Xu and D. Holliday, "A Hybrid Modular Multilevel Converter with Novel Three-Level Cells for DC Fault Blocking Capability," *IEEE Trans. Power Del,* vol. 30, no. 4, pp. 2017-2026, 2015.

[14] N. Mittal, B. Singh, S. Singh, R. Dixit and D. Kumar, "Multi level inverters: A literature survey on topologies and control strategies," in *in Proc. Int. Conf. Power Control and Embedded Systems*, Allahabad, India, 2012.

[15] J. Rodriguez, S. Bernet, P. Steimer and I. Lizama, "A Survey onNeutral-Point-Clamped Inverters," *IEEE Trans. Ind. Electron,* vol. 57, no. 7, pp. 2219-2230, 2010.

[16] F. Wu, B. Li and J. Duan, "Calculation of switching loss and current total harmonic distortion of cascaded multilevel grid-connected inverter and Europe efficiency enhancement considering variation of DC source power," *IET Power Electron,* vol. 9, no. 2, pp. 336-343, 2016.

[17] A. Rathore, J. Holtz and T. Boller, "Generalized Optimal Pulse Width Modulation of Multilevel Inverters for Low-Switching-Frequency Controlof Medium-Voltage High-Power Industrial AC Drives," *IEEE Trans.Ind. Electron,* vol. 60, no. 10, pp. 4215-4224, 2013..

[18] X. Li, Q. Song, W. Liu, H. Rao, S. Xu and L. Li, "Protection of Non permanent Faults on DC Overhead Lines in MMC-Based HVDC Systems.," *IEEE Trans. Power Deliv,* vol. 28, pp. 483–490, , 2013.

[19] J. Xu, P. Zhao and C. Zhao, "Reliability Analysis and Redundancy Configuration of MMC with Hybrid Submodule Topologies.," *IEEE Trans. Power Electron,* vol. 31, pp. 2720-2729, 2016.

[20] J. Wei, "Review of Current Control Strategies in Modular Multilevel Converter, Norwegian University of Science and Technology," Norwegian University of Science and Technology, Norway, 2016.

[21] Y. Kumar and G. Poddar, "Balanced Submodule Operation of Modular Multilevel Converter-Based Induction Motor Drive for Wide-Speed Range.," *IEEE Trans. Power Electron,* vol. 35, pp. 3918-3927, 2020.

[22] Y. Xu, Z. Xu, Z. Zhang and H. Xiao, "A Novel Circulating Current Controller for MMC Capacitor Voltage Fluctuation Suppression.," *IEEE Access,* vol. 7, pp. 120141-120151, 2019.

[23] B. Li, Z. Xu, S. Shi, D. Xu and W. Wang, "Comparative Study of the Active and Passive Circulating Current Suppression Methods for Modular Multilevel Converters.," *IEEE Trans. Power Electron,* vol. 33, pp. 1878-1883, 2018.

[24] M. Perez, J. Rodriguez, E. Fuentes and F. Kammerer, "Predictive Control of AC–AC Modular Multilevel Converters.," *IEEE Trans. Ind. Electron,* vol. 59, pp. 2832-2839, 2012.

[25] A. Marquez, J. Leon, S. Vazquez, L. Franquelo and M. Perez, "A

comprehensive comparison of modulation methods for MMC converters.," in *In Proceedings of the IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, 2017.

[26] K. Shenai, "Prospects of Wide band gap (WBG) Semiconductor Power Switching Devices.," *IEEE Trans. Electron Devices,* vol. 62, pp. 248-257, 2015.

[27] M. Perez, S. Bernet, J. Rodriguez, S. Kouro and R. Lizana, "Circuit Topologies, Modeling,Circuit topologies Modeling, Control Schemes and Applications of Modular Multilevel Converters.," *IEEE Trans. Power Electron.,* vol. 30, pp. 4-17, 2015.

[28] A. Nami, L. Jiaqi, F. Dijkhuizen and G. Demetriades, "Modular Multilevel Converters for HVDC Applications: Review on Converter Cells and Functionalities.," *IEEE Trans. Power Electron,* vol. 30, pp. 18-36, 2015.

[29] M. Vatani, B. Bahrani, M. Saeedifard and M. Hovd, "Indirect Finite Control Set Model Predictive Control of Modular Multilevel Converters.," *IEEE Trans. Smart Grid,* vol. 6, pp. 1520-1529, 2015.

[30] S. Du, A. Dekka, B. Wu and N. Zargari, "Modular Multilevel Converters: Analysis, Control, and Applications," in *John Wiley & Sons, Inc.: Hoboken, NJ, USA*, USA, 2017.

[31] M. Raju, J. Sreedevi, R. Mandi and K. Meera, "Modular multilevel converters technology': A comprehensive study on its topologies, modelling, control and applications.," *IET Power Electron,* vol. 12, pp. 149-169, 2019.

[32] F. Martinez-Rodrigo, D. Ramirez, A. Rey-Boue, S. De Pablo and L. Herrero-De Lucas, "Modular multilevel converters: Control and applications.," *Energies,* vol. 10, 2017.

[33] A. Marquez, J. Leon, S. Vazquez and L. Franquelo, "comprehensive comparison of modulation methods for MMC converters.," in *In Proceedings of the IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society; IEEE*, 2017.

[34] B. McGrath and D. Holmes, "Multicarrier PWM Strategies for Multilevel Inverters," *IEEE Trans. Ind. Electron,* vol. 49, pp. 858-867, 2002.

[35] H. Pinheiro, F. Botteron, C. Rech, L. Schuch, R. Schuch and H. Hey, "Space Vector Modulation for Voltage-Source Inverters' A Unified Approach," in *In Proceedings of the IEEE 2002 28th Annual Conference of the Industrial Electronics Society. IECON 02; IEEE, 2002*, 2002.

[36] A. Lesnicar and R. Marquardt, "An innovative modular multilevel converter topology suitable for a wide power range," in *In Proceedings of the 2003 IEEE Bologna Power Tech Conference Proceedings, IEEE: Bologna, Italy*, Bologna, Italy., 2003.

[37] A. Dekka, B. Wu and N. Zargari, "A Novel Modulation Scheme and Voltage Balancing Algorithm for Modular Multilevel Converter," in *IEEE Trans. Ind. Appl*, 2016.

[38] M. Nguyen and S. Kwak, "Nearest-Level Control Method with Improved Output Quality for Modular Multilevel Converters," *IEEE Access,* vol. 8, pp. 110237-110250, 2020.

[39] P. Meshram and V. Borgate, "A Simplified Nearest Level Control (NLC) Voltage Balancing Method for Modular Multilevel Converter (MMC)," *IEEE Trans. Power Electron,* vol. 30, pp. 450-462, 2015.

[40] S. Ke, Z. Dan, M. Jun, L. Tolbert, W. Jianze, B. Mingfei, J. Yanchao and C. Xingguo , "Elimination of Harmonics in a Modular Multilevel Converter Using Particle Swarm Optimization-Based Staircase Modulation Strategy," *IEEE Trans. Ind. Electron.,* vol. 61, pp. 5311-5322, 2014.

[41] K. Shenai, "Wide Band gap (WBG) Semiconductor Power Converters for DC Microgrid Applications," in *In Proceedings of the 2015 IEEE First International Conference on DC Microgrids (ICDCM); IEEE*, 2015.

[42] K. Shenai, "Power Electronic Module: Enabling the 21st-century energy economy," *IEEE Power Electron. Mag.,* vol. 1, pp. 27-32, 2014.

THEME FOCUS:

ENERGY CRISIS, CARBON CAPTURE AND STORAGE TECHNOLOGIES FOR CLIMATE CHANGE MITIGATION

CARBON DIOXIDE SEQUESTRATION: POTENTIALS AND OPPORTUNITIES FOR CEMENT INDUSTRY IN NIGERIA

[1]K.A. Olonade, and [2*]A. U. Adebanjo
[1]Department of Civil and Environmental Engineering, University of Lagos, Akoka, Nigeria
[2]Department of Civil Engineering, Osun State University, Osogbo, Nigeria

ABSTRACT

Cement production contributes about 10% of carbon-dioxide (CO_2) of the global greenhouse gases emitted into the atmosphere, causing devastating effect of climate change. In this paper, an overview of effect and sources of CO_2 emission in cement production was presented. A meticulous estimate of carbon-dioxide emitted in Nigeria cement industry was made, while potential and opportunities for CO_2 sequestration in Nigeria was x-rayed. Challenges for utilizing these opportunities and solutions to address the challenges were equally presented. It is shown that Nigeria produces about 54 million tonnes of cement per annum, corresponding to equivalent amount of CO_2 emitted, which is huge. Nigeria is categorised among the largest emitter of CO_2 for its cement productions. Unfortunately, at present none of the cement industries examined in this review has the technology to capture CO_2 for sequestration. Therefore, there is need for collaborative researches to develop local techniques to utilize this dangerous gas, which in itself a raw material if adequately captured. The government and stakeholders in the cement industries are also called upon to develop policies to checkmate continuous release of CO_2 to the atmosphere, if the country's dream of achieving SDGs on climate change comes to reality.

Keywords. Carbon capture technique, carbon-dioxide sequestration, climate change, global warming, greenhouse gases.

1. INTRODUCTION

Nigeria continues to be a formidable competitor in the African cement industry, with some of the continent's leading manufacturers based within its borders. Between 2011 and 2013, the country achieved a self-sufficiency state in the production of cement, when domestic production exceeded national demand for the product, and since then, the country has been exporting to neighbouring countries as a viable source of foreign exchange. The country's total production capacity is expected to be around 54 million metric tonnes (MMT) per year by 2021 (Ohimain, 2014; Perili, 2021). On a global scale, cement production has both positive and negative consequences. On the positive side, the cement industry may provide local residents with employment and business opportunities, especially in remote areas of developing countries where other avenues for economic development are limited. On the other hand, activities such as limestone quarrying, sourcing of other raw materials, biodiversity disruption, and carbon (iv) oxide (CO_2) emissions during the manufacturing process may have a negative impact on the environment (Inegbenebor *et al.,* 2018).

The amount of CO_2 emitted from cement industries is becoming a source of concern for most nations around the world. It is predicted that if policies and technologies are not implemented in developing countries to strategically revamp the current situation, the emission of CO_2 from cement industries, as well as other notable sources in this region will have a devastating impact on the environment and the gains that have been recorded globally in goals 11- Sustainable Cites and Communities, 13- Climate Action, 14-Life below Water, and 15- Life on Land of the Sustainable Development Goals (SDG).

Several technologies have been developed around the world in the last half-century to reduce the impact of CO_2 emissions; some of these technologies have been deemed perfect, while others are still being studied by scientists. According to Thakur *et al*. (2018), one such technology is Carbon Capture and Sequestration (CCS), which is well recognized in industrial systems but can be very expensive; it is estimated that the capturing aspect accounts for more than 80% of the cost of operation, and storage capacity may also be an issue, particularly in large scale operations where the amount of CO_2 is substantial. Nonetheless, CCS has a high potential for providing a corrective solution to the threat of CO_2 emissions. Furthermore, the fact that the stored CO_2 can be used in biofuel technology attests to the concept's ingenuity and can be a driving force for developing economies in future.

Nigeria, as a member of the United Nations General Assembly and an active competitor in the African cement industry, as well as a rapidly developing economy, has a critical role to play in ensuring that the continent's contribution of CO_2 to greenhouse gasses is relatively reduced by harnessing technology such as Carbon Dioxide Capture and Sequestration (CCS). In an attempt to assess the current situation, this paper assessed the contribution of the cement industry to global carbon emissions, carefully explained some of the prevalent effects of CO_2 emissions on climate change, and presented an overview of the cement industry in Nigeria from the pre-colonial era to the present. In addition, efforts were made to comprehend some of the various advances and challenges of implementing CCS technology in a developing country like Nigeria, as well as to identify some of the potentials and opportunities of carbon dioxide capture for the Nigerian cement market.

2. CEMENT INDUSTRY AS A MAJOR EMITTER OF CO_2

The outstanding characteristics of concrete over other construction materials have made it a material of choice in the construction sector of the global economy. In the global context, demand for concrete in infrastructure construction has risen, and scholarly surveys show that between 1990 and 2010, the demand for concrete nearly doubled those of steel and wood put together (Monterio *et al.,* 2017, Adebanjo *et al.,* 2021). Cement is a very important part of the concrete composites alongside inert mineral aggregates and water that constitutes the binding matrix, it is practically manufactured in most countries due to its importance as a building material and the geographic availability of the primary raw ingredients (Worrell *et al.,* 2001).

Until recently, the role of the cement sector in greenhouse gas emissions had not received great attention. In the previous 50 years, most of the emissions recorded have come from the combustion of fossil fuels (coal, petroleum and gas) with substantial contributions from forest removal and agricultural activities. However, the cement industry in recent times has proven to be an important source of industrial emissions of greenhouse gasses and contributes about 5-7% of worldwide anthropogenic greenhouse emissions. A report by International Energy Agency modelling shows that energy-related emissions of CO_2 must be halved by 2050 in order to fulfil the environmental imperative of sustainable climate change (Barcelo *et al.,* 2014, Bjerge and Brevik, 2014).

China is the world's largest cement manufacturer, responsible for about 57.1% of the global cement production, and as a result, the cement industry in China emits the highest amount of CO_2 as shown in Figure 1. In 2010, China's CO_2 emission from the production of cement peaked at 1000 million tonnes and increased by almost 20% when evaluated in 2010. As of 2014, China remains the top country by CO_2 emissions from cement production in the world. China emitted 338.912 million metric tonnes (MMT) of CO_2 from cement manufacturing, accounting for 60.30% of global CO_2 emissions from cement production. China, India, the United States of America, Turkey, and Brazil make up the top five nations, accounting for 72.42% of the global CO_2

emissions from cement manufacturing which was approximately 562.007 MMT, Figure 2 shows a representation of CO_2 emissions as of 2014 across the globe (Knoema, 2020). The production of carbon emissions from the cement industry in China is affected by numerous factors such as energy efficiency, applied processes and technologies, use of alternative materials, and the level of management and the same is true for other nations of the world (Gao *et al.,* 2017).

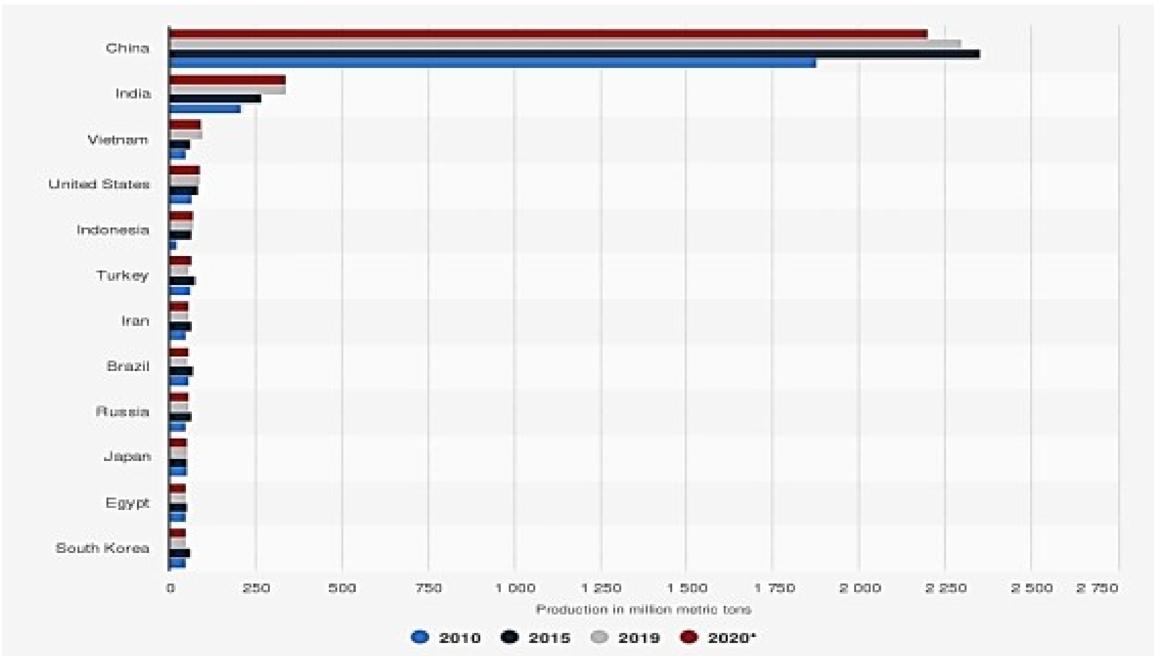


Figure 1: Major countries in worldwide cement production from 2010-2020 (in million metric tonnes)
Source: Statista (2021)

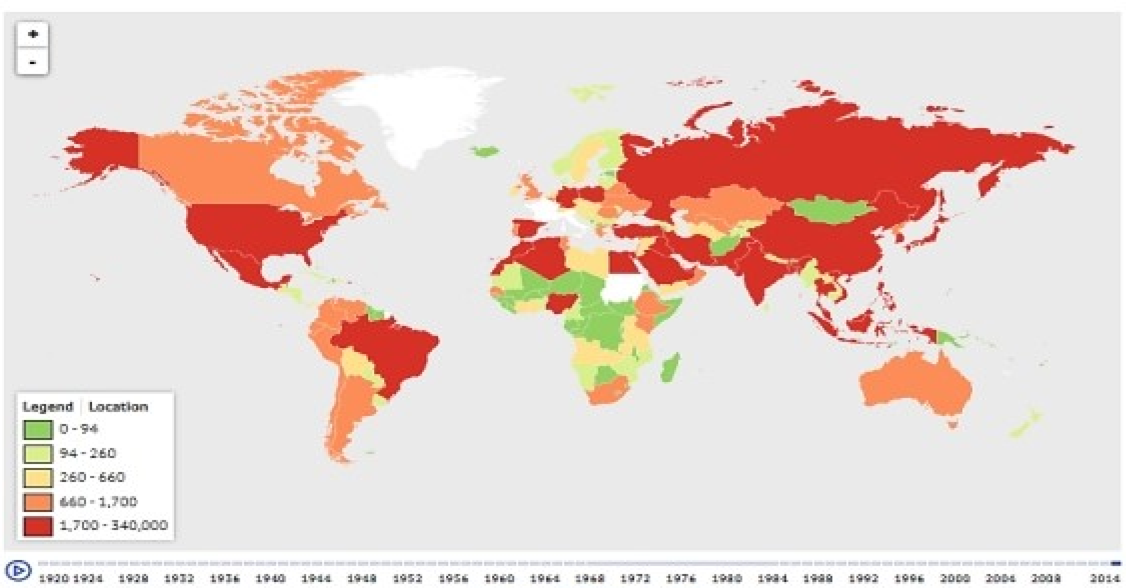


Figure 2: Global CO_2 emissions from cement production in million metric tonnes (MMT) as of 2014

Source: Knoema (2020)

On a worldwide scale, it is anticipated that increased cement production will result in a significant increase in global CO_2 emissions. In the early '90s, global CO_2 emissions from cement plants were barely more than half a billion tons but by 2006 the value had nearly tripled, reaching 1.88 billion tonnes. With this trend in mind and the exponential rate of the modern industrial revolution, environmentalists believe that, if, the current trends continue without fundamental regulations and strategies in place to address the problem, CO_2 emissions from the worldwide cement sector will be around 2.5 billion tonnes in 2050 (Benhelal *et al.,*2013; Boden *et al.,* 2011).

3. CARBON DIOXIDE EMISSION AND ITS EFFECT ON CLIMATE CHANGE.

The emission of CO_2 remains a major concern for most governments throughout the world. Although recent findings by Peter *et al.,* (2019) suggest that; the growth of carbon emission in developed societies has slowed in the last two decades, much of the progress made in these climes has been thwarted by the consistent unregulated actions of developing and underdeveloped societies on this subject, therefore, making it difficult to assess the quality and quantity of progress made.

According to Peters *et al.* (2019), the present inability to establish a globally accepted strategy for reducing carbon emission will bolster the global warming narrative. It is well known that greenhouse gases tend to maintain the earth's temperature at a certain level in order to sustain life. However, the uncontrolled combustion of fossil fuels and other human activities are increasing thereby trapping more heat than is necessary and causing global warming, this has been seen as one of the most serious threats facing humanity today. For example, Gillet *et al.,* (2011) believe that the knowledge that carbon emissions inflict permanent damage should motivate many people to take action to combat climate change; using a Canadian Earth System Model to illustrate substantial regional variations continuing at virtually constant global mean temperatures and precipitation at a near-zero carbon dioxide emissions in 2100. Their calculations indicated how terrible the situation might be if not managed, at the current pace of warming and by the year 3000, the West Antarctic Ice Sheet might have completely collapsed, resulting in a 3- 4 metre rise in sea level (Gillet *et al.,* 2011).

Another aspect of climate change that environmentalists are concerned about is the vast amount of dry land that would result from global warming as shown in Figure 3. As the earth warms, certain areas are projected to grow wetter, while others that are currently dry are expected to become dryer. This is because, just as global warming affects the world's extreme cold regions, hotspots like Australia, Southern Africa, the Middle East, Southern Asia, the Sahel region of Africa, and some parts of the United States are becoming drier due to an imbalance in evapotranspiration, which is expected to lead to drought if it persists for a long time. By 2050, scientists predict that the amount of territory affected by drought will have increased, and that water resources in afflicted areas will have decreased by up to 30% (Arndt *et al.,* 2010; Miller *et al.,* 2009; Serreze *et al.,* 2009). These changes are partly caused by a phenomenon known as the Hadley Cell, whereby warm air in the tropics rises, loses moisture to tropical thunderstorms, and thereafter descends as dry air in the subtropics. As a result of this, it is expected that Semi-arid and desert areas will continue to grow as jet streams continue to shift to higher latitudes, causing storm patterns to shift as well.

Greenhouse gas emissions have a wide range of environmental and health consequences. They contribute to climate change by trapping heat, resulting in record high temperatures and intense rainstorms, as well as changes in temperature and rainfall patterns, which affect plant and animal behaviour and have serious consequences for humans. Other implications of climate change produced by greenhouse gases include harsh weather conditions that contribute to respiratory sickness from smog and air pollution, disturbances in the food supply network, and more wildfires (Nunez, 2019).

Figure 3: A corn farm affected by drought in Texas, USA.
Source: USDA

4. OVERVIEW OF CEMENT PRODUCTION IN NIGERIA

Nigeria's cement industry dates back to the colonial era; Niger Cement was the country's first indigenous cement, which commenced commercial activities in 1957 at Nkalagu in the then Eastern Region. West African Portland Cement (WAPCO) began operations in the Western area of Nigeria three years later, and the Cement Company of Northern Nigeria (CCNC) was established in 1967 (FGN, 2009). The government constructed more cement plants in the 1970s. During this time, the number of cement factories expanded from three in 1967 to eight in the seventies, with an estimated production capacity of 2.8 MMT per annum; by the 1980s, the production capacity had nearly doubled, and local output peaked at 3.6 million MMT per annum. Between 1980 and 2000, a series of political events cut the number of operational plants by half, resulting in cumulative production of 2.2 MMT per annum (FGN , 2009; Ohimain, 2014).

The government devised and implemented the backward integration policy (BIP) in 2002, which mandates that cement import permits be granted only to importers who can demonstrate that they are establishing facilities in Nigeria to produce local cement. The program provides incentives such as a VAT and customs duty exemption for cement manufacturing equipment imports. According to Ohimain (2014), after the BIP was implemented, all of the dormant existing government-owned cement plants were privatized, and the private sector installed additional production and bagging capacities. This praiseworthy step showed that within a decade Nigeria's cement industry had increased production capacity considerably from 4.03 MMTPA in 2000 to 45 MMTPA, representing a 1000 % spike in production. In the meanwhile, 14 new cement factories of varying capacities were under development as of 2014 (Ohimain, 2014).

The cement industry in present-day Nigeria is dominated by three major players, with Dangote Cement Plc holding 60.6 % of the market share with a local installed capacity of 29.3 MMT per annum, Lafarge Africa Plc holding 21.8 % share with a production capacity of 10.5 MMT per annum, and BUA Group accounting for 17.6 % share and 8.0 MMT per annum (Adekoya, 2020). The country's cement production capacity is now approximately 49 MMT per annum, with yearly demand just slightly more than 21 MMT. Despite this self-sufficiency, it is expected that the production capacity will rise further to 53.8 MMT by 2021 as some of the sector's main companies are constructing additional lines of production around the Nation (Perili, 2021).

The increase in production capacity has resulted in several economic benefits for the country, but it is not without the negative impacts of greenhouse gases caused by CO_2 emissions. According to the Carbon Dioxide Analysis Centre (CDIAC), emissions from cement manufacturing in Nigeria grew from 491 thousand metric tons (TMT) of CO_2 in 1965 to 9.97 MMT of CO_2 in 2014, rising at an annual rate of 8.29% on average and is just about 10 per cent of the total CO_2 emissions from fossil-fuels as shown in Figures 4 and 5. In 2017, Dangote Cement, a major competitor in the cement industry made its sustainability report available to the public in line with standard practice and reported a total emission of 8.45 MMT in all its domestic operations as well as providing 37,000 direct, indirect and induced jobs in Nigeria (Global Cement News, 2019).

If Hendriks *et al.* (2004) are correct in their claim that for every 1kg of cement produced, 0.9kg of CO2 is emitted, then with a predicted production capacity of 53.8 MMT by 2021, yearly CO_2 emissions in Nigeria are estimated to be in the neighbourhood of 48.5 MMT. These numbers are mainly conservative since they exclude emissions from closely related activities such as limestone quarrying and other emissions produced during cement transportation to end-users. Odemba (2011) showed that carbon emissions had a positive and significant influence on Nigeria's GDP, with a percentage increase in emissions from fossil fuels, solid fuels, bunker fuels, and cement manufacture resulting in a 0.71, 0.56, 0.62, and 0.44-unit increase in GDP, respectively. According to Adesina and Adejuwom (2008), biological productivity in Nigeria would decline as a result of global warming with significant shortages in fuel wood as an unbearable side effect. Also, consider the fact that Nigeria in recent times has witnessed a clear shift in long-term rainfall patterns toward drier conditions. Climate change has had a negative impact on the availability of water resources for power generation and agriculture. As a backdrop to the preceding argument, it clearly shows that developing a climate change-response development strategy would not only be economically advantageous for Nigeria, but that including climate change mitigation into the broader economic growth plan is also critical for the country's survival. This will aid in reducing the negative economic impacts of carbon emissions.

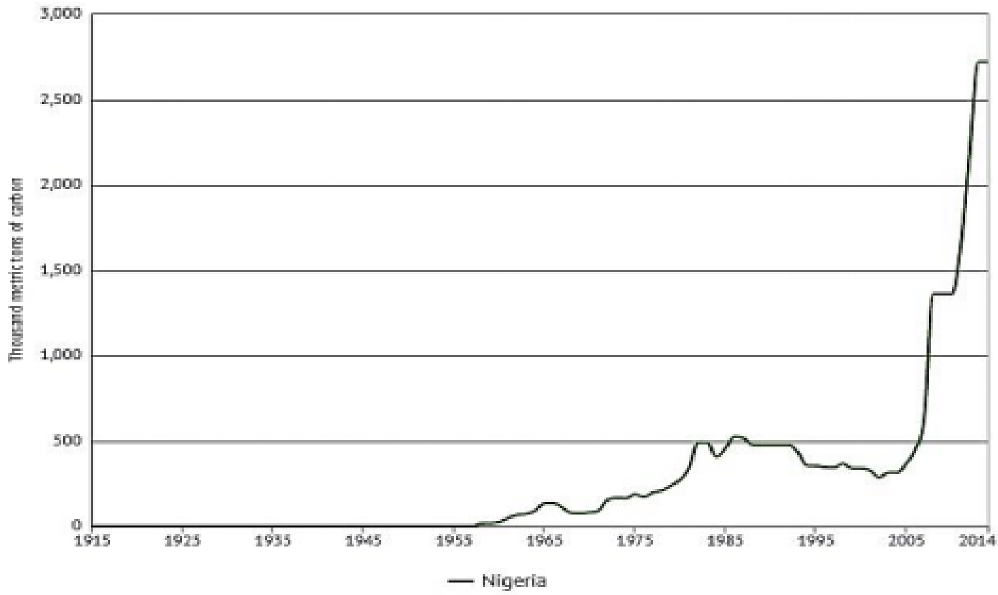


Figure 4: CO2 emissions from cement production in Nigeria between 1915 – 2014
*To convert to CO2, the values of emission in carbon is multiplied by 3.667
Source: Knoema (2020)

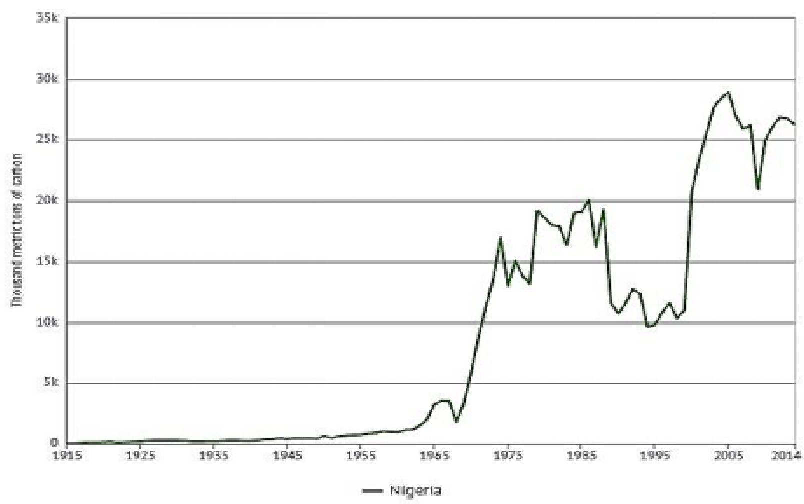


Figure 5: Nigeria - Total CO2 emissions from fossil fuels between 1915 -2014
*To convert to CO2, the values of emission in carbon is multiplied by 3.667
Source: Knoema (2020)

5. CARBON DIOXIDE SEQUESTRATION: TECHNIQUES AND CHALLENGES

Goal 13 of the Sustainable Development Goals (SDG) is about taking immediate action to combat the negative effects of climate change in our immediate environment. To accomplish this, it is expected that reducing and capturing CO_2, the most commonly produced greenhouse gas, will play a significant role in achieving this goal. In a 2021 report on progress toward the SDGs, the

Secretary-General emphasized that, despite the gains recorded in the ecosystem from the COVID-19 global lockdown, preliminary data indicates that failure to address climate change caused by greenhouse gasses will pose a threat to all other SDG goals because emissions still increased in 2020, combined with the fact that the preceding years (2015-2019) are on record to be the warmest in the history of the world.

Scientists suggest that, in order to keep global warming temperature at 1.5°C by 2030, global emissions must be reduced by 45% (IPCC, 2018). When compared with 2010 levels, emissions from developing nations decreased by around 6.2% in 2019 while those from developing countries increased by 14.4% in 2014. There are several explanations for the disparities in the results attained in both situations, one of which being the former's adoption of Carbon Capture and Sequestration (CCS) technology. Rahman *et al.* (2017) described CCS as the removal of CO_2 directly from industrial or utility plants and subsequent storage in a secure medium. It is one of the most significant technologies available for reducing CO_2 emissions. CCS is still the most advantageous technology for reducing CO_2 today, and it is also the most cost-effective in a large-scale setting. Given the rising pace of emissions into the atmosphere, it is critical to guarantee that CO_2 emissions from burning of fossil fuel and other emerging sources, such as the cement industry, are captured and reduced as soon as possible before they are released into the environment. As a result, the pollution caused by the release of these gases will be reduced, and efforts will be made to use the CO_2 collected in the development of cleaner and efficient energy systems (Han *et al.,* 2012; Huang *et al.,* 2008; Martunus *et al.,* 2008).

In terms of CO_2 mitigation, there are three well-established strategies typically employed to reduce CO_2 emissions into the atmosphere: carbon sinking, carbon minimization, and carbon sourcing. As previously mentioned, CCS comes under the first approach, in which CO_2 is collected at the source before being released into the atmosphere, transported to an injection location via an impermeable medium, and then stored in geological or biological formations for an extended period of time. In geological carbon sequestration (GCS), CO2 is secured in deep geologic formations in order to avoid its contribution to global warming, a schematic diagram of the process has been presented as Figure 6 in this paper while biological carbon sequestration (BCS), on the other hand, entails the effects of the ecosystem on the natural and anthropogenic processes of carbon management, which is based on the earlier findings that terrestrial and aquatic ecosystems in the United States are important carbon sinks and accounts for the sequestration of around one-quarter of the country's CO_2 emissions (Duncan and Morrissey, 2011; Yu *et al.,* 2019).

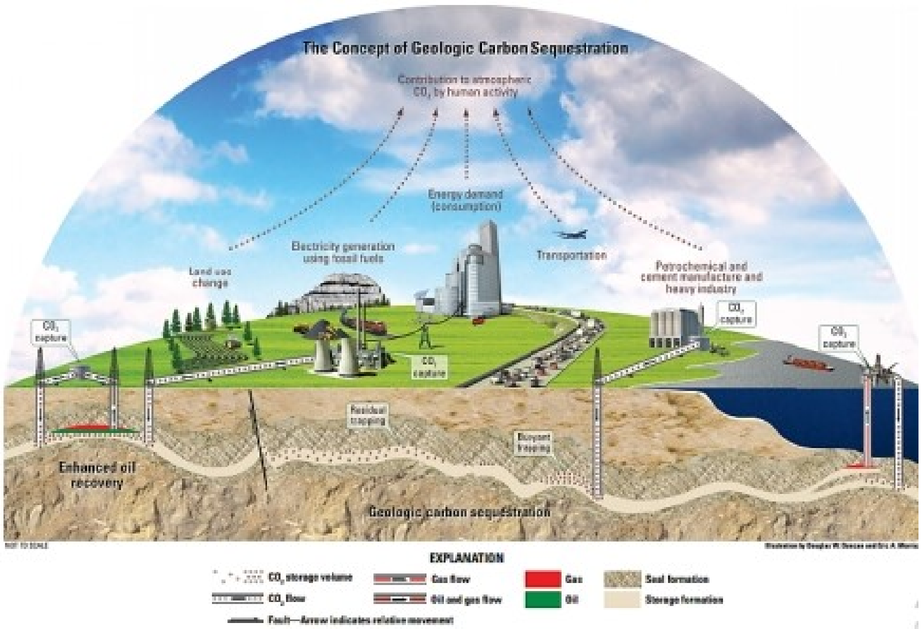


Figure 6: Schematic diagram illustrating the theory of geologic carbon sequestration.
Source: Duncan and Morrissey, 2011

5.1 Techniques of Carbon Capture and Sequestration Technology

In terms of CCS, there are a variety of techniques that may be used, and each of these approaches can be roughly classified into two sub-techniques: separation and capture techniques. The most common separation techniques as described by Figueroa *et al.* (2008) and Yang *et al.* (2008) are gas phase separation, absorption, adsorption, membrane system as well as a hybrid processes involving a combination of the last two techniques. The absorption process, according to Herzog and Golomb (2004), occurs when CO_2 gas is absorbed in a liquid solvent by the creation of a chemically linked compound. As a result, once the solvent has been bound, the resultant product is transferred to a separate compartment and heated to release CO_2. They also described the adsorption process as including the selective absorption of CO_2 onto a solid surface, which is then regenerated by adjusting the pressure or temperature to release the adsorbed CO_2. The active gas is isolated from flue gas in the membrane system by selectively permeating it via a membrane material.

The capturing approach also includes the employment of any of the most often documented capture procedures in the literature, namely the post combustion capture system (PCCS-1), the pre-combustion capture system (PCCS-2), and the oxyfuel capture system (OCS) (Rahman *et al.,* 2017). In PCCS-1, just before the emissions are released into the environment, a final processing stage is used to remove the majority of the CO_2 from the emission stage of the combustion process. The most common commercial CO_2 separation technique is wet scrubbing with aqueous amine solutions. CO_2 is extracted from the exhaust gas using an amine solvent at a temperature of 50°C. The CO_2 absorbed by the solvent, which is then heated to a higher temperature, cooled, and continuously recycled for use in the next separation cycle. The extracted CO_2 is then dried, compressed, and transferred to a secure storage location; this process is believed to be the most effective for existing power plants, with an estimated recovery rate of 800 tonnes per day (Gibbins and Chalmers, 2008; Herzog and Golomb, 2004; Thakur *et al.,* 2018).

The majority of the capturing for PCCS-2 occurs before the combustion begins, and this is accomplished by gasifying (partially combusting) the fossil fuel with some oxygen at high pressures to produce a synthetic mixture of H2 and CO, which is then steamed and passed through a catalyst system to enable what is referred to as the water-gas shift (WGS). CO_2 separated in this way, results in the production of a fuel gas that is rich in hydrogen at a much lower heat than is required in PCCS-1 process. As a result, in terms of energy consumption, the PCCS-2 is more efficient than the PCCS-2 (Pennline *et al.,* 2008; Guerrero-Lemus and Martínez-Duart, 2012).

Oxyfuel capture system (OCS) requires the use of oxygen as the only active gas in the combustion process to produce a flue gas containing CO_2 and compensated vapour that can be easily separated. However, if the CO_2 to be captured comes from the combustion of coal, the oxides of nitrogen and sulphur must be carefully removed from the CO_2 mixture before compression and storage in a suitable medium (Gibbins and Chalmers, 2008). Apart from the previously described technologies, there are emerging technologies in the industry, some of which are still in the experimental stage and have not been adopted in large scale capturing. These technologies include solid sorbent adsorption, liquid solvent absorption, mineralization, and membranes technology. Though still in its early stages, the membrane technology has shown a lot of promise for capturing and sequestering CO_2 emissions and is regarded as the most suitable CCS technology for the future (Ho *et al.,* 2008; Khalilpour *et al.,* 2015; Krishnamurthy *et al.,* 2014; Zevenhoven *et al.,* 2009).

5.2 Challenges of Carbon Capture and Sequestration Technology in Developing Countries

The use of CCS technology is fraught with difficulties, some of which are; high implementation costs, life cycle effects, storage capacity, lack of favourable government policies, and high energy demand. Among these challenges, the cost of implementing and commercializing this technology is the most significant. In developed countries, the average cost of capturing and storing one tonne of CO_2 is $ 0.5-5 and $ 6-12 for onshore and offshore conditions, respectively, whereas some studies have revealed that the cost of operation (cost of sourcing CO_2 from emission plants and cost of transportation to storage site) can be as high as $56 in the early stages of operation (Metz *et al.,* 2005, Oh, 2010, Theeyattuparampil *et al.,* 2013). Furthermore, estimating the cost of a large-scale CCS system is difficult because the cost of external and social influences is frequently explicitly excluded in most of the available scenarios where the cost implication was evaluated.

According to the British Geological Survey (BGS), energy demand is an intrinsic aspect of CCS technology, the cost of capturing and compressing CO_2 increases a coal plant's fuel demand by 25-40%, whereas the cost of electricity incurred by end-users for obtaining electricity from a new power plant with CCS or a pre-existing power plant with a very close storage location increases by 21-91%. As a result, applying the technology to pre-existing plants or plants with far storage locations will be more expensive, because CCS implementation requires more energy and cost than CO_2 emissions, supporting an energy-intensive process like this may be difficult for developing countries with epileptic power generation and distribution infrastructures. Therefore, market-driven CCS development will never occur and political attitudes will be influenced if the public does not accept it. However, it is important to remember that the costs of climate change will be significantly higher (BGS, 2021; Thakur *et al.,* 2018).

Given the wide range of geologic formations available in most emerging nations as well as the teeming population's reliance on groundwater for existence. If there is a CO_2 leak owing to low-density seals and ineffective geological traps, the soil would become acidic, and agricultural life will be lost. According to Galadima and Garba (2010), if the storage is not effectively protected against leakage, it might have a significant impact on the livelihood of the population who are primarily farmers.

The usage of CCS technology will not be embraced by the big wigs in the sectors if there are no stringent laws in place to regulate emissions in developing nations. For example, Figure 7 depicts the number of policies implemented by three developed countries over a 15-year period; in the United States, there were close to 15 policies to promote the use of CCS technologies between 1990 and 2015, and this has proven to be effective because recent statistics show that the amount of CO_2 emission per Gross Domestic Product (GDP) reduced considerably from 0.53kg CO_2/2010USD in 1990 to 0.27 kg CO_2/2010USD in 2018 as a result of their implementation. Some of the policies implemented in those climes borders around strategic planning, research, development and deployment of CCS innovations, tax relief for companies in the industry and other financial incentives (Shirmohammadi *et al.,* 2020).

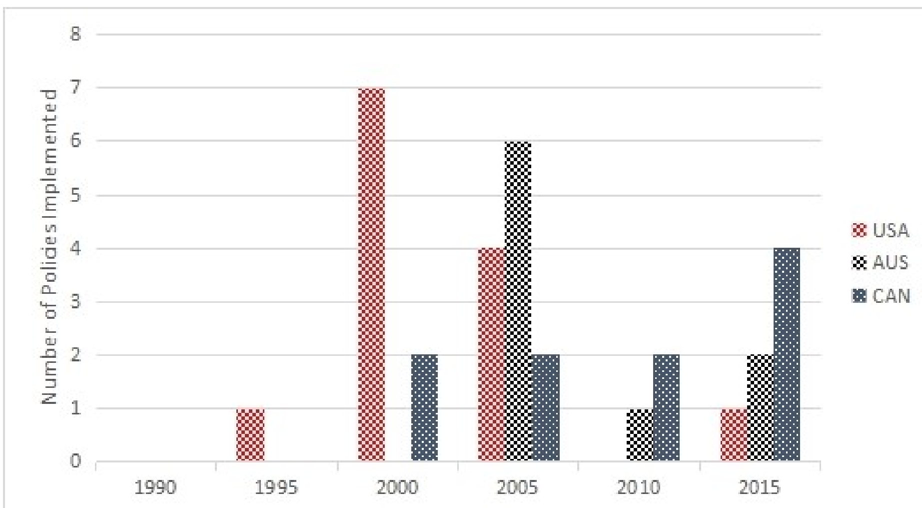


Figure 7: CCS policies implemented in three developed nations within a 15-year period
Source: Shirmohammadi *et al.* (2020)

6. POTENTIALS AND OPPORTUNITIES OF CARBON DIOXIDE CAPTURING FOR NIGERIAN CEMENT MARKET.

Nigeria has had a considerably stable administration in the previous two decades, with a generally smooth change of power from one political party to the next, resulting in positive economic progress. Many have seen the country's numerous infrastructural developments in this era as proof of a stable government. The cement sector is not immune to this trend, since it is reported in the literature that the number of cement manufacturing units grows every year. Despite this commendable achievement, the government and other stakeholders have implemented few, if any, strategic policies to reduce carbon emissions arising from the activities of such industries and promote the use of CCS technology in the country.

The Kwale and Ovade Ogharefe projects are notable examples of the few CCS technology deployed by the government. The former, which is overseen by the Nigerian National Petroleum Corporation (NNPC), Nigerian Agip Oil Company Ltd, and Phillips Oil Company Nigeria Ltd, has reduced CO_2 emissions by 800,000 metric tonnes as of 2008, while the latter is expected to reduce CO_2 emissions by approximately 25 million metric tonnes by 2017 (Anastassia *et al.,* 2010). In both situations, the technology was exclusively used in the oil and gas industry, with no implementation in the cement industry. Given the massive amounts of CO_2 emissions produced in recent years by the cement industry, one would expect the country to be at the forefront of the discussion on sustainable methods of converting this readily available raw material into an effective form of renewable energy, but this has not been the case.

However, it is important to note that the adoption of CCS technology in Nigeria's cement sector, has a lot of promise for the country. As of now, Nigeria is mainly dependent on fossil fuels for power generation, and because the amount of electricity generated is relatively low in comparison to its population, many enterprises and small companies must rely on the usage of generators to carry out their daily operations. If the infrastructure is in place, CO_2 collected from these facilities can be processed and transferred to a nearby gas turbine for power generation thereby increasing the quantity of electricity available for generation.

Researchers like Peters *et al.* (2011), Thakur *et al.* (2018) and Yoshida and Ihara (2004) have shown that industrially collected CO_2 may be used to make key products and chemicals for biofuels and biorefineries. Furthermore, because it is easily converted into other useful products like carbonates, poly (carbonates), carbamate derivatives, and carboxylic acids, which form excellent aprotic polar solvents and fine chemical intermediates, it is bound to have a wide acceptance in the oil and gas sector, paints and coatings industries, electronics, and pharmaceutical industries. CO_2 as a commodity can be used in firefighting, food industry, fish farms, agricultural greenhouse and other chemical industries (Psarras *et al.,* 2017).

7. CONCLUSION

Cement manufacturing produces around 10% of the world greenhouse gases in the form of CO_2, when released into the atmosphere it creates severe impacts on the climate. Presently, Nigeria produces around 54 million tonnes of cement each year and there are plans by the manufacturing companies to increase this figure in the near future thereby resulting in a massive quantity of CO_2 emissions. As of today, there are no active Carbon Capture Technologies and policies in the nation to mitigate the massive quantity of CO_2 emitted on a daily basis. The non-existence of this technology puts the entire nation at risk, and one can only expect the worse in terms of occasional climate change. As a result, the Government needs to make policies that will aid joint research to create home grown technologies, especially when the cost of the readily available technologies are taken into consideration. Also, if the country's ambition of reaching the SDGs on climate change were to become a reality, the Government and cement industry stakeholders must create rules to halt the continual emission of CO_2 into the atmosphere.

REFERENCES

Adekoya, F. (2020) Local cement production capacity to hit 53.8mtpa by 2021, Guardian News Paper https://guardian.ng/business-services/industry/local-cement-production-capacity-to-hit-53-8mtpa-by-2021/

Adesina, F.A & Adejuwon, J.O., (2008). Climate Change and Potential Impact On Biomass Energy Production In Nigeria. A Preliminary Assessment. Paper Presented at The International Workshop On The Impact Of Global Climate Change On Energy Development, Lagos, Nigeria, March 28-30.

Anastassia, M., Fredrick, O., & Malcolm, W. (2010). The future of Carbon Capture and

Storage (CCS) in Nigeria. *Science World Journal*, 4(3). doi:10.4314/swj.v4i3.51848

Arndt, D.S., M.O. Baringer, and M.R. Johnson, eds. (2010): State of the climate in 2009. Bulletin of the American Meteorology Society 91(6):S1-S224.

Barcelo, L., Kline, J., Walenta, G. & Gartner, E. (2014). Cement and carbon emissions. , 47(6), 1055–1065. doi:10.1617/s11527-013-0114-5

Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO_2 emissions in cement industry. *Journal of Cleaner Production*, 51, 142–161. doi:10.1016/j.jclepro.2012.10.049

Bjerge, L. M. & Brevik, P. (2014) CO_2 Capture in the Cement Industry, Norcem CO_2 Capture Project (Norway), 12th International Conference on Greenhouse Gas Control Technologies, GHGT-12 Edited by Tim Dixon, Howard Herzog, Sian Twinnin Energy Procedia, (63) 6455-6463, ISSN 1876-6102,

Boden, T., Marland, G., Andres, B., (2011) Global CO_2 Emissions from Fossil-fuel Burning, Cement Manufacture, and Gas Flaring: 1751e2008. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.. cdiac.ornl.gov/ftp/ndp030/global.1751_2008.ems (accessed 02.04.12.).

British Geological Survey (2021) Understanding carbon capture and storage Discovering Geology — Climate change https://www.bgs.ac.uk/discovering-geology/climate-change/carbon-capture-and-storage/

Duncan, Douglas W. and Morrissey, Eric A. (2011) The Concept of Geologic Carbon Sequestration U.S. Geological Survey Fact Sheet 2010–3122, 2p available at http:// pubs.usgs.gov/fs/2010/3122/

Federal Government of Nigeria, (2009) Report of The Vision 2020 National Technical Working Group On Manufacturing Thematic Area, 2009.

Figueroa, J.D, Fout, T., Plasynski, S., McIlvried, H. & Srivastava, R. D. (2008) Advances in CO_2 capture technology—the US Department of energy's carbon sequestration program. *Int J Greenh Gas Control*; 2(1):9–20.

Galadima, A., & Garba, Z. . (2010). Carbon capture and storage (CCS) in Nigeria: fundamental science and potential implementation risks. *Science World Journal,* 3 (2). doi:10.4314/swj.v3i2.51802

Gao, T., Shen, L.; Shen, M.; Liu, L.; Chen, F.,& Gao, L. (2017). Evolution and projection of CO_2 emissions for China's cement industry from 1980 to 2020. *Renewable and Sustainable Energy Reviews*, 74(), 522–537. doi:10.1016/j.rser.2017.02.006

Gibbins, J. & Chalmers, H. (2008) Carbon capture and storage. *Energy Policy* 36(12):4317–22.

Gillett, N.P., Arora, V.K., Zickfeld, K., Marshall, S.J.& Merryfield, W.J. (2011). Ongoing climate change following a complete cessation of carbon dioxide emissions., 4(2), 83–87. doi:10.1038/ngeo1047

Global Cement News (2019) "Dangote Cement release sustainability report for 2018" https://www.globalcement.com/news/item/9353-dangote-cement-release-sustainability-report-for-2018 Retrieved on 15/07/2021

Guerrero, L.R, Martínez, D.J. (2012) Renewable energies and CO_2. *Lect Notes Energy*:3

Han, J.H, Ahn, Y.C, Lee, J.U, & Lee, I.B. (2012) Optimal strategy for carbon capture and storage infrastructure: a review. *Korean Journal of Chemical Engineering*, 29(8):975–84.

Hendriks, C. A.,Worrell, E., Jager, D. De, Blok, K., & Riemer, P. (2004).Emission

Reduction of Greenhouse Gases from the Cement Industry, 1–11.

Herzog, H. & Golomb, D. (2004) Carbon capture and storage from fossil fuel use. *Encycl Energy* 1:1–11.

Ho M.T, Allinson, G.W, Wiley, D.E.(2008) Reducing the cost of CO_2 capture from flue gases using pressure swing adsorption. *Ind Eng Chem Res*. 47(14):4883–90.

https://doi.org/10.1016/j.egypro.2014.11.680.

Huang, Y., Rezvani, S., McIlveen-Wright, D., Minchener, A., & Hewitt, N. (2008) Technoeconomic study of CO_2 capture and storage in coal fired oxygen fed entrained flow IGCC power plants. *Fuel Process Technology* 89(9):916–25.

Inegbenebor, A. I., Mordi, R.C., Idowu, A.O., Siyanbola, T.O., Akanle, B.M., Evbuoma, I.K. & Inegbenebor, A.O. (2018) Consequences of the Activities of a Nigerian Cement Industry on the Environment, *International Journal of Applied and Natural Sciences (IJANS)* ISSN(P): 2319-4014; ISSN(E): 2319-4022 .,7(4), 67-74

IPCC (2018) Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp

Khalilpour R, Mumford K, Zhai H, Abbas A, Stevens G, Rubin ES. (2015) Membranebased carbon capture from flue gas: a review. *Journal of Cleaner Production*, 103:286–300.

Knoema (2020) Nigeria - CO_2 emissions from cement production https://knoema.com/atlas/Nigeria/topics/Environment/CO2-Emissions-from-Fossil-fuel/CO2-emissions-from-cement-production

Krishnamurthy S, Rao VR, Guntuka S, Sharratt P, Haghpanah R, Rajendran A, Amanullah M, Karimi IA, Farooq S. (2014) CO2 capture from dry flue gas by vacuum swing adsorption: a pilot plant study. *American Institute of Chemical Engineering Journal* 60(5):1830–1842.

Martunus, M., Othman, M., Zakaria, R., & Fernando, W. (2008) CO_2 emission and carbon capture for coal fired power plants In Malaysia And Indonesia;

Metz, B., Davidson, O., de Coninck, H., Loos, M. & Meyer, L. (2005) Carbon dioxide capture and storage; In: IPCC Report 2005 (Eds.) Cambridge University Press, UK. pp 431. Available from Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU ENGLAND

Miller J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K.R.T. Whelan, M. Patterson, & B. Witcher. (2009). Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. Coral Reefs 28:925-937.

Monterio, P.J.M., Miller S.A and Horvath A. (2017) Towards Sustainable Concrete, Nature Materials, 16: 698-699

Nunez, Christina (2019) Carbon dioxide levels are at a record high. Here's what you need to know. National Geographic

Oh TH. (2010) Carbon capture and storage potential in coal-fired plant in Malaysia—A review. *Renew Sustain Energy Rev*, 14(9):2697–709.

Ohimain, E. I (2014). The Success of the

Backward Integration Policy in the Nigerian Cement Sector. *International Journal of Materials Science and Applications.* 3(2):70-78. doi: 10.11648/j.ijmsa.20140302.19

Pennline, H.W., Luebke, D.R, Jones, K.L, Myers, C.R, Morsi, B.I, Heintz, Y.J. & Ilconich, J.B. (2008) Progress in carbon dioxide capture and separation research for gasification-based power generation point sources. *Fuel Process Technol* 89(9):897–907.

Perilli, David (2021) The price of cement in Nigeria, Global Cement https://www.globalcement.com/news/item/12333-the-price-of-cement-in-nigeria

Peters, G. P., Andrew, R. M., Canadell, J. G., Friedlingstein, P., Jackson, R. B., Korsbakken, J. I., Le Quéré, C. & Peregon, A. (2019). Carbon dioxide emissions continue to grow amidst slowly emerging climate policies. *Nature Climate Change*,–. doi:10.1038/s41558-019-0659-6

Peters, M., Köhler, B., Kuckshinrichs, W., Leitner, W., Markewitz, P., & Müller, T.E., (2011). Chemical technologies for exploiting and recycling carbon dioxide into the value chain. *ChemSusChem* 4, 1216–1240.

Psarras, P.C., Comello, S., Bains, P., Charoensawadpong, P., Reichelstein, S., Wilcox, J., (2017). Carbon capture and utilization in the industrial sector. *Environ. Sci. Technol*. 51, 11440–11449.

Rahman, F. A., Aziz, M. M. A., Saidur, R., Bakar, W. A. W. A., Hainin, M. ., Putrajaya, R., & Hassan, N. A. (2017). Pollution to solution: Capture and sequestration of carbon dioxide (CO2) and its utilization as a renewable energy source for a sustainable future. Renewable and Sustainable Energy Reviews, 71, 112–126. doi:10.1016/j.rser.2017.01.011

Serreze, M.C., A.P. Barrett, J.C. Stroeve, D.N. Kindig, & M.M. Holland. (2009). The emergence of surface-based Arctic amplification. *The Cryosphere* 3:11-19. doi:10.5194/tc-3-11-2009.

Shirmohammadi, R., Aslani, A., Ghasempour, R. (2020) Challenges of carbon capture technologies deployment in developing countries. *Sustainable Energy Technologies and Assessments.* Volume 42, 100837-1-14, ISSN 2213-1388. https://doi.org/10.1016/j.seta.2020.100837.

Statistia (2021) Major countries in worldwide cement production from 2010 to 2020(in million metric tons). https://www.statista.com/statistics/267364/world-cement-production-by-country/ Accessed July 30, 2021

Thakur, I. S., Kumar, M., Varjani, S. J., Wu, Y., Gnansounou, E., & Ravindran, S. (2018). Sequestration and utilization of carbon dioxide by chemical and biological methods for biofuels and biomaterials by chemoautotrophs: Opportunities and challenges. *Bioresource Technology*, 256, 478–490. doi:10.1016/j.biortech.2018.02.039

Theeyattuparampil, V.V, Zarzour O.A, Koukouzas, N., Vidican, G, Al-Saleh, Y.& Katsimpardi, I. (2013) Carbon capture and storage: state of play, challenges and opportunities for the GCC countries. *Int J Energy Sect Manag*; 7(2):223–42.

Yang, H., Xu, Z., Fan, M., Gupta, R., Slimane, R.B, Bland, A.E & Wright, I. (2008) Progress in carbon dioxide separation and capture: a review. *J Environ Sci* ; 20(1):14–27.

Yoshida, M. & Ihara, M. (2004). Novel methodologies for the synthesis of cyclic carbonates. *Chem. Eur. J.* 10, 2886–2893.

Yu, X., Ye, S., Olsson, L., Wei, M., Krauss, K.W., & Brix, H., (2019). A 3-year in-situ measurement of CO2 efflux in coastal wetlands: understanding carbon loss through ecosystem respiration and its partitioning: Wetlands, First Online, https://doi.org/10.1007/s13157-019-01197-0.

Zevenhoven R, Fagerlund J. (2009) CO2 fixation by mineral matter; the potential of different mineralization routes. In: IOP conference series: *Earth and environmental science*. IOP Publishing.

STATUS AND PROSPECTS OF CARBON CAPTURE STRATEGY IN FOSSIL POWER PLANTS: AN UPDATED REVIEW (2010-2020)

Abba Mas'ud Alfanda [b]*, Kaoshan Dai [a,b,c], Jianze Wang [a,b,c],

[a] MOE Key Laboratory of Deep Earth Science and Engineering, Chengdu, China; [b] Department of Civil Engineering and Institute for Disaster Management and Reconstruction, Sichuan University, Chengdu, China; [c] Failure Mechanics & Engineering Disaster Prevention and Mitigation, Key Laboratory of Sichuan Province, Sichuan University, Chengdu, China; Corresponding Email: meetabba22@yahoo.co.uk

ABSTRACT

Minimizing carbon dioxide emissions from fossil fuel power plants has been a key environmental issue for decades. To avoid the negative impact of greenhouse gases on the environment, many parts of the world are gradually turning to low-carbon energy systems, which makes it necessary to meet the increasing energy demand, upgrade existing power plants and avoid high construction costs of new power generation facilities. The use of carbon capture and storage (CCS) technology to retrofit existing coal-fired power plants is seen as a promising and cost-effective solution to alleviate global warming. However, the effective use of CCS requires extensive modeling, optimization, and cost-benefit evaluation of the outputs of retrofitting plants. Machine learning models have been widely used to accurately estimate and optimize key performance outputs that are difficult to obtain from physical measurements. From an implementation point of view, applying these models to power plant retrofits is still a challenging task. This article systematically reviews the latest knowledge of machine learning tools, their application progress and limitations in CCS simulation.

Keywords. *Carbon capture and storage, fossil power plant retrofitting, machine learning, energy generating facilities*

1. INTRODUCTION

Despite rapid development in renewable energy, fossil fuel power plants (FFPPs) have occupied as large as 64.1% of global electricity consumption in 2018 (IEA, 2021). This trend will increase as new FFPPs are been constructed and may continue to serve for another three to four decades (IEA, 2021). High energy demands for a relatively cheap, affordable and flexible energy source, lead to heavy reliance on fossil-fuel fired power plants (See Figure 1). Moreover, the proven economically recoverable global coal reserves are estimated to last for about 150 years, indicates that coal will remain a major energy source now and in the foreseeable future (Wu et al., 2010; Osei et al., 2017; EIA, 2021). However, the combustion of fossil fuel in power generation plants and various industrial processes has produced a huge amount of greenhouse gases, particularly CO_2 which accounted for approximately 70% of global warming (Manaf et al., 2016; Wu et al., 2010). According to IEA (2018), coal-fired power plants emit twice as much carbon dioxide per unit of electricity as natural gas.

With increasing environmental concerns, the reduction of greenhouse gas emissions for coal-fired power plants has become a major concern threatening global industrialization and urbanization (Wu et al., 2010; Sharma et al., 2019). Although coal-fired power plants have a greater impact on climatic change than any other fossil fuel, shutting the facilities down would not be a practical solution (Osei et al., 2017). In this sense, carbon capture and storage (CCS) can be utilized as a practical and sustainable solution in reducing carbon dioxide emissions. The main approaches employed to capture CO_2 include pre-combustion, post-combustion capture (PCC), and oxy-combustion (Mores et al., 2012; Kenarsar et al., 2013). In post-combustion carbon dioxide capture, the carbon dioxide is absorbed and separated from other flue gas components. While the carbon in the fuel is separated before combustion in the case of pre-combustion carbon dioxide capture (Baghban et al., 2015).

Among these technologies, post-combustion carbon capture (PCC) with amine-based chemical absorption is the most commercially available technology in retrofitting traditional fossil-fired power plants. Post-Combustion Carbon Capture is easier to integrate into the existing plant without substantially changing the configuration technology of the plant. Again, it is flexible as its maintenance does not stop the operation of the power plant and it can be controlled. Conversely, thermal energy for regeneration involved is usually obtained from extracted steam from the low-pressure steam turbines, which in turn reduces the efficiency of the coal-fired power plant. Therefore, it is necessary to compromise between CO_2 capture level and energy consumption through process optimization while improving efficiency and reducing the cost of CO_2 capture. To perform optimization, it is required to develop an accurate model for the post-combustion carbon capture process through mechanistic and statistical models, or machine learning (ML) based model techniques. Many studies (Chen et al., 2021; Wu et al., 2010; Ben-Mansour et al., 2016; Liang et al., 2015; Li et al., 2015; Zhou et al., 2010) have recognized ML techniques as the most powerful tool in complex process modelling to coordinate the couplings between carbon and electricity for achieving low-carbon energy systems.

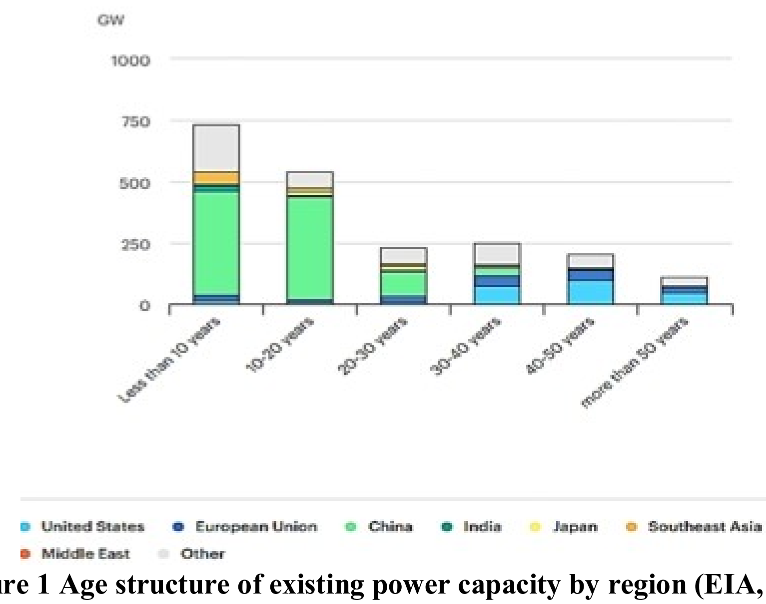


Figure 1 Age structure of existing power capacity by region (EIA, 2018)

Over the past 10 years, there has been significant progress in the development of ML simulation for the post-combustion carbon capture (PCC) technology. A systematic Literature Review (SLR) approach was chosen for its ability to offer high quality and well-defined transparent approach for **identifying, evaluating, and summarizing the findings from** large quantities of resources. Thus, this review aims to systematically extract relevant contributions of machine learning modeling techniques of CCS in FFPPs in the form of research questions:

(i) What are the current ML models used in CCS simulation and optimization?

(ii) What are the performance measures

for rating the effectiveness of ML techniques in CCS ML?

(iii) What are the ML limitations identified in the last decades?

2. METHODOLOGY

A systematic review was conducted based on Xiao and Watson (2019) framework shown in Figure 2. The framework involves sequential steps of literature search, analyzing and synthesizing the findings. A deep search of the major electronic databases (Google Scholar, Sage, Science Direct, Scopus, and Web of Science) was conducted to identify studies reporting on the application of machine learning in simulation and optimization of carbon capture processes of FFPPs. Then, the search of these keywords (Carbon capture and storage, fossil power plant, machine learning, retrofitting, artificial intelligence, Artificial Intelligence, AI, Machine Learning, ML, deep learning, DL) either in the title, abstract, or keywords only in peer-reviewed journals were selected for this systematic review (See Figure 3). Articles published over the past decade were selected using keywords 396 records relevant articles were further identified from the database via repeated search processes.

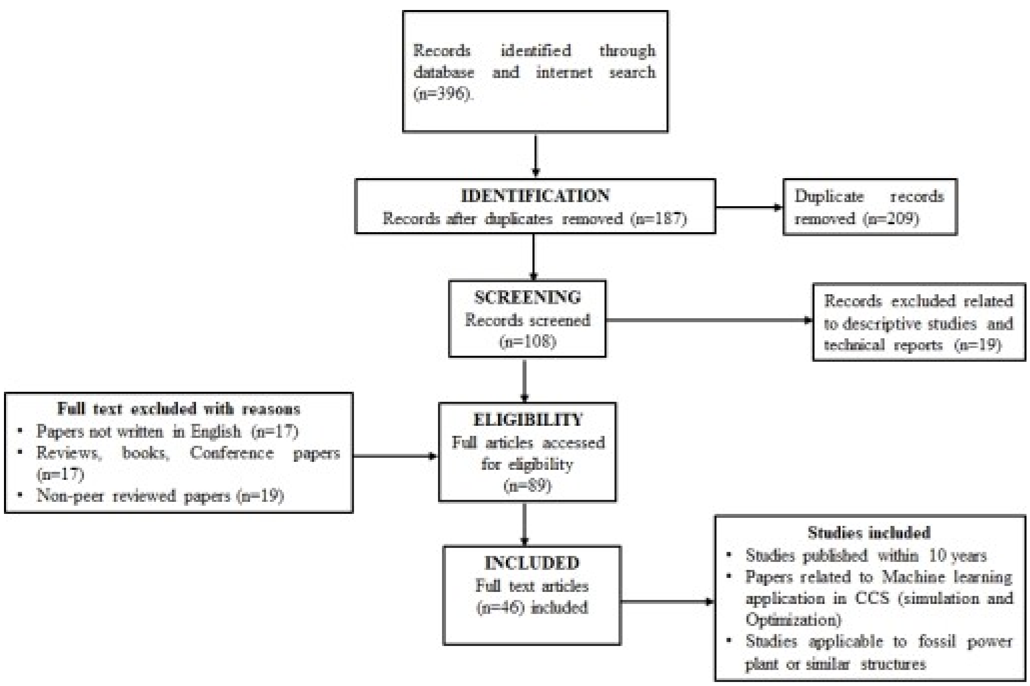


Figure 2 Systematic Review Flowchart

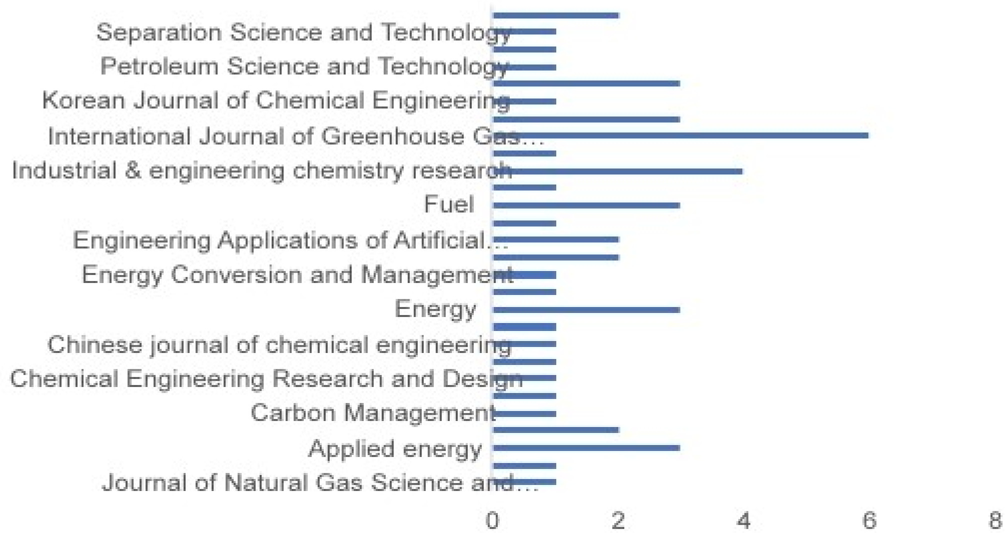


Figure 3 Frequency of Publications in Top Journals

In total, 187 articles were extracted and exported to EndNote software according to exclusion criteria. These articles were screened twice by authors independently. First, 209 duplicate articles were removed. After screening, 53 articles were discarded, the full-text of the refined list (46 articles) was screened to finalize eligible articles that complied with the specified inclusion criteria (see Fig 2). Data extracted from the selected studies were summarized in the form tables. The tabulated information included authors, year of publication, ML models adopted, and key findings were presented in the next section.

Table 1 Typical Literature matrix adopted for the SLR

Refs	ML techniques	Input(s)	Output(s)	CCS Method	Performance/ Strength
Sipöcz et al.(2011)	ANN with sensitivity analysis	Temperature, mass flow, mass fraction, solvent lead load, solvent circulation rate, removal efficiency	Mass flow CO_2 captured, rich load, specific duty	PCC	Prediction of solvent rich load and amount CO2 captured have maximum error below 2.8% and 0.17% respectively
Sharma et al. (2019)	Adaptive network-based fuzzy inference system (ANFIS) and multi-gene genetic programming (MGGP)	load and the CO2 emission	COE, annual CO_2 emissions	PCC	R^2 for MGGP and ANFIS is 0.99 and 0.96 respectively. Also, ANFIS model fails to replicate the expected sensitivity analysis.
Hoseinpour et al. (2018)	GA-RBF(genetic algorithm- radial	Temperature, pressure, mass	solubility of CO_2 (xCO_2)	PCC	R^2 for GA-RBF and Hybrid-ANFIS

	basis function neural networks, Hybrid-ANFIS, and GEP (gene expression programming)	fraction of TBAB in feed aqueous solution (wTBAB)			models was 0.9994 and 0.9927 respectively.
Mohagheghian et. al. (2015)	Feedforward artificial neural networks (FFANN)	Reduced temperature and pressure	CO_2 capture rate	PCC	Accurate prediction with 0.00175% RMSE
Mirarab et al. (2015)	ANN (artificial neural networks)	Water content, ionic liquid content, temperature, pressure	CO_2 capture rate	PCC	Small difference between the estimated results of ANN approach and experimental data of CO_2 capture rate for the training, validation, and test data sets
Zhou et al. (2010)	Adaptive-network-based fuzzy inference system(ANFIS)	Steam flow rate,CO_2 concentration in flue gas, Ratio between amine and flue gas flow rate	CO_2 production rate, CO_2 absorption efficiency, Heat duty, Lean loading	PCC	High accuracy, can model irregular non-linear function enable interpretation of the interrelationships among the parameter

3. RESULTS AND ANALYSIS

In this contribution, out of the total 94 articles identified shown in Figure 3, 49 met the criteria for full-text review but only 40 were eligible for inclusion. Analysis of the 40 articles is presented in terms of CCS Machine learning approaches, inputs and output variables as well as accuracy performance measures. It is worth noting in Figure 4, during the Covid -19 pandemic there is a decline in the number of research papers, which could be attributed to the subsequent coal consumption downturn recovery in the power sector due to the Covid-19 pandemic. At the end of 2019, increasing power consumption is observed due to a recovering demand for coal-fired electricity generation.

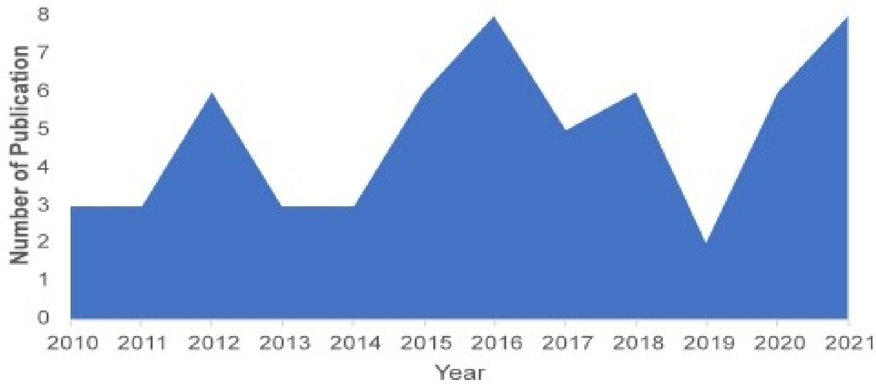


Figure 4: Trend of CCS-Machine Learning research evolution (2010 to 2021)

The most frequently used machine learning often used interchangeably with the term machine learning is the artificial neural network (ANN). ANN provides good correlations between the inputs and outputs, unfortunately, it cannot explain the relationships among the parameters (Helei et al., 2021). Another study reported that deep learning models have better model, accuracy and generalization ability, especially for multi-step ahead predictions (Li et al., 2018). Therefore, various deep multi-layer neural networks techniques have been developed in the solvent-based PCC process to address difficulties typically related to traditional ANN such as overfitting, local minima at the unsupervised stage, optimal number of layers and neurons per layer, and choice of the activation function. These strategies are aimed at (i) reducing fossil fuel burning (ii) improving coal-fired plant efficiency (iii) capture and storage of carbon dioxide (iv) enhancement of CO_2 partial pressure in the exhaust gas (28 studies). Moreover, 14 studies proposed Particle Swarm Optimization (PSO) to improve the optimization efficiency of the ANN model is consider and thus alleviate the effect of unavoidable modelling mismatches (e.g Baghban et al., 2015; Ahmadi, 2016; Wu et al.,2020; Xi et al.,2021; Sipöcz et al., 2011; Zhou et al., 2010, etc.). Satisfactory validation results proved that the accuracy of the PSO was 10 times higher than the conventional single-hidden layer (Wu et al., 2010). This technique allows one to find the best future control sequence for the PCC process.

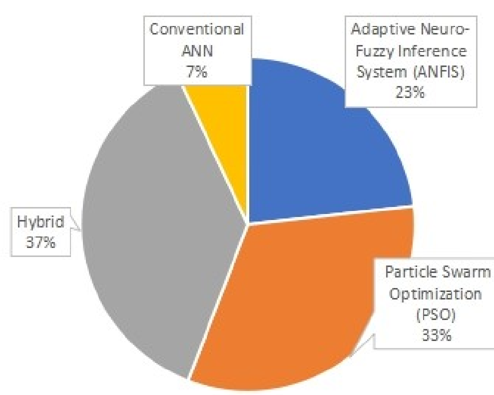


Figure 5 Break-down of the Common ML techniques

Another common approach is Adaptive Neuro-Fuzzy Inference System (ANFIS) implemented in 10 studies. The Neuro-fuzzy approach model is typically attractive for modeling the CO_2 capture process due to the following advantages: (i) It can model irregular non-linear functions among the data (ii) it is knowledge base capacity enables interpretation of the interrelationships among input-output parameters (ii)High accuracy of modeling (Zhou et al., 2010). Zhou et al. (2010) developed single-hidden layer feed-forward back-propagation neural network (FFBNN) models and adaptive network-based fuzzy inference system (ANFIS) models for the PCC process to predict the steady-state values of re-boiler heat duty, absorption efficiency, lean solvent loading and CO_2 production rate. Another comparative by Sharma et al. (2019) used an adaptive network-based fuzzy inference system (ANFIS) and multi-gene genetic programming (MGGP) to model Indian coal-fired power plants with CO_2 capture. MGGP model is better in predicting the cost and emission of the resulting plants with CO_2 capture. Due to its higher degree of correlation, ANFIS model fails to replicate the expected sensitivity analysis results. Precisely, MGGP has R^2 value of more than 99% between the predicted and actual values, as against the 96% correlation for the ANFIS approach.

Many studies have now focused on hybrid simulation approaches using multiple performance error measures can determine the accuracy of prediction to experimental data. In total, 23 studies have applied this approach (e.g., Zhou et al.,2010; Zhou et al.,2016; Baghban et al.,2015; Hoseinpour et al., 2018; Zarei et al.,2018; Sharma et al.,2019). For example, Chan et al. (2017) proposed a PWL-ANN algorithm to explore the relationships among key operational parameters of the CO_2 capture process system. In another study, Ahmadi (2016) compared the PSO-ANN and Genetic algorithm (GA)- least squares support vector machine models in terms of MAE and R^2. The PSO-ANN and GA-LSSVM methods yielded the mean absolute error (MAE) and coefficient of determination (R^2) values of 1.736 and 0.995 as well as 0.51930 and 0.99934, respectively.

Thus, the respective choice of the appropriate machine learning approach depends on the proper selection of operational parameters (inputs and outputs). To this end, physical parameters are incorporated in the formulation of the ANN inputs and output. Different outputs reviewed to reflect the performance of the PCC process include CO_2 production rate, solubility of CO_2, annual CO_2 emissions and Mass flow CO2 captured among others (Chu et al., 2016). The process parameters enable prediction and optimization and improving the efficiency of the CO_2 capture process (Zhou et al., 2016). Amongst the various inputs of CCS, reduced temperature and pressure are commonly utilized to obtained carbon capture rates. This is because retrofitting the existing coal-fired power plant easily and treat flue gas stream with low CO_2 partial pressure. Moreover, reducing lean solvent flow rate to the barest minimum will minimize the energy consumption in the regenerator of the coal-fired power plant. Altogether, it is shown multiple inputs and outputs are used for design, process prediction and performance estimation

The error is determined by comparing the current network output to the correct output (which is available in a supervised learning scenario). To evaluate the performance and accuracy of the optimal ML model, coefficient of determination (R^2), mean absolute percentage error (MAPE), and root mean square error (RMSE) were calculated using the following Eqns. (1) - (3):

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(Y_{Act,i} - Y_{Pred,i}\right)^2}{\sum_{i=1}^{n}\left(Y_{Act,i} - \overline{Y}_{Pred,i}\right)^2} \quad (1)$$

$$MAPE = \left[\frac{1}{n}\sum_{i=1}^{n}\left|\frac{Y_{Act,i} - Y_{Pred,i}}{Y_{Act,i}}\right|\right] \times 100 \quad (2)$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(Y_{Act,i} - Y_{Pred,i}\right)^2\right]^{0.5} \quad (3)$$

The coefficient of determination (R^2) is a number that specifies how well data fit into a statistical model such as a regression line or curve. It provides a measure of how well-observed outcomes are replicated by the model, based on the proportion of total variation of outcomes explained by the model. It is used to measure the error rate of a regression model and it represents the standard deviation of the model prediction error. A smaller value indicates better model performance Similarly, MAPE provides a useful measure of prediction accuracy in a forecasting method, it usually expresses accuracy as a percentage. RMSE of a model prediction for the estimated variable Y_{Pred} is defined as the square root of the mean squared error. Mean Squared Error (MSE) is the average squared difference between outputs and targets, lower MSE values are better, while zero means no error. Regression R Values measure the correlation between outputs and targets. An R-value of 1 means a close relationship, 0 a random relationship.

To enhance the control performance PCC process, PSO algorithm is applied in the IPC design to solve the receding horizon optimization problem and search for the best control actions. Interestingly, Mac Dowell et al. (2013) identified that more than 50% of energy cost in the PCC plant is associated with the cost of solvent regeneration, which accounts for most parts of the total annualized cost. Therefore, seeking for optimal operation conditions with minimum energy consumption and a satisfied capture degree appears most important consideration in designing a PCC plant. This motivated Manaf et al. (2021) to analyze the trade-offs mainly between the cost of CO_2 emission and the cost of PPCCS. The model is based on mixed-integer non-linear programming (MINLP) formulation for predicting the practicality and feasibility of CCS at large-scale commercialization. The key contribution here is determining the most feasible time for the realization of CCS commercialization considering both present and forecast trends and to estimate profit/loss of the PP-CCS.

4. CONCLUSIONS AND FUTURE PERSPECTIVE

The Systematic Literature Review (SLR) summarizes current machine learning applications and considers future potential in fossil fuel power plant CCS potentials. It does this by synthesizing 40 relevant studies out of 396 studies developed in 10 years (2010 to 2020) indicated in Figure 2. These studies are analyzed in terms of the number of publications by year, publication channels, type of ML simulation and optimization models and limitations. Machine learning based Carbon Capture and Storage (CCS) research is a rapidly evolving technology, most deep learning models require further improvements in terms of reduction in expensive computational costs. Future work will include two limitations identified in the current review. First, optimization of large energy requirement for regeneration of cheaper potential absorbents (apart from amine solution). Secondly, harnessing simulation optimization of green gas and carbon capture processes to cope with complex evolving hybrid ML models. Finally, development of a feasible optimization model on integrated design, scheduling and control of large-scale PCC plant to optimize the design and operating conditions base on a machine learning model could be future research direction.

REFERENCES

Ahmadi, M. A., Kashiwao, T., Rozyn, J., & Bahadori, A. (2016). Accurate prediction of properties of carbon dioxide for carbon capture and sequestration operations. *Petroleum Science and Technology*, 34(1), 97-103. https://doi.org/10.1080/10916466.2015.1107847

Al-Habaibeh, A., Sen, A., & Chilton, J. (2021). Evaluation tool for the thermal performance of retrofitted buildings using an integrated approach of deep learning artificial neural networks and infrared thermography. *Energy and Built Environment*, *2*(4), 345-365.

Aminian, A. (2017). Estimating the solubility of different solutes in supercritical CO2 covering a wide range of operating conditions by using neural network models. *The Journal of*

Supercritical Fluids, 125, 79-87. https://doi.org/10.1016/j.supflu.2017.02.007

Ashraf, W. M., Uddin, G. M., Arafat, S. M., Afghan, S., Kamal, A. H., Asim, M., ... & Krzywanski, J. (2020). Optimization of a 660 MW e Supercritical Power Plant Performance—A Case of Industry 4.0 in the Data-Driven Operational Management Part 1. Thermal Efficiency. *Energies*, 13(21), 5592.

Baghban, A., Ahmadi, M. A., & Shahraki, B. H. (2015). Prediction carbon dioxide solubility in presence of various ionic liquids using computational intelligence approaches. *The Journal of supercritical fluids*, 98, 50-64. https://doi.org/10.1016/j.supflu.2015.01.002

Chan, C. W., Zhou, Q., & Tontiwachiwuthikul, P. (2012). Part 4a: Applications of knowledge-based system technology for the CO2 capture process system. *Carbon Management*, *3*(1), 69-79. https://doi.org/10.4155/cmt.11.76

Chan, V., & Chan, C. (2017). Learning from a carbon dioxide capture system dataset: Application of the piecewise neural network algorithm. *Petroleum*, 3(1), 56-67. https://doi.org/10.1016/j.petlm.2016.11.004

Chen, G., Luo, X., Zhang, H., Fu, K., Liang, Z., Rongwong, W., ... & Idem, R. (2015). Artificial neural network models for the prediction of CO2 solubility in aqueous amine solutions. *International Journal of Greenhouse Gas Control*, 39, 174-184. https://doi.org/10.1016/j.ijggc.2015.05.005

Chen, X., Wu, X., & Lee, K. Y. (2021). The mutual benefits of renewables and carbon capture: Achieved by an artificial intelligent scheduling strategy. *Energy Conversion and Management*, 233, 113856. https://doi.org/10.1016/j.enconman.2021.113856

Chowdhury, F. A., Yamada, H., Higashii, T., Goto, K., & Onoda, M. (2013). CO2 capture by tertiary amine absorbents: a performance comparison study. *Industrial & engineering chemistry research*, 52(24), 8323-8331. DOI:10.1021/ie400825u

Chu, F., Yang, L., Du, X., & Yang, Y. (2016). CO2 capture using MEA (monoethanolamine) aqueous solution in coal-fired power plants: Modeling and optimization of the absorbing columns. *Energy*, 109, 495-505. https://doi.org/10.1016/j.energy.2016.04.123

Fotoohi, F., Amjad-Iranagh, S., Golzar, K., & Modarress, H. (2016). Predicting pure and binary gas adsorption on activated carbon with two-dimensional cubic equations of state (2-D EOSs) and artificial neural network (ANN) method. *Physics and Chemistry of Liquids*, 54(3), 281-302. https://doi.org/10.1080/00319104.2015.1084877

Fu, K., Chen, G., Liang, Z., Sema, T., Idem, R., & Tontiwachwuthikul, P. (2014). Analysis of mass transfer performance of monoethanolamine-based CO2 absorption in a packed column using artificial neural networks. *Industrial & Engineering Chemistry Research*, 53(11), 4413-4423. https://doi.org/10.1021/ie403259g

Ghorbani, M., Zargar, G., & Jazayeri-Rad, H. (2016). Prediction of asphaltene precipitation using support vector regression tuned with genetic algorithms. *Petroleum*, 2(3), 301-306.

Han, B., & Bian, X. (2018). A hybrid PSO-SVM-based model for determination of oil recovery factor in the low-permeability reservoir. *Petroleum*, 4(1), 43-49. https://doi.org/10.1016/j.petlm.2017.06.001

He, Z.R., Sahraei, M.H. and Ricardez-Sandoval, L.A. (2016). Flexible operation and simultaneous scheduling and control of a CO2 capture plant using model predictive control. *International Journal of Greenhouse Gas Control*, 48. 300-311. https://doi.org/10.1016/j.petlm.2017.06.001

Hoseinpour, S. A., Barati-Harooni, A., Nadali, P., Mohebbi, A., Najafi-Marghmaleki, A., Tatar, A., & Bahadori, A. (2018). Accurate model based on artificial intelligence for prediction of carbon dioxide solubility in aqueous tetra-n-butylammonium bromide solutions. *Journal of Chemometrics*, 32(2), e2956. https://doi.org/10.1002/cem.2956

IEA. (2018). Age structure of existing coal power capacity by region, IEA, Paris Retrieved from https://www.iea.org/data-and-statistics/charts/age-structure-of-existing-coal-power-capacity-by-region

IEA. (2021). Renewables Information: Overview, IEA, Paris Retrieved from https://www.iea.org/reports/renewables-information-overview.

Kim, Y., Jang, H., Kim, J., & Lee, J. (2017). Prediction of storage efficiency on CO2 sequestration in deep saline aquifers using artificial neural network. *Applied energy*, 185, 916-928. https://doi.org/10.1016/j.apenergy.2016.10.012

Kim, Y., Jang, H., Kim, J., & Lee, J. (2017). Prediction of storage efficiency on CO2 sequestration in deep saline aquifers using artificial neural network. *Applied Energy*, 185, 916–928. doi:10.1016/j.apenergy.2016.10.012

Lawal, A., Wang, M.H., Stephenson, P. and Obi, O. (2012). Demonstrating full-scale postcombustion CO2 capture for coal-fired power plants through dynamic modelling and simulation. *Fuel,* 101, pp. 115-128. https://doi.org/10.1016/j.fuel.2010.10.056

Li, F., Zhang, J., Oko, E., & Wang, M. (2015). Modelling of a post-combustion CO2 capture process using neural networks. *Fuel*, 151, 156-163. https://doi.org/10.1016/j.fuel.2015.02.038

Li, F., Zhang, J., Shang, C., Huang, D., Oko, E., & Wang, M. (2018). Modelling of a post-combustion CO2 capture process using deep belief network. *Applied Thermal Engineering*, 130, 997-1003. https://doi.org/10.1016/j.applthermaleng.2017.11.078

Liang, Z. H., Rongwong, W., Liu, H., Fu, K., Gao, H., Cao, F., & Tontiwachwuthikul, P. P. (2015). Recent progress and new developments in post-combustion carbon-capture technology with amine based solvents. *International Journal of Greenhouse Gas Control*, 40, 26-54. https://doi.org/10.1016/j.ijggc.2015.06.017

Liao, P., Li, Y., Wu, X., Wang, M., & Oko, E. (2020). Flexible operation of large-scale coal-fired power plant integrated with solvent-based post-combustion CO2 capture based on neural network inverse control. *International Journal of Greenhouse Gas Control*, *95*, 102985. https://doi.org/10.1016/j.ijggc.2020.102985

Lin, Y.J., Wong, D.S.H., Jang, S.S. and Ou, J.J. (2012). Control strategies for flexible operation of power plant with CO2 capture plant. *Aiche Journal*. 58(9), pp. 2697-2704. https://doi.org/10.1016/j.ijggc.2020.102985

Mac Dowell, N., Samsatli, N. J., & Shah, N. (2013). Dynamic modelling and analysis of an amine-based post-combustion CO2 capture absorption column. *International Journal of Greenhouse Gas Control*, *12*, 247-258.

Manaf, N. A., Milani, D., & Abbas, A. (2021). An intelligent platform for evaluating investment in low-emissions technology for clean power production under ETS policy. *Journal of Cleaner Production*, 128362. https://doi.org/10.1016/j.jclepro.2021.128362

Manaf, N.A., Cousins, A., Feron, P. and Abbas, A. (2016). Dynamic modelling, identification and preliminary control analysis of an amine-based post-combustion CO2 capture pilot plant. *Journal of Cleaner Production*, 113, pp. 635-653. https://doi.org/10.1016/j.jclepro.2015.11.054

Meesattham, S., Charoensiritanasin, P., Ongwattanakul, S., Liang, Z., Tontiwachwuthikul, P., & Sema, T. (2020). Predictions of equilibrium solubility and mass transfer coefficient for CO2 absorption into aqueous solutions of 4-diethylamino-2-butanol using artificial neural networks. *Petroleum*, 6(4), 385-391. https://doi.org/10.1016/j.petlm.2018.09.005

Mirarab, M., Sharifi, M., Behzadi, B., & Ghayyem, M. A. (2015). Intelligent prediction of CO2 capture in propyl amine methyl imidazole alanine ionic liquid: an artificial neural network model. *Separation Science and Technology*, 50(1), 26-37. https://doi.org/10.1080/01496395.2014.946145

Mohagheghian, E., Zafarian-Rigaki, H., Motamedi-Ghahfarrokhi, Y., & Hemmati-Sarapardeh, A. (2015). Using an artificial neural network to predict carbon dioxide compressibility factor at high pressure and temperature. *Korean Journal of Chemical Engineering*, 32(10), 2087-2096. https://doi.org/10.1007/s11814-015-0025-y

Moioli, S., Pellegrini, L. A., Ho, M. T., & Wiley, D. E. (2019). A comparison between amino acid based solvent and traditional amine solvent processes for CO2 removal. *Chemical Engineering Research and Design*, 146, 509-517. doi:10.1007/s11814-015-0025-y

Muhammad Ashraf, W., Moeen Uddin, G., Muhammad Arafat, S., Afghan, S., Hassan Kamal, A., Asim, M., ... & Krzywanski, J. (2020). Optimization of a 660 MWe Supercritical Power Plant Performance—A Case of Industry 4.0 in the Data-Driven Operational Management Part 1. Thermal Efficiency. *Energies*, *13*(21), 5592. doi:10.3390/en13215619

Narku-Tetteh,J.., Muchan,P., Saiwan, C., Supap, T., & Idem, R. (2017). Selection of components for formulation of amine blends for post combustion CO_2 capture based on the side chain structure of primary, secondary and tertiary amines. *Chem. Eng. Sci.,* 170 pp. 542-560. https://doi.org/10.1016/j.ces.2017.02.036

Nwaoha, C., Tontiwachwuthikul, P., & Benamor, A. (2018). A comparative study of novel activated AMP using 1, 5-diamino-2-methylpentane vs MEA solution for CO2 capture from gas-fired power plant. *Fuel,* 234, 1089-1098.

Osei, P. A., Akachuku, A., Decardi-Nelson, B., Srisang, W., Pouryousefi, F., Tontiwachwuthikul, P., & Idem, R. (2017). Mass transfer studies on catalyst-aided CO2 desorption from CO2-loaded amine solution in a post-combustion CO2 capture plant. *Chemical Engineering Science*, 170, 508-517. https://doi.org/10.1016/j.ces.2017.02.004

Pacheco, R., Sánchez, A., La Rubia, M. D., López, A. B., Sánchez, S., & Camacho, F. (2012). Thermal Effects in the Absorption of Pure CO2 into Aqueous Solutions of 2-Methyl-amino-ethanol. *Industrial & engineering chemistry research*, 51(13), 4809-4818.

Pouryousefi, F., Idem, R., Supap, T., & Tontiwachwuthikul, P. (2016). Artificial neural networks for accurate prediction of physical properties of aqueous quaternary systems of carbon dioxide (CO2)-loaded 4-(Diethylamino)-2-butanol and Methyldiethanolamine blended with Monoethanolamine. *Industrial & Engineering Chemistry Research*, 55(44), 11614-11621. https://doi.org/10.1021/acs.iecr.6b03018

Sanchez-Fernandez, E., de Miguel Mercader, F., Misiak, K., van der Ham, L., Linders, M., & Goetheer, E. (2013). New process concepts for CO2 capture based on precipitating amino acids. *Energy Procedia*, *37*, 1160-1171. https://doi.org/10.1016/j.egypro.2013.05.213

Sanchez-Fernandez, E., Heffernan, K., Van Der Ham, L., Linders, M. J., Goetheer, E. L., & Vlugt, T. J. (2014). Precipitating amino acid solvents for CO2 capture. *Opportunities to reduce costs in Post combustion capture. Energy Procedia*, 63, 727-738.

Shahsavand, A., Fard, F. D., & Sotoudeh, F. (2011). Application of artificial neural networks for simulation of experimental CO2 absorption data in a packed column. *Journal of Natural Gas Science and Engineering*, 3(3), 518-529. https://doi.org/10.1016/j.jngse.2011.05.001

Sharma, N., Singh, U., & Mahapatra, S. S. (2019). Prediction of cost and emission from Indian coal-fired power plants with CO2 capture and storage using artificial intelligence techniques. *Frontiers in Energy*, *13*(1), 149-162. https://doi.org/10.1007/s11708-017-0482-6

Sipöcz, N., Tobiesen, F. A., & Assadi, M. (2011). The use of Artificial Neural Network models for CO2 capture plants. *Applied Energy*, 88(7), 2368-2376.

Wu, X., Shen, J., Wang, M., & Lee, K. Y. (2020). Intelligent predictive control of large-scale solvent-based CO2 capture plant using artificial neural network and particle swarm optimization. *Energy*, *196*, 117070. https://doi.org/10.1016/j.energy.2020.117070

Wu, Y.X., Zhou, Q. and Chan, C.W. (2010). A comparison of two data analysis techniques and their applications for modeling the carbon dioxide capture process. *Engineering Applications of Artificial Intelligence*, 23(8), 1265-1276. https://doi.org/10.1016/j.engappai.2010.06.012

Xi, H., Liao, P., & Wu, X. (2021). Simultaneous parametric optimization for design and operation of solvent-based post-combustion carbon capture using particle swarm optimization. *Applied Thermal Engineering*, 184, 116287. https://doi.org/10.1016/j.applthermaleng.2020.116287

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. Journal of Planning Education and Research, 39(1), 93-112.

Zarei, M. J., Gholizadeh, F., Sabbaghi, S., & Keshavarz, P. (2018). Estimation of CO2 mass transfer rate into various types of Nanofluids in hollow Fiber membrane and packed bed column using adaptive neuro-fuzzy inference system. *International Communications in Heat and Mass Transfer*, 96, 90-97. https://doi.org/10.1016/j.icheatmasstransfer.2018.05.022

Zhou, Q., Chan, C. W., & Tontiwachwuthikul, P. (2010). An application of neuro-fuzzy technology for analysis of the CO2 capture process. *Fuzzy sets and systems*, *161*(19), 2597-2611. https://doi.org/10.1016/j.fss.2010.04.016

Zhou, Q., Wu, Y., Chan, C. W., & Tontiwachwuthikul, P. (2011). Modeling of the carbon dioxide capture process system using machine intelligence approaches. *Engineering Applications of Artificial Intelligence*, 24(4), 673-685. https://doi.org/10.1016/j.engappai.2011.01.003

TECHNO-ECONOMIC EVALUATION OF THERMAL AND CATALYTIC PYROLYSIS PLANTS FOR THE CONVERSION OF HETEROGENEOUS WASTE PLASTICS TO LIQUID FUELS IN NIGERIA

Emmanuel Okon Osung and Sunday Boladale Alabi*

Department of Chemical and Petroleum Engineering, University of Uyo,Uyo, Akwa Ibom Nigeria
*Corresponding author: Email: sundayalabi@uniuyo.edu.ng; Mobile: 08063043106

ABSTRACT

Techno-economic potentials f thermal and catalytic pyrolysis plants for the conversion of waste plastics to liquid fuels have been widely studied. Unfortunately, it was not obvious which of these two plants is more profitable as existing studies used different assumptions and cost bases in their analyses, thereby making it difficult to compareeconomic potentials of the plants. Consequently, in this study, industrial-scale thermal and catalytic waste plastics pyrolysis plants were designed and economically analyzed using ASPEN PLUS. Amorphous silica-alumina was considered the optimum catalyst, with 3:1 feed to catalyst ratio. Based on 20,000 tons/year of feed and 20 % interest rate, discounted payback period (DPP), net present value (NPV)(₦ millions), internal rate of return (IRR) and present value ratio (PVR) were obtained as 3.14 years, 2208, 34.88 % and 1.703 for the catalytic plant, respectively, and 2.52 years, 2426.4, 42.01 % and 2.099 for the thermal plant, respectively. Sensitivity analysis at a feed rate of 50,000 tons/year gave a slightly higher NPV for the catalytic plant – thermal (9838) and catalytic (9861) – making it a more economically efficient method of processing large amounts of waste plastics into liquid fuels. The thermal plant had a slightly higher profitability, while the catalytic plant showed better scale economy and would produce higher quality liquid fuels. Therefore, catalytic pyrolysis of heterogeneous waste plastics is recommended for commercialization in Nigeria.

Keywords: Waste Plastics, Heterogeneous, Liquid Fuels, Thermal Pyrolysis, Catalytic Pyrolysis

1. INTRODUCTION

The plastics industry obtains its energy and feedstock requirements mainly from petroleum and natural gas. According to Bhatti (2010), production of plastics consumes about 8% of the world's annual oil production – 4% as feedstock and another 4% in the form of energy used during manufacture, and annual plastics production consumes about 400 million tons of oil and gas globally. Sarkerand Rashid (2013) reported that about 129 million tons of waste plastics are produced annually in the world, out of which about 77 million tons (60 %) are produced from petroleum. According to Thorat et al. (2013), over 100 million tons of plastics are produced yearly on a global basis, out of which about 25 million tons are dumped as waste. Currently, over 8300 million tons of plastics are produced in the world annually, out of which over 78% are dumped as waste (Ogwo et al., 2013; Ayo et al., 2018). In Nigeria, over 100,000 tons of plastics are produced per year, but more than 80% of plastic wastes generated goes to landfills and dump sites (Babayemi et al., 2018; Hanafi, 2018).Since 1950, more than 1 billion tons of waste plastics have been dumped, and the dumping of waste plastics will continue, as long as the traditional practice of landfilling continues (Sahu et al., 2012). Dumping such huge amount of highly calorific materials as waste is a sheer waste of lots of crude oil, and natural gas used in making plastics.

A survey of alternative fuels shows that waste plastics, due to their high calorific values (36 – 46 MJ/kg) and abundance in local communities, are among the most promising resources for energy production (Panda and Singh, 2013). Both plastics and petroleum products are mostly composed of hydrocarbons, although molecules in plastics have longer carbon chains than those in petroleum products. Interestingly, plastics have calorific values in a similar range as fossil fuels (Gao, 2010). Studies on the performance, emission and combustion characteristics of waste plastics-derived fuel in diesel engines show that waste plastic pyrolysis oil represents a good alternative to diesel (Mani *et al*., 2009; Mani *et al*., 2010; Mani *et al*., 2011; Mohammadu*et al*., 2012). It has been observed that liquid fuels obtained from waste plastics pyrolysis are not only similar to regular gasoline in properties but also give better mileage (Samantsinghar and Behera, 2012; Panda and Singh, 2013).

Consequently, converting waste plastics into liquid fuels can provide huge amount of energy which can, in turn, reduce dependence on natural reserves of fossil fuels, and minimize environmental pollution. One of the best techniques for conserving petroleum and protecting the environment by decreasing the volume of waste plastics is pyrolysis because of its high rate of conversion of plastics into oil which can be upgraded for use as fuel in engines. In the process, the polymer chains of the plastics are decomposed at high temperatures into a variety of useful smaller molecular-weight hydrocarbon molecules. It produces solid residues and a volatile fraction, part of which can be condensed to a liquid composed of paraffins, olefins, naphthenes and aromatics (PONA), being the main product while the remaining is a non-condensable high-calorific value gas (Das and Pandey, 2007).

Pyrolysis can proceed with or without the use of a catalyst. Pyrolysis of plastics without the aid of a catalyst is known as thermal pyrolysis, and usually requires high temperatures. In catalytic pyrolysis, decomposition of plastics is performed in the presence of a catalyst, and requires a relatively lower temperature. In some studies (Kpere-Daibo, 2009; Gao, 2010; Panda and Singh, 2013; Sarker and Rashid, 2013), it was observed that catalytic pyrolysis requires lower heating time and temperature, has higher reaction rate and produces higher quality fuels, with higher liquid yield and narrow products distribution, compared to thermal pyrolysis, but involves long material resistance time between molecules of plastics or primary pyrolysis products and catalysts, undesired contact between pyrolysis products and catalysts, difficulties in recovering catalysts for reuse, and requires high heat transfer rates.

Thermal and catalytic pyrolysis plants have been widely studied because of their promise and near-term technical viability in converting waste plastics to liquid fuels; however, it was not obvious which of the plants is more promising. Previous techno-economic studies on pyrolysis of heterogeneous waste plastics were based on a single plant or process. Also, they used different assumptions and cost bases, thereby making it difficult to compare the economics of thermal and catalytic pyrolysis plants. Kpere-Daibo(2009) asserted that since catalytic pyrolysis requires a lower cracking temperature (due to lower activation energy), and a shorter cracking time, yields fuels with narrow products distribution, and has a higher selectivity to liquid products, the energy costs on the one hand and the costs of subsequent upgrading procedures for the products on the other hand, should be lower. Hence, catalytic pyrolysis should be cheaper than thermal pyrolysis. This assertion was, however, not backed up with detailed economic costing and evaluation that can guide investment in waste plastics pyrolysis. Therefore, the profitability of the catalytic plant should be compared with that of thermal plant for waste plastics pyrolysis.

The aim of this study is, therefore, to identify the more promising plant of the two heterogeneous waste plastics pyrolysis plants – thermal and catalytic pyrolysis plants.

2. METHODOLOGY

2.1. Modeling and Simulation of the Pyrolysis Plants

ASPEN PLUS (ASPEN Tech, Inc.) was the tool used to model and simulate the pyrolysis plants since its library includes; a physical property database for the various components used in the simulation, and it has been used in modeling thermal decomposition of plastics (Kannan*et al.*, 2012; Sahu*et al.*, 2012). Simulating a complete plastics pyrolysis plant allows investigation of technological feasibility and limitations of the plant before its economic aspects are examined, and generates accurate material and energy balances for detailed and accurate estimation of the costs of utility and other materials required for its economic analysis. Also, effects of process parameters, such as temperature and pressure, can be studied and optimized.

Material and energy balances were arbitrarily based on 20,000 ton/yr waste plastics. Waste plastics was composed of PP (9.57 %); LDPE (17.29 %); LLDPE (17.29 %); HDPE (34.57 %); PS (9.57 %); PVC (1.07 %); and PET (10.64 %), representing common plastics in a municipal solid waste stream. Developing conceptual flow sheets for plants was the first step in developing their models. Chemical components and related thermodynamic models, together with unit operations and their operating and input conditions were selected and specified. Then, the various units of the two plants were simulated in the sequences of their flow sheets, with the output of a unit serving as an input to a succeeding unit, until synthesis and test-running of the complex plants were achieved.

Figures 1 and 2 present the various stages in the thermal plant, while the various stages in the catalytic plant are presented in Figures 1 and 3. The processes depicted in Figure 1 are common to both the thermal and the catalytic pyrolysis plants. In the feed preparation stage, waste plastics were washed in a washer tank using a 1:1 plastic to water ratio by mass, to reduce the level of contaminants. The clean waste plastics were shred into small spherical pieces of 3.0 mm mean diameter before being purged and dried to 0.0 % water content by N_2 at 176.7˚C. The dried plastics were sent into a dehydrochlorination reactor where low-temperature (300 ˚C) pyrolysis was used to remove HCl. The HCl gas was cooled to 43 ˚C and dissolved in water to form aqueous HCl, while the plastic melt was sent into the main pyrolysis reactor for thermal or catalytic pyrolysis. The volatile stream leaving the pyrolysis reactor was cooled to 300 ˚C and fed into the first distillation column which split it into fuel gas collected at the top of the column, and fuel oil separated into light fuel oil (LOIL) and heavy fuel oil (HOIL) fractions in the second distillation column. LOIL, which was composed of gasoline-range hydrocarbons, was heated up to room temperature while the HOIL, which contained diesel-range hydrocarbons, was cooled down to same temperature as that of LOIL to avoid wax deposition in pipe lines during transportation. LOIL and HOIL were the main products of the pyrolysis, while HCl and hydrocarbon fuel gas were the by-products.

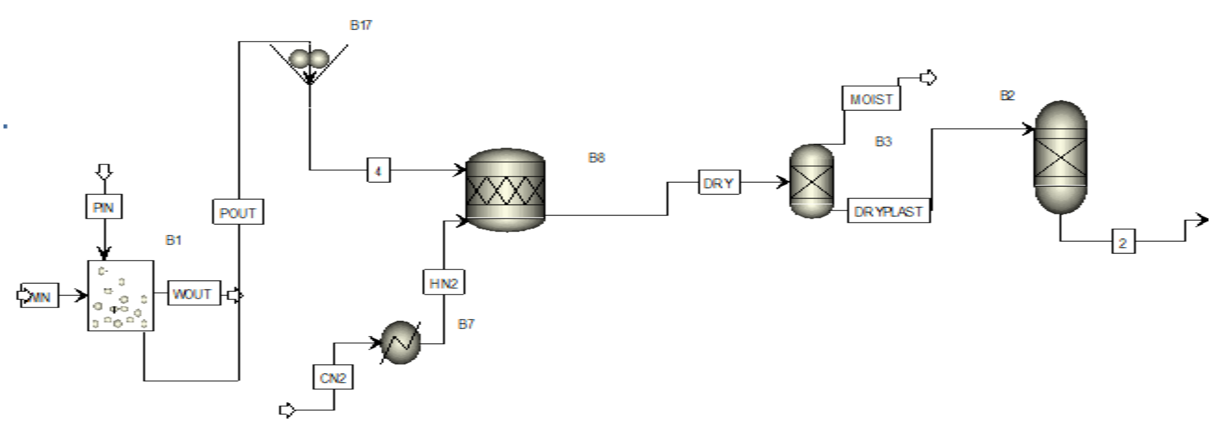


Figure 1: PFD for washing, crushing, drying and dechlorination in both the thermal and catalytic plants

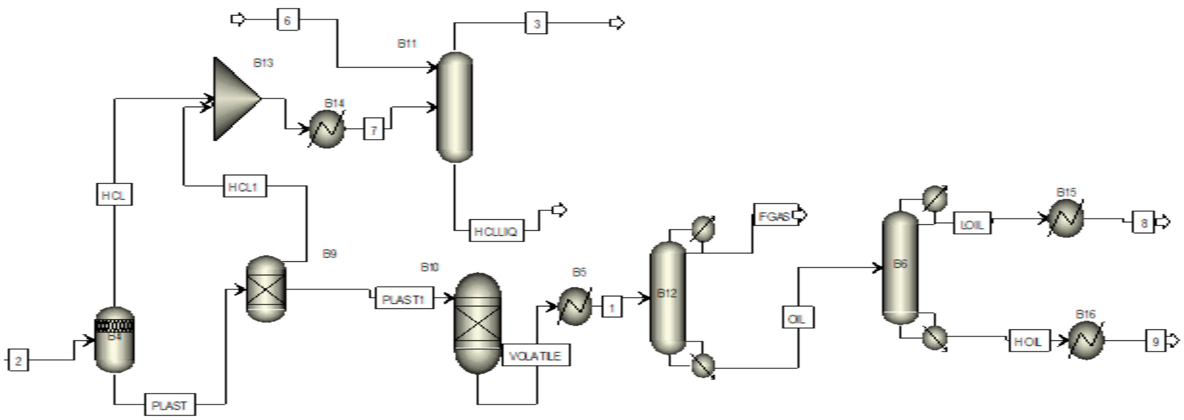


Figure 2: PFD for HCl absorption, plastics pyrolysis and products separation in the thermal plant

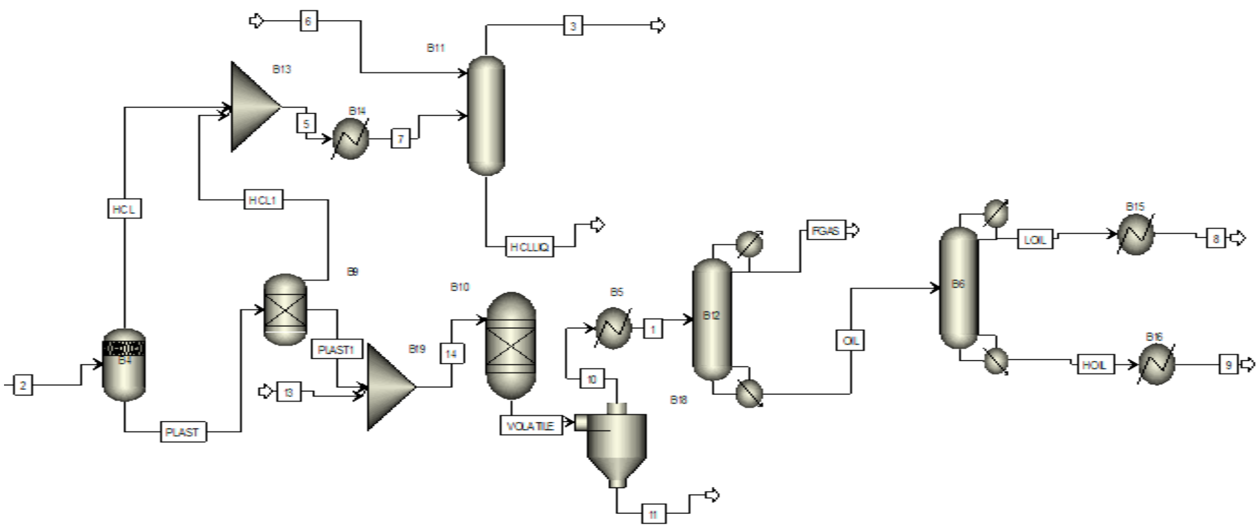


Figure 3: PFD for HCl absorption, plastics pyrolysis and products separation in the catalytic plant

2.2. Economic Evaluation

Estimation of the capital cost of each of the plants was performed by mapping modeling results from ASPEN PLUS into Icarus Process Evaluator (IPE) and relating each unit in the simulation model to a specific type of process equipment. Working capital was set at 15% of fixed capital cost. Mapping simulation results into IPE enhances effective sizing and costing of equipment to generate an accurate estimate of the capital cost of a plant.

Total manufacturing cost was estimated from heat and mass balances, prices of raw materials, chemicals, and utilities as well as operating labour cost and fixed capital cost. Depreciation was calculated using a straight-line method over 10 years, with salvage value of 10 % while tax rate was set to 45 %. All other items of manufacturing cost were estimated by the method presented in Turton*et* *al*. (2012) based on fixed capital, utility and labour costs. Labour cost was estimated from the published work by Ringer *et al*. (2006). Table 1 presents the estimated operating expenses for the two pyrolysis plants.

To gain economic insights into the plants, discounted payback period (DPP), net present value (NPV), internal rate of return (IRR) and present value ratio (PVR) were calculated. Their values are presented in Table 2. For the calculations, constant full scale plant operation and 100% market for the liquid fuels and by-products were assumed. The selling prices of LOIL and HOIL used for the economic assessment were ₦155.00 and ₦190.00/L, respectively. Current retail petroleum gasoline and diesel pump prices in Nigeria are ₦165.00/L and ₦200.00/L, respectively.
Sensitivity of NPV to production scale, interest rate and plant life was investigated. Scales investigated were 15, 000, 25, 000, 40,000, 50,000 and 60,000 ton/yr of waste plastics. The interest rate was varied from 10 to 45%, and the plant life was prolonged to 15 and 20 years.

3. RESULTS AND DISCUSSION

The total capital cost of the catalytic plant is higher than that of the thermal plant (refer to Table 1). This is due to the addition of catalyst regeneration unit to the catalytic plant. The higher cost of materials in the catalytic pyrolysis plant (refer to) is mainly due to the cost of catalyst. Making efforts to use low-cost, but effective catalysts or reducing the quantity of the catalysts used, where possible could go a long way to reducing the material cost of the catalytic pyrolysis plant. From the same Table 1, the total operating cost of the catalytic plant is also higher than that of the thermal plant due to the cost of catalyst, and the additional heating requirements in the catalyst regeneration unit.

Table 1: Estimated operating expenses of the plants at 20,000 ton/yr of waste plastics

Element	**Yearly Cost (₦/Year)**	
	Thermal Pyrolysis Plant	**Catalytic Pyrolysis Plant**
Total capital investment:	6,705,810,000	9,435,155,000
Raw material:		
Gross material expenses	5,076,708,112	6,084,708,112
By-product credit	4,063,637.44	3,822,498.72
Net material expenses	5,072,644,476	6,080,885,612

Direct expenses:		
Total utility cost	274,306,052.4	284,567,986.4
Total labor cost, C_{OL}	468,368,000	468,368,000
Supervision and clerical, $0.14C_{OL}$	65,571,520	65,571,520
Miscellaneous:		
Laboratory charges, $0.15C_{OL}$	70,255,200	70,255,200
Maintenance and repairs, $0.05C_{FC}$	134,566,200	178,731,000
Operating supplies, $0.15C_{maint.\ and\ repairs}$	20,184,930	26,809,650
Subtotal	758,945,852	809,735,370
Total direct expense	1,033,251,904	1,094,303,356
Total direct + net material costs	6,105,896,380	7,175,188,968
Indirect expenses:		
Depreciation,$0.1C_{FC}$	283,308	376,180
Local taxes and insurance, $0.015C_{FC}$	42,496.2	56,427
Plant overhead, $0.5(C_{OL}+ C_{super..and\ clerical} + C_{maint.})$	334,252,860	356,335.260
Total indirect expenses	334,578,664.2	356,767,867
Total manufacturing expenses (cost of raw material + direct expenses + indirect expenses)	6,440,475,044	7,531,956,836
General expenses:		
Admins cost, 0.15(C_{OL} + sup. and clerical + maint. and repairs)	100,275,858	106,900,578
Distribution and selling cost, 0.05 (Tot. Manu. Expenses)	322,023,752.2	376,597,841.8
Research and Development, 0.05 (Tot. Manu. Expenses)	322,023,752.2	376,597,841.8
Total General Expenses	744,323,362.4	860,096,261.6
Total Operation Expenses:	7,184,798,408	8,392,053,096

Table 2: Profitability measures of the two pyrolysis plants

Profitability Measure	Thermal Pyrolysis	Catalytic Pyrolysis
DPP – time criterion (years)	2.52	3.14
NPV – cash criterion (₦ millions)	2,426.4	2,060.8
DCFRR –interest rate criterion (%)	42.01	34.88
PVR– cash flow criterion	2.099	1.703

It is observed from Table 2 that the baseline financial performance of the two plants are encouraging, with positive NPVs (₦ Millions) of 2,426.4 and 2,060.8, estimates of 42.01 % and 34.88 % IRR, and PVRs of 2.1 and 1.7 for the thermal and catalytic plants, respectively. The plants are profitable, as their NPVs are positive, their IRR values are higher than the 20 % interest rate used in this work, and their PVRs are greater than unity. The thermal plant is slightly more profitable than the catalytic plant. Payback periods of 2.52 and 3.14 years, are reasonably good since they guarantee against loss by minimizing time-related risks and the plants are low-risk, although values less than 2 years would be preferred (Seider*et al.*, 2004).

NPVs of the plants are highly sensitive to production capacity, discount rate and economic life. In Figure 4, significant economy of scale is observed in the proposed plants, as an increase in production scale produces a significant increase in the NPVs of the two plants. As the production capacity increases by 5,000 tons, the NPV (₦ millions) of the thermal plant increased by about 1,000, while that of the catalytic plant increased by 1,120. For 50,000 and 60,000 ton/yr, NPVs (₦ millions) of the thermal plant were 9,838 and 10,896.8, respectively, while the catalytic plant had 9,861.1 and 10,976, respectively. Increase in the profitability of a waste plastics pyrolysis plant with plant capacity was also observed in earlier studies (Westerhuot*et al.*, 1998; Sahu*et al.* 2012), and is due to better cash flows achieved at higher production capacity due to cost savings. Total capital costs tend to increase very slowly as production capacity increases, implying that a larger production capacity augments profitability of liquid fuels production process because of its relatively small amount of capital costs. NPVs of the plants approached each other with increasing scale, showing a better scale economy for the catalytic plant.

NPVs of the plants decreased significantly with a rise in the interest rate used for discounting cash flows (Figure 5). As interest rate increases, revenues from sales of products near the end of the project are heavily discounted since cash flows are discounted to time zero, whereas the capital investment at time zero remains constant. As a result, NPVs of the plants decreased with a rise in interest rate.

NPVs of the two plants increased with lengthening of economic life. This is obvious since lengthening of economic life gave the plants longer periods of time to gain revenues from sales of products and by-products. The difference in the NPVs of the two plants became larger with the lengthening of their economic lives, showing a better increase in the NPV of the thermal plant with increasing economic life (refer to Figure 6).

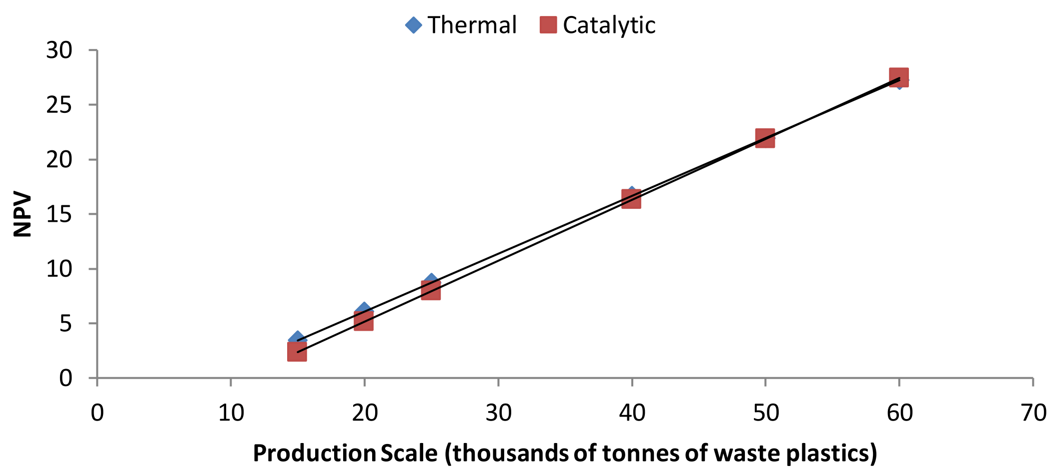


Figure: 4: Variation of NPV with production scale

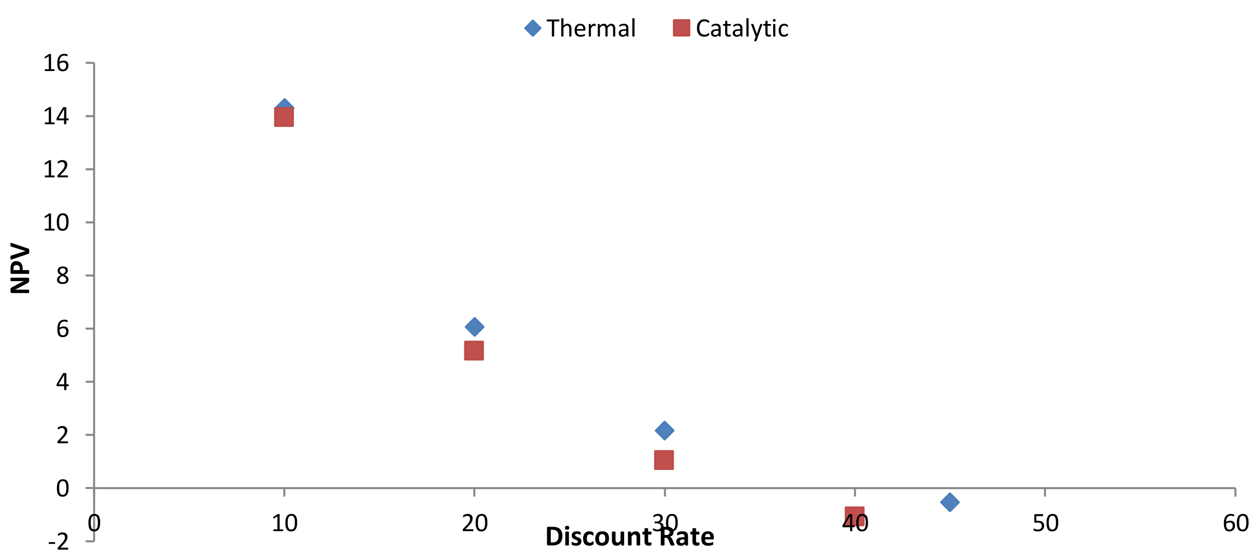


Figure 5: Variation of NPV with discounted rate.

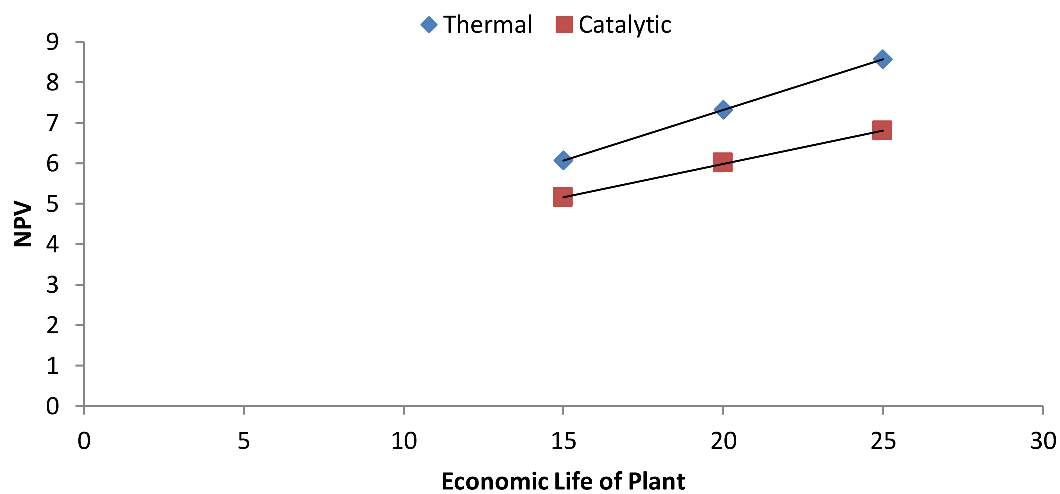


Figure 6: Variation of NPV with plant life.

4. CONCLUSION

In this study, the techno-economic potentials of thermal and catalytic pyrolysis plants for the conversion of heterogeneous waste plastics to liquid fuels were investigated using ASPEN PLUS Software Package. Based on 20000 tonnes/year of feed and 20% interest rate, discounted payback period (DPP), net present value (NPV)(₦ millions), internal rate of return (IRR) and present value ratio (PVR) were obtained as 3.14 years, 2208, 34.88% and 1.703 for the catalytic plant, respectively, and 2.52 years, 2426.4, 42.01% and 2.099 for the thermal plant, respectively. Sensitivity analysis at a feed rate of 50,000 tonnes/year gave rise to a slightly higher NPV for the catalytic plant – thermal (9838) and catalytic (9861) – making it a more economically efficient method of processing large amounts of waste plastics into liquid fuels. The thermal plant had a slightly higher profitability,while the catalytic plant showed better scale economy and would produce higher quality fuels. Hence, it could be concluded that for commercial conversion of heterogeneous waste plastics to liquid fuels, catalytic pyrolysis is superior to thermal pyrolysis.

REFERENCES

ASPEN PLUS.(2003). *ASPEN PLUS User Guide*.Aspen Technology Limited, V 7.1, Cambridge, Massachusetts.

Ayo, A. W. Olukunle, O. J. &Adelabu, D. J. (2017). Development of a Waste Plastic Shredding Machine.*International Waste Resources*. 7; 281.

Babayemi J. O., Ogundiran M. B., Weber R.

& Osibanjo O. (2018).Initial Inventory of Plastics Imports in Nigeria as a Basis for More Sustainable Management Policies.*Health and Pollution*.8 (18).

Bhatti, J. A. (2010). Current State and Potential for Increasing Plastics Recycling in the U.S.MEng.Dissertation.Columbia, Columbia University, Department of Earth and Environmental Engineering.

Das, S. &Pandey, S. (2007). Pyrolysis and catalytic cracking of municipal plastic waste for recovery of gasoline range hydrocarbons. BTech Project. Rourkela, National Institute of Technology, Department of Chemical Engineering.

Gao, F. (2010). Pyrolysis of plastic wastes into fuels. PhD Thesis. New Zealand, University of Cantebury, Department of Chemical and Process Engineering.

Hanafi, A. (2018). Plastic pollution: Nigeria‘s untapped waste wealth’s fuels environmental disaster, Punch Newspapers. 18 – 19.

Kannan, P., Shoaibi, A. A. &Srinivasakannan, C. (2012.). *Optimization of waste plastics gasification process using ASPENPLUS*. 279 – 296.

Kpere-Daibo, T. S. (2009). Plastic Catalytic Degradation Study of the Role of External Catalytic Surface, Catalytic Reusability and Temperature Effects.PhD Thesis.London, University of London, Department of Chemical Engineering.

Mani, M., Nagarajan, G. &Sampath, S. (2011). Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine. *Energy*, 36; 212 – 219.

Mani, M., Nagarajan, G., &Sampath, S. (2010). An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation.*Fuel*; 89:1826 –1832.

Mani, M., Subash, C.&Nagarajan, G. (2009).Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil.*Applied Thermal Engineering*, 29; 2738 – 2744.

Mohammadu, P.,Nikbakht, A. M., Farhadi, K., Mohebbi, A. &Far, M. K. (2012). Experimental investigation of performance and emission characteristics of DI diesel engine fueled with polymer waste dissolved in biodiesel blended diesel fuel. *Energy*. 46; 596 – 605.

Ogwo, P. A., Obasi, L. O., Okoroigwe, D. S. &Dibia, N. O. (2013). From Plastic Bag Wastes to Wealth: A Case Study of Abia State University, Nigeria. *Environmental Management and Safety*. 4(1); 35 – 39.

Panda, A. K. & Singh, R. K. (2013).Experimental optimization of process for the thermo-catalytic degradation of waste polypropylene to liquid fuel.*Advances in Energy Engineering*. 1(3); 74 – 84.

Rinker, M., Putche, V. &Scahill, J. (2006).

Large-scale pyrolysis production: a technology assessment and economic analysis. Technical Report NREL/TP-510 – 37779. Golden, Colorado,(U.S.A), National Renewable Energy Laboratory (NREL): 93.

Sahu, J. N., Mahalik, K. K., Nam, H. K., Ling, T. Y., Woon, T. S., Rahman, M. S. A., Mohanty, Y. K., Jayakumar, N. S. &Jamuar, S. S. (2012). Feasibility Study for Catalytic Cracking of Waste Plastic to Produce Fuel Oil with Reference to Malaysia and Simulation using ASPEN PLUS. *Environmental Progress and Sustainable Energy*, 0 (0) 1 – 10.

Samantsinghar, L. &Behera, D. K. (2012). Energy recovery through depolymerisation of plastic reclaimed from msw- a feasibility study for Bhubaneswar. *Sustainable Development and Green Economics*.1 (1); 2315– 4721.

Sarker, M. and Rashid, M. M. (2013).Mixture of LDPE, PP and PS waste plastics into fuel by thermolysis process.*Engineering and Technology*. 1 (1); 01 – 16.

Seider, W.D., Seader, D. and Lewin, D.R. (2004).*Product and Process Design Principles: Synthesis, Analysis, and Evaluation*, Wiley, New Jersey, 802p.

Thorat, P.V., Warulkar, S. andSathone, H. (2013). Pyrolysis of waste plastic to produce liquid hydroocarbons.Advances in Polymer Science and Technology, 3(1); 14 – 18.

Turton, R., Richard, C. B., Whiting, W. B., and Shaeiwitz, J. A. (2012).*Analysis, Synthesis and Design of Chemical Processes*. Pearson Education, Boston, 1045p.

Westerhout, R.W.J., Van koningsbruggen, M. P., Van Der Ham, A. G. J., Kuipers, J. A. M. and Van Swaaij, W. P. M. (1998). Techno-economic evaluation of high temperature pyrolysis processes for mixed plastic waste. *Chemical Engineering Research and Design*. 73; 427 – 439.

NIGERIA'S FAST DISAPPEARING FORESTS AS AN IMPENDING ENVIRONMENTAL AND ENERGY CRISIS: A REVIEW

E. O. Atanda[1]., S. N. Onuoha[1]., M. A.Obomeghie [2] and S. N. Achekuogene[3]
[1]Department of Agricultural & Bio-Environmental Engineering Technology, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
[2]Department of Electrical & Electronics Engineering Technology, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
[3]Department of Mechanical/Transport Section, Auchi Polytechnic, P.M.B 13, Auchi, Edo State, Nigeria.
Email: olugbenga_atanda@yahoo.com; sollywise2000@gmail.com; mayoboms@yahoo.com; billans4u@yahoo.com

ABSTRACT

Wood is a product of felled trees from the forest. Fuel-wood is the most patronized source of energy in the rural areas in Nigeria for domestic cooking. Statistics show that many of the trees felled from the forests in Nigeria were used as fuel-wood and coal in the rural areas. Wood is also the immediate source of energy after the sun to the farmers, as wood and other crop residues are readily available as fuel for on-farm processing of crops such as rice, oil-palm, cassava, among others. This paper examines Nigeria's fast disappearing forests as an impending environmental and energy crises. Deforestation has been identified as a major threat to both environmental and energy crisis in Nigeria. The impending environmental and energy crisis in Nigeria are such that there is the continuous removal of forest trees either by bush burning or indiscriminate felling without replacing them. Moreover, the rate of deforestation should be drastically reduced to the barest minimum because of its adverse effect on the climate, environment and economic usefulness of forest trees. The paper discusses the status of forestry and environmental crisis in Nigeria. It highlights major benefits of forests to the environmental and economic development of Nigeria. Some effects of deforestation on the environment such as encouragement of soil erosion, loss of useful organic matter, reduction in the amount of rainfall in the area concerned, among others were discussed. It also identifies some causes of deforestation in Nigeria to include unfavourable climatic factors, farming activities, mining/industrialization, natural disasters, timber exploration, among others. The paper further suggested management practices for saving Nigerian forestry from both environmental and energy crisis to include proper forest regulations, selective exploration, discouragement of deforestation, regeneration, afforestation and taunya farming.

Keywords: Forest, Environmental, Energy, Farming, Trees, Farmers

1. INTRODUCTION

Nigeria is naturally endowed with vast expanse of forest land, the swamp forests in the extreme Southern part of the country, the tropical rainforest in the South-Western axis and the wooded savannah in the Middle belt. Nigeria ranks among the countries of the world with abundant forest resources (Ogundele *et al.,* 2016). Mfon *et al.,* (2014) stated that forests in

Nigeria occupied about 110,890km^2 , that is, forests is about 12.18% of vegetation cover of the country. The world as a whole is blessed with wide expenses of forestland. These forest areas provide the means of livelihood for nearly 500million forest dwellers and nearby residents or settlers who depend directly on food, fibre, folder, fuel and other resources taken from the forest (World Bank, 1991).

The forest according to Food and Agricultural Organization is "any vegetal formation with a minimum of 10percent crown cover of trees (minimum height of 5metres) or bamboos, generally associated with wild flora, fauna and natural soil conditions, and not subject to agricultural practices" (FAO, 1991). Going by this definition, forests are predominantly trees and woody vegetation growing more or less closely together. The forest protects and regulates water resources, protects against soil erosion, serves as carbon sequestration, stores and cycles nutrients, breaks down and absorbs pollution and performs other functions such as stabilising the climate, among others. Besides the production of biological resources, one other function of the forest is its significant role in the sustainability of our environment (Okekunle, 2002).

Most Nigerians have always depended on the forest for their survival, economic development as well as environmental amelioration. The level of community nutrition is sometimes linked to fuel wood availability and cost while others depended directly on forest for their livelihood; among them are high numbers of forest and wood workers (Aliyu *et al.,* 2014). This is apart from contributing substantially to the Gross Domestic Product (GDP). In spite of its importance, the natural forest has continued to deplete rapidly in the world especially in Africa continent and particularly in Nigeria (Ogundele *et al.,* 2016).

Deforestation all over the globe is threatening the sustainability of the environment but has had bad effects in Nigeria due to their high rates. Deforestation puts at risk all aspects of the environment, the economy and the citizens of the country (FORMECU, 1996). In Nigeria, the scenario is not different, as regional breakdown of deforestation from 1979 to 1995 shows that total forest declined by 48% in the North Central, 7% in the North East, 60% in the North West, 53% in the South East, 13% in the South-South and 12% in the South-West (FORMECU,1996). In the year 2000, the forest cover was estimated at 13.5million hectares compared to 17.5 million hectares in 1990 (FAO, 2001) indicating a forest cover loss of close to four hundred thousand hectares per annum with a decline of about 2.6%. Forest/woodlands now stand at only 13% of the total land area (FAO, 2001).

Sadly, however, the Nigerian Government is yet to take appreciable measures towards halting the decline in our environmental quality (Mohammed *et al.,* 1996). To this end, Nigerian forests have been left to the fate of taking care of themselves, a responsibility they cannot shoulder while under the onslaught of logging (Okekunle, 2002). Consequently, all the forest reserves and natural forests are fast disappearing with the attendant problem that comes with it. The impending environmental and energy crisis in Nigeria is so visible that the populace can almost feel the impact as majority of the trees felled from the forests especially in the rural areas are used as fuel wood and coal. This has further put lot of pressures on available natural forests and forest reserves in Nigeria since majority of the farmers who cuts these forests in Nigeria live in the rural areas. In addition, fuel wood and coal has being the most patronized source of energy in these rural areas for their day to day domestic activities and on-farm processing of crops such as rice, oil-palm, cassava, among others. This paper therefore examines the causes of Nigeria's fast disappearing forests that have resulted to an impending environmental degradation and energy crises. To achieve this objective, the paper discusses the status of the forestry and its attendant impact on environmental growth of Nigeria. It highlights major benefits of forests to the environmental and economic development of Nigeria. It identifies some effects of deforestation on the environment as well as some causes of deforestation in Nigeria. The paper further suggested management practices for saving Nigerian forestry from both environmental and energy crisis.

2. STATUS OF THE FORESTRY AND ENVIRONMENTAL CRISIS IN NIGERIA

Forest constitutes the greatest celebration of nature to appear on the face of the planet since the first flickering of life (Myers, 1985). They are exceptionally complex ecologically, and they are remarkably rich biotically. According to the Food and Agriculture Organization (FAO, 1991), about one-third of the world's land area is forested. With respect to the Nigerian environment, the total forest area of all types in the country was estimated at about 360,000 km^2 which is about one – third of the country's total land area of 983,213 km^2. Out of these areas, savannah is about 773,789km^2 whereas 133,717km^2 is rainforest (Nigeria Yearbook, 1975). Generally, forests are found as a climatic climax in the Southern part of the country which then changes to savannah woodland and ultimately grassland as we move northward. Nigerian forests are grouped into three different formations namely: mangrove forest, fresh water swamp forest and lowland rainforest as shown in Table 1.

Table 1: Area of Vegetation Types in Nigeria

Vegetal Type	Area (Km^2)	Percentage of total land area
Mangrove/Coastal Forest	12,782	1.3
Fresh Water Swamp Forest	25,563	2.6
Lowland Rain Forest	25,372	9.7
Derived Savannah	75,707	7.7
Guinea Savannah	400,168	40.7

Sudan Savannah	342,158	34.8
Sahel Savannah	31,463	3.2

Source: Egboh (1990): Forestry Policy in Nigeria, University of Nigeria Press

According to Mortimore (1989), drought incidence is on the increase everywhere in the country as aridity is intensifying in areas north of latitude 11^0N. Former fixed dunes are being mobilised; agricultural lands are becoming less productive as desertification spreads its wings; fadama lands are drying out; gully erosion is defying solution; floods are becoming more frequent and more devastating. Waters and land in crude oil producing areas are becoming more increasingly polluted by oil spills; the continuous flaring of gas and bush burning add to the problem of greenhouse gases in our immediate atmosphere, while our industrialists continue to discharge poisonous gases, toxic solids and dangerous effluents into our air, land watercourses.

Akinsanmi (1999) stated that Nigerian environmental problems vary depending on the region and geographical location. While the arid North's environmental problems include desertification, shortage of water, dust and sand dunes encroachment; the environmental problems in the South include deforestation, coastal erosion, urban sanitary problems and oil pollution. Whereas water and air pollution are mainly featured in industrial and urban areas, land degradation and soil erosion are common problems in many states of Nigeria. A World Bank Environmental Report in 1990 identified the principal environmental problems facing Nigeria and which requires immediate attention to include land degradation, vegetation and forest degradation as well as air and water contamination.

3. MAJOR BENEFITS OF THE FOREST TO THE ENVIRONMENTAL AND ECONOMIC DEVELOPMENT OF NIGERIA

Forest is very important for several reasons. It is very necessary for government to encourage the planting of trees because of its usefulness in the following ways:

i. Provision of food: Forest including savannah provides food such as fruits, bush meat, vegetables, among others.
ii. Provision of fuel: Dead forest wood serves as firewood or source of fuel used for cooking and other purposes.
iii. Provision of medicinal herbs: The forest also provides medicinal herbs used by local healers and pharmaceutical industries.
iv. Provision of employment and income: Forest provide employment to some people, for example, forest guards and those involved in lumbering activities. It also provide source of income to the rural people.
v. Forest serves as wind-breaks: Forest, especially in the Northern part of Nigeria, serves as wind-break, thereby

reducing the speed of wind and controlling wind erosion.

vi. Formation of rain: Forest, because of their cool environment, help in the condensation of water vapour, resulting in the formation of rain.

vii. Prevention of soil erosion: Forest helps to absorb water splash on the soil and also due to vegetative cover, soil erosion is prevented. It also checks desertification and control floods.

viii. Addition of nutrients to the soil: Forest adds nutrients or improves the fertility of the soil through the decay of fallen leaves.

ix. Home of wild animals: Forest serves as the home of all wild animals like lion, tiger, antelope, rabbit, snakes, among others.

x. Forest serves as tourist centres: Forest, because of its beautiful scenery serve as tourist centre.

xi. Provision of foreign exchange: Forest serves as a source of revenue to the government. It also provides foreign exchange earnings for the country through the export of timber and its bye-products.

xii. Provision of timber: Forest provides timber for construction works like furniture, canoes and other domestic and industrial constructions.

xiii. Provision of pulp: Forest provides pulp used for tissue and paper making

xiv. Beautification of the environment: Forest trees planted around homes, industries and offices help to beautify the environment.

xv. Reduction of atmospheric pollution: Forest help in the purification of the air by removing carbon dioxide and adding oxygen to the atmosphere during photosynthesis.

xvi. Source of raw materials: Forest provides raw materials such as gum, latex, resins, ropes, dyes, fibres, rubber, palm-produce, oil seeds for both domestic and industrial purposes.

xvii. Research/educational purpose: Forest provides avenues to carry out Research/educational purposes.

4. SOME EFFECTS OF DEFORESTATION ON THE ENVIRONMENT

Deforestation has some negative effects on the environment and these include:

i. Deforestation encourages and also increases soil erosion.

ii. It leads to loss of organic matter, resulting in the loss of soil fertility.

iii. It reduces the amount of rainfall in the area. It can causes destruction of watershed.

iv. It decreases soil moisture retention.

v. It decreases the leaching of plant nutrients.

vi. It destroys the micro-climate and warns up the environment.
vii. It also reduces the forest fauna (wild life) population in the area concerned.
viii. It may lead to desert encroachment as sand particles are more likely to drop in areas without trees.
ix. It depletes the supply of forest produce (raw materials) to industries like timber.

5. SOME CAUSES OF DEFORESTATION IN NIGERIA

Distinguishing between the agents of deforestation and its causes is very important in order to understand the major determinants of deforestation (Chakravarty *et al.,* 2012). The agents of deforestation are those slash and burn farmers, ranchers, loggers, firewood collectors, infrastructure developers and others who are cutting down the forest. Causes of deforestation are the forces that motivate the agents to clear the forests (Chakravarty *et al.,* 2012).

i. Similarly, Pearce and Brown (1994) identified two main forces that affect deforestation such as Competition between humans and other species for the remaining ecological niches on land and in coastal regions. This factor is substantially demonstrated by the conversion of forest land to other uses such as agriculture, infrastructure, urban development, industry and others.
ii. Failure in the working of the economic systems to reflect the true value of the environment. Basically, many of the functions of tropical forest are not marketed and as such are ignored in decision making. Additionally, decisions to convert tropical forests are themselves encouraged by fiscal and other incentives. This latter factor has been termed indirect cause of deforestation but remained by far the most important.

Though the forests contribute substantially to the Gross Domestic Product (GDP), but the policies to regulate human interference with the forests contribute substantially to the GDP. The policies to regulate human interference with the forests so as to safeguard against depletion of this important resource have not been seriously pursued. This therefore reflects a government fiscal policies working at cross purposes with the value of the forest resources. In addition, most incentives which the government is expected to provide for the people to serve as alternative to forest resources are not provided, for example, the high cost of fossil fuels has forced people to utilize firewood and charcoal as alternative energy, high rate of unemployment has made people to turn to forest for means of survival and therefore has resulted to serious forest depletion. Furthermore, defective forest policies of the government greatly encourage deforestation, for instance most laudable policies like afforestation programmes, rainforest management (such as enrichment planting, taungya system, among others), creation of forest reserves, in–situ conservation processes among others are underfunded and neglected. The resultant effect of this is further deforestation.

Notwithstanding of the above scenarios, the following factors have been attributed to contribute substantially to deforestation in Nigeria:

i. Unfavourable climatic factors: Persistent and prolonged drought can lead to death of forest species. Also, wind blasts can destroy vegetation on its path.
ii. Farming activities: Man's farming activities can cause forest destruction through the use of forest land for crop production or grazing livestock, practising of bush fallowing or shifting cultivation which progressively leads to deforestation because the short fallow periods do not allow for sufficient forest regeneration.
iii. Timber exploitation: The practice of selective elimination of certain tree species in a natural forest causes deforestation. Also, the exploitation of timber for furniture, export, among others can cause deforestation.
iv. Mining/Industrialization: Forest trees are destroyed when the land is cleared for excavation for mining minerals. Also, petroleum exploration and sitting of industries involves clearing of forest.
v. Natural Disasters: Fire is the most serious problem to which forest are exposed, especially during the dry season. Bush burning is caused by fire used by farmers. Such fire may extend to the forest, thereby destroying tree species. Other natural disasters which can cause deforestation include landslide, earthquakes, volcanic eruptions and prolonged flooding.
vi. Timber exploitation: Government inadvertently introduces policies that can encourage felling of fuel woods and timber exploitation.

6. SUGESTED MANAGEMENT PRACTICES FOR SAVING NIGERIA FOREST FROM BOTH ENVIRONMENTAL AND ENERGY CRISIS

In order to ensure the continuous supply of timber from the forest and to save Nigeria forest from both environmental and energy crisis, the following suggested management practices are further suggested for adoption:

1. Forest Regulations: These are laws promulgated by government in form of edicts, decrees and bye-laws to prevent people from exploiting or indiscriminate tapping of forest resources. These regulations, therefore, ensure the prevention of forest resources. Forest regulation in Nigeria include the prohibition of bush burning; ban on indiscriminate cutting of timber trees; encouraging people to plant trees; ban on collection of leaves and firewood from the forests; ban on farming in forest reserves; ban on the cutting down of

under-aged trees, among others. In addition, interested farmers or lumbers are expected to obtain license from regulating government ministry so as to secure permission to enable them cut down trees for human needs. The felling quantity should be based on the number of forest stands which must be determined before felling.

2. Selective Exploration: Selective exploration is the process of cutting only mature trees in a forest. It is a way of concentrating certain selected species of timber in a forest reserve. The system allows for the cutting of older trees while the younger ones remain as cover to the surface of the forest. Some advantages of selective exploration include:

i. It ensures the concentration of selected species of timber in a forest.
ii. It protects the soil from erosion.
iii. It ensures the continuous supply of timber.
iv. It serves as a revenue base for the government.
v. It prevents indiscriminate felling of timber by giving licenses to saw millers by state forestry department of the ministries of agriculture and natural resources.
vi. It also prevents illegal felling of trees and farming by using forest guards to police the forest.
vii. Undesirable species of timbers are eliminated by this method.

3. Discouragement of deforestation: Deforestation is the continuous removal of forest stands (trees) either by bush burning of indiscriminate felling without replacing them. Economic trees such as iroko, obeche, omo, mahogany, among others are cut down so that they can be used for various purposes such as furniture like tables, chairs, doors, among others. Uncontrolled deforestation should be discouraged and if possible reduced to the barest minimum because of its adverse effects on both on the climate and the environment.

4. Regeneration: Regeneration is the process of forest re-growth after it has been exploited. It is a deliberate government policy in the restoration of deforested area after exploitation to balance the ecosystem. There are two main types of regeneration and these include natural regeneration and artificial regeneration. In natural regeneration, there is re-growth of new plants from old stumps. Under favourable environment, there exists the growth and development of new trees or volunteer trees from old stumps. The artificial regeneration on the other hand involves the natural planting of new forest seedlings in a deforested

area. In the words, forest trees are established deliberately in a plantation. Some advantages of natural regeneration include: it is less expensive when compare with artificial regeneration; it does not require formal stages in plantation establishment; it brings about the stabilization of natural ecosystem in the area of its establishment; it does not require special management skills, etc.

5. Afforestation: Afforestation is the process of establishing forest plantations in any area. It involves the complete removal of natural vegetation before planting new forest species. In Nigeria, it is popularly referred to as tree planting campaign in which two seedlings of trees are recommended to be planted to replace any one plant harvested. Early stages of afforestation may include taungya farming (which is the planting of trees and crops on the same piece of land) to maximise the use of land and protect seedlings. Afforestation has many advantages as it leads to addition of organic matter resulting in an increase in soil fertility; it provides a regular supply of raw material such as timber for industries; it prevents desert encroachment; it increases the forest fauna (wild life) in the area concerned; it builds-up the micro-climate and cools up the environment; it prevents the leaching of plant nutrient, among others.

6. Taungya farming: Taungya farming involves the planting of both food crops and forest trees on the same piece of land. In other words, it is a system which involves the integration of agriculture with forestry. Some conditions that may favour the practice of taungya farming include:

i. Scarcity of land: Taungya farming can easily be practised where land is scarce.
ii. Over-population: Land becomes scarce where there is over – population which can lead to the practice of the system.
iii. Unemployment: Mass underemployment or unemployment does lead people to practise taungya farming.
iv. Government policies: Government can put in place policies which will make people practise taungya system.
v. Low standard of living: This factor does force people to resort to the practice of taungya system as a means of alternative way of increasing their standard of living.
vi. Granting of incentive: Incentives such as loans to farmers can help them to take part in additional farming.

7. CONCLUSION

Deforestation in Nigeria has been mainly attributed to the rural farmers and grassroots poor people whose means of survival were basically embedded in the forests but on the other hand are been denied access to available forest resources. Other agents of forests depletion are mainly developmental projects oriented found in the Nigerian economic sectors like agriculture, oil and gas, transport, mining and materials, amongst others that contributed to technological growth. Persistent deforestation is further compounded by the fact that the majority of the Nigerian populace lacked in-depth knowledge of the consequences of deforestation. Ways of reducing deforestation must therefore go hand in hand with improving the welfare and environmental knowledge of the rural farmers and the populace otherwise they would fail. Urgent mitigating measures and strategies would remain elusive since these will vary from region to region and will change over time. Effective implementation is very essential including stakeholders participation, development of management plans, monitoring and enforcement of the suggested management practices for saving Nigerian forests from both environmental and energy crisis. The stakeholders should recognize the critical roles of government at the three levels of administration and also empower the civil society and the private sector to take proactive role in reducing deforestation by working in conjunction with government.

8. REFERENCES

Akinsanmi, F.A. 1999: Updating Environmental Information. Invited Lead Paper presented at the 26th Annual Conference of Forestry Association of Nigeria held in Maiduguri, Borno State, 7th to 12th November, 1999.

Aliyu, A., Modibbo, M.A.,Medugu, N.I and Ayo,O. 2014: Impacts of Deforestation on Socio- Economic Development of Akwanga in Nasarawa State. International Journal of Science, Environment and Technology, 3(2):403-416.

Chakravarty, S., Ghosh, S.K., Suresh, C.P.,Dey, A.N and Shukla, G. 2012: Deforestation: Causes, Effects and Control Strategies In: A.Okia (ed) Global Perspectives on Sustainable Forest Management. Available online at http:/www/Intechopen.com/books/global-pespectives-on-sustainable-forest-management/deforestation-causes-and-control strategies.

Egboh ,E.O. (1990): Forestry Policy in Nigeria, University of Nigeria Press, Nsukka, Nigeria

FAO, 1991: Food and Agriculture Organization Second Interim Report on the State of the Tropical Forest, Forest Resources Assessment 1990 Project Mimeo. Paper presented at the 10th World Forestry Congress in Paris, France.

FAO, 2001: State of the World's Forests. Food and Agriculture Organization, Rome.

FORMECU, 1996: Statistics of Forest Reserves in Nigeria. Forestry Management, Evaluation and Co-ordinating Unit, Benin, Nigeria.

Mfon, P., Akintoye, O.A., Mfon, G., Olorundami, T., Ukata, U and Akintoye, T.A. 2014: Challenges of Deforestation in Nigerian and the Millennium Development Goals. International Journal of Environment and Bioenergy, 9 (2):76-94.

Mohammed, R, Jimeta, U and Gisilembe,A,M. 1996:Legislation and the Environment: Towards a more effective regulatory framework in the Savannah and Sahel belts of Nigeria In: Issues in Environment Monitoring in Nigeria, The Nigerian Geographical Society, Pp 129-132.

Mortimore, M.J. 1989: Adapting to Draught: Farmers, Famine and Desertification in West Africa, Cambridge,

Myers, N. 1989: Deforestation Rates in Tropical Forests and their Climatic Implications.

Nigeria Yearbook, 1975: Times Press Limited, 120Pp.

Ogundele, A.T., Oladipo, M.O and Adebisi, O.M. 2016: Deforestation in Nigeria: The Needs for urgent Mitigating Measures. IIARD-International Journal of Geography and Environmental Management, Volume 2 No1 Pp 15-26.

Okekunle,A,T. 2002 : The Role of the Forests in the Amelioration of the Nigerian Environment

The Nigerian Field, Volume 67:31-33 , April, 2002 Edition, Publication of the Nigerian Field Society.

Pearce, D and Brown, K.1994: Saving the World's Tropical Forests In: K. Brown and D.Pearce (eds) The Causes of Tropical Deforestation. The Economic and Statistical Analysis of factors giving rise to the loss of the tropical forest, UCL Press, Pp 2-26.

World Bank, 1991: The Forest Sector, a World Bank Policy Paper, Washington, D.C, World Bank.

THE DESIGN AND FABRICATION OF A MOBILE WASTE INCINERATOR FOR RURAL DEVELOPMENT

[1]Ramonu, O. J. and [2]Joseph, O. O.

[1]john.ramonu@federalpolyilaro.edu.ng and [2]olakunle.joseph@federalpolyilaro.edu.

ABSTRACT:

Incineration is one of the methods of waste disposal. It is better than burning waste in an open air as it is being done in most rural settlements. The incineration process as a complementary Rural Waste Management Program will reduce the quantity of waste dumped into the rivers and on the road sides. This study presents the design and fabrication of an incinerator for rural waste disposal for the purpose of reducing its volume and destroying hazardous substances or pathogens present in the waste. The incinerator was designed to treat a bulk waste of 300 kg and a volume of 6.81 m^3. The combustion chamber is made of refractory material with high refraction properties and dimensioned to be 1.83m x 2.44m X 1.53m with a volume of 6.81m^3. The incinerator has two charging ports. The ashes dropped into a collector made of angle bar, flat sheet metal and a wheel with the volume of 0.91m^3 and a dimension of 2.44m X 1.22m X 0.31m. Subsequently, the flue gas escaped through the chimney installed on the roof of the incinerator. The incinerator has a centrifugal blower which provides and accommodates a large flow of air to the fire chamber. The dimension of the incinerator is 2.135 x 1.830 x 2.440 m and a volume of 9.53 m^3 including the ash chamber. The design and construction of waste green technology incinerator was designed to dispose wastes generated. The incinerator eliminates contaminant and filter particulate from the flue gas before its release into the atmosphere which will help improve the pollution problem experienced as a result of poor means of waste disposal.

Keywords. *Design,Fabrication,Mobile,Waste,Incinerator,Rural*

1. INTRODUCTION

Incineration is a waste treatment process that involves the combustion of organic substances or waste materials (Knox and Andrew, 2005). Incinerator and other high temperature waste treatment systems are described as ‘thermal treatment’. Incinerator converts waste materials into ash, flue gas and heat. The ashes are mostly formed by the inorganic constituent of the wastes and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be free of gaseous and particulate pollutants’ before they are dispersed into the atmosphere. In some cases, the heat generated by incineration process can be used to generate electric power. (Michaels, 2009).

Incinerator reduces the solid mass of the original waste to about 20% and volume to 15% depending on the composition of the waste (Ramboll, 2006). Incineration with energy recovery is one of the several wastes to energy (WTE) technologies such as gasification, pyrolysis and anaerobic digestion. While incineration and gasification technologies are similar in principle, the energy produced from incineration is of high temperature heat whereas combustible gas is often the main energy product from gasification, Incineration and gasification may be implemented without energy and materials recovery.

Waste combustion is particularly popular in a country like Japan, where land is a scarce resource for landfills. Denmark and Sweden are leading countries in energy generation from incineration, localized combination of heat and power facilities and supporting district heating schemes (Kleis, et al, 2005). Some of the European countries rely heavily on incineration for handling municipal waste, in particular Luxembourg, Netherlands, Germany, and France. (Ramboll, 2016). Studies on waste composition in some Nigerian cities indicate that about 25% of most urban wastes in Nigeria comprise of paper and nontoxic materials, which can be burnt in suitably designed incinerators to generate heat or recover useful materials for tiles industries. Presently, these waste materials are either burnt uncontrollably to reduce volume or disposed as landfills with adverse health implications (Cheremisinoffs, 1990). Incineration is an environmentally and technically superior method of waste management to others due to its reliability, safety and efficiency. Other methods of waste disposal includes: ocean dumping, sanitary landfill, open dumping and recycling. The first Czech Republic incinerator was built in 1905 in Brnos (Lapcik, 2011). The best practice of waste management is the reduction of waste generation, thus, decreasing incinerator use, emissions and health and environmental risks. Waste management has defied a number of strategies both in developing and developed countries, aborting most efforts made by international bodies, federal governments, state and city authorities (Adejobi and Olorunnimbe, 2012). One of the common practices in waste management is the provision of dump site for landfill where all manners of waste are dumped. Scavengers normally recover recyclables items and indiscriminately set the fields on fire causing dangerous infernos (Adewole, 2009). Investigations showed that effluent from landfills caused by rainwater, known as leachate, peculates through the waste which contains heavy metals and other hazardous compounds (Mahmood, *et al.,* 2013). It was reported by Akinbile and Yusoff (2011), that the analysis of deep boreholes water at sites around landfills did not indicate strongly polluted water, though, requiring treatment before use while soil around the landfills was found to be unsuitable for crop production due to the presence of dangerous and unfavourable elements in a the soil. However, investigations of water from shallow boreholes and wells sited near the dump sites showed that they are highly polluted (Akinbile and Yusoff, 2011). In order to properly manage waste, there is need for the sorting of the waste to determine the treatment process required to manage them. Most municipal solid waste in developing countries contains about 50% of organic waste. (Adigio and Amula, 2011). In most developed countries, healthcare wastes are treated by incineration technology and the incinerated ash is disposed as landfills. Subsequently, studies have shown that the ashes from the incineration of waste has been actively recycled in the areas of roadbed, asphalt paving, and concrete products in many of European and Asian countries (Abdulahi, 2009).

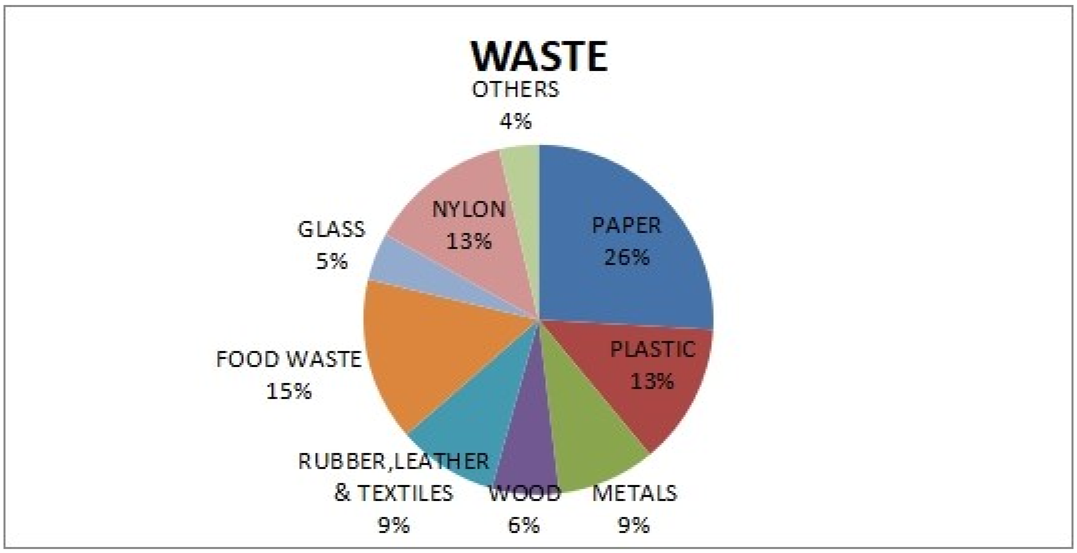


Figure 1**:** Pie chart showing total municipal solid waste (MSW) generated

The figure above shows that paper has the highest percentage of 25.9%,plastic has13.1%, metals has 9.1%, wood has 6.2%, rubber, leather & textiles has 9.3%, food waste has 15.1%, glass has 4.4%, yard trimming has 13.3% and others has 3.6%. Paper has the highest percentage due to its much usage in packaging of goods and also for dissemination of information.

In Nigeria, the waste management system in the rural areas is very poor. The predominant method of waste management by open waste burning causes serious environmental pollution. Poor waste disposal and management methods contribute largely to the environmental pollution. Thus, the need for efficient waste management in the rural communities is imperative. The design and fabrication of a modern waste incinerator is to contribute to the technological development, health and safety of the rural settlement.

2. METHODOLOGY/ MATERIALS AND METHOD/ PROCEDURES

The suitability of each material used for fabrication was duly investigated before they were selected and used. Some of the basic factors that were considered for material selection include suitability and availability of materials, strength, thermal conductivity, refractoriness, corrosion and permeability among others. The following material were used for the fabrication of the incinerator:

Sheet Metal

The Sheet metal is a metal formed by an industrial process into thin, flat pieces. This sheet metal gauges are based on thickness 2mm, the sheet metal is cut, bent and stretched into desired shape, which is done by cutting the sheet metal.

Special tools, such as band saws and chops saws are used in the sheet metal fabrication process; these ensure even cutting throughout the process. Once all the components are formed, they are then assembled, tacked and welded into position.

Angle Plate

The angle plate is a fixture used to support the sheet metal in other to obtain a rigid frame, the angle plates are based on the accuracy, all external and internal are finished by grinding of the chips to ascertain a smooth surface, and the angle irons are in standard length 25mm × 25mm.

Hinge

A hinge is a mechanical bearing that connects two solid objects, typically allowing only a limited angle of rotation between them. Two objects connected by an ideal hinge rotate relative to each other about a fixed axis of rotation. These hinges are joined with a screwing method, the hinges helps to open the combustion chamber door.

Chimney

A chimney provides ventilation for hot flue gases or smoke generated from the combustion chamber. It ensures that the gases flow smoothly, the process of drawing air into the combustion chamber is known as the stack. The space inside the chimney is called flue. The chimney of diameter 228.6mm, thickness 5.08mm and height of 701.04mm is well constructed to transfer flue gases to the external environment via stack effect.

Gas cylinder

A gas cylinder is a pressure vessel used to store gases at above atmospheric pressure. Inside the cylinder the stored gas may be in a liquid state, dissolved state, or compressed gas. The gas cylinders are placed upright on a flattened bottom at one end with the valve at the top.The gasis preferred to maintain good combustion and safe. A gas cylinder of 12kg is selected to ensure adequate and sufficient flow of gas throughout the combustion process.

Valve

The valve is a device that regulates, directs or controls the flow of a fluid by opening, closing, or partially obstructing various passageways. Valves are technically fittings. In an open valve, fluid flows in a direction from higher pressure to lower pressure. A lower pressure valve is fitted to the pipe and higher pressure valve is fixed to the top of the cylinder in other to regulate the gas.

Hose

A hose is a flexible hollow tube designed to carry fluids from one location to another. Hoses are also sometimes called pipes. Hose design is based on a combination of application and performance.

Common factors are size, pressure rating, weight, length and chemical compatibility. A hose of length 4572mmis connected to the valve on the cylinder gas, it serves as a passage for gas to the burner for easy burning of the refuses.

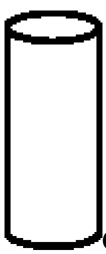
Metal mesh

A mesh is a barrier made of connected strands of metal, a metal mesh is a metal materials which consists of drilled holes to convey the passage of ashes gotten from the burnt waste. A metal mesh of dimension 549mm × 610mm × 6mm was used. A metal mesh helps to separate the ash from the waste, the ash been removed is then dropped into the ash tray, for further usage.

Castor wheel

A caster is a wheeled device typically mounted to the bed that enables relatively easy rolling movement of the incinerator. The castor wheel varies in size; Wheel materials include cast iron, plastic, rubber, forged steel, stainless steel, aluminum, and more. The selected wheel castor for the incinerator is the rubber type of size?, in other to ease the movement of the incinerator.

Design Analysis



Chimney

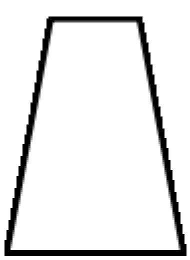
Area of a cylinder = $2\pi r^2$ + h ($2\pi r$)

$= 2 \times 3.142 \times (0.05)^2 + 0.701\,(2 \times 3.142 \times 0.05)$

$= 0.236m^2$

Volume of a cylinder = $a \times h = 0.1596 \times 0.701 = 0.112m^3$

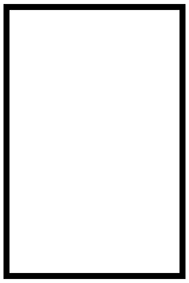
Combustion chamber



Perimeter of a trapezium= $a + b + c + d = 0.61 + 0.305 + 0.305 + 0.4575$

= 1.6778m

Area of a trapezium $= \frac{1}{2}(a+b)h = \frac{1}{2} \times (0.61 + 0.4575) \times 0.305 = 0.1627 m^3$



Area of a rectangle $= l \times w = 0.61 \times 1.22 = 0.744m \times 4 = 2.976 m^2$

Perimeter of a rectangle $= 2l + 2w = 2 \times 0.61 + 2 \times 1.22 = 3.66m \times 4 = 14.64m$

Volume of a cuboid $= lwh = 0.61 \times 1.22 \times 1.22 = 0.907 m^3 \times 4 = 3.628 m^3$

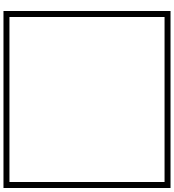
Bed

Perimeter of a rectangle $= 2l + 2w = 2 \times 1.22 + 2 \times 0.61$

$= 3.66m$

Area of a rectangle $= l \times w = 1.22 \times 0.61 = 0.744 m^2$

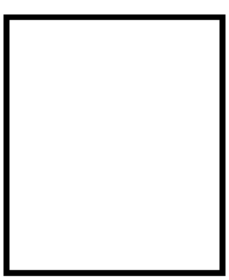
Gas housing



Area of a square $= s^2 = 0.61^2 = 0.372m \times 4 = 1.488 m^2$

Perimeter of a square = 4s = 4 × 0.61 = 2.44m

Volume of a cube $= s^3 = 0.61^3 = 0.227 m^3 \times 4 = 0.908\ m^3$



Ash tray

Area of a rectangle = l × w = 0.61 × 0.549 = 0.335m^2

Perimeter of a rectangle = 2l + 2w = 1.22 + 1.098 = 2.318m

Volume of a cuboid = l × w × h = 0.61 × 0.549 × 0.25 = 0.084m^3

Total volume for the mobile Incinerator = 0.112 + 3.628 + 0.908 + 0.084 = 4.732m^3

2.1 Method of Machine Testing or Evaluation.

The mobile waste incinerator has been designed, fabricated and tested. The result of the test showed that the mobile waste incinerator can be used in the rural and urban communities for effective waste burning and reduction in volume and mass. The incinerator was designed to treat a bulk waste of 100kg and the volume for the solid waste in the incinerator for batch treatment is 3.79 m^3. According to the design of the incinerator, the incinerator was able to reduce waste to 15-20% of the solid waste that is been charged in the incinerator. The volume of ash content that left in the incinerator was reduced to 15kg (85% of reduction).It was observed during the machine testing and evaluation that the maximum temperature of the burning chamber which is about 200°C is capable of burning a 100kg municipal waste.

3. RESULTS AND DISCUSSION

The incinerator was designed to treat a bulk waste of 100 kg and the volume for the solid waste in the incinerator for batch treatment is 3.79 m^3. According to the design of the incinerator to reduce waste to 15-20% of the solid waste that is been charged in the incinerator. The volume of ash content that will be left in the incinerator will be reduced to 15kg (85% of reduction). The maximum temperature of the burning chamber capable of burning a 100kg municipal waste is about 150 -200°C depending on the constituent of the waste. When the incinerator is charged with the appropriate mix and quantity of 100kg waste, the operator should close the door and start the burn cycle. The burn cycle should not be interrupted by opening the charging door until after 20 to 30 minutes burn to check for complete burn. The incinerator was designed to treat a bulk waste of 100kg and the volume for the solid waste in the incinerator for batch treatment is 3.79m^3. The total volume of the incinerator including the ash chamber is 4.693m^3. The mobile waste incinerator was designed, fabricated and tested. The result of the test showed that the mobile waste incinerator can be used in the rural and urban communities for effective waste burning and reduction in volume and mass.

4. CONCLUSION AND RECOMMENDATION

A mobile waste incinerator has been designed and fabricated for rural development which significantly reduces the environmental pollution caused by poor waste disposal. The machine is very significant in effective waste treatment that will impact positively on environmental protection and pollution prevention.

REFERENCES

Abdulahi M.M. (2009). Municipal Solid Waste Incineration Bottom Ash as Road Construction

Materials *AU J.T* 13(2), PP 121 - 128

Adejobi O, S. and Olurunnimbe. R.O. (2012*).* Challenges of waste Management and Climate Changes in Nigeria, Lagos State metropolis experience, *African Journal of Scientific Research* 7(1) 346 –362

Adewole, A, T (2009). Waste Management towards sub stainable delve in Nigeria. *A case study of Lagos State, International NGO Journal* 4(4) 173 - 179

Adigio, E. M. and Amula, E. (2011). Appraisal of Waste Management in Yenagoa Metropolis, *International Research, Journal in Engineering Science & Technology*, (7) 114 -124

Akinbile, C. O. and Yusoff Y. (2011). *Environmental Impact of Landfill on Groundwater Quality and AgriculturalSoils in Nigeria, Soil & Water Resources,* (7) 18–26

Cheremisinoff, P. N. (1990). Focus on high hazard pollutants, *Pollution Engineering* 22 (2) PP.67-79.

.Kleis, H., Dalager, S., 2004. 100 Years of Waste Incineration in Denmark. Babcock & Wilcox Vølund, and Rambøll, Denmark.

Knox, A. and Andrew A. (2005). An Overview of Incineration and EFW Technology as Applied to the Management of Municipal Solid Waste (MSW).

Lapcik, V.. Expert Report for Environmental Impact Assessment Documentation as of Appendix 5 to Act No 100/2001 Coll., as amended, for the project “Municipal-Waste-to-Energy Plant Chotíkov (ZEVO Chotíkov)”. Prepared for the Regional Office of the Plzeň Region. Ostrava, December 2011.

ASSESSMENT OF STREAMFLOW RESPONSE UNDER THE INFLUENCE OF CLIMATE CHANGE IN HADEJIA-NGURU WETLANDS, NIGERIA

U. A. Ibrahim[1]*, S. Dan'azumi[2] and M. A. Mohammed[1]

([1]Department of Civil and Water Resources Engineering, University of Maiduguri
[1]Department of Civil Engineering, Bayero University Kano)
*Corresponding author's email address: uaibrahim@unimaid.edu.ng
Telephone number: 08037655236

ABSTRACT

The influence of climate change on streamflow of the Hadejia-Nguru wetlands (HNWs) catchment was investigated by simulating monthly streamflow data from 2017 to 2050. An integrated Water Evaluation and Planning (WEAP) software was employed for the analysis. Observed precipitation and temperature data (1980 – 2016) of the HNWs catchment, as well as 5 Global Circulation Models (GCMs) output of Relative Concentration Pathways (RCP4.5) scenario were utilized. The Scenarios were built under a combination of 5 GCMs and 3 assumed future climate conditions of changing precipitation and temperature; Increased Precipitation Unchanged temperature, Increased temperature unchanged precipitation and Increased precipitation increased temperature. The simulation demonstrated that the impact of climate change could alter the hydrology of the HNWs catchment under these diverse scenarios. Furthermore, it revealed that streamflow under Scenario 3 might suffer a maximum decrease of up to 10%. Likewise, a high possibility of mild to moderate drought occurrences were revealed in Scenarios 2 and 3 respectively. Thus, from the anticipated changes in the streamflow, the study established that HNWs catchment is very vulnerable to drought due to climate change. The analysis suggest that a comprehensive plan is needed to manage water resources in the HNWs catchment. Furthermore, assessments of climate change adaptation strategies for reservoir operations proposed by the Basin's decision makers should be evaluated for sustainable water resources development.

Keywords: Wetlands, WEAP model, streamflow, simulation, climate change

1. INTRODUCTION

Climate change ascribed to the greenhouse gases (GHGs) emissions has been the focus of research in the last decade. According to IPCC (2007), the trends and fluctuations in climatic factors such as carbon dioxide content of the atmosphere, temperature, rainfall pattern are more severe in recent time, especially in developing countries. Thus, uncertainty about the rate and extent of change makes water resources planning challenging (Bhave *et al.,* 2018). A declining tendency of runoff has been exposed in many river basins of Nigeria as reported in the studies of Ayeni *et al.* (2015); Ezemonye *et al.* (2016); Oyerinde *et al.* (2017); Mahmood & Jia (2018); Okafor & Ogbu (2018); Umar *et al.* (2018). The fifth Intergovernmental Panel on Climate Change (IPCC)'s report also indicated that the intensity and frequency of extreme events are expected to change in the future (IPCC, 2013). However, these events can be expected to act in conjunction with a range of other pressures. The Study of Nwankwoala (2012) revealed that wetlands are important elements of Nigeria's watershed systems. However, a lot of the hydrological and water resources problems experienced in the country are the resultant effects of wetlands degradation. Temperature and precipitation are most significant variables of climate change, but potential future changes is rather difficult, due to uncertainties in the forecast of global and long-term temperature and precipitation patterns.

Several studies have demonstrate that Hadejia-Nguru Wetlands (HNWs) is suffering under existing water stress from pressures such as drought and upstream irrigation demands (Hollis *et al.,* 1993; Thompson & Hollis, 1995; Goes, 1999, 2005; Barbier & Thompson, 2011; Dami *et al.,* 2017; Ayeni *et al.,* 2019). These pressures will be significantly exacerbated by climate change resulting in reduced rainfall and increasing temperatures. Moreover, it could reduce streamflow and diminish the area of wet season inundation within the wetlands. Therefore, due to these problems and its intensity, water resources tools are needed to predict and show response to changes in the productive status of the wetlands. Thus, the study is aimed at using WEAP model to predict streamflow changes in the context of water management, climatic variability and climate change.

2. Materials and Methods

2.1 The Study Area and Datasets

The HNWs is positioned in the semi-arid region of Northern Nigeria, approximately between latitudes 12^0 15'N and 13^0 00'N and longitudes 10^0 00'E and 11^0 00'E as presented in Figure 1. The land surface area covers about 3,500km^2 as demonstrated in the study of Okali & Bdliya (1998). The area is a complex flood-plain, comprising of seasonally flooded lands and dry uplands. The HNWs climate is characterized by two distinct seasons; wet season (May – September) and dry season (October – April) with a varying precipitation pattern between 500 mm to 600 mm (Nigerian Meteorological Agency, 2017). The peak runoff flow normally occurs in August and September during which the banks overflow and the area inundated (Umar & Ankidawa, 2016). Likewise, the temperature ranges from 12°C during the harmattan season (cold) to about 40°C during the hot season. The annual average evaporation is around 3000 mm (Nigerian Meteorological Agency, 2017). However, as result of high amount of evaporation, the wetlands survives from drought by receiving water from rivers around the upstream region of the basin.

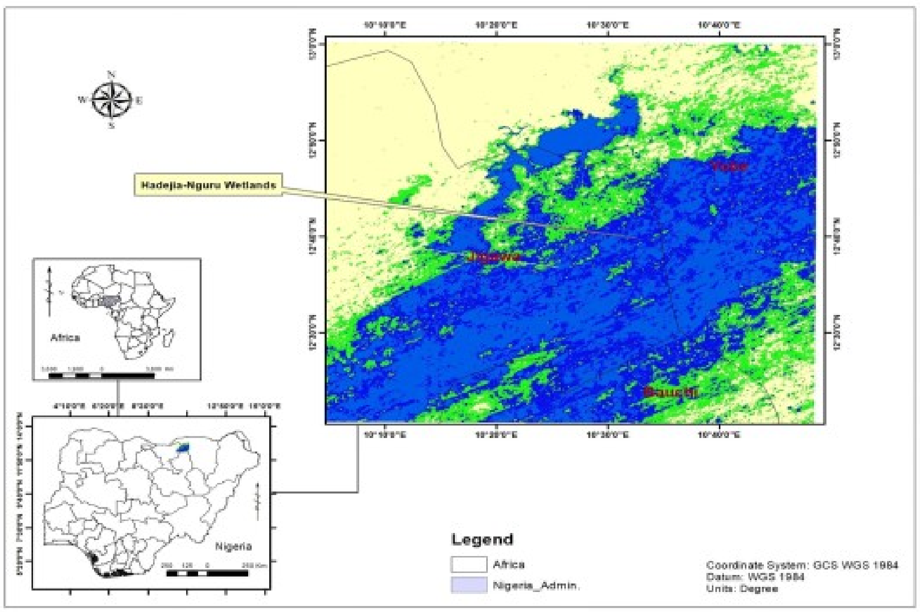


Figure 1: Location of Hadejia-Nguru Wetlands, Nigeria

In this study, monthly observed streamflow series at Gashua, Hadejia and Katagum gauge stations on Rivers Yobe, Hadejia and Jama'are respectively (covering HNWs) for the period 1980 to 2016 were obtained from Hadejia Jama'are Komadugu Yobe Basin Trust Fund (HJKYB-TF), Damaturu. More so, meteorological datasets (daily precipitation and temperatures – maximum/minimum) of Bauchi, Hadejia, Kano and Nguru stations of the Nigerian Meteorological Agency (NiMet) were also obtained from HJKYB-TF. Daily outputs of five Bias-corrected Global Circulation Models (GCMs) of these stations under IPCC's Representative Concentration Pathways Scenarios – RCP4.5 for the period (2017 – 2050) were obtained from the International Center for Tropical Agriculture, the Consultative Group for International Agricultural Research's Research Program on Climate Change, Agriculture and Food Security [www.ccafs-climate.org/data_bias_correction] (Navarro-

Racines *et al.,* 2015). The five GCMs are presented in Table 1. Furthermore, future synthetic climate change scenarios were built by combining assumed future conditions of monthly average precipitation and temperature with RCP4.5 scenario GCM outputs to predict future streamflow changes at Gashua, Hadejia, and Katagum gauge stations, the a comparison was made between the built scenarios. The daily datasets were aggregated using Hydrognomon 4 software to obtain monthly dataset for WEAP calibration. Additionally, simulation of the climate change scenarios was carried out for the period 2017 – 2050.

Table 1: List of selected GCMs under RCP4.5 Scenario

Model	Modelling Group, Country
CNRM_CM5	Météorologiques/Centre Européen de Recherche et Formation Avancée en Calcul Scientifique, France
CSIRO_MK3_6_0	Commonwealth Scientific and Industrial Research Organisation in collaboration with Queensland Climate Change Center of Excellence, Australia.
GFDL_CM3	National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory, USA
MIROC_ESM_CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies, Japan
NCAR_CCSM4	National Center for Atmospheric Research, USA

2.2 The WEAP Model

WEAP model was developed in 1988 by the Stockholm Environment Institute (Sieber & Purkey, 2011; Khasawneh, 2015). It is scenario-driven decision support system that addresses both bio-physical and socio-economic factors affecting a river system and the level of domestic, agricultural and industrial demand (Sieber & Purkey, 2011). The model helps planners to analyze a wide range of water management practices through a scenario-based approach. These scenarios could reflect the change in climate variability and state of a watershed condition. The study of Yates *et al.* (2005); Sieber & Purkey (2011) showed that the model could forecast future development through an actual or observed resources for the system called current account scenario.

2.3 Climate Change Scenarios

The WEAP model was applied to the reliably observed precipitation and temperature data series of 1980–2016. The model evaluates the climatic unevenness streamflow at Gashua, Hadejia and Katagum gauging stations. Three future climate conditions were assumed, namely; (i) increased precipitation and unchanged temperature (IPUT) (ii) increased temperature and unchanged precipitation (ITUP) and (iii) increased temperature and increased precipitation (IPIT). Therefore, three future synthetic climate change scenarios were developed under a combination of the five GCM's and the three assumed future climate conditions as demonstrated in Table 2.

2.4 Running the WEAP model

The current year account also known as the "Base Scenario" has been used in simulating streamflows based on historical precipitation and temperature data series of 1980 - 2016. The scenarios were made based on variety of assumptions of hydrological trends known as "Reference Scenarios". However, the Base scenario was employed to predict the future streamflows with respect to each reference scenario, and this was applied for the period 2017 – 2050.

Table 2: Summary of Developed Future Synthetic Climate Change Scenarios

Scenarios	Climate Models	Precipitation	Average temperature	Assumptions
1	CISRO_MK3_6_0 CNRM_CM5 GFDL_CM3 MIROC_ESM_CHEM NCAR_CCSM4	Increased	Unchanged	5% increase in Precipitation
2	CISRO_MK3_6_0 CNRM_CM5 GFDL_CM3 MIROC_ESM_CHEM NCAR_CCSM4	Unchanged	Increased	0.5^0C increase in average temperature
3	CISRO_MK3_6_0 CNRM_CM5 GFDL_CM3 MIROC_ESM_CHEM NCAR_CCSM4	Increased	Increased	5% and 0.5^0C increase in precipitation and average temperature respectively

3. RESULTS AND DISCUSSION

3.1 Impact of Climate Change on the Hydrology of HNWs

The projected changes of the average monthly streamflow in the future period (2017 – 2050) under scenarios 1, 2, and 3 for Gashua, Hadejia and Katagum gauge stations are represented in Figure 2, 3 and 4 respectively.

i. Scenario 1

Comparisons between the assumed climate condition (IPUT) and the ensemble of 5 GCMs indicates that peak flows predicted by CNRM_CM5 and CISRO_MK3_6_0 models for all the stations were higher than others for the whole time period (Figure 2). In contrast, NCAR_CCSM4 model predicts the lowest flow, with particular exception in the period 2017-2031 for Gashua and Katagum stations, where the lowest value was predicted by MIROC_ESM_CHEM. This could be attributed to the uncertainties associated with the GCMs in predicting precipitation and temperatures. The investigation of Flato *et al.* (2013) strongly support the present findings.

ii. Scenario 2

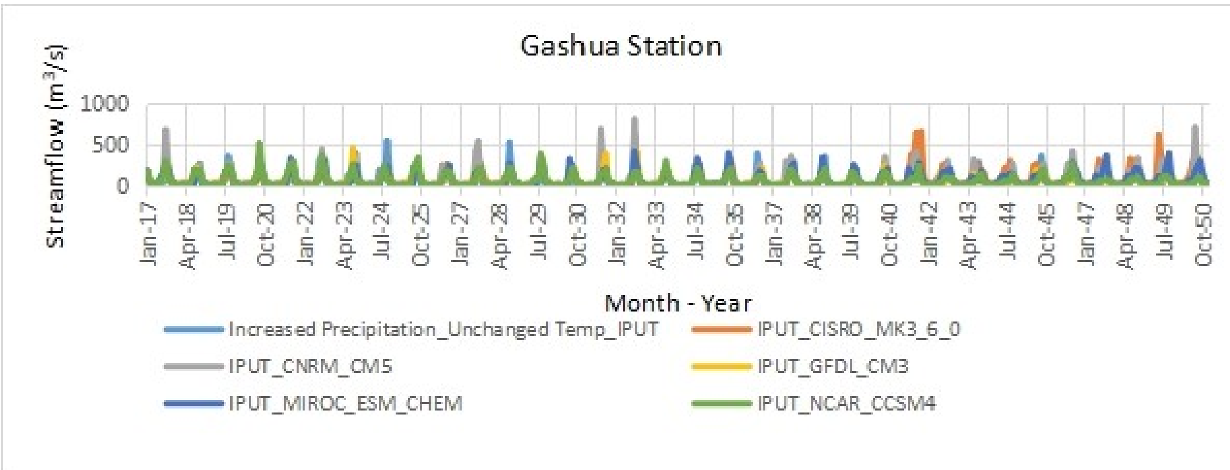
Increased temperature without change in precipitation climate condition, predicted slightly decreased in streamflow compared to climate condition of Scenario 1. Comparisons between the assumed climate condition (ITUP) and the ensemble of 5 GCMs indicated that CNRM_CM5 model predicted higher peaks than other models for Gashua and Katagum stations. While MIROC_ESM_CHEM model predicted higher peaks at Hadejia station for the whole time period. In contrast, NCAR_CCSM4 model predicted the lowest flow for all the stations. The increased temperature climate condition of this scenario might be attributed to the shortages in streamflow prediction. Thus, decreasing the risk of flooding along Hadejia, Jama'are and Yobe rivers.

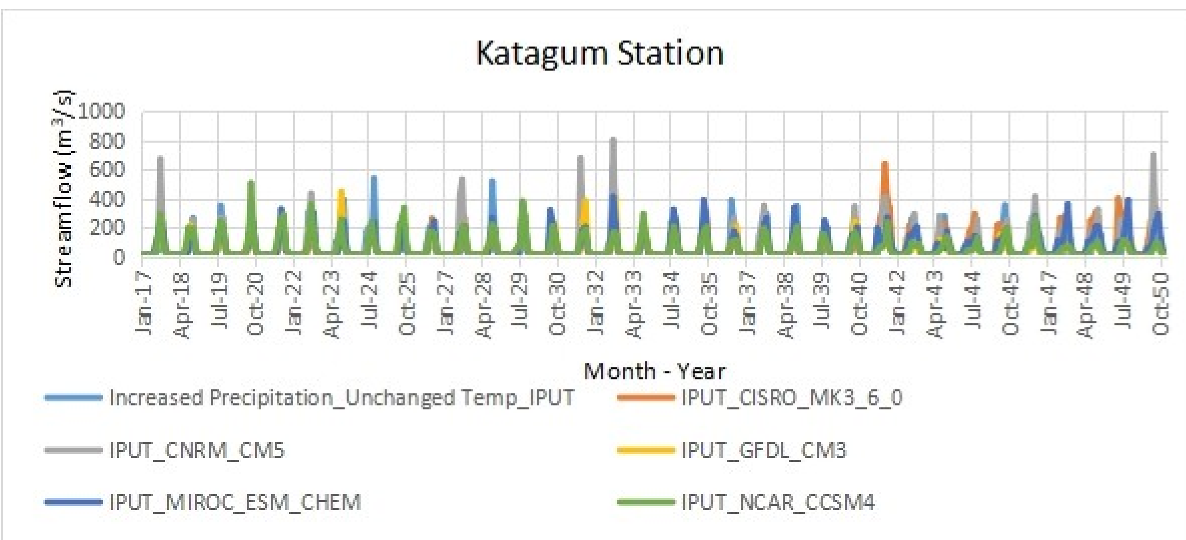
iii. Scenario 3

Comparisons between the assumed climate condition (ITIP) and the GCMs indicates that peak flows predicted by CNRM_CM5 and CISRO_MK3_6_0 models for Gashua and Katagum stations were higher than others for the whole time period. However, only CISRO_MK3_6_0 model predicted higher peak flow for Hadejia station. The predicted streamflow under this scenario resulted to reduced flows compared to Scenario 1 and 2 with increasing precipitation assumed condition. Perhaps, projected changes in the temperature of this Scenario might have influenced this behavior by overriding precipitation increase.

4. CONCLUSION

The study evaluates the streamflow variations in the HNWs catchment at Gashua, Hadejia and Katagum gauge stations using WEAP software. The application of WEAP model was based on soil moisture method. Data for the catchments' precipitation and temperature for a period of 1980 to 2016 have been modified for the model input; alongside 5 RCP4.5 scenario GCM outputs to develop three different synthetic climate change scenarios. Therefore, investigation revealed that the impact of climate change will modify the hydrology of the HNWs catchment under these diverse scenarios. The analysis of the scenarios specifies that the streamflow may suffer a maximum decrease of up to 10% under Scenario 3 for the period of simulation (2017 – 2050). It further predicted that the possibility of mild to moderate drought occurrences is maximum for scenarios 2 and 3 respectively.





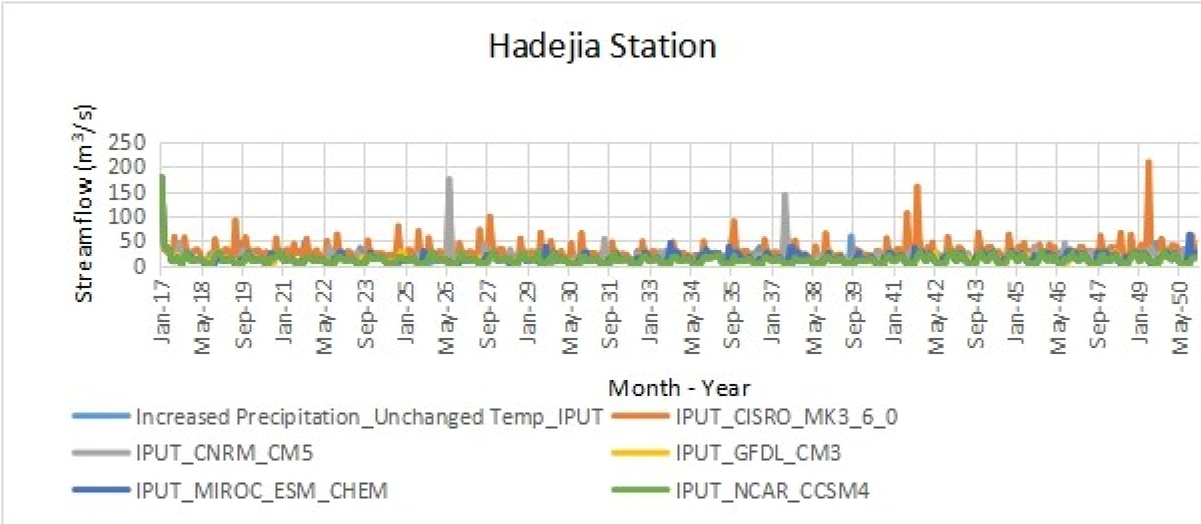
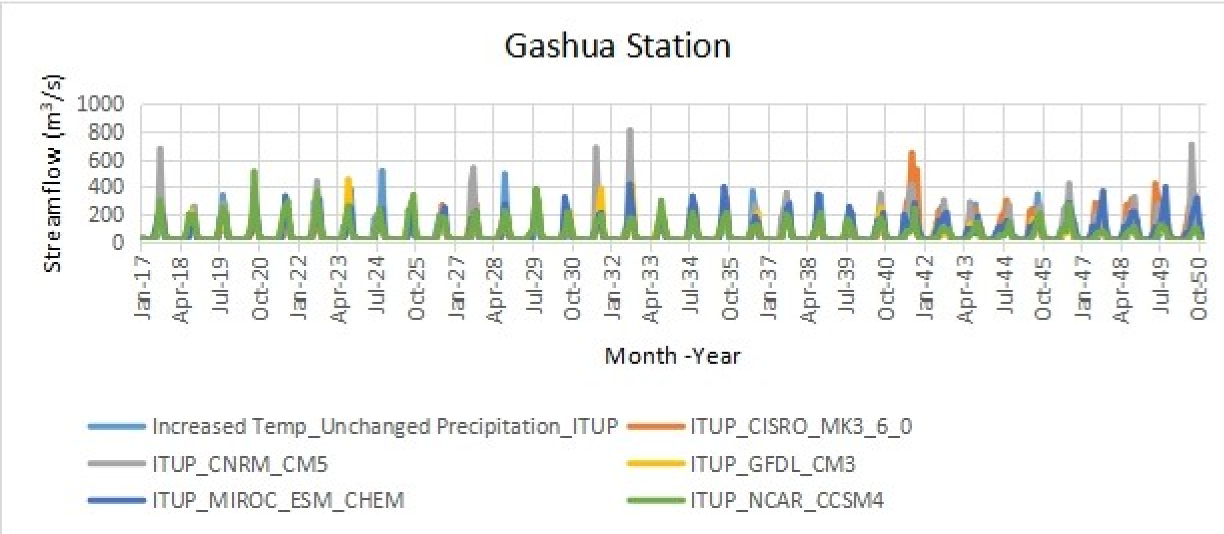
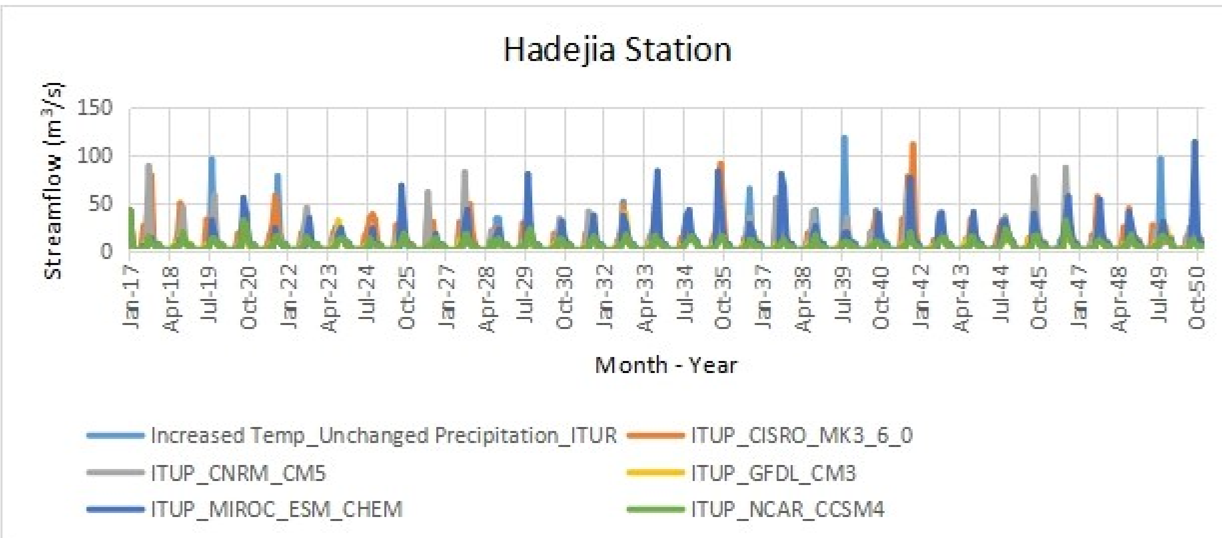


Figure 2: WEAP simulated monthly streamflow under Scenario 1


Gashua Station
Streamflow (m³/s)
1000
800
600
400
200
0
Jan-17 Apr-18 Jul-19 Oct-20 Jan-22 Apr-23 Jul-24 Oct-25 Jan-27 Apr-28 Jul-29 Oct-30 Jan-32 Apr-33 Jul-34 Oct-35 Jan-37 Apr-38 Jul-39 Oct-40 Jan-42 Apr-43 Jul-44 Oct-45 Jan-47 Apr-48 Jul-49 Oct-50
Month -Year
Increased Temp_Unchanged Precipitation_ITUP
ITUP_CISRO_MK3_6_0
ITUP_CNRM_CM5
ITUP_GFDL_CM3
ITUP_MIROC_ESM_CHEM
ITUP_NCAR_CCSM4


Hadejia Station
Streamflow (m³/s)
150
100
50
0
Jan-17 Apr-18 Jul-19 Oct-20 Jan-22 Apr-23 Jul-24 Oct-25 Jan-27 Apr-28 Jul-29 Oct-30 Jan-32 Apr-33 Jul-34 Oct-35 Jan-37 Apr-38 Jul-39 Oct-40 Jan-42 Apr-43 Jul-44 Oct-45 Jan-47 Apr-48 Jul-49 Oct-50
Month - Year
Increased Temp_Unchanged Precipitation_ITUR
ITUP_CISRO_MK3_6_0
ITUP_CNRM_CM5
ITUP_GFDL_CM3
ITUP_MIROC_ESM_CHEM
ITUP_NCAR_CCSM4

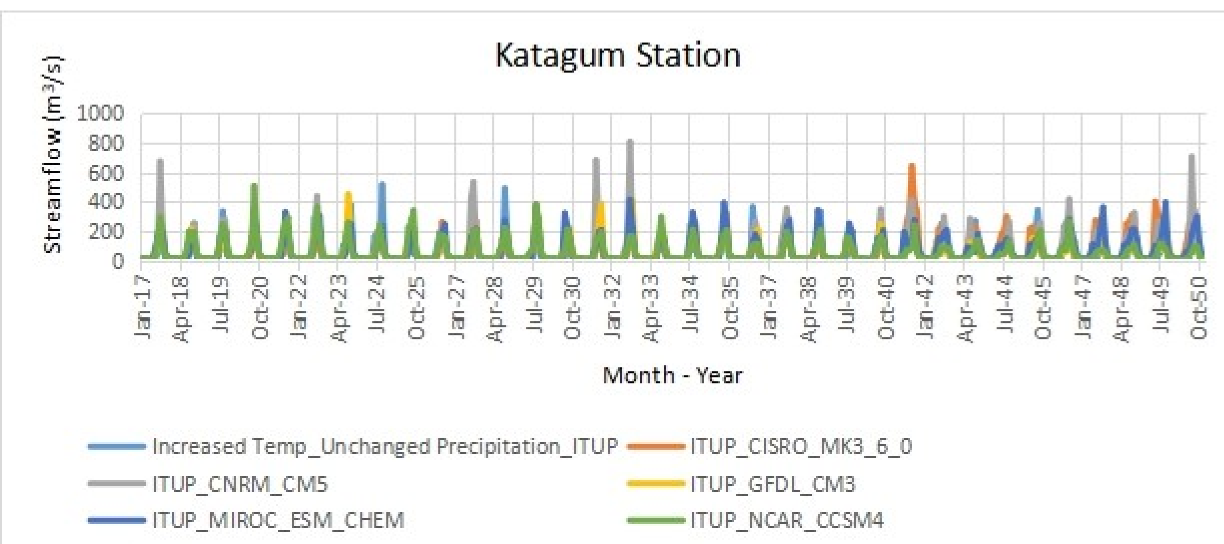
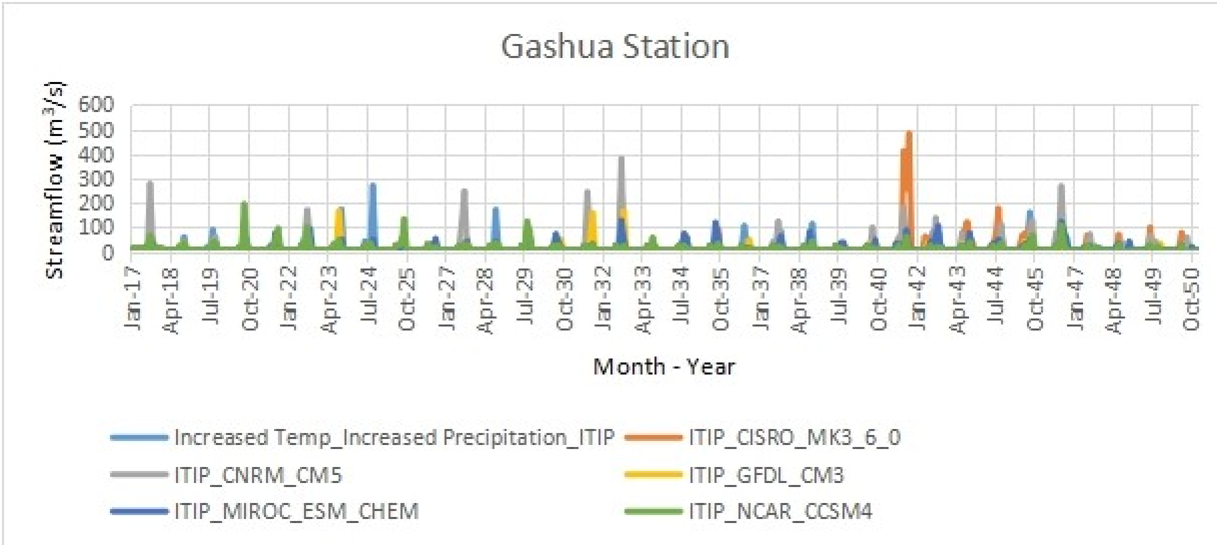
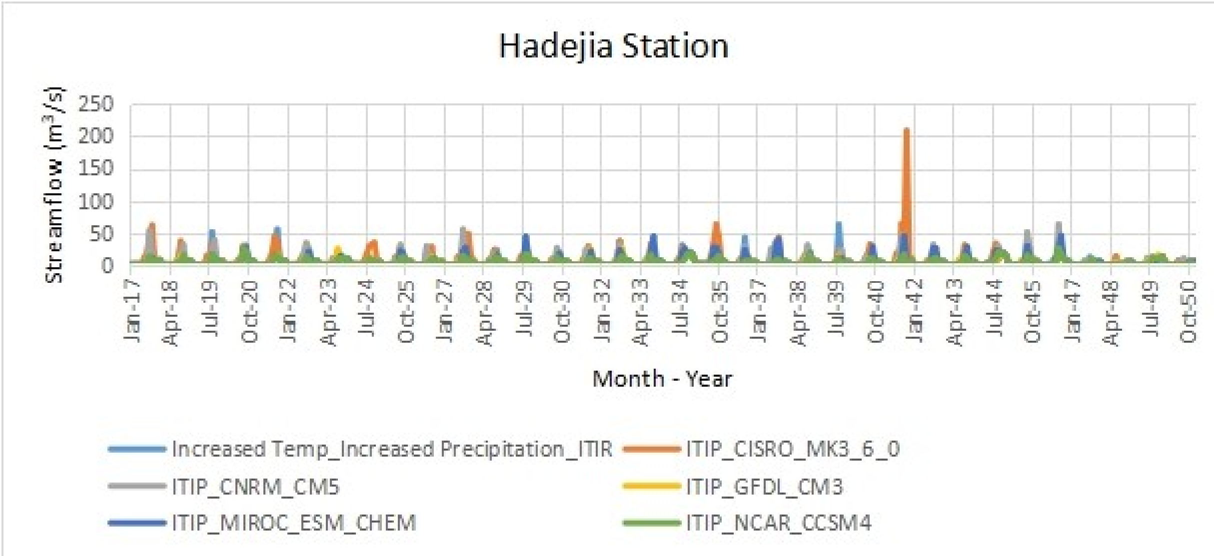

Katagum Station
Streamflow (m³/s)
1000
800
600
400
200
0
Jan-17 Apr-18 Jul-19 Oct-20 Jan-22 Apr-23 Jul-24 Oct-25 Jan-27 Apr-28 Jul-29 Oct-30 Jan-32 Apr-33 Jul-34 Oct-35 Jan-37 Apr-38 Jul-39 Oct-40 Jan-42 Apr-43 Jul-44 Oct-45 Jan-47 Apr-48 Jul-49 Oct-50
Month - Year
Increased Temp_Unchanged Precipitation_ITUP
ITUP_CISRO_MK3_6_0
ITUP_CNRM_CM5
ITUP_GFDL_CM3
ITUP_MIROC_ESM_CHEM
ITUP_NCAR_CCSM4

Figure 3: WEAP sim



ulated monthly streamflow under Scenario 2



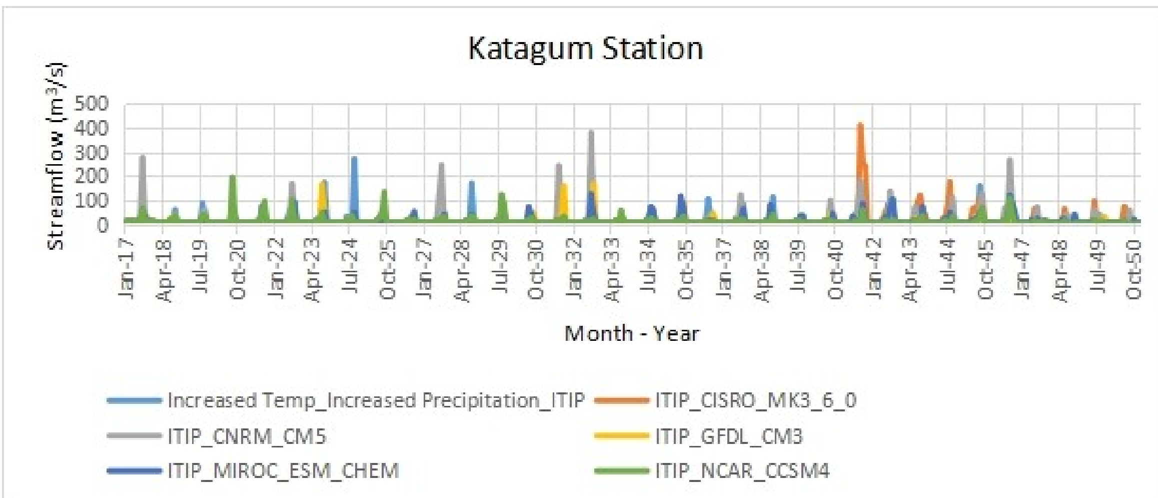


Figure 4: WEAP simulated streamflow under Scenario 3

Thus, according to the anticipated changes in the streamflow, HNWs is expected to be very vulnerable to drought due to climate change. Generally, the model was capable of investigating the possible future impacts of climate change on monthly streamflow of HNWs catchment. However, this analysis suggests that a comprehensive plan is needed to manage water resources in the HNWs catchment. Likewise, further investigations should be conducted by applying WEAP to develop adaptive strategies for climate change mitigation on HNWs catchment.

REFERENCES

Ayeni, A. O., Kapangaziwiri, E., Soneye, A. S. O., & Engelbrecht, F. A. (2015). Assessing the impact of global changes on the surface water resources of southwestern Nigeria. *Hydrological Sciences Journal*, 60(11), 1956–1971. https://doi.org/10.1080/02626667.2014.993

645

Ayeni, A. O., Ogunsesan, A. A., & Adekola, O. A. (2019). Provisioning ecosystem services provided by the Hadejia Nguru Wetlands , Nigeria – Current status and future priorities. *Scientific African*, *5*, e00124. https://doi.org/10.1016/j.sciaf.2019.e00124

Barbier, E. B., & Thompson, J. R. (2011). The Value of Water : Floodplain versus Large-scale Irrigation in Northern Benefits Nigeria. *Ambio*, *27*(6), 434–440.

Bhave, Ajay Gajanan, D. C., & Suraje Dessai, and D. A. S. (2018). Water Resource Planning Under Future Climate and Socioeconomic Uncertainty in the Cauvery River Basin in Karnataka, India. *Water Resources Research*, *54*, 1–21. https://doi.org/10.1002/2017WR020970

Dami, A., Kuchali, I. B., & Ayuba, H. K. (2017). The Influence of Climate Variability on Hadejia-Nguru Wetlands, Yobe State, Nigeria. *International Journal of Geography and Geology*, *6*(5), 105–112. https://doi.org/10.18488/journal.10.2017.65.105.112

Ezemonye, M. N., Emeribe, C. N., & Anyadike, R. N. C. (2016). Estimating Stream Discharge of Aboine River Basin of Southeast Nigeria using Modified Thornthwaite Climatic Water Balance Model. *J. Appl. Sci. Environ. Manage*, *20*(3), 760–768.

Goes, B. J. M. (1999). Estimate of shallow groundwater recharge in the Hadejia – Nguru Wetlands , semi-arid northeastern Nigeria. *Hydrogeology Journal*, *7*, 294–304.

Goes, B. J. M. (2005). *Pre-water audit for the Komadugu-Yobe River Basin , Northern Nigeria and Southern Niger*. Kano, Nigeria.

Hollis, G. E., Adams, W. M., & Aminu Kano, M. (Eds.). (1993). *The Hadejia-Nguru Wetlands: Environment, Economy and Sustainable Development of a Sahelian Floodplain Wetland*. Gland, Switzerland and Cambridge, UK: IUCN.

IPCC. (2007). *Climate Change 2007. The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Full report*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. (V. B. and P. M. M. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, Ed.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Khasawneh, E. H. (2015). Climate Change Impacts on Water Resources in Desert Area Considering Irregularity in Rainfall Intensity and Distribution : A Case Study in Wadi Mujib Basin, Jordan. *Journal of Environment and Earth Science*, *5*(14), 34–44.

Mahmood, R., & Jia, S. (2018). Analysis of causes of decreasing inflow to the Lake Chad due to climate variability and human activities. *Journal Hydrol. Earth Syst. Sci.*, *2*.

Navarro-Racines, C. E., Tarapues-Montenegro, J. E., & Ramírez-Villegas, J. A. (2015). *Bias-correction in the CCAFS-Climate Portal: A description of methodologies*. Decision and Policy Analysis (DAPA) Research Area. International Center for Tropical Agriculture (CIAT). Cali, Colombia.

Nigerian Meteorolgical Agency. (2017). *Nigerian Meteorolgical Agency; Drought and Flood Monitoring Bulletin*. Abuja, Nigeria.

Nwankwoala, H. O. (2012). Case Studies on Coastal Wetlands and Water Resources in Nigeria. *European Journal of Sustainable Development*, *1*(2), 113–126.

Okafor, G. C., & Ogbu, K. N. (2018). Assessment of the impact of climate change on the freshwater availability of Kaduna River basin , Nigeria. *Journal of Water and Land Development*, *38*, VII–IX. https://doi.org/10.2478/jwld-2018-0047

Okali, D., & Bdliya, H. (Eds.). (1998). *Guidelines for the Wise Use of the Hadejia-Nguru Wetlands*. Gland, Switzerland: HNWCP/IUCN.

Olalekan, E. I., Abimbola, L. M., Saheed, M., & Damilola, O. A. (2014). Wetland Resources of Nigeria : Case Study of the Hadejia-Nguru Wetlands. *Poultry, Fisheries & Wildlife Sciences*, *2*(2). https://doi.org/10.4172/2375-446X.1000123

Oyerinde, G. T., Fademi, I. O., & Denton, O. A. (2017). Modeling runoff with satellite-based rainfall estimates in the Niger basin Modeling runoff with satellite-based rainfall estimates in the Niger basin. *Cogent Food & Agriculture*, *3*(1), 1363340. https://doi.org/10.1080/23311932.2017.1363340

Sieber, J., & Purkey, D. (2011). *WEAP Water Evaluation and Planning System: User Guide*. Somerville, MA: Stockholm Environment Institute, US Center.

Thompson, J. R., & Hollis, G. E. (1995). Hydrological modelling and the sustainable development of the Hadejia-Nguru Wetlands, Nigeria. *Hydrological Sciences Journal*, *40*(1), 97–116. https://doi.org/http://dx.doi.org/10.1080/02626669509491393

Umar, A. S., & Ankidawa, B. A. (2016). Climate Variability and Basin Management: A Threat to and from Wetlands of Komadugu Yobe Basin, North Eastern Nigeria. *Asian Journal of Engineering and Technology*, *04*(2), 25–36.

Umar, D. A., Ramli, F. M., Aris, Z. A., Jamil, N. R., & Abdulkareem, J. H. (2018). Runo ff irregularities , trends , and variations in tropical semi-arid river catchment. *Journal of Hydrology: Regional Studies*, *19*, 335–348. https://doi.org/10.1016/j.ejrh.2018.10.008

Yates, D., Sieber, J., Purkey, D., & Huber-Lee, A. (2005). WEAP21 – A demand-, priority- and preference-driven water planning model – Part 1: Model characteristics. *Journal of Water International*, *30*(4), 487–500.

MITIGATING EFFECT OF EMISSION OF GREENHOUSE GASES THROUGH CARBON CAPTURE AND STORAGE

Jibril, Hassan
Federal Ministry of Environment, Abuja, Nigeria
Email: jibhas1@gmail.com

ABSTRACT

Projections informed that by 2050 the energy demand will doubled due to climate change and rising population. This worrisome forecast has attracted concerted efforts to speedily institute potent energy management policies that may prevent energy crisis in the future. Study focuses on analysis of CCS technology to identify the source of carbon emissions as preventing CO_2 from entering the atmosphere is more expensive than the alternative. To change the behaviour of carbon intensive industries, and individuals through effective government policies and regulations that would drastically reduce carbon emissions. The CCS technology evolvement in Europe which had two large scale facilities in operation in Norway, and future developments in China, with eight large scale facilities, either in construction or in the planning phase. The North America, USA and Canada where specific policies and regulations led to development of recent CCS projects, including new legislation offering tax credits for CCS projects in the USA from 2018 onwards, and Mexico government led national programme of CCS deployment to ensure affordability of energy, security of supply, and mitigate impact on climate change. The rapid deployment of clean, renewable energy is crucial to meet the climate goals, limiting the global average temperature so that the worst impact of climate change can be avoided. The evolution of solar and wind energy has been driving force to low carbon energy transition. Nigeria must control greenhouse emissions, reduces gas flared, deploy CCS facilities, harness gas for power generation, and introduce electric vehicles to meet the UN climate agreement.

Keywords: *climate change, emissions, atmosphere, CCS, CO_2, greenhouse gases, renewable energy*

1. INTRODUCTION

Climate change (global warming) refers to a raising of global temperatures, increasing extremes of the hydrologic (water) cycle resulting in more frequent floods, droughts, cyclone and sea level rise. Climate is the expected atmospheric conditions found in a region, which differ from weather. The difference is function of time scale. Weather describes atmospheric conditions occurring over minutes to weeks whereas climate describes conditions occurring over multiple years. The burning of fossil fuels (coal, petroleum and gas) has made greenhouse gases more common in the atmosphere. Greenhouse gases include things such as water vapour (clouds), carbon dioxide, methane and ozone (4,6). These gases form a shield which reflects the energy radiated towards space back to the earth. The more heat our atmosphere captures, the warmer our planet gets. Water cycle processes (evaporations, condensation, precipitation, infiltration, runoff and transpiration) plays a vital role in the global mobilisation of chemicals through natural and anthropogenic activities. Water cycle processes will be alter as a function of climate change (4,5,7).

Fossil energy, such as petroleum, coal, and natural gas which have been the dominant sources of energy for industrial production, electrification and transportation are highly polluting and exhaustible (2,3). Carbon dioxide (CO_2) is currently present in the atmosphere at a concentration of 0.04% which is one in 2500 molecules (3,9,11). Before the advent of industrial revolution, the concentration of CO_2 in the atmosphere was lower, at 0.028%, or one in 3500 molecules (1,4,7,9,11). Since the world started using the carbon in fossil at an industrial scale, and converting it to CO_2 by burning these fuels, it has cause a small, marginal change in terms of concentration, but one with large consequences for the equilibrium of the movement of carbon (4,11). Since the advent of industrial revolution, about 500 million tonnes of CO_2, had been released into the atmosphere by fossil fuel burning which contributed to climate change (10). The carbon cycle of the planet is now out of balance as indicated by figure 1 below (9,10), Carbon Capture and Storage (CCS) facilities are required to ensure continue consumption of fossil fuel.

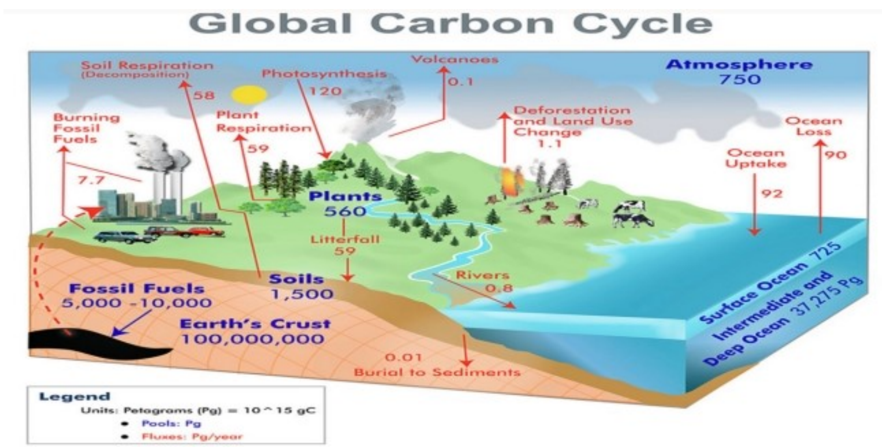


Figure 1: Global Carbon Cycle, Source: (1,4,8,)

1.1 Paris Climate Agreement

The Paris Climate Change Agreement of December 2015 was a critical turning point, with short term goal to reduce the peak carbon emissions in the atmosphere as soon as possible, and the long term goal to limit the increase in global average temperatures to well below 2ºC to achieve neutral carbon balance in the atmosphere (7,8,11). Negative emission technologies appear to be indispensable, unless a drastic, radical, much more ambitious (and, one could also argue, highly unlikely) reduction in global CO_2 emissions occurs. the scale of the necessary negative emissions is extremely large for 2ºC of global warming. It would amount to 600-800 billions tonnes of CO_2, that is 15 to 20 years worth of current annual emissions, for the period until end of the century (4,8). The alternative is either to renounce the objectives of the 'well below 2ºC target' of the Paris Climate Change agreement, or drastic, unprecedented reductions in global emissions, which have yet to materialise (4,8,11).

At present, climate pledges by countries in the agreement are not sufficient to achieve well below 2ºC of global warming (5,11). They are too weak to achieve the agreement's aspirations and put the world on a trajectory for around 3.5ºC of global warming (8,10,11). Yet these countries agreed to review each individual country's contribution every five years (8,9). There is more carbon available to the global economy than the quantity that the atmosphere can absorb, for 2ºC of global warming (9,11). Leave the fossil fuels underground when the carbon budget has been used up will lead to divestment from fossil fuels, that is the action of selling investments in fossil fuel extraction (4). This movement, led by large institutional investors, has mostly been focused on renewables and largely ignored investments in oil and gas (4,8,11).

The other response is to continue to access these carbon reserves, but stop a fraction of CO_2 from entering the atmosphere with CCS (4,8). When the carbon budget is used up, CCS allows the use of additional fossil fuels and access to the additional wealth they represent, which would otherwise be left underground (3,8,9). Majority of 2ºC scenarios modelled by climate scientists include a 'carbon overshoot', which is then compensated later if global emissions are to stay within the carbon budget (4). In practice, 90% of the 203 models of the Intergovernmental Panel on Climate Change, the leading authority on climate change science, assume that CO_2 will be taken out of the air (4,8). That is because, in any realistic scenario, emissions cannot be cut fast enough to keep the total stock of CO_2 and other greenhouse gases in the atmosphere below the limit of the atmosphere's budget (4,8,9).

1.2 The Concept of Carbon Capture and Storage Technology

It is the removal of the greenhouse gas (CO_2) from the use of fossil fuel or biomass. It prevents the accumulation of that gases in the atmosphere, transport it to a storage site to isolate it permanently from the earth's atmospheric carbon cycle, typically by injecting it at a depth of several thousands of meters into a geological reservoir, such as a depleted oil or gas field, or a saline aquifer (4,5,7). The general principles of CCS gives an overview of the scale of a CCS facility, and that of geological reservoirs used for storage (4,5,7). It also presents briefly the basic principles of geology to achieve permanent storage of CO_2 deep underground (4,5).

CCS is a critical technology capable of prevent dangerous levels of global warming (5). It’s contribution to CO_2 emissions reduction may prove, throughout the century to be significant than the contribution of other low-carbon options (4,5,7). CCS recognised that phasing fossil fuels and their CO_2 emissions entirely out of the global economy is, at best, incredibly expensive, and at worst, impossible within the timescale for action on climate change mandates (5,8). Others advocates aim to retain carbon-intensive industrial activities with CCS, in order to maintain the employment they provide and the benefits they bring to the local and national economy in a timely manner to effectively address global warming (8,11).

2. CCS METHODOLOGY

Combustion is the process by which the primary energy contained in fossil fuels and biomass is being transformed into an energy vector. The combustion principle setting out the basis to understand CO_2 capture technology processes. There are three types of CO_2 capture technologies which can be applied to the large majority of industrial processes emitting CO_2 to the atmosphere; post-combustion capture, a family of technologies implemented after combustion takes place, capture by oxyfuel combustion, where fuel is burned in oxygen without nitrogen and, pre-combustion capture, where carbon is removed prior to combustion, leaving a carbon free fuel hydrogen to burn (3,4,5).

2.1 Post-Combustion Capture

Post-Combustion Capture relies on the preferential affinity of certain materials for CO_2, For example, a certain group of chemicals, called amines, can be mixed with water to selectively capture CO_2 from other combustion gases, such as nitrogen (4,8,9,10). These chemicals amine solvents, were first patented a long time ago in the 1930s (4,8,9). The technology has obviously evolved and improved since, but the fundamental principles have remained the same. Amine solvents are used extensively in the oil and gas industry (4,10). Some hydrocarbon reservoirs contain natural gas mixed in high proportions with CO_2. For example, the CCS facility at Sleipner in the North Sea in Northern Europe (4) (Fig. 2).

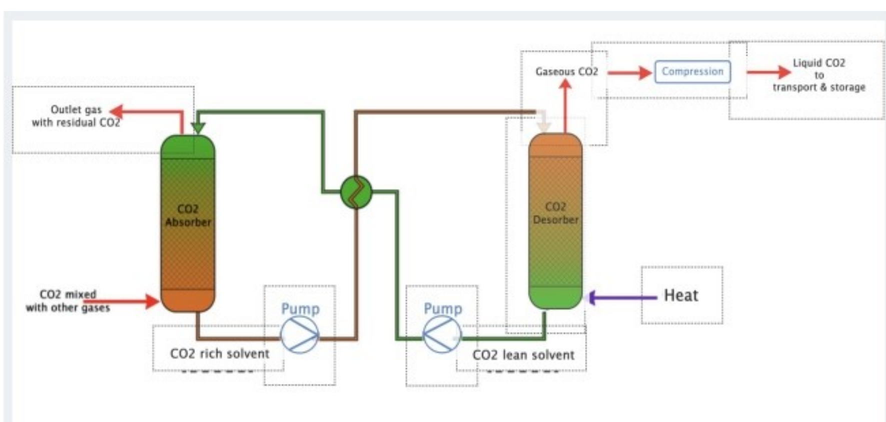


Figure 2: Post-Combustion Capture Processes, Source: (10)

The gases are separated at source so that natural gas can be purified to be commercialised. This is where decades of experience with these technologies come from (4,5,8,10). They have been adapted in the last decade for combustion gases. Another example of the use of solvent technology for CO_2 capture is the use of amine solvents to generate food grade CO_2, which is found in our daily lives as bubbles of gas in soda drinks. When applied at industrial scale, these chemical solvents can treat very large volumes of gases (3,4). This requires engineering of very specific devices, capable of contacting millions of cubic meters of gases with millions of cubic meters of solvents (1,4,10). The most important characteristics of post-combustion capture it does not require any major modification to power plants and other industrial processes (1,4,5,10).

2.1.1 The Example of China

Retrofitting CCS to existing power stations matters to tackle the emissions of countries that built a large number of fossil fuel power stations in the last decade. These power stations are now expected to continue to run for 20 to 50 years. Closing them down to stop their CO_2 emissions would have an enormous financial cost, since it requires writing off these new facilities, paying back investors and banks, and building new ones to replace them (16). The case in countries, such as India or China, where great progress has been made to provide access to electricity to many millions of people (16).

As a result of efforts to provide access to electricity to its population and its economy, the People's Republic of China is now both the world’s leader in renewable electricity capacity and also the world’s largest emitter of CO_2, with around half of its emissions from coal-fired power stations (16). This accounted for around 4.5 of the 36 billion tonnes of CO_2 which entered the atmosphere in 2014 (1,16). China had around 900 gigawatts (GW) of installed coal-fired power capacity in 2016, with nearly 200GW under construction (1,16), which represents almost 50% of global coal-fired capacity (1GW roughly the size of a large nuclear power station). The International Energy Agency (IEA) estimates that these power stations represent potential emissions of 85 billion tonnes of CO_2, if they were to continue to operate as often as they are now for the remainder of their lives. Adding CCS to coal-fired power stations in China represents a major opportunity for CO_2 emission reductions.

The IEA also estimates that some 310 GW of existing coalfired power capacity, that is 1 in 3 coal power plants, meets a number of basic criteria for being suitable for a retrofit with CCS, in terms of access to geological storage, suitability of the existing station such as space, access, and the design of its turbines and costs. Post-combustion capture can be added to existing power stations, it also makes sense to ensure that new ones are located, designed and engineered to facilitate a retrofit with CCS. The concept is called CCS-readiness. If a new power station is located to guarantee access to geological storage, because post-combustion capture does not modify the power station itself, CCS-readiness can be implemented without any noticeable additional cost (16).

2,1.2 The United Kingdom Example

The UK has published technical guidelines on CCS-readiness, which all new large fossil fuel (and biomass) power stations are expected to compliant (1,4). The main message is that there are many post-combustion capture facilities, in a range of industries and that they capture tens of millions of tonnes every year (1). Over the last decade, there has been a large effort in research and development to develop further methods to separate CO_2 from other gases, with the objective of reducing the cost of CO_2 capture (1,4,16). Better molecules and processes have been developed and are now commercially available (1,4). Alternative methods to solvents are also being developed, but are not considered to be commercially available for application at large scale power plants (4,16).

2.2 Capture By Oxyfuel Combustion

Air enters an Air Separation Unit, where it is processed to be separated into its two major components: nitrogen and oxygen (5,8,10). Very high purity oxygen enters the boiler of the power station together with the fuel (8). In the absence of nitrogen to dilute the combustion gases, a fraction of the combustion gases is recycled to the inlet of the boiler to play the role of the diluent that nitrogen would otherwise play (5,8,9,10). These recycled combustion gases don't contain fuel anymore and cool down the boiler to ensure that the temperatures stay at an acceptable level (8,9,10). The heat generated by the combustion taking place in the boiler is used to raise steam to drive turbines and produce electricity (8,9). The combustion gases leave the boiler consisting of around 90% CO_2 and enter a step represented here as capture, where the other combustion gas - water - is condensed into a liquid (10). The resulting stream with 95 to 99% CO_2 is compressed to be transported to permanent geological storage as illustrated by figure 3 below (4,8,10).

The principles of oxyfuel combustion can also be used in the steel-making and the cement-making industries (4,10). Oxyfuel combustion has been demonstrated at pilot scale on coal-fired boilers in Germany, Spain and Australia. The largest of these facilities is at a scale representative of a 20th of the size of a large scale power station (4,8,9,10). Although there are no commercial scale projects in operation or in construction in 2018, Oxyfuel combustion technologies (and power generation CCS) could be on the verge of an important breakthrough (4,5,6,7,8,10) (Fig. 3).

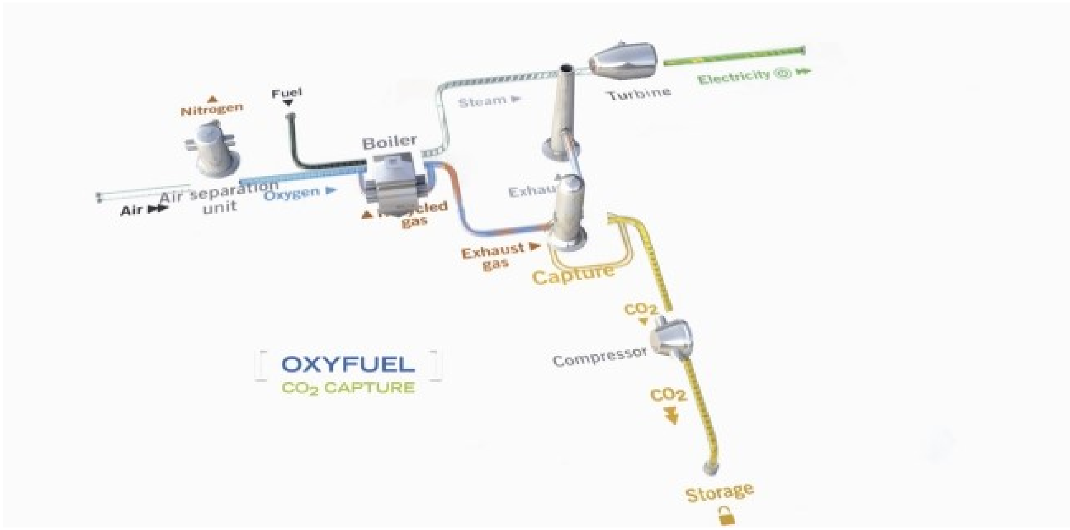


Figure 3: Capture by Oxyfuel Combustion Processes, Source: (10)

2.2.1 The United States Example

A new concept of power generation with Oxyfuel technology is expected to begin operation in the state of Texas, USA, in 2018, at a 10th of the size of a large scale power station (8). This new facility is large enough to power more than 40,000 homes (8,9). The concept could scaled-up to produce carbon-free electricity at a cost comparable to gas-fired power stations without CO_2 capture (8). Drastic cost reductions would come, in this case, from a technological breakthrough in combustion and turbine technology (9). Combustion at high pressure, much higher than ever tested for power generation, may allow electricity generation turbines to use directly the combustion gases of Oxyfuel combustion, which are 90% CO_2 (8,9) The role of this novel CO_2 turbine is to convert the primary energy from the fuel into mechanical energy and then electricity (8). CO_2 is thus inherent to the design of the power generation cycle, giving the major added benefit that CO_2 is available for transport to geological storage, without any energy penalty (8,9).

There are a handful of power stations using gasification in the USA and in Europe. A few more are under construction or in advanced planning stages in China and Japan (16). But none of these include CCS. The syngas from the gasifier is sent directly to gas turbines, without removing the CO_2, to generate electricity (16). The first power station with gasification and pre-combustion capture came close to starting commercial operation in 2017 (16). There are currently no large-scale commercial CCS power station using pre-combustion capture in operation (16). Two commercial projects are in the early phase of development in China and in South Korea (16). The Kemper County CCS project in the state of Mississipi, USA, planned to start commercial operations in 2017, but was hindered by several factors not related to the carbon capture part of the plant (16). It has now been converted to a gas-fired power station, without running the part of the power plant intended to convert coal into syngas, and thus without the carbon capture unit (16). It was initially expected to capture 65% of the CO_2 from coal gasification, equivalent to 3 millions tonnes of CO_2 per year (16).

2.3 Pre-Combustion Capture

Air enters an Air Separation Unit where it is separated into its two major components, nitrogen and oxygen. High purity oxygen then enters the next conversion step, the gasifier (4,8,9). Solid fuel is reacted in the gasifier at high temperature and high pressure with oxygen and steam to form a synthesis gas, or syngas (4,8). This high-pressure syngas is a mixture high-pressure of hydrogen and carbon monoxide, two gases which can be used for combustion and CO_2 and water (4,8,9,10).

The second step after the gasifier is the shift reaction. Fig. 4. The syngas now consists of high pressure hydrogen, CO_2 and water (4,8,9). The removal of 90 to 95% of the CO_2 is carried out in the capture unit, where solvents selectively react with carbon dioxide but not hydrogen. CO_2 is then compressed to be transported to permanent geological storage (4,8). This leaves nearly pure hydrogen, which is burned in a gas turbine to produce electricity (8,9,10). Since the combustion of hydrogen produces water and no CO_2, there are no emissions to the atmosphere from the power plant stack (4,8,9). The hydrogen can alternatively be stored or transported away to be used as a raw material for various chemical products or as a carbon-free energy vector (4,8,9).

Figure 4: Pre-Combustion Capture Processes, Source: (10)

Tackling the excess of CO_2 accumulating in the atmosphere ideally requires keeping it away from the atmosphere indefinitely (1,4,10). Yet, it is impossible to guarantee that CO_2 will stay away from the atmosphere forever (4,5,11). We have no idea what the planet or our society (societies) will look like in 10,000 years (4,10). So, for the purpose of addressing climate change, it is extremely important that CO_2 is geologically stored, away from the atmospheric carbon cycle, and without any human intervention, for at least 1,000 years, and preferably for 10,000 years (1,4,5,10,11). If CO_2 is stored away from the atmosphere for a much shorter period - that is, for days, years or for decades - we are effectively passing the problem to our future selves, our children and grandchildren (4,10,11). A good example is the carbon stock contained in a tree, which then returns to the atmosphere when that tree dies (1,4).

Enhanced weathering is the natural process in which rocks are broken and dissolved on the land surface (13,14), which involves accelerating the natural process of rock weathering, which currently absorbs around 3% of global fossil fuel emissions (14). Blue carbon habitat restoration, Carbon stored in a coastal or marine ecosystem is known as blue carbon. Conserving and restoring coastal ecosystems so that they can continue to draw CO_2 out of the air has been suggested as a way to mitigate climate change (13). Afforestation and reforestation; Afforestation is the planning of trees where there were previously none, whereas reforestation is the restoration of areas where the trees have been cut down or degraded (13). This is on e of the most feasible options, although it still has drawbacks and uncertainties (13,14) (Fig. 5).

2.3.1 Direct Air Capture

Direct Air Capture is the engineering of devices to suck CO_2 out of the air and then storing it permanently away from the atmosphere. Sieving one out of 2500 molecules of air is energy intensive, much more so than sieving from concentrated sources, and this ultimately has a financial cost (5,10,11). Unlike other options involving the use of land or forests, direct air capture needs very little land. Carbon in the land reservoir and in the ocean reservoir is vulnerable to reversal, that is conversion to CO_2 (or methane, CH_4) by living organisms, including humans (3,5,10). It may eventually return to the atmosphere within a timescale that is not compatible with the climate (10,11). To stay within the limits of the carbon budget, the same amount of carbon would have to be removed, again, from the atmosphere (5,10,11). For carbon entering the geological reservoir, there is a sufficient guarantee that it will be removed from the atmosphere over a timescale that is compatible with the climate (3,5,10,11).

2.4 Geological Storage of Carbon

Figure 5 indicates Scottish Carbon Capture and Storage Reservoir. The aim of storage is to keep the captured CO_2 out of the atmosphere for at least 10,000 years and the volumes of CO_2 plan to store are very large (3,5,10,11). As an example, a large coal-fired power station might emit 10 million tonnes of CO_2 every year, but using the density of gas about 2 kilograms for each cubic metre (2 kg / m^3) at surface conditions amounting to store around 5000 million cubic metres of gas (10,11). Compare it to the Great Pyramid of Giza in Egypt, which has a volume of around 2.5 million cubic metres (3,5,10). So the CO_2 from one large coal-fired power station would have the same volume as two thousand 'Great Pyramids', for each year of operation (5,10,11). Yet there are more than 6,000 coal-fired power plants in the world today (10,11). There are many other sources of CO_2, such as gas-fired power stations, cement plants and steel works. So building tanks to hold the CO_2 is impractical, but would need far too many (5,10). The one sure way to store fluids such as CO_2 for long periods of time is to use geology (3,5,11). The reasons are confident it will work in natural geological systems have stored fluids for very long periods of time (3,5,10). A good example is the oil in the North Sea (between the UK and mainland Europe). This oil was generated at least 20 million years ago, and has been held underground ever since (10,11). Some of the very earliest oil generated here may have been stored for even longer, since when dinosaurs were running around on the surface, unsuspecting that a meteorite impact was going to end their reign forever (3,5,10,11).

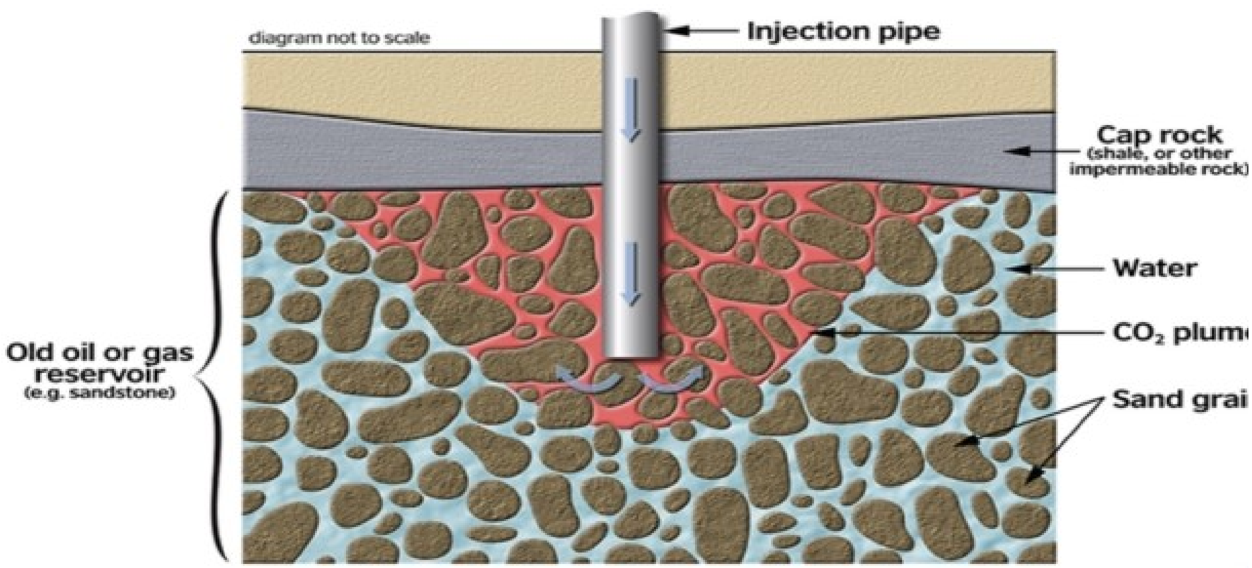


Figure 5: Scottish Carbon Capture and Storage Reservoir, Source: (1,4)

CO2-EOR both stores CO_2 underground, and generates revenue from the sale of the produced oil, which pays for the storage (14,15). CO2-EOR also provides valuable experience of transporting very large volumes of CO_2, and of injecting it into the ground (14,15). An important point is that the majority of the CO_2 that is injected is permanently trapped underground, even though the aim is to recover oil. It has been suggested that CO2-EOR sites could be converted, at the end of their commercial lives, as stores for yet more CO_2 (14,15). This is attractive as the infrastructure such as pipes and injection wells are in place, and have already been paid for (14,15) (Figures 6 and 7).

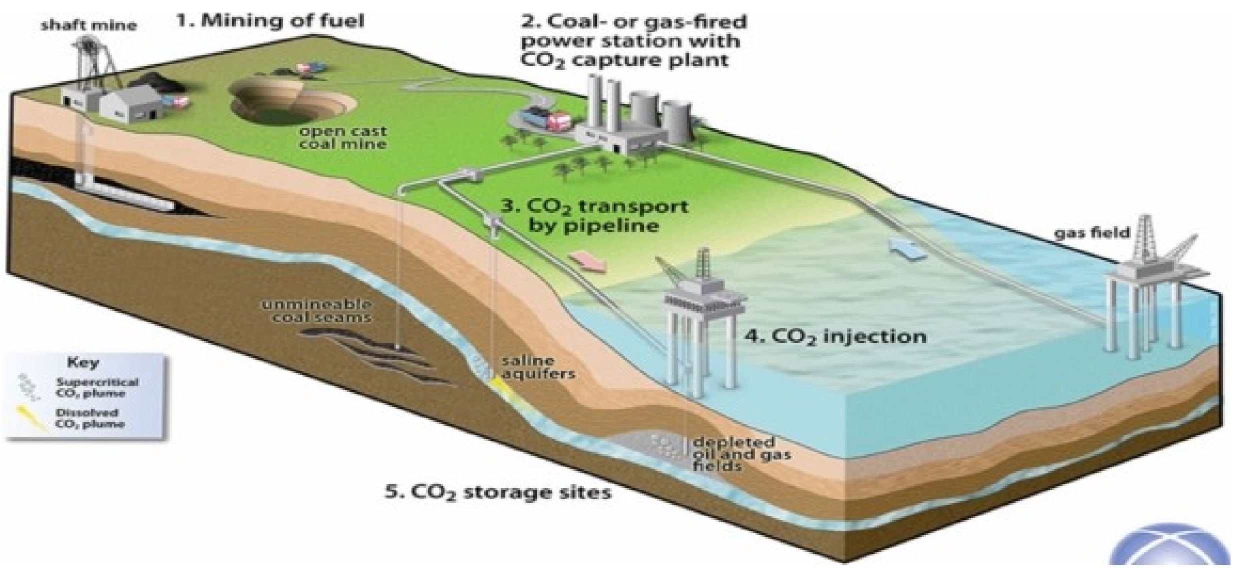


Figure 6: CO2 Storage Site, Scottish Carbon Capture and Storage, Source: (4,10)

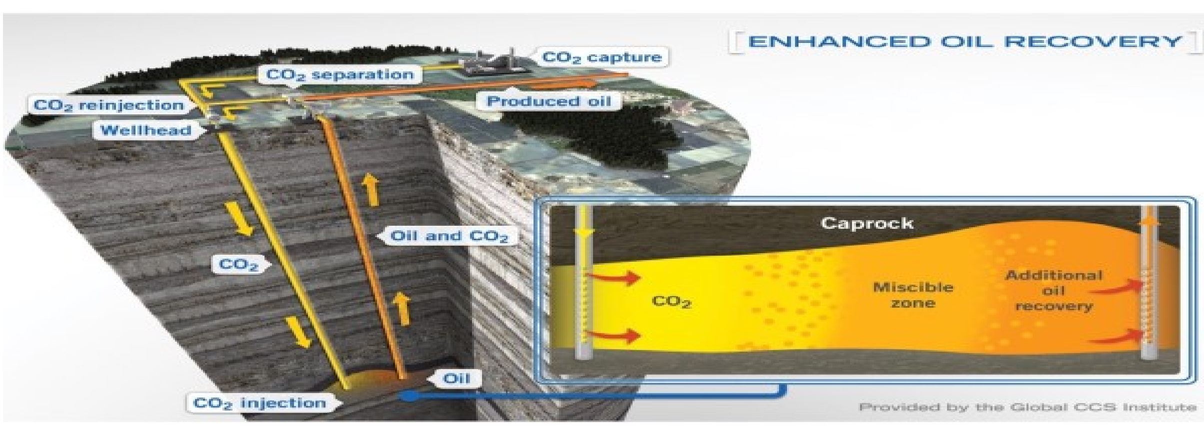


Figure 7: EOR Structure, Source: (1,4)

3. RESULTS AND DISCUSSION

To reach carbon neutrality, CO_2 emissions in the global energy system must go down to zero (3,5,7,9). This can only be achieved if we tackle direct emissions of end-use sectors, direct emissions from industries, and the indirect emissions originating from the production of energy vectors.

3.1 Power Generation

Over two-thirds of electricity is generated from fossil fuels, according to the International Energy Agency. The sector is undergoing a radical shift, with the acceleration and deployment of electricity generated from renewable sources, and new installed capacity of wind turbines and solar panels is increasing rapidly, whilst, in North America, natural gas is rapidly replacing coal for thermal power generation (7,10,11).

Decreasing carbon emissions in the electricity sector alone will not lead to the carbon reductions necessary to achieve carbon neutrality (7). Significant increasing the use of electricity and hydrogen as energy vectors would modify the flow of CO_2 through the global energy system (7,11). One example of changes to the end-user are electric vehicles, which could replace conventional engines in the transport sector, and the use of electric radiators and heat pumps in homes and offices, in the building sector (7,10). Heat pumps are effectively refrigerators in reverse, well suited for the temperature range of our homes, they use electricity to take heat from colder ambient air or a local water source, and return it at a higher temperature into the water of radiators (7,10,11).

The use of hydrogen by the end user may involve domestic cars powered via a technology called fuel cells. These cars have recently started entering the market. Hydrogen fuel cells also power local networks of buses and are highly suitable for heavy goods trucks (7,11). Residual emissions from CCS facilities, associated with indirect emissions, would need to be brought down close to zero, with the right incentive to do so (7,8,10,11). CCS has the potential to decarbonise two of the largest contributing sectors to CO_2 emissions in the global energy system. To achieve net zero carbon emissions in the global energy system and tackle both direct emissions and indirect emissions (7,10,11). CCS in industry and power generation must be combined with efforts to reduce the overall CO_2 input with energy efficiency, renewable and nuclear electricity production (10,11).

A small number of countries with a favourable geography have considerably decarbonised their electricity production with hydropower, nuclear energy or a combination of both (11). But, other rely on their conventional power stations and the low-cost, large scale, long term, high carbon energy storage contained in coal piles, and high carbon energy storage of the large volumes of oil and natural gas pipelines (7.10,11). These countries must eventually use CCS extensively to achieve carbon neutrality in electricity production (10,11).

3.2 Transport Sector

Vehicles transport system is responsible for about one-quarter of all energy-related CO_2 emissions, and set to increase to one-third by 2050, growing faster than any other sector (5,7,9). To achieve carbon neutrality of the global energy system, the use of hydrogen made with CCS would need to gradually increase to replace all transportation fuels made from crude oil (5,9,10,11). Indirect emissions occurring in the transport and building must be tackled with the extensive use of electricity and hydrogen, both carbon-free energy vectors (7). These two vectors can be produced with a combination of renewable energy, nuclear energy and CCS (5,7). When molecules of natural gas (CH_4) are converted to Hydrogen (H_2), Carbon Dioxide (CO_2) is inevitably produced and can be separated using CCS (7). But what actually makes hydrogen a carbon-free energy vector? It can burned with Oxygen (O_2) to release energy in the form of heat, without the CO_2 emissions. Hydrogen can also be reacted with oxygen in a fuel cell to produce electricity, instead of heat as illustrated by equation (1) below.

$$H_2 + O_2 \rightarrow H_2O \qquad (1)$$

where H = Hydrogen, and O = Oxygen

Fuel cells rely on electron transfer to produce energy from a fuel, for example hydrogen or natural gas, without combustion (5,7). To deploy hydrogen into a widely used carbon free energy vector in the economy, the infrastructure to transport hydrogen to the end-user is critical (5,7).

The extent to which hydrogen is used will be determined by the developments of a suitable transport infrastructure, of large-scale storage interim facilities and, most importantly, by addressing the environmental impacts of providing the primary energy for the production of hydrogen and by addressing the social impacts of using hydrogen in our cities and our homes (8,9,10,11). A holistic approach looking at the whole energy system is necessary to take into account primary energy supply, energy security and decarbonisation, and the use of CCS is critical for that industry.

3.3 Climate-Driven CCS Facilities

The construction of more recent CCS facilities in the USA after 2008 can be attributed to a federal tax credit in an effort by the US government to kick-start more CCS facilities (1,13). The tax credit applied to both the use of EOR and the capture of anthropogenic CO_2, as opposed to using underground natural sources of CO_2. In terms of storage in deep saline aquifer formations, which are truly climate driven CCS facilities, two offshore facilities are in operation in Norway, a country that implemented a tax on CO_2 emissions coming from offshore facilities in 1996 (1,13).

There are two climate-driven CCS facilities in operation in North America; Decatur BECCS facility in Illinois received most of its capital investment from the US government, and a smaller fraction from the private sector, while the Quest facility in Alberta received investment from the province of Alberta and the federal government of Canada (1,13) The Gorgon facility in Australia is expected to become the largest CO_2 facility for injection into a deep saline aquifer formation, with up to 4 million tonnes being injected per year (1). This is one of Australia's liquified natural gas mega-projects, a CCS facility treating raw natural gas with undesirable CO_2.

The total investment cost for the liquefied natural gas production facility is well over $50 billion (1,13,). The cost of the Gorgon CCS facility, one of the largest CCS facilities ever built, in comparison, around $2 billion, under 5% of the total cost (1). The license for exploitation and production of the natural gas reservoir from the state of Western Australia requires that the CO_2 off-gas is injected in a nearby offshore aquifer, instead of being vented to the atmosphere (1).

If the world were to act decisively on climate change, it would invest in CCS proportionally to its contribution to global CO_2 emission reductions (1,13). CCS would then be deployed in many regions of the world. Every region of the world, and every country, is unique and would need to implement CCS in its own specific way (1).

There are currently two CCS facilities in construction in China, due to start operation in 2019 and 2020, and another six in early stages of planning. They could potentially add up to 5 million tonnes of CO_2 capture per year by the early 2020s. These are exciting and extremely encouraging developments, in particular, to address future emissions from coal in electricity generation (1).

The growth of renewable electricity sources in China is expected to flatten the past increasing trend in coal-fired electricity generation in China (6). Existing plants may, however, continue to provide nearly as much electricity, and produce as much CO_2, for the next 25 years as they do today, unless they can be fitted with CCS (1).

The US Congress expanded a modest and limited tax credit for CCS, known as 45Q, which creates a meaningful support for CCS and accelerate the deployment of the technology. For geologically stored CO_2, tax credits have risen to $50 per tonne, and to $35 per tonne for CO_2 utilisation, including Enhanced Oil Recovery, when they were previously $20 and $10 per tonne, respectively (13,14). Importantly, the cap on the total volumes of CO_2 has been removed for CCS facilities starting construction before 2024. There is no longer a limit on how much CO_2 can be stored geologically for the tax credit to apply (13,14). This sends out a clear, positive signal for future CCS facilities and creates a carbon pricing mechanism aimed directly at CCS (13,14). Although $50 per tonne of CO_2 is not sufficient today to make every type of CCS facilities financially attractive, it may unlock a wave of innovative projects, leading to new infrastructure, storage sites and technology improvements, giving birth to many CCS facilities (13,14). This could prove to be one of the most important steps taken by any country to show decisive action to reach the goals of the Paris Agreement (13,14,15).

The unit cost of electricity with CCS is often compared to that of electricity from wind and solar power (13,14). These are two well-established technologies, which benefited for decades from patient support from government programmes and subsidies from the taxpayer (13). Thus, their unit cost of energy is reported to be lower (13,14). Until CCS costs in power generation can be reduced through the learning that comes from building and operating more than the two pioneering plants in operation today, and replicating the strategy that brought the costs of wind and solar power down roughly 70% over the past decade, the unit cost of electricity with CCS will remain unknown, and unavoidably and unnecessarily high (13,14). Comparing the unit cost of electricity with CCS to that of wind and solar power is also somewhat misleading (14). On one side, there is firm capacity to deliver low-carbon electricity reliably and on-demand (13,14). On the other side, the same capacity offers low-carbon but variable energy that is not available on-demand, although it is predictable (13,14,15). It is necessary to include the cost of long-term energy storage to wind and solar unit costs of electricity, in order for them to be a truly alternative technological solution to electricity production with CCS. The prospect of meeting the climate change challenge is not a utopian or an idealistic goal. It is, as of today, an 'unsolved' problem. But unsolved does not mean that it is unsolvable (13,14,15).

3.4 CCS Prospects

The rulebook for CCS and the future CCS infrastructure has yet to be fully written, but it is relatively clear that, without the certainty and the long-term guarantees that only governments can provide, the development of CCS will be, at best, extremely slow (1). CCS trying to prevent, compared to natural levels, an excess of CO_2 in the atmosphere caused by human activities (3,4,5). Examples of tools that governments can use to stimulate, at national and regional levels, the deployment of CCS by commercial organisations are policies and regulations (5,8). Since there are no technical barriers to CCS, and the Earth's geology has the capacity to store global CO_2 emissions for many, many decades, policies and regulations supporting CCS are one of the few remaining pieces of the puzzle before widespread deployment can happen (4,5,8,10).

Majority of CCS facilities in operation or under construction in 2018 are linked to a specific type of reservoir: oil-producing reservoirs (1). CO_2 is injected into a series of wells for the recovery of additional oil that could not be recovered with alternative methods only, for example, water injection alone (1). A fraction of the CO_2 is trapped in the reservoir's pore space, and the remaining fraction exits the reservoir further away, via other wells. It is separated from oil, recycled and re-injected into the reservoir (1). The other type of reservoirs are deep saline formations, or aquifers (1). To meet climate targets, CCS needs to become truly global, because CO_2 emissions are. CCS needs to diversify in its applications (cement, steel, electricity and hydrogen). And needs to diversify in geological storage, with the majority of CO_2 injected into deep saline formations, or aquifers (1).

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

If the end game is global warming, then the focus must be CO_2 emissions, not renewable energy. The limitations to 100% renewable energy come from the lack of a low-cost, large-scale, long term method to store energy at the scale of the energy system of a country, with the exception of hydropower and fossil fuels (5,7,11). CCS is already being use widely across the planet, but not yet at the scale required to make a meaningful contribution on global CO_2 emissions reduction.

Global energy is currently undertaking a series of radical shifts: Rapid deployment of renewable energy technologies for electricity production, mostly wind and solar power, through falling costs. The growing electrification of energy, this is the transformation of energy into electricity to be used by consumers for energy services, A cleaner energy mix in China, and a shift towards economic development orientated towards services rather than manufacturing (1).

There is no credible way to decarbonise highly carbon intensive industries (cement, steel, refineries). Unless the alternative is to renounce the idea of limiting the atmosphere's carbon budget, i.e. giving up on 2ºC of climate change, CCS offers value in this sector. Since the production of hydrogen from natural gas is considerably cheaper than alternative methods of production which use electricity to split water molecules, CCS is likely to offer, at the very least, competitive value in that sector. In the electricity sector, the unit cost of energy from coal-fired or gas-fired power plants without CCS is lower. But, the alternative to not adding CCS is to eventually exceed the atmosphere's carbon budget, offering very little value. CCS is only one possible use for the geological subsurface, there are others such as nuclear waste storage and energy storage.

4.2 Recommendation

Renewable energy is the success story of the previous decade in terms of decarbonising energy. Rapid growth is expected to continue over the next two decades. But unlikely to match the formidable increase in global energy demand over the same period, and the use of carbon-containing fossil fuels is expected to grow (3,7,8,9).

The latest scenario for global energy of the IEA, the so-called 'New Policies Scenario' takes account of plans and climate commitments announced by countries since Paris 2015, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies. But the national pledges under the Paris Agreement fall short of the objective of a target well below 2ºC of global temperature increase (7,8,9). 'Renewables step up, coal strikes out' and 'Bright future for renewables'. The COVID-induced fall in carbon emissions last year, put emissions closer to the 2ºC pathway, there is a good chance that much of that dip proves transitory (1).

The scenario indicates that, over the period 2017-2040, a very large capacity of low-carbon sources of electricity generation - 164GW, equivalent to twice the installed electricity capacity of a country like the United Kingdom - is expected to be added globally, every year (7,8,9). However, 65GW of electricity generation capacity using coal, gas and oil is expected to be added too, over the same period (7,9). That is as much as 40% of the projected installed capacity of low-carbon electricity sources (renewables and nuclear) energies (7,8,9).

Beyond electricity, renewable sources of energy meet 40% of the increase in energy demand. Yet, the energy demand from fossil fuels across all sectors of the economy is expected to continue to grow, but at a decreasing pace (1). Natural gas uses rises by 45% as renewable energy continues to break records, it is clear that the overall demand for fuels containing carbon - coal, oil and gas - continues to grow too (1). So, are we going to stop using fossil fuels before we use up the atmosphere's carbon budget? Most likely not. And if we do use up the carbon budget, will we continue to use fossil fuels without preventing their emissions from entering the atmosphere? CCS has the potential to significantly reduce the carbon emission that follows from the use of fossil fuels in power production and large scale industries to effectively address climate change concerns.

REFERENCES

(1) BP (2019) Statistical Review of World Energy, retrieve at https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html [Accessed 30th August, 2021]

(2) Chabert M, Morvan M, Nabzar L. Advanced screening technologies for the selection of dense CO_2 foaming surfactants. 18th SPE Improved Oil Recovery Symposium; 2012; Tulsa, Oklahoma, USA.

(3) Chabert M, Morvan M, Nabzar L. Advanced screening technologies for the selection of dense CO_2 foaming surfactants. 33rd IEA EOR Symp; 2012.

(4) Energy Technology Institute (2015) The evidence for deploying Bio-Energy with CCS: BECCS in the UK, retrieve at https://www.eti.co.uk/insights/the-evidence-for-deploying-bioenergy-with-ccs-beccs-in-the-uk [Accessed 27th August, 2021]

(5) Filip Neele Etisalat.al (2013) 'Developing Corrective Measures For CO_2 Storage' retrieve at https://www.mirecol-co2.eu/download/EnergyProcedia_63-2014.pdf [Accessed 30th August, 2021]

(6) International Energy Agency in IEA (2015) Energy Technology Perspectives, retrieve at https://www.iea.org/reports/energy-technology-perspectives-2015 [Accessed 30th August, 2021]

(7) International Energy Agency (2015) World Energy outlook Special Report, Energy and Climate Change, retrieve at https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf [Accessed 31st August, 2021]

(8) International Energy Agency (2013) Technology Roadmap: Carbon Capture and Storage, retrieve at https://www.iea.org/publications/freepublications/publication/technology-roadmap-carbon-capture-and-storage-2013.html [Accessed 30th August, 2021]

(9) IEA (2013) Technology Roadmap: Carbon Capture and Storage 2013, retrieve at https://www.iea.org/publications/freepublications/publication/technology-roadmap-carbon-capture-and-storage-2013.html [Accessed 28th August, 2021]

(10) IPCC (2014) Climate Change 2014, Mitigation of Climate Change, Fifth Assessment Report, Figure 6-

12, retrieve at https://www.ipcc.ch/report/ar5/wg3/ [Accessed 31st August, 2021]

(11) Kennedy, C. (Ed.) 2009. 'Getting to Carbon Neutral: A Guide for Canadian Municipalities.' Toronto and Region Conservation Authority, retrieve at http://www.utoronto.ca/sig/CarbonNeutralReport_May52010_Final.pdf [Accessed 30th August, 2021]

(12) Mexican government's roadmap for 'Carbon Capture, Utilisation and Storage' retrieve at https://www.gob.mx/sener/documentos/technology-roadmap-ccus [Accessed 29th August, 2021]

(13) Moro, M., Lonzo, L. (2017) 'Electricity carbon intensity in European Member States', retrieve at

(17)

https://www.sciencedirect.com/science/article/pii/S1361920916307933 [Accessed 30th August, 2021].

(14) Réveillère A, Rohmer J, Manceau JC. Hydraulic barrier design and applicability for managing the risk of CO_2 leakage from deep saline aquifers. Int J Greenhouse Gas Control; 2012; 9; 62-71.

(15) Solbakken JS, Skauge A, Aarra MG. Supercritical CO_2 foam – the importance of CO_2 density on foam performance. SPE 165296, SPE EOR Conf; Kuala Lumpur, Malaysia, 2013.

(16) The UK-China (Guangdong) CCUS Centre retrieve at http://www.gdccus.org/en/ [Accessed 30th August, 2021]

EFFECTS OF SCREEN SIZE AND OPERATING SPEED ON THE PERFORMANCE PARAMETERS OF A DEPODDING MACHINE FOR FRESH MELON PODS

Adebayo, A. A. and Olaoye, J. O.

[1]Department of Agricultural and Bioenvironmental Engineering Technology,
Auchi Polytechnic, Auchi, P.M.B. 13 Auchi, Edo State, Nigeria.
[2]Department of Agricultural and Biosystems Engineering,
University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria.
[1]ajibolaadebayo975@yahoomail.com (08130117083), [2]jolanoye@unilorin.edu.ng(08035812797)

ABSTRACT.

A multi-powered melon depodding machine was a newly developed post-harvest fresh melon processing machine that makes use of hammer-mill mechanism to depod/extract melon seeds from its pods. Size reduction with the use of hammers is energy intensive process that breaks the large size fresh melon pods to small particle sizes with the aim of extracting its seeds. Therefore, there is need for mixing the net energy required for propelling melon processing machines to ensure effective contributions of melon seeds production to the economic growth of Nigeria. One of the objectives of this new depodding device was to eliminate the limitations associated with the traditional and other existing mechanized melon depodding methods. The various operating components of the melon depodding machine are the hopper, rotor shaft, concave screen, hammers, rotor disk and a 5.5 kW electric motor or compressed ignition engine. In this study, the operational factors are the screen size and operating speed, while the performance parameters are depodding performance index (DPI), material discharged index (MDI), machine performance index (MPI), mechanical damage index (MEDI) and melon pod throughput (C_t). However, effects of these operating factors on the performance parameters of the melon depodding machine were determined. The performance parameters of the machine were evaluated using a $4 \times 3 \times 3$ factorial experimental design with four screen size (15, 20, 25 and 30 mm) and three operating speed (650, 850 and 1200 rpm). Statistical software SPSS 18 was used to carry out the Analysis of variance (ANOVA) and Duncan's New Multiple Range Test (DNMRT). The ANOVA result showed that screen size was significant to both depodding performance index (DPI) and material performance index (MPI) at $P \leq 0.05$, while the operating speed and its interactions were not significant at $P \leq 0.05$. Again, DNMRT results also confirmed that the percentage mean values of the DPI and MPI at different screen sizes are siginificantly different at $P \leq 0.05$. Also, the evaluation experimental data was subjected to further statistical analysis using SPSS to plot graphs that showed the interactions between the operational factors and the machine parameters. The graphs also revealed that operating speed and screen size have significant effects on the (MEDI) of the depodding machine at $P \leq 0.05$ and this agreed with the results of DNMRT. However, the evaluated results showed the highest values of $\text{DPI} = 97\ \%$, $\text{MDI} = 98\ \%$, $\text{MPI} = 97\ \%$, $\text{MEDI} = 0.8\ \%$ and the melon pods throughput was $C_t = 150\ \text{kg/h}$.

***Keywords**:* fresh melon pod, depodded melon materials, fermented melon materials

1. INTRODUCTION

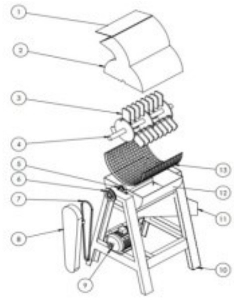
Melon *(Citrullus lantus)* is widely reported to have originated from the western Kalahari region of Namibia and Botswana in Africa, where it is found in wide diversity together with other citrullus species. It is also grown in India, China, Japan and other Asian countries between 10th-16th centuries (Vander-vossen *et al.,* 2004). FAO (2002) reported that total world production of melon seeds in 2002 was 576,600 tonnes produced from 608,000 ha of farmland and out of which Nigeria produces 347,000 tonnes. By implication, Nigeria alone produces over 60 % of the World production of melon seeds. In Nigeria, there are two major types of melon fruits; one with bitter pulp called *bara* melon and the other type is used as source of water during draught period called water melon. Melon pod comprises of epicarp, mesocarp and endocarp. The epicarp is tough and difficult to process unless it is fermented. However, oil extracted from melon is classified as good energy source; for it has some fuel quality parameters that make it economical for biodiesel production (Ogunwa *et al.,* 2015). This will increase the industrial demands in future for melon seeds as raw material and this will encourage local farmers to produce more melon seeds (Giwa *et al.*, 2010; Giwa and Akanbi, 2020). Therefore, it became imperative to develop an efficient processing technique for this valuable seeds that would sustain the high future demand for the melon seeds.

Oloko and Agbetoye (2006), Agbetoye *et al.* (2013), Nwakuba (2016), Ejiroghene *et al.* (2018) and Osasumwen *et al.* (2020) designed and fabricated melon depodding machines that are highly efficient in depodding only the fermented melon pods. However, Jackson *et al.* (2013) shows that fermentation of melon pods do not alter the nutrients and mineral compositions of the melon seeds. Therefore, depodding the fresh melon pods, without fermenting the pods remain a serious challenge. However, the conventional traditional melon processing techniques and the existing melon depodding machines were characterized with low seed extraction rate, associated with high seed wastages. Most of the existing melon depodding machines were efficient in depodding fermented melon pods with low depodding performance on fresh melon pods; this does not encourage large-scale production of egusi-melon seeds. Hence, an efficient processing technique and machines are required to process fresh melon pods within two days and at the same times support medium and large scales production of melon seeds.

2. MATERIALS AND METHOD

The developed melon depodding machine was designed to use hammer-mill mechanism to break/crush the back of the fresh melon pod and carefully extract its seeds from the broken pods without breaking the seeds. The major functioning components are the frame, hopper, hammer gang, concave screen, and pulp outlet as shown in Figures 1 and 2. The performance evaluation of the fresh melon depodding machine was carried out in the fabrication laboratory of the Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria.

Figure 1: Pictorial view of the melon depodding machine



ITEM NO.	DESCRIPTION
1	LOCK GATE
2	HOPPER
3	HAMMERS
4	SHAFT
5	PILLOW BEARING
6	PULLEY
7	BELT
8	BELT GUARD
9	ELECTRIC MOTOR
10	FRAME
11	DISCHARGE CHUTE
12	DEPODDING DRUM
13	SCREEN

Figure 2: Assembly drawing of the melon depodding machine

2.1 Experimental Procedure

The essential steps in machine development were adopted in the development of the fresh melon depodding machine as enumerated by Olaoye (2011); Oloko and Agbetoye (2006) and Olaoye (2016). The essential components of the melon depodding machine were identified, designed and constructed. Appropriate performance indices were established to meet the requirements for the evaluation of the machine integrity and the products quality. However, during evaluation of the fresh melon depodding machine, the data generated from the runs and the calculated machine parameters were tabulated as shown in Table 1.

2.2 Performance Evaluation Equations

Derived evaluation equations used for determining the performance parameters of the developed fresh melon depodding machine are stated in Equations (1) through (6).

2.2.1. Percentage of Extractable Seeds ($\mathbf{i}$)

This is defined as the ratio of mass of extractable melon seeds to that of mass of certain quantity (i.e. 5 kg) of melon pods from which the seeds were extracted. Percentage of extractable seeds (i) from a certain mass (i.e. 5 kg) of melon pods was derived by Oloko and Agbetoye (2006) and was used for estimating the extractable seeds ($\boldsymbol{i}$) as shown in Equation (1).

$$\boldsymbol{i} = \frac{\mathrm{M_e}}{\mathrm{M_p}} \times 100\ \% \qquad (1)$$

Where, $\mathrm{M_e}$ is the mass of the seeds depodded from certain mass of fresh melon pods (kg)

$\mathrm{M_p}$ is the mass of 5 kg of fresh melon pods fed into the machine (kg)

2.2.2 Material Discharge Index (MDI)

This is the ratio of mass of unwanted melon materials discharged from the machine outlet to the total mass of unwanted materials fed into the machine. The Equation (2) was derived and used by Adebayo (2019) for estimation of the material discharge index (MDI).

$$\mathbf{MDI} = \frac{\mathrm{M_2}}{\mathrm{M_1} - (\mathrm{M_1} \times \boldsymbol{i})} \times 100\ \% \qquad (2)$$

where, $\mathrm{M_1}$ is the mass of fresh melon pods fed into the machine (kg),

$\mathrm{M_2}$ is the mass of discharged unwanted depodded melon materials (kg),

$\mathrm{M_1}$ - ($\mathrm{M_1} \times \boldsymbol{i}$) is the obtainable mass of unwanted melon materials (kg).

2.2.3 Depodding Performance Index (DPI)

This is the ratio of the mass of depodded melon seeds (broken and unbroken melon seeds) to the mass of extractable melon seeds in the fresh melon pods (5kg) fed into the machine. The Equation (3) was derived and used by Adebayo (2019) for estimation of the depodding performance index (DPI).

$$\mathbf{DPI} = \frac{\mathrm{M_3}}{\mathrm{M_1} \times \boldsymbol{i}} \times 100\ \% \qquad (3$$

) where, M_3 is the actual mass of melon seeds depodded by the machine (kg)

2.2.4 Machine Performance Index (MPI)

This is the product of Materials Discharge Index and Depodding Performance Index. The Equation (4) was derived and used by Adebayo (2019) for estimation of the machine performance index (MPI).

$$\mathbf{MPI} = (\mathrm{MDI} \times \mathrm{DPI})\ \% \quad (4)$$

2.2.5 Mechanical Damage Index (MEDI)

This is the ratio of mass of broken/deformed melon seeds depodded to the mass of extractable seeds in percentage. The Equation (5) was derived and used by Adebayo, (2019) for estimation of the mechanical damage index (MEDI).

$$\mathbf{MEDI} = \frac{M_4}{M_1 \times i} \times 100\ \% \quad (5)$$

where, M_4 is the mass of depodded broken melon seeds by the machine (kg)

2.2.6 Throughput (C_t) of melon Depodded

This is the total mass of fresh melon pods depodded by the machine over the total operating time. It is the rate at which the machine depodded the fresh melon seeds from the pods. The Equation (6) was derived and used by Olaoye (2018) for estimation of the throughput of the machine.

$$\mathbf{C_t} = \frac{M_p}{T}\left(\frac{kg}{hr}\right) \quad (6)$$

where, M_p is the mass of the total fresh pods fed into the machine (kg)

T is the total time for the depodding operation (hr)

2.3 Statistical Analysis

The two operational factors used in evaluation of the melon depodding machine are screen size (S) at four levels (i.e. 15, 20, 25 and 30 mm) and operating speed (P) at three levels (i.e. 650, 850 and 1200 rpm) and the two factors were replicated thrice. The experimental design was 4 x 3 x 3 factorial design and the total experimental runs were 36 runs. The machine performance data were generated with their replicates and results were recorded and tabulated as shown in Table 1. The statistical analysis of variance (ANOVA) were determined and used for determining the effects of the operational factors on the performance parameters of the of the melon depodding machine at $P \leq 0.05$. Also, additional statistical results were obtained by using Duncan's New Multiple Range Tests (DNMRT) to compare the percentage mean values among different levels of the experimental factors. Tables 2 to 5 showed the statistical results of (ANOVA) of the effects of the operational factors on the performance parameters of the machine at $P \leq 0.05$. Also, Tables 6 and 7 showed the statistical results of (DNMRT) which compare the percentage mean values among different levels of the experimental factors.

Table 1: Effect of Operating Speed (P) and Screen Size (S) on the Performance Parameters of the Melon Depodding Machine (Replicated Thrice)

Experimental Factors	Material Discharged Index MDI(%)	Depodding Performance Index DPI(%)	Machine Performance Index MPI (%)	Mechanical Damage Index MEDI (%)	Depodding Throughput Capacity C_a (kg/h)
P_1S_1	98.96 ± 0.25	76.54 ± 0.10	75.76 ± 0.11	2.66 ± 0.54	150.15
P_1S_2	97.96 ± 0.90	87.32 ± 0.34	85.44 ± 0.52	2.04 ± 0.21	150.15

P_1S_3	98.00 ± 1.02	96.31 ± 0.83	96.12 ± 3.32	1.52 ± 0.26	150.15
P_1S_4	98.89 ± 0.39	96.46 ± 1.05	95.74 ± 1.43	1.38 ± 0.76	150.15
P_2S_1	98.37 ± 0.26	77.75 ± 0.48	74.47 ± 0.62	1.62 ± 0.13	150.15
P_2S_2	97.85 ± 0.78	87.29 ± 1.53	85.39 ± 1.74	1.23 ± 0.57	150.15
P_2S_3	97.85 ± 0.72	96.85 ± 1.21	94.65 ± 1.97	1.11 ± 0.63	150.15
P_2S_4	98.00 ± 8.00	96.70 ± 1.12	94.82 ± 1.26	0.92 ± 0.80	150.15
P_3S_1	98.22 ± 0.80	79.69 ± 1.56	78.15 ± 1.72	1.49 ± 0.25	150.15
P_3S_2	95.85 ± 2.96	82.45 ± 4.42	84.28 ± 3.37	1.38 ± 0.23	150.15
P_3S_3	97.48 ± 2.00	97.77 ± 0.76	95.85 ± 1.46	0.99 ± 20.12	150.15
P_3S_4	97.85 ± 2.06	97.35 ± 0.96	96.26 ± 1.31	0.87 ± 0.22	150.15

*P is the operating speed; P_1 = 1200 rpm, P_2 = 850 rpm and P_3 = 650 rpm
*S is the concave screen size; S_1 = 15 mm, S_2 = 17 mm, S_4 =23 mm and S_4 =30 mm
*Mean of three replicates of each parameter $\pm$ standard deviation

3. RESULTS AND DICUSSION

The performance data of the fresh melon depodding machine for the various experimental runs were recorded and tabulated in Table 1. Tables 2 to 5 showed the results of (ANOVA), Tables 6 and 7 showed the results of (DNMRT) and the effects of the operational factors on the performance parameters of the melon depodding machine are discussed as follows:

3.1 Discussion

3.1.1 Effect of Screen Size and operating Speed on the material discharge index (MDI)

The results obtained using statistical analysis of variance (ANOVA) in Table 2 showed that the two operational factors (i.e. screen sizes and operating speeds) have no significant effect on the material discharge index (MDI) of the melon depodding machine at $P \leq 0.05$. This was also confirmed by the Duncan's New Multiple Range Tests (DNMRT) in Tables 6 and 7, which showed that mean values of the (MDI) were not significantly different at different screen sizes and operating speeds. However, results obtained from the evaluation data in Table 1 showed that the highest material discharge index (MDI) obtained was 97.85 % for most of the screen sizes and operating speeds. Although, slight dropped in (MDI) was observed from 97.85 to 95.85 % at speed range of 850 to 1200 rpm. This agreed with Agbetoye *et al.* (2013) which dropped from 65 to 45 % at the speed range of 112 to 229 rpm for the unsliced fresh melon pods, Nwakuba (2016) whose values of the material discharge efficiency dropped from 53.4 to 22.0 % at the speed range of 300 to 400 rpm for fermented melon pods and that of Oloko and Agbetoye (2006) dropped from 82.4 to 38.9 % at the speed range of 300 to 400 rpm for fermented melon pods.

Table 2: Analysis of Variance (ANOVA) for the Effect of Operating Speed and Screen Size on the Material Discharge Index (MDI)

Source	Type III Sum of Squares	Degree of freedom	Mean Square	F	Significance
Corrected Model	20.435[a]	11	1.858	1.033	.450^{NS}
Intercept	345326.646	1	345326.646	1.920E5	.000*
Speed	7.392	2	3.696	2.055	.150^{NS}
Screen Size	8.724	3	2.908	1.617	.212^{NS}
Speed * Screen Size	4.318	6	0.720	.400	.872^{NS}
Error	43.166	24	1.799		
Total	345390.247	36			
Corrected Total	63.601	35			

a. R Squared = 0.321 * Significant at $P \leq 0.05$

3.1.2 Effect of Screen Size and operating Speed on Depodding Performance Index (DPI)

The statistical analysis of variance (ANOVA) results in Tables 3 showed that only the screen size was significant on depodding performance index (DPI) at $P \leq 0.05$, while the operating speed and its interactions were not significant at $P \leq 0.05$. Also, Duncan's New Multiple Range Tests (DNMRT) results in Tables 6 and 7 confirmed that the percentage mean values of (DPI) at different screen sizes are significantly different at $P \leq 0.05$, while that of the operating speed and its interactions are not significant. The graphs in Figure 3 showed the highest depodding fermented melon pods.

performance index (DPI) (i.e. 98 to 94 %) for screen sizes of 25 and 30 mm at all operating speeds, with throughput of over 150 kg/h of fresh melon pods. This high depodding performance results for fresh melon pods indicated significant improvement over the existing one; Agbetoye *et al.* (2013) rated to have unsliced fresh melon depodding efficiency ranging between 74.8 to 53.4 % for unsliced melon pods and 77.4 to 53.4 % for fermented melon pods at the operating speeds ranging between 229 to 122 rpm; Nwakuba (2016) have depodding efficiency ranging between 62.1 to 31.8 % at the operating speed range of 300 to 400 rpm for

Table 3: Analysis of Variance (ANOVA) for the Effect of Operating Speed and Screen Size on the Depodding Performance Index (DPI)

Source	Type III Sum of Squares	Degree of freedom	Mean Square	F	Significance
Corrected Model	2231.326[a]	11	202.848	177.463	0.000*
Intercept	290494.051	1	290494.051	2.541E5	0.000*
Screen Size	2210.909	3	736.970	644.744	0.000*
Operating Speed	1.327	2	.664	.581	0.567^{NS}
Screen Size * Operating Speed	19.090	6	3.182	2.783	0.034^{NS}
Error	27.433	24	1.143		
Total	292752.810	36			
Corrected Total	2258.759	35			

a. R Squared =0.988 (Adjusted R Squared = 0.982)

* Significant at $P \leq 0.05$

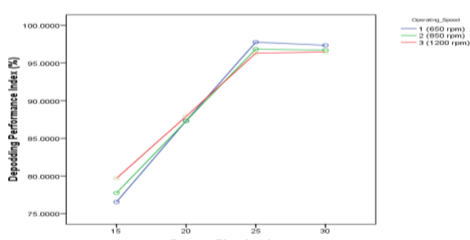


Figure 3: Effects of Screen Size and Operating Speed on Depodding Performance Index (DPI)

3.1.2 Effect of Screen Size and operating Speed on the machine performance index (MPI)

Also, the statistical analysis of variance (ANOVA) results in Tables 4 showed that only the screen size was significant on machine performance index (MPI) at P ≤ 0.05, while the operating speed and its interactions were not significant. Also, Duncan's New Multiple Range Tests (DNMRT) results in Tables 6 and 7 confirmed that the percentage mean values of (MPI) at different screen sizes are significantly different at P ≤ 0.05., while that of the operating speed and its interactions are not significant. The graphs in Figure 4 showed the highest performance index (MPI) (i.e. 97 to 95 %) for screen sizes of 25 and 30 mm at all operating speeds. Also, machine performance index (MPI) results for this machine appeared to be higher than that of Agbetoye *et al.* (2013) rated between 65.4 to 32.6 % at the speed range of 229 to 122 rpm for unsliced fresh melon pods.

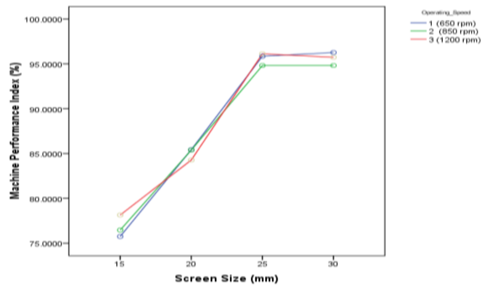


Figure 4: Effects of Screen Size and Operating Speed on Machine Performance Index (MPI)

Table 4: Analysis of Variance (ANOVA) for the Effect of Operating Speed and Screen Size on the Machine Performance Index (MPI)

Source	Type III Sum of Squares	Degree of freedom	Mean Square	F	Significance
Corrected Model	2264.903[a]	11	205.900	62.016	.000*
Intercept	280416.142	1	280416.142	8.446E4	.000*
Operating Speed	2.999	2	1.499	.452	.642^{NS}
Screen Size	2247.235	3	749.078	225.618	.000*
Operating Speed*Screen Size	14.669	6	2.445	.736	.625^{NS}
Error	79.683	24	3.320		
Total	282760.727	36			
Corrected Total	2344.586	35			

a. R Squared = 0.966 (Adjusted R Squared = 0.950)

* Significant at $P \leq 0.05$

3.1.3 Effect of Screen Size and operating Speed on the mechanical damage index (MEDI)

The analysis of variance (ANOVA) results in Table 5 showed that both the screen size and operating speed have significant effects on mechanical damage index (MEDI) at $P \leq 0.05$. Also, this was corroborated by Duncan's New Multiple Range Tests (DNMRT) results in Tables 6 and 7 shown that mean values of the mechanical damage index (MEDI) at different screen size and operating speed are significantly different at P $\leq$ 0.05. Again, Figure 6 showed a fall in mechanical damage index (MEDI) in the range of 2.7 to 0.80 % as the screen sizes varied from 15 to 30 mm at all operating speeds. However, (MEDI) was observed to be excessively high (i.e. 2.7%) at the highest operating speed (i.e. 1200 rpm), but lower range of (MEDI) (i.e. 0.8 to 1.2%) were observed at lower operating speeds (i.e. from 850 to 650 rpm) at higher screen sizes (i.e. 25 and 30 mm) as shown in Figure 6. The seed peeling/shelling was due to excessive impacted energy on the melon pods at highest speed (i.e. 1200 rpm) and longer waiting time of the melon pods in the crushing chamber at lowest screen sizes (i.e. 15 and 17 mm).

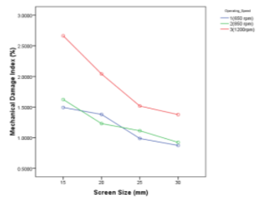


Figure 5: Effects of screen size and operating speed on mechanical damage index

Table 5: Analysis of Variance (ANOVA) for the Effect of Operating Speed and Screen Size on the Mechanical Damage Index (MEDI)

Source	Type III Sum of Squares	Degree of freedom	Mean Square	F	Significance
Corrected Model	8.552^{a}	11	.777	3.670	0.004*
Intercept	74.132	1	74.132	349.982	0.000*
Operating Speed	3.887	2	1.944	9.176	0.001*
Screen Size	4.049	3	1.350	6.372	0.002*
Operating Speed * Screen Size	.615	6	.103	.484	0.814^{NS}
Error	5.084	24	.212		
Total	87.767	36			
Corrected Total	13.635	35			

a. R Squared = 0.627 (Adjusted R Squared = 0.456)

3.1.4 Throughput (kg/h)

The results obtained from the measured samples during evaluation shown that the melon pod throughput of this depodding machine was rated as 150.15 kg/h per batch, while the continuous throughput of this machine was estimated to 200 kg/h of fresh melon pods. However, the capacities of the prototypes of Oloko and Agbetoye (2006), Agbetoye et al. (2013) and Nwakuba (2016) were less than 80 kg per batch.

Table 6: Duncan's Multiple Range Test (DMRT) of the Effect of Screen Size on the Performance Parameters of the Depodding Machine

Experimental Factor	**Material Discharged Index MDI**(%)	**Depodding Performance Index DPI**(%)	**Machine Performance Index MPI**(%)	**Mechanical Damage Index MDI**(%)
S_1	98.52^{a}	77.99^{a}	76.79^{a}	1.927^{ab}
S_2	97.22^{a}	87.51^{b}	85.04^{b}	1.550^{ab}

S_3	97.78[a]	96.98[c]	95.60[cd]	1.206[bc]
S_4	98.25[a]	96.84[cd]	95.61[d]	1.058[cd]

*S is the concave screen size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm
*P is the Operating speed; P_1= 1200 rpm, P_2= 850 rpm, P_3= 650 rpm
* Means in each column with the same letters are not significantly different at $P \leq 0.05$

Table 7: Duncan's Multiple Range Test of the Effect of Operating Speed on the Performance Parameters of the Depodding Machine

Experimental Factor	Material Discharged Index MDI(%)	Depodding Performance Index DPI(%)	Machine Performance Index MPI(%)	Mechanical Damage Index MEDI(%)
P_1	98.45[a]	89.74[a]	88.33[a]	1.183[a]
P_2	98.02[a]	89.65[a]	87.87[a]	1.223[ab]
P_3	97.35[a]	90.10[a]	88.57[a]	1.8993[c]

*S is the concave screen size; S_1 = 15 mm, S_2 = 17 mm, S_4 = 23 mm and S_4 = 30 mm
*P is the Operating speed; P_1= 1200 rpm, P_2= 850 rpm, P_3= 650 rpm
* Means in each column with the same letters are not significantly different at $P \leq 0.05$

4. CONCLUSION

The summary of the results obtained from the various analyses of the performance evaluation data of the developed melon depodding machine are stated as follows:

i. The (ANOVA) result showed the screen size was significant to both depodding performance index (DPI) and machine performance index (MPI); while the operating speed and its interactions were not significant to these two parameters at $P \leq 0.05$. Again, (DNMRT) results also confirmed that the mean values of the (DPI) and (MPI) at different screen sizes are significantly different at $P \leq 0.05$.
ii. The (ANOVA) and (DNMRT) of the data analyzed showed that operating speed and screen size have significant effects on Mechanical Damage Index (MEDI) at $P \leq 0.05$.
iii. The results obtained from the evaluation data shows that the highest material discharge index (MDI) obtained at all the screen size and operating speed was 97 %.
iv. The results obtained from the evaluation data showed that the highest depodding performance index (DPI) and machine performance index (MPI) are 98 % and 94 % respectively at screen sizes 30 mm and 25 mm and at all operating speed.
v. The results obtained from the evaluation data showed that the highest mechanical damage index (MEDI) of 2.7 % was obtained at the highest operating speed 1200 rpm and lower screen size of 15 mm. However, (MEDI) was observed to be decreases from 1.7 to 0.8 % as the screen size increases from 15 to 30 mm.
vi. The results obtained from the evaluation data shows that the continuous melon pod throughput (C_t) of the depodding machine to be 200.15 Kg/h of the fresh melon pods.

REFERENCES

Adebayo, A. A. (2019). Development of Depodding Cum Washing Machines for Fresh *Egusi- melon* Pods. Unpublished Ph.D. Dissertation Thesis. *Department of Agricultural and Biosystems Engineering. Faculty of Engineering and Technology, University of Ilorin, Ilorin, Nigeria.*

Agbetoye, L. A. S., Owoyemi, G. O. and Oloko, S. A. (2013) Design Modification and Performance Evaluation of Melon (Citrulluslanatus) Depodding Machine. *Global Research Analysis (GRA)*. Vol. 2 (7): 61-65.

Food and Agriculture Organization (FAO) Rome (2002) Agricultural Services Bulletin No. 124.

Giwa, S. O. and Akanbi, T. A. (2020. A Review on Food uses and Prospect of egusi melon for Biodiesel Production. Bio-Energy Resources. Vol. 10.

Giwa, S. O., Abdullah, L. C. and Adam, N. M. (2010). Investigating Egusi Seed Oil as Potential Biodiesel Feedstock. Energies. Vol. 3 (4): 607-618.

Jackson, B. A., Adamade, C. A., Azogu, I. I. and Oni, K. C. (2013) Melon Pod Fermentation and its effects on Physio-chemical Characteristics of Melon Seeds. *Academic Journals*. Vol. 8 (17): 664-669.

Nwakuba, N. R. (2016) Performance Testing of a Locally Developed Melon Depodding Machine. *International Journal of Agriculture, Environment and Bioresearch.* Vol. 1(1): 7 - 25.

Ogunwa, I. K., Ofodile, S. and Achugasim, O. (2015) Feasibility Study of Melon Seed Oil as a Source of Biodiesel. *Journal of Power and Energy Engineering.* Vol. 3:24 - 27.

Olaoye, J. O. (2011) Development of a Sugarcane Juice Extractor for Small Scale Industries. *International Journal of Agricultural Technology.* Vol. 7(4): 931-944. Available online http://www.ijat-aatsea.com. ISSN 1686-9141.

Olaoye, J. O. (2016) Performance Testing of a Small Scale Equipment for Depulpping Locust Bean Seed. *Transactions of the ASABE*. 59(3); 821 – 828.

Olaoye, J. O. and Aturu, O. B. (2018) Design and Fabrication of a Mechanized Centrifugal Melon Shelling and Cleaning Machine. *International Journal of Agricultural Technology.* Vol. 14(6): 881-896. Available online http://www.ijat-aatsea.com. ISSN: 2630-0613 (Print) 2630-0192 (Online)

Oloko, S. A. and Agbetoye, L. A. S. (2006). Development and Performance Evaluation of a Melon Depodding Machine. *Agricultural Engineering International: the CIG Ejournal.* Vol. VIII.

Orhorhoro, E. K., Oyejide, J. O. and Salisu, S. (2018) Design and Simulation of Continuous Melon Fruit Depodding Machine. *Nigeria Journal of Technological Research (NJTR).* Vol. 13 (2): 51-57.

Osasumwen, G. O., Aniekan, E. I. and Lucky, E. C. (2020). Design and Fabrication of a Modular Melon Depodding Machine for Optimum Performance in Nigeria Agricultural Sector. European Mechanical Science. Vol.4 (3): 103-112.

Vander-vossen, H. A. M., Denton, O. A. and El Tahir, I. M. (2004) Citrullus Lanatus (Thumb) Matsum and Nakai Vegetables. *Plant Resources of Tropical Africa (PROTA)* Foudation/Backhuyl Publishers/CTA Wageningen, Netherlands. Pp. 185 - 191.

ADVERTORIALS

Please insert Adverts accordingly

Front Cover, Iner Front Cover, Back Cover and Inner Back Cover pages or as the case may be.