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Ideas for evidence-based energy policies and strategies in West Africa

Volume II

The ECOWAS Sustainable Energy Journal (ESEJ)

The ECOWAS Sustainable Energy Journal (ESEJ) is a peer reviewed journal published annually by the Economic Community of West African States (ECOWAS) Centre for Renewable Energy and Energy Efficiency (ECREEE), Achada Santo Antonio, C.P 288, Praia, Cape Verde.

ESEJ is aligned with the objective of ECREEE which is to promote renewable energy and energy efficiency markets in West Africa by addressing technical, financial, policy and regulatory barriers. Moreover, with the ongoing energy landscape transformation in the region the importance of having relevant, evidence-based knowledge to aid in decision-making cannot be overemphasized.

By increasing the knowledge level of decision makers, science has played a key role in shaping the energy landscape, influencing decisions to cater for the needs of the present and, even, future generations. For the ECOWAS region, with issues of data availability and scarcity of country-specific research studies, the need to stimulate and cultivate the development of scientific, yet policy relevant, research projects have never been more pressing, especially in light of the region's sustainable development ambitions. Through its link with the ECOWAS Youth Leadership Development in Energy, ESEJ particularly aims to gives a voice to West African youth, by providing a platform through which they may contribute to informing decisions in the energy sector in the region.

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Publisher
ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) in cooperation with KAS.

Volume 2, Number 1, October 2022

ISBN 978-3-98574-112-0

The ECOWAS Sustainable Energy Journal (ESEJ)

Table of Content

Nigeria's Electricity Vision 30-30-30: Exploring the Techno-Economic and Environmental Implications
Al-Amin B. Bugaje, Michael O. Dioha, Bemdoo Saka Abdulrasheed Isah
Onyinye Anene-Nzelu........ **1**

Driving Policies through Research to Enhance Energy Management in Public Buildings in Nigeria
Chimaobi Nna, Azizat O. Gbadegesinb, Olanrewaju Oluwasanyaa........ **23**

The Impact of Climate Action on Energy Security in West Africa: Evidence from Burkina Faso, Ghana and Nigeria
Gideon Ofosu-Peasah, Eric Ofosu Antwi, William Blyth, Khadija Sarquah........ **53**

Impact of COVID-19 on Electricity Supply-Demand in West-Africa
Oluwarotimi Delano Thierry Odoua, Aissatou N'diayea, Ghafi Kondi Akara, Windmanagda Sawadogoc , Abdou Latif Bonkaneyd, Tchègoun Michel Atchikpae , Rabani Adamoua........ **95**

Development of a Platform for the Evaluation and Technical-Financial Study of Solar Pumping Systems in the ECOWAS Region
Egas Sidney Mascarenhas, Patrício Fernandes Andrade, Yannick Andrade........ **119**

Renewable and Non-renewable Energy and Economic Transformation of Developing Countries: Inward Approach to Sub-Saharan Africa
Enobong Ebitu **127**

Soumission de Proposition de Recherche pour la Politique Energetique en Afrique de L'ouest
BOSSE Galo Ginette, ABOUA Angui Christian Dorgelès Kevin. **143**

Nigeria's Electricity Vision 30-30-30: Exploring the Techno-Economic and Environmental Implications

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Abstract

Nigeria's Vision 30-30-30 (V30) outlines an ambitious goal of incorporating 13.8 GW of renewable energy (RE), a 30% share of the total electricity generation capacity mix, by 2030. However, there are still some challenges to be overcome before the full realization of this vision. In this paper, we examine some of these challenges from the technical, environmental, and economic perspectives and outline policy recommendations to facilitate the realization of this energy vision. From a technical perspective, we examine the voltage profiles at different stages of RE intake to demonstrate a compelling technical case for RE integration. Our analysis suggests that the Nigerian electricity grid will require massive infrastructure investments and smart controls to maintain system security. From an environmental perspective, aggressively pursuing V30 will reduce CO2 emissions by ~12% and substantially decrease air pollutants in 2030. From an economic perspective, massive market reforms are required to attract investments. We estimate that an additional 24% increase in average annual investment is required to make V30 a reality. Our model projects that achieving V30 will increase market revenue from on-grid generation by ~146% in 2030. Finally, we propose robust financing models and highlight policy reforms needed to establish a competitive electricity market.

Keywords:
Electricity; Energy Policy; Renewable Energy; Nigeria; PSS/E; TIMES model; MYTO model

1.0 INTRODUCTION

Electricity is essential to realizing many of the United Nations Sustainable Development Goals (SDGs), such as poverty eradication, quality education, good health, decent jobs, etc. [1]. Despite the importance of electricity to the socio-economic development of society, access to electricity continues to elude many households in Nigeria, and about 44.6% of the population does not have electricity access [2]. Those with access experience frequent blackouts and brownouts because of the poor electricity infrastructure system in the country. Some households and businesses resort to using captive diesel and gasoline generator sets as a backup to ameliorate the impacts of erratic power supply from the central grid. This generator sets release CO_2 and local air pollutants that endanger human health. The central electricity supply system is also dominated by fossil natural gas accounting for around 80% of the power generation and thus, contributes significantly to the national greenhouse gas (GHG) inventory [3].

Presently, there is widespread poverty in the country [4], and nearly 50% of Nigerians still live below the poverty margin [5]. With one of the lowest per capita electricity demands in the world (145 kWh)[5], Nigeria's human development index (HDI), as of 2018, was low at 0.534 and a global rank of 158 out of 189 countries [6]. Consequently, Nigeria needs to continue to focus on its development objective and enhance access to electricity for its people. Nigeria's electricity requirement and the resultant GHG emissions are poised to increase rapidly in the future, given the projected population increase and a fossil fuel-dominated power supply system. The concern assumes even greater significance as Nigeria has pledged to reduce its GHG emissions in line with global climate agreements [7]. Sustaining rapid economic development and satisfying unmet electricity demand while limiting GHG emissions becomes a significant challenge for Nigerian policymakers. This development has put the Nigerian energy system at crossroads with systematic structural changes required over the long term.

As a response to these challenges, in 2016, the Nigerian government developed the Nigerian Sustainable Energy for All (SE4ALL) Action Plan with Vision 30:30:30 (V30) that seeks to achieve 30% (13.8 GW) of electricity generation from renewable energy [8]. The plan outlined different targets for the various forms of renewable energy (RE) for on- and off-grid generation. V30 will improve electricity access in the country, provide employment opportunities for the teeming unemployed population, and go a long way to support Nigeria towards achieving its Nationally Determined Contributions by limiting GHG emissions. Notwithstanding, while the benefits of RE are numerous, some challenges come with the integration of RE into the energy system. Understanding the challenges and opportunities in the implementation of the Nigerian V30 is pivotal to unlocking the untapped potentials of the Nigerian electricity supply system.

Researchers have previously analyzed many policies directed at cultivating the RE potential in Nigeria with a view of re-directing investments from the private sector. Ref. [9] discussed the many pitfalls of unactualized policy recommendations stemming from a stark clash between vision and reality. The authors in [10] made a case for the correlation between RE and socio-economic development. They outlined a multi-tier timeframe framework to addressing RE policy gaps in Nigeria that covers policy design, access to finance, capacity building, and regulatory standards. Ref. [11] used a multi-objective model based on fuzzy goal programming to investigate the socio-economic, environmental, and energy sector impact of achieving the sustainable development goals in Nigeria. To our knowledge, there has not been any research that presents a technical analysis of the Nigerian grid after incorporating RE. Also, a similar multi-objective analysis that focuses on V30 and enabling policy recommendations is novel.

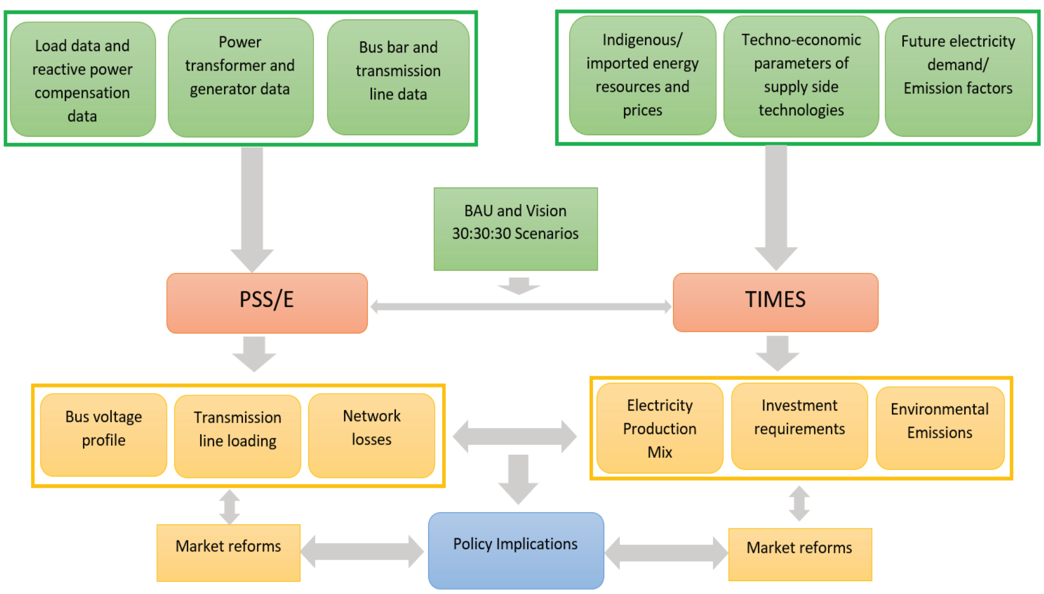
5 Additional information is available at: https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC?locations=NG&start=1980

In this context, the main research questions (RQ) underpinning our study are as follows: (1) What is the impact of Nigeria's V30 on the electricity grid from the perspective of network security? (2) How will Nigeria's electricity production mix change due to V30? (3) What are the economic and environmental implications of Nigeria's V30? (4) What market reforms are needed to facilitate the smooth implementation of Nigeria's V30?

In terms of contribution to the state-of-the-art in this domain, we introduce the first model-based analysis to understand Nigeria's opportunities and challenges towards achieving its ambitious RE targets. We explore some of the challenges from a grid security point of view that may hamper the reality of V30 and present significant infrastructural investments required to achieve this. We present a compelling environmental argument for aggressively pursuing V30 that results in improved quality of life. We also outline the economic investments required to facilitate the V30 ambition and the projected revenues from actualizing this vision. Finally, we outline key policy recommendations and bold market reforms needed to achieve V30. At this juncture, it is worthwhile to mention that for the grid security implication of V30, we revised the V30 energy projections to suit current realities and conform to projections of the Nigeria grid expansion master plan. Other than that, whether V30 will be realized or not is beyond the scope of our study. Our interest here is to examine how the energy system of Nigeria will respond to the implementation of this energy vision.

The rest of the paper is structured as follows. Section 2 introduces the different methods employed in the study, and Section 3 discusses the key results. Section 4 highlights the policy implications of the study, while Section 5 outlines the concluding remarks.

2.0 METHODS



The core of this research is based on the modelling of Nigeria's electricity supply system using various energy and financial modelling tools. To answer research RQ1 on the impacts of V30 on the Nigerian grid, the Power System Simulator for Engineering (PSS/E) was applied. To answer RQ2 and RQ3 on the electricity production mix, economic and environmental implications of V30, we applied TIMES (The Integrated MARKAL EFOM System) model generator. To answer RQ4 on the market reforms needed, the Multi-Year Tariff Order (MYTO) methodology was employed to model cost-reflective tariffs for the electricity market.

Energy modelling and scenario analysis have proven to be one of the best approaches for energy policy analysis [12]. To this end, this study established two scenarios to study the impacts of Nigeria's V30. In consultation with relevant stakeholders, we develop the business-as-usual (BAU) scenario that assumes no significant effort towards achieving the Nigerian Electricity V30. Next, we develop the V30 scenario that assumes the full implementation of V30. Then we compare the V30 scenario results with the BAU case to understand the implication of achieving this ambitious energy vision. An overview of the general study framework is shown in Figure 1, while the key assumptions characterizing our scenarios are presented in Table 1

Figure 1 General study framework

Table 1 Scenarios description

	BAU (GW)		V30 (GW)	
	2015	2030	2015	2030
Gas	3.08	8.00	3.08	13.00
Coal	0.00	1.50	0.00	3.20
Nuclear	0.00	0.00	0.00	2.00
Large Hydro	1.10	3.60	1.10	4.70
Small Hydro	0.02	0.80	0.02	1.20
Solar PV - Utility	0.00	3.00	0.00	5.00
Solar Thermal (CSP)	0.00	0.00	0.00	1.00
Wind	0.00	0.40	0.00	0.80
Biomass	0.00	0.10	0.00	1.10
RE Off-grid	0.03	6.29	0.03	8.10

2.1 Power System Simulator for Engineering (PSS/E)

The study on grid security was carried out using the Power System Simulator for Engineering (PSS/E) version 33.12 software. The Siemens PTI Power System Simulator (PSS/E) is a package of programs for power system transmission network and generation performance studies in both steady-state and dynamic conditions. PSS/E handles power flow, balanced and unbalanced fault analysis, network equivalent construction, and dynamic simulation [13].

The power flow study was conducted to determine the feasibility of realizing the assumptions and studying the grid's voltage profile based on V30. The voltage profile is a suitable metric to describe the security of the grid. At the time of writing, the existing wheeling capacity of the grid is approximately 7.3 GW. Also, there is no on-grid generation from solar PV, wind, solar thermal, biomass or geothermal energy sources. Based on these facts, the grid capacity assumptions for V30 were deemed infeasible and subsequently revised. The new assumptions follow the Transmission Expansion Master Plan document [14]. Table 2 shows the projected generation capacity of the grid as presented in the Transmission Master Plan report [14]. The report projects approximately 10GW in 2020, 15GW in 2025, 23GW in 2030, and 28GW in 2035. We note that the Transmission Master Plan report [14] did not consider the generation composed of 30% RE. Therefore, we revised the assumptions to include a 30% share of renewable energy and summarized the scenarios below.

- A generation profile of 4.19 GW in 2015 with 0% share of renewable
- A generation profile of 6.73 GW in 2020 with 0% share of renewable
- A generation profile of 15 GW in 2025 with 30% share of renewable
- A generation profile of 20 GW in 2030 with 30% share of renewable

Table 2 Revised scenarios based on the Transmission Expansion Masterplan

DISCO	Disco	2020 (MW)	Increase 2020-2025	2025 (MW)	Increase 2025-2030	2030 (MW)
IKEDC	1-Ikeja	1250	16.08%	1451	39.57%	2025
IBEDC	2-Ibadan	1225	45.31%	1780	50.28%	2675
AEDC	3-Abuja	745	35.70%	1011	66.92%	1688
BEDC	4-Benin	1273	37.47%	1750	39.98%	2450
KAEDCO	5-Kaduna	590	78.31%	1052	93.96%	2040
JEDC	6-Jos	442	48.64%	657	86.06%	1222
EEDC	7-Enugu	1090	22.29%	1333	25.22%	1669
PHEDC	8-Port Harcourt	946	55.39%	1470	43.42%	2108
EKEDC	9-Eko	1320	25.08%	1651	35.51%	2237
KEDCO	10-Kano	705	34.04%	945	59.22%	1505
YOLA	11-Yola	309	99.03%	615	83.14%	1126
Total MW		9895	38.61%	13715	51.26%	20746
Export MW		387		1540		1831
Total load MW		10282		15255		22577

2.2 The TIMES model generator

The TIMES model generator was used to examine the least-cost configuration of the Nigerian electricity supply technologies under the BAU and V30 scenarios. TIMES was developed by the Energy Technology Systems Analysis Programme (ETSAP) community – an implementing agreement of the International Energy Agency (IEA). TIMES is a multi-period technology-rich techno-economic model generator that uses linear programming to produce a cost-optimal national or multi-regional energy system to examine the energy system's dynamics over a long-term perspective [15]few energy system models have been developed with disaggregated sub-national regional detail, building type and urban/rural divisions. This paper addresses this key gap. Disaggregating the residential sector by building categories allows improved representation of the range of energy transition options across building categories. We incorporated a novel detailed building stock module into a 16-region TIMES energy systems model for Kazakhstan, using statistical data on the housing stock and building energy audit reports. We then explore the introduction of a coal ban and use scenario analysis to identify the most cost-effective heating technologies for the different regions and different building types. Implications of the residential sector policies to the supply side energy infrastructure were also quantified. The energy transition (from solid fuels to cleaner alternatives. The "selling point" of TIMES model is its ability to combine a rich technology database with an economically optimizing solver.

With perfect foresight and a partial equilibrium model, TIMES contains high-level features of the Energy Flow Optimization model (EFOM). Moreover, just like its forbearer—MARKAL (Market Allocation), it can represent the entire energy system of a defined jurisdiction from the point of primary energy production, through the conversion processes, and to the final end-use sectors. It also accounts for the various infrastructures and materials associated with the energy chain. Beyond integrated energy system modelling, TIMES can also be used for sectoral level assessment. Consequently, these characteristics make TIMES a perfect framework for modelling the Nigerian electricity generation mix.

The objective function of TIMES is to maximize the overall surplus or minimize the total discounted cost of the energy system while respecting the various constraints (technical, environmental, policy, etc.) imposed by the user. The total discounted cost encompasses the investment, fuels, operation & maintenance costs, etc. The objective function of TIMES is given by Equation (1)

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR-y} \times ANNCOST\ (r, y) \qquad (I)$$

where NPV represents the objective function of TIMES (i.e., the net present value of the total cost of all regions); R the number of regions in the study area; YEARS the set of years in the model for which there are costs; the discount rate; REFYR the reference year for discounting; and the total annual cost in region r and year y.

Over the years, TIMES has shown itself to be a reliable framework for examining the dynamic transformation of the energy system. It has been applied in many studies for national-level energy system analysis, such as Switzerland [16]ambitious carbon dioxide (CO2 and Portugal [17]combined with new generating technologies, we evaluate its importance by modelling the Portuguese system either as an isolated or as part of an integrated Iberian system. To design the low carbon roadmap for 2050 in Portugal, TIMES – The Integrated MARKAL-EFOM (MARKet ALlocation-Energy Flow Optimisation Model. Another key feature of TIMES is its capability to handle uncertainties through scenario analysis. A detailed technical description of TIMES model is presented in Loulou et al. [18].

Like other types of bottom-up models, TIMES is rich in technology representation and thus requires numerous kinds of data. To successfully construct a model on TIMES framework, the user is required to specify the energy service demands (Nigeria's electricity demand in this case); the global assumptions (time frame, discount rate, and the number of regions); costs of electricity generation technologies; technical parameters of electricity generation technologies; domestic and imported energy resources and environmental emission factors. Since TIMES is a perfect foresight model, it matches the electricity demand with supply at each defined time frame.

Projection of Nigeria's electricity demand (Figure 2) has been taken as the electricity demand of the "Greater Effort Pathway" scenario in the Nigerian Energy Calculator 2050 (NECAL2050) report [19]. The TIMES model is built as a single region (Nigeria) model considering a discount rate of 10%. The modelling time horizon is for 2015—2030 with 5-year intervals. An annual time slice was used. The model also includes renewable (e.g., wind, solar, and biomass) and non-renewable (coal, natural gas, and nuclear) energy resources. The techno-economic data of electricity technologies have been taken from various studies and are presented in Table 3. The future projections of energy prices have also been taken from various sources[6,7] and are presented in Table 4. The emission factors used in this study are presented in Table 5. The key outputs of a typical TIMES model run consist of the supply-side and demand-side technology deployment, electricity capacity and generation mix, technologies investment, annual investment costs, etc. Accordingly, the preceding data has been used to develop a TIMES model for the electricity generation system of Nigeria.

6 https://www.eia.gov/outlooks/aeo/
7 https://www.statista.com/statistics/583796/uranium-oxide-price/

Figure 2 Nigeria Electricity demand projection

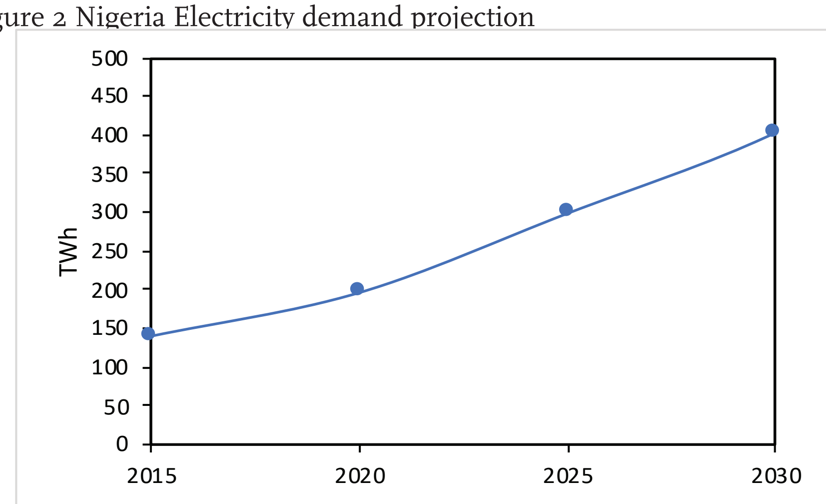


Table 3 Assumptions on techno-economic parameters of technologies [20][21][22][23].

	Input (fuel)	Lifetime (yrs.)	Efficiency	Lead time (yrs.)	Capital cost ($/kW)		Fixed O&M cost ($/kW-yr)	Variable O&M cost ($/kW-yr)
					2015	2030		
Gas Turbine	Natural Gas	35.00	0.39	2.00	1000	800	16.00	2.01
Coal Plant	Coal	50.00	0.34	4.00	1800	1600	33.00	1.20
Large Hydro	Hydro	45.00	1.00	5.00	1900	1500	21.90	3.20
Solar PV Utility	Solar	25.00	1.00	1.00	1100	900	64.00	-
Biomass	Agric. Residues	30.00	0.31	3.00	2900	2600	64.00	6.63
Small Hydro	Hydro	50.00	1.00	3.00	3100	2900	25.80	-
CSP	Solar	30.00	1.00	2.00	5050	4300	200.00	-
Wind	Wind	25.00	1.00	1.00	1760	1500	12.00	-
Nuclear	Uranium	45.00	0.35	7.00	5880	5550	89.00	0.50
Solar PV Off-grid	Solar	25.00	1.00	1.00	2800	2400	18.00	-
Self-fossil	Oil	8.00	0.35	-	600	600	48.00	11.00

Table 4 Projection of energy prices (US$/GJ)

Item	2015	2030
Agricultural residue	2.10	3.30
Coal	1.88	2.46
Diesel	16.64	26.58
Gasoline	18.90	27.44
Natural gas	2.14	3.55
Uranium	0.11	0.11

Table 5 Emission factors (kt/PJ) [24][25][26][27]

Fuel type	CO_2	NOx	SO_2
Biomass	-	0.0174	0.0125
Coal	94.60	0.1361	0.0500
Oil	72.60	5.6750	0.2786
Natural gas	55.82	0.0139 (OCGT) 0.0083 (CCGT)	-

2.3 Feed-In-Tariff Calculator

The Multi-Year Tariff Order (MYTO) is an incentive-based tariff model built to reward performance above benchmarks, reduce technical and non-technical/Commercial losses, and translate to cost recovery and improved performance standards from all the operators across the power value chain in the Nigerian Electricity Supply Industry. It calculates wholesale and retail prices for electricity in the Nigerian Power Industry by using a unified methodology to determine total industry revenue directly proportional to measurable performance improvement and standards.[8] The MYTO methodology uses a building block approach in estimating the transmission and distribution tariffs. The generation tariff is determined using a benchmark Long Run Marginal Cost of the most economically efficient new entrant that involves calculating the full life cycle cost of the lowest-efficient-cost entrant generator, considering current costs of plants and equipment, return on capital, operations and maintenance, and fuel cost.[9]

The draft regulations on feed-in tariff for the renewable energy sourced electricity in Nigeria, 2015 proposed the Long-Run Marginal Cost (LRMC) and Levelized Cost of Energy (LCOE), as the methodology used to set Feed-Inn Tariffs (REFITs) for the qualifying REFIT Technologies. The Long-run marginal cost measures the cost to produce one unit of electric energy without a fixed plant capacity. This methodology allows the cost of capital and the project's operating cost to be recovered over the Power Purchase Agreement (PPA) term based on a reasonable level of output/capacity.

Table 3 presents the assumptions used to estimate the generation cost for each generation feedstock. These assumptions form the benchmark estimate of the wholesale price for the generation. The assumptions on techno-economic parameters of the generation technologies, capital costs, fixed operations and maintenance cost, variable cost, and fuel cost are also available in Table 3. The available capacities for the aggregated technologies are assumed to follow the data in Table 1.

The Fixed O&M and variable cost remain constant for the different periods, and except otherwise stated, the fuel cost is captured in the variable cost. All analyses are in United States dollars.

8 https://nerc.gov.ng/index.php/home/myto
9 https://nerc.gov.ng/index.php/home/myto/406-generation-tariff

Table 6 Projection of generation available capacity

Available capacity (GWh)	Time	2015	2030
Gas	6,132	18,887	49,056
Coal	6,132	-	9,198
Nuclear	6,132	-	-
Large hydro	5,256	6,745	22,075
Small hydro	5,256	123	4,906
Solar PV - Utility	4,380	-	18,396
Solar Thermal (CSP)	4,380	-	-
Wind	4,380	-	2,453
Biomass	6,132	-	613
RE Off-grid	4,380	184	38,570

Table 6 presents the projected availability of generators. We estimate a 70% load factor for gas, coal, nuclear, and biomass plants, a 60% factor for large and small hydro, and a 50% factor for solar PV – utility, solar thermal (CSP), wind, and RE off-grid generation technologies.

3.0 RESULTS AND DISCUSSION

3.1 Grid security

The grid security is discussed from a voltage security outlook, with 2015 as a baseline. Figure 3 outlines the Nigerian grid sectioned into eight distinct areas. In 2015, a load profile of 4.19 GW (of which 81 MW is transmission losses) was serviced from a generation mix of mostly gas/steam (3.08 GW) and hydro generation (1.11 GW). The voltage profile of the grid (for the year 2015) is presented in Figure 4. The voltage profile in most regions of the grid is within the limits of 0.85pu to 1.1pu. While the Grid code specifies a range of 0.85pu – 1.05pu for 330kV buses and 0.85pu – 1.10pu for 132kV buses, most regions (the Northern part of the country) are on the lower side of the range. Low voltages (often due to power transmission over long distances) and high voltages (often due to lightly loaded transmission lines) are detrimental to grid security. As a result, compensation devices like capacitor banks and reactors are used to ensure that the voltage profile stays within stipulated limits.

Interestingly, implementing V30 (a scaled-down version of the vision based on current realities and projections) improves the voltage profile of the grid. The voltage profile of the grid that corresponds to this scaled-down vision is presented in Figure 5. The Port-Harcourt region has a voltage profile that is slightly above the ideal (1.0pu). However, the overall grid is in good shape, especially in the Northern part of the country. This improved voltage profile partly results from deploying generation much closer to loads, which is the case for the Northern part of the country that has abundant solar capacity. For a 20 GW projected load profile, the generation mix consisted of 5.82 GW of solar and wind, 4.08GW of hydro and 10 GW of gas. This improved voltage profile comes at the cost of massive infrastructure upgrades and new investments (132KV and 330KV transmission lines, transformers, capacitor banks/reactors). By 2025, to support a 15 GW load profile, 142 new transmission lines, 81 new 2 winding transformers (-WD), 69 new 3-WD transformers, and 32 new compensation devices (capacitor banks and reactors) are required. Existing equipment will also need to be upgraded, often to double or triple original capacity. Furthermore, new equipment and upgrades are required to sustain a 20 GW load profile by 2030. These further additions include 33 transmission lines, eight new 2-WD transformers, five new 3-WD transformers, and 12 new compensation devices.

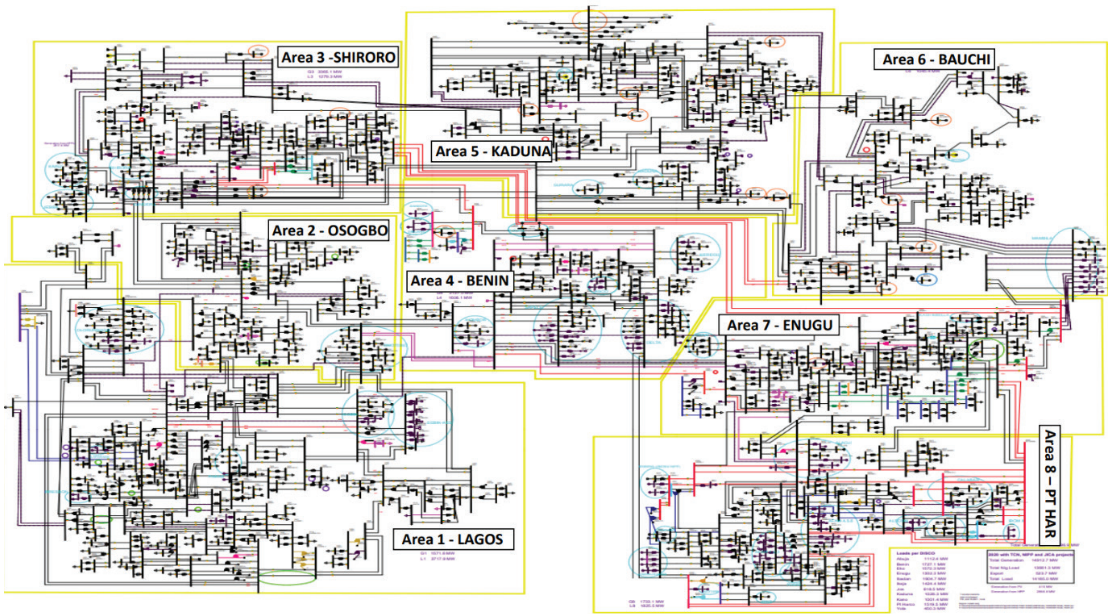


Figure 3 Nigerian grid sectioned into eight regions: Lagos, Osogbo, Shiroro, Benin, Kaduna, Bauchi, Enugu, and Port Harcourt.

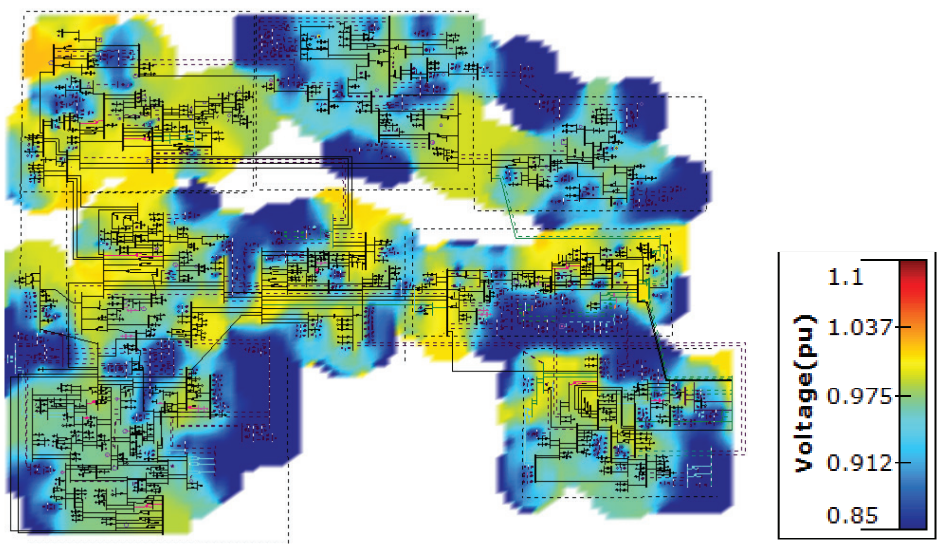


Figure 4 Load flow results for 4.19 GW representing the voltage profile of the Nigerian grid in 2015. The voltage profile across the eight regions is on the lower side of the acceptable range.

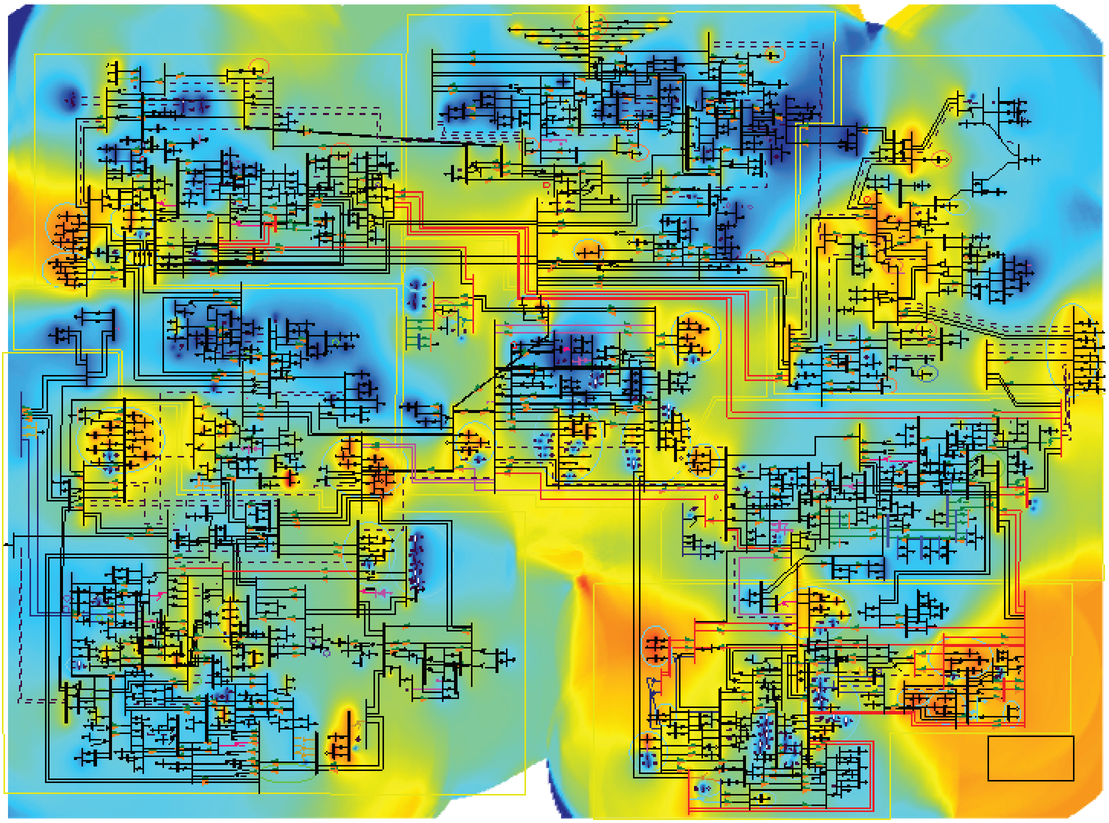


Figure 5 Load flow for 20 GW representing the projected voltage profile of the Nigerian grid in 2030. The voltage profile across the eight regions is closer to the ideal.

3.2 Electricity production, Emissions & Investment

Figure 6 shows the electricity production mix for the two scenarios. The captive fossil (diesel and gasoline) generators dominate the electricity production mix for the modelling time frame. We have earlier discussed the lack of electricity access because of the gap between demand and supply capacity of Nigeria's electricity system. Therefore, innovative and robust energy strategies will be needed to reduce the power supply-demand gap [10]. Our analysis (Figure 6) also shows that despite implementing the V30 policy, fossil power generation will continue to dominate the Nigerian electricity production mix. This scenario, therefore, calls for more ambitious energy policies to reduce the high dependence of the Nigerian populace on finite fossil fuels. Moreover, pursuing ambitious energy policies will also help to boost energy security in the country. Ambitious green policies also reduce the effects of local air pollution associated with using captive fossil generation. Another potent insight derived from the result is the inability of V30 to serve the significant growth of electricity demands in the country. This inability can be attributed to the suppressed demands that are usually not accounted for in many energy-planning models. Consequently, there is a need to start emphasizing strategies to improve demand-side management to reduce the pressure on the electricity supply-side of the Nigerian energy system.

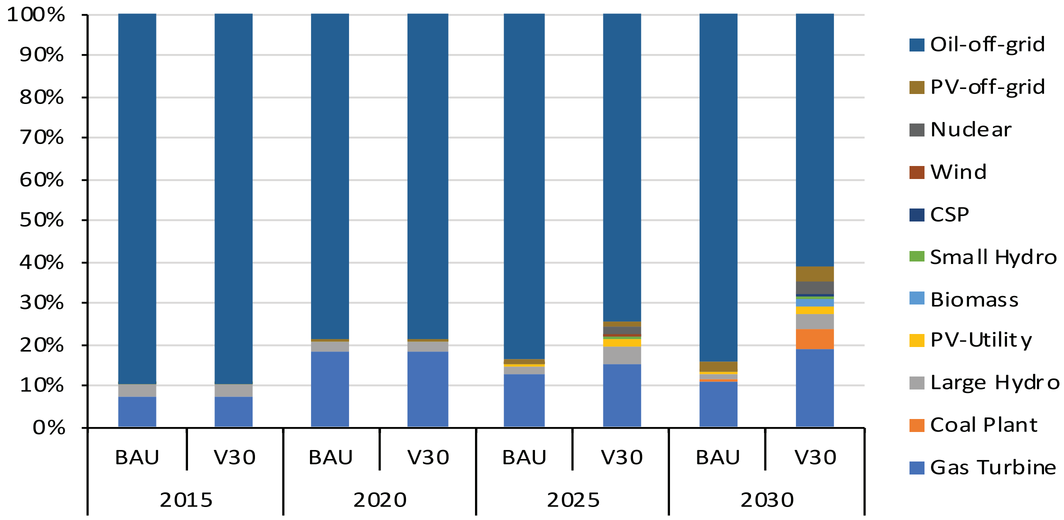


Figure 6 Electricity production mix. Fossil fuel-based generation dominates the electricity system in 2030

The electricity production mix shows that gas turbines account for the second-largest source of electricity production for the modelling timeframe but at different magnitude in each time frame. This gas dominance is because of the anticipated increase in capacity installation as well as the advantage of having a huge reserve of the resource. Despite the integration of 13.8 GW of RE (including large hydro) as per V30, our analysis shows that RE will account for less than 30% of the electricity production mix. This share falls below the plan of the V30 policy [2]. Therefore, for Nigeria to realize the dream of having 30% of its electricity production from RE by 2030, the Nigerian government needs to step up its "game" towards the development of RE in the country.

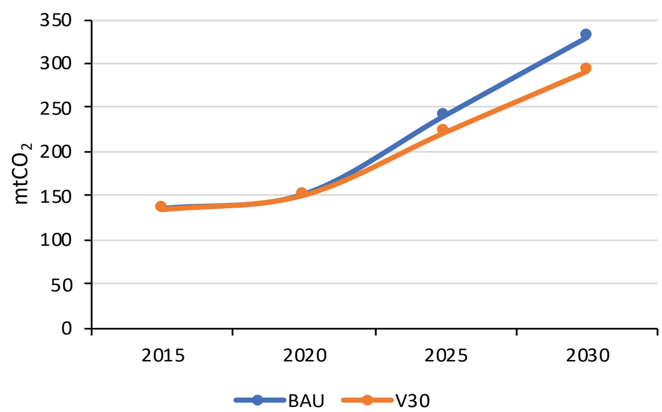


Figure 7 CO2 emission trajectory

To decarbonize the Nigerian electricity production mix, RE technologies will play a significant role [28]. Our analysis on environmental emissions shows that in the BAU case, CO_2 emission increases at a Compound Annual Growth Rate (CAGR) of 6.09% from 136 million tonnes of carbon dioxide ($mtCO_2$) in 2015 to around 330 $mtCO_2$ by 2030 (Figure 7). The huge growth recorded in CO_2 emissions is due to fossil generation growth (grid-connected and off-grid systems). However, in the V30 scenario, our analysis shows that in 2030, CO_2 emission drops to 291 $mtCO_2$ which is about a 12% reduction compared to the BAU case. This reduction is due to the relatively high penetration of RE technologies in the V30 scenario, limiting captive fossil generation growth. Figure 8 shows the emission of local air pollutants. NO_x and SO_2 emissions grow at CAGRs of 5.71 and 6.01% from 10 and 0.5 million tonnes (mt) to around 23 and 1.2 mt, respectively. As anticipated, in 2030, with the higher penetration of RE in the V30 scenario, NO_x and SO_2 emissions drop by 26 and 25%, respectively, compared to the BAU values.

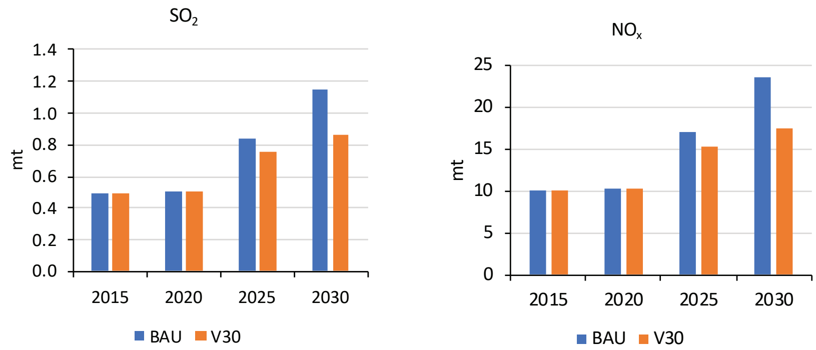


Figure 8 Emissions of local air pollutants

Figure 9 shows the projection of annual investment costs. In the BAU scenario, investment is seen to grow at a CAGR of 8.24%, from US$2.5 billion in 2015 to around US$8.2 billion in 2030. The magnitude of growth in investment requirement is on account of the massive investment expected to occur in the sector in the future to serve the country's growing energy-thirsty population. Owing to the relatively higher cost of RE technologies in Nigeria (in comparison to the conventional technologies), the annual investment costs in the V30 is expected to reach US$11.6 billion in 2030. In terms of the average annual investment needed for the period 2015-2030, our analysis indicates that about US$1.3 billion and US$1.6 billion will be needed yearly in the BAU and V30 scenarios. This result indicates that average annual investments will increase by 24% in the V30 scenario compared to the BAU case. This further implies that an additional US$0.3 billion investments will be needed annually to make Nigeria's V30 a reality. Therefore, there is a need to deviate from the current financing model and look for other alternative and robust financing sources to keep V30 away from a mere fantasy [29]. It is important to note that the annual investments estimated here have not considered transmission and distribution infrastructures and they are only based on technical feasibility and does not reflect real-world situation (for example, it does not reflect financial leakages/corruption in the system) which constitutes the actual investment requirements in a real world. As a result, the actual investment requirements may be higher than those analyzed here.

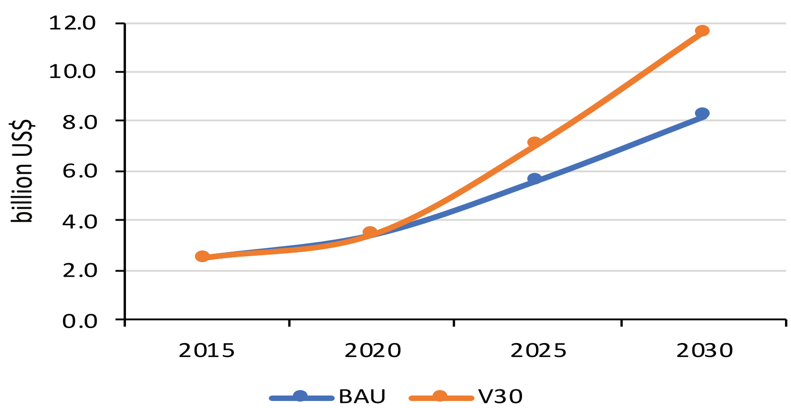


Figure 9 Projection of annual investment costs

3.3 Feed-In-Tariff

Table 7 presents the capacity and energy payments required in the wholesale market for the BAU scenario. To achieve the BAU scenario of on-grid generation of 17.4 GW by 2030, the generation section of the Nigerian Electricity industry requires a revenue of US$99.5 trillion. Considering a baseline of 25.6 trillion US$ in 2015, the projected revenue for 2030 increases by 288%.

Table 7 Projection of capacity and energy payments (US$) in the wholesale market for BAU scenario

Energy source	2015		2030	
	Capacity payments (US$ Billion)	Energy payments (US$ Billion)	Capacity payments (US$ Billion)	Energy payments (US$ Billion)
Gas	15300	30	32000	78.8
Coal			12000	8.8
Nuclear				
Large hydro	10000	17	26000	56
Small hydro	306	0.156	11000	6.2
Solar PV			14000	
Solar Thermal				
Wind			2900	
Biomass			1300	
TOTAL	25600	47.2	99200	150

Table 8 presents the capacity and energy payments required in the wholesale market to achieve the V30 scenario. To build and utilize an on-grid capacity of 32 GW by 2030, the Nigerian Electricity market needs a market revenue of US$244.3 trillion. Considering a baseline of 25.6 trillion US$ in 2015, the projected revenues for 2030 will increase by 853%. The V30 scenario projected revenues are expected to increase in 2030 by 146% compared to the BAU scenario.

Table 8 Projection of capacity and energy payments (US$) in the wholesale market for V30 scenario

Energy source	2015		2030	
	Capacity payments (US$ Billion)	Energy payments (US$ Billion)	Capacity payments (US$ Billion)	Energy payments (US$ Billion)
Gas	15300	30	52000	128.2
Coal			26000	18.8
Nuclear			56000	4.9
Large hydro	10000	17	28000	73.8
Small hydro	306	0.156	17200	9
Solar PV			23600	
Solar Thermal			21200	
Wind			5900	
Biomass			1300	
TOTAL	25600	47.2	14400	234.7

4.0 POLICY IMPLICATIONS

4.1 Market constraints to on-grid renewable energy investments in Nigeria

Over the years, several challenges have inhibited the development and deployment of utility-scale renewable energy in Nigeria. However, this paper argues that analyzing barriers to investment into low-carbon technologies needs to be understood within the broader contexts of the structure, conduct, and performance of the electricity industry in the country. Several studies have exhaustively discussed the intractable regulatory, infrastructural, and market barriers that have trapped the Nigerian electricity supply industry (NESI) in a low equilibrium with decaying infrastructure, unstable power supply, widespread inefficiencies, and monetary losses [10][30][31]. Figure 10 provides a snapshot of the multiple challenges facing NESI. This paper focuses on three mutually reinforcing binding constraints to mobilizing the necessary investments required to achieve V30.

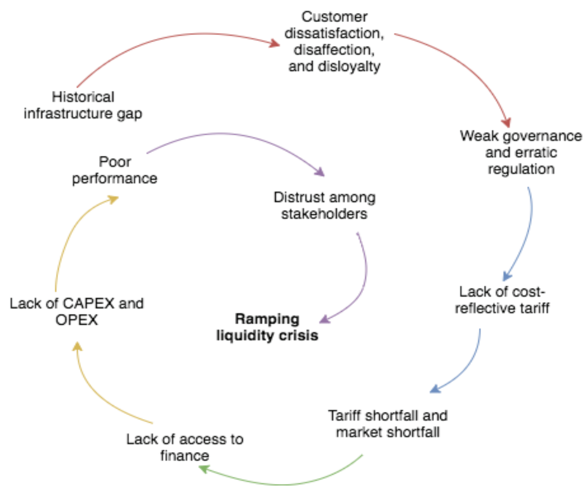


Figure 10 Challenges facing Nigeria electricity supply industry
Source: Adapted from Guerra (2019)

The first constraint concerns the lack of a competitive electricity market and policy uncertainty. Although the Electric Power Sector Reform Act (EPSRA) aimed to create a competitive electricity market following the National Electric Power Authority (NEPA) privatization (2013, this is yet to be achieved. On the contrary, the NESI operates under an inefficient market structure where stakeholders exert significant market power at different stages of the electricity value chain, thereby inhibiting new generation capacity from potential new renewable energy investors. For example, the Nigeria Bulk Electricity Trading (NBET) monopsony is a barrier to entry for new on-grid renewable energy investments in Nigeria. Currently, all grid-connected power is sold via the NBET, government-owned bulk electricity buyer, and cannot be traded directly to the distribution companies (Discos) or willing buyers in the wholesale market. While this is initially conceived to mitigate financial risks in the NESI until Discos become creditworthy, it has contributed to weak payment discipline, generated enormous contingent public liabilities, and limited on-grid RE generation. In essence, NBET's monopsony has prevented competition and stifled efficiency in the wholesale electricity market. A case in point is the stalled power purchase agreement (PPA) with 14 solar independent power producers (IPP) worth US$2.5 billion to build 1.125 GW of on-grid solar since 2016 [32]. After initially agreeing on a FiT of US$0.115 per kWh, NBET later reneged on the agreement and proposed to pay US$0.075 per kWh instead. Moreover, the Nigerian Minister of Finance, who chairs the board of NBET, has failed to approve the put and call options agreement (PCOA), which is necessary to ensure bankability of the solar projects and allow developers to reach financial close. This has constrained any prospects of the deployment of grid-connected solar soon, in addition to creating policy uncertainty for potential RE investors in the future. Other cases of market power abuse include the natural monopolies of regional Discos and the domination of a few generating companies with little competition.

The second barrier relates to the liquidity crisis and distrust in the electricity market. Lack of financial solvency is a major risk factor to any potential large-scale RE deployment in Nigeria. The underlying problem is the lack of cost-reflective tariff and high aggregate technical, commercial, and collection losses (ATC&C) of the distribution companies. For instance, in the first quarter of 2019, the wholesale market shortfall of Discos amounted to NGN 137.3 billion (approximately US$ 335 million), of which non-cost reflective tariff accounted for 48.8% [30]. Indeed, the revenue collected from the end-user tariff is not sufficient to cover even electricity generation costs [31]. This has created a downward spiral of financial losses throughout the industry and elevated investment risks for all stakeholders, including mounting liabilities and shrinking fiscal capacity for NBET. On the other hand, lack of stable electricity and estimated billing have fuelled end-users distrust of the Discos, electricity theft, and non-payment of electricity bills. Without solving the liquidity crisis affecting the electricity industry, investors into grid-connected renewables would lose confidence in the financial sustainability of the market as adding any new generating capacity to the grid would only exacerbate the problem. This is further worsened by a lack of bilateral trading arrangements allowing project developers to directly sell grid-connected electricity to creditworthy buyers willing to pay cost-reflective tariffs. Therefore, any market reform must be poised to solve the liquidity issue if it were to succeed.

The third constraint to achieving V30 relates to the lack of modern grid infrastructure. According to [33], energy transition is only possible in African countries if the following prerequisites are met: backup generation and energy storage, modern transmission and distribution infrastructure, and advanced grid management capability. Given the challenges associated with intermittent wind and solar electricity and grid digitization surrounding energy transition, these are required. However, the Nigerian grid is fragile with frequent shutdowns and load rejections, making it impossible to accommodate high shares of variable renewables effectively. Currently, the grid operator and distribution companies do not have cutting-edge capabilities for real-time monitoring, efficient load management, and effective metering resources. Without a significant overhaul of the electricity systems network and infrastructure, achieving V30 would be significantly hampered.

4.2 Market reforms to facilitate investments into on-grid renewable in Nigeria

According to the analysis above, it can be observed that the structure of the NESI, the conduct and financial performance of participants within it, as well as the regulation of the Nigerian authorities, present formidable barriers to achieving the clean energy targets of V30. As such, there is an urgent need for a holistic market reform that tackles the root causes of barriers to new investments and efficient market operations in the industry. While we do not claim to provide an exhaustive list of reform measures to support renewables deployment in Nigeria, we have provided three crosscutting recommendations following extant literature and global practice (Figure 11).

First, there is a need to establish a more competitive electricity market. Significant market power, especially with the wholesale market and distribution spectrum of NESI, inhibits competition, efficiency, and incentives to develop new energy sources. There is a need to create a parallel electricity market (PEM) to facilitate bilateral trading among stakeholders and allow credit-worthy customers to purchase electricity directly from generators. For example, if the 14 solar IPPs were allowed to sell power directly to large and bankable clients, there would not have been the need for tariff deadlocks, preventing the projects from reaching financial close. Besides, breaking up NBET's monopsony could help to foster wholesale market competition and flexibility, especially when retail distributors can generate sufficient revenues and minimize ATC&C losses, thereby unlocking new investments. Whereas the "willing buyer, willing seller" arrangement is supposedly acknowledged by stakeholders in the NESI, it has not been fully exploited due to regulatory uncertainty, stakeholder distrust, and technical constraints. Regulators need to provide clear guidelines, targets, and timelines regarding the transition to a competitive wholesale market. Currently, the EPSRA only provides a broad framework without practical details about the transition to a more competitive market.

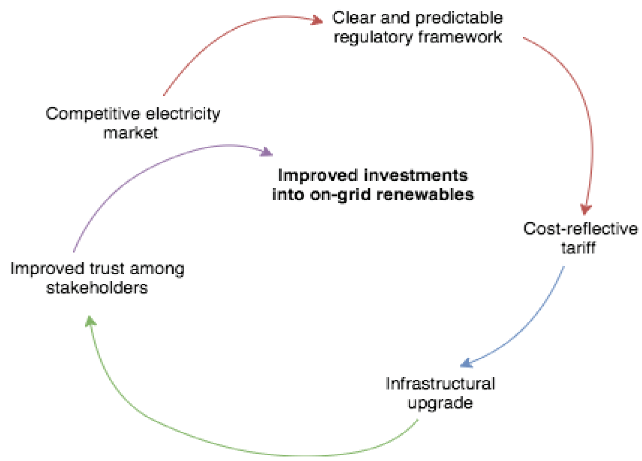


Figure 11 Market reforms to mobilize investments into on-grid renewables

Second, there is a need to ensure cost-reflective tariffs and a predictable regulatory framework in the electricity sector. Lack of cost-reflective tariff and revenue shortfall has been the most pressing issue in the NESI. Although the cost of low-carbon technologies has fallen significantly over the last few years, emerging RE investors in Nigeria need an attractive tariff especially considering the high risk and uncertainty of doing business in Nigeria due to factors such as exchange rate volatilities, high inflation rates, and lack of credible support mechanisms. Revenue underperformance will partly be plugged through the PEM as it would improve market liquidity, decrease the fiscal burden of NBET, and allow for better service for end-users. However, policymaking around the tariff framework needs to be significantly enhanced. In recent years, NERC has been slow in implementing a cost-reflective MYTO tariff to protect customers. This has exacerbated the liquidity crisis and stakeholder distrust. The recent announcement of a cost-reflective tariff review effective from July 1, 2021, by NERC is a welcoming development if properly implemented and geared towards ensuring efficiency in the industry [18]. Meanwhile, disputes over tariffs and put and call options agreements (PCOAs) with solar IPPs have put on hold prospects of integrating clean energy into the grid. Establishing competitive electricity with cost-reflective tariffs, legally binding and predictable RE policy, and strong collaboration among all stakeholders would boost investor confidence and unlock investments into large-scale renewables. Additionally, strengthening the political independence of regulators, addressing overlapping mandates of authorities, synchronizing fragmented RE policies, and imposing current regulations, would help to create a favourable environment for RE penetration. Nonetheless, potential setbacks to PEM, such as discriminatory concerns, technical constraints, and stakeholder buy-in, need to be adequately addressed beforehand to ensure efficient PEM.

The third market condition to achieve V30 is an infrastructural upgrade to facilitate integrating high shares of intermittent clean energy into the grid. Our modelling in section 3.1 underscored the scale of infrastructural gaps and the modern infrastructures needed to reach V30. Similarly, our results in section 3.2 indicated that average annual investments need to increase by 24% annually to realize V30. Yet, beyond physical infrastructures such as modern transmission and distribution systems, digital technologies (e.g., smart meters, machine learning, and artificial intelligence) need to be acquired by system operators and distributors to improve grid management capability in terms of real-time monitoring, demand, and supply projections, weather forecast, among others. Likewise, capacity building for technicians and managers will be crucial. Improved electricity infrastructure would also ensure a stable electricity supply, thereby boosting customers' trust and willingness to pay. More broadly, providing these essential smart grid infrastructures would make it possible to achieve the goal of generating 9.1 GW of on-grid renewable energy by 2030.

Our study is not without some limitations. The PSS/E package used in this study considers ideal weather conditions for variable renewable energy sources (VRES), and it does not consider the dynamical interaction of the VRES on the power system network. The TIMES model generator is employed in this study does not capture macro-economic feedbacks in the economy. Due to its long-term modelling architecture, it becomes difficult to capture temporal variabilities associated with the deployment of high shares of variable renewable energy sources (VRES). Furthermore, the MYTO is an annual modelling framework and hence does not allow for monthly updates of the macroeconomic parameters. Also, some of the assumptions used in the model are fixed by NERC, so it does not reflect the actual numbers (e.g., FOREX and inflation). Future research areas include examining the macro-economic implications of the V30 (e.g., the impacts on GDP, job creation/ labour, productivity, etc.). Owing to the uncertainties in the future cost of technologies – sensitivity analysis may be needed to examine how the investments computed here may change. Future studies could also apply other power sector-dedicated models with high temporal resolutions such as PLEXOS and IRENA FLEXTool to examine flexibility issues in the power system due to RE deployment. In addition, a detailed comparative assessment between Nigeria and other countries may be needed to understand potential policies, challenges, and innovative mechanisms needed to mobilize rapid investments to facilitate energy transition in constrained market contexts. While acknowledging the limitations in our paper design, we believe that our study will provide useful information for Nigerian policy makers and energy planners towards realizing Nigeria's electricity Vision 30-30-30.

5.0 CONCLUSIONS AND OUTLOOK

It is crucial to highlight that the trends in the industry suggest that natural gas will play a pivotal role in the energy future of Nigeria, especially towards displacing self-generation from gasoline and diesel systems. This adoption of natural gas has the potential for massive emission reductions and can support a modified version of V30. It is thus crucial for the FGN to accelerate the installation of relevant infrastructure that enables this transition, from the Southern region of Nigeria, where the fuel source is abundant, to the Northern region where embedded generation is required. Our results from Section 3.1 support the value of embedded distributed generation from a grid security perspective, and a policy that facilitates this will be relevant to the stakeholders in the industry, especially the transmission operator. While we recommend infrastructural upgrades, it is also important to note that substantial investments will be pivotal to realize V30. Our engagements with stakeholders indicated that from 2018 to the present, only around US$1.6 billion had been mobilized for the Nigerian electricity transmission sub-sector. Moreover, over 100 ongoing projects are scheduled to have been completed by 2020 as outlined in the Master Plan [14], but a significant number of these projects are yet to be completed. This indicates that there is a shortfall in the investments needed to put the sector on the path towards realizing V30. This shortfall in revenue could hamper the possibility of achieving any ambitious energy policy set out by the FGN. In the short term, policymakers would be remiss not to utilise internally generated revenues by the transmission company in upgrading sensitive infrastructure and completing critical projects. There may be a need to attract foreign investment to augment the shortfall in domestic revenues to develop and upgrade grid infrastructure in the long term.

Lastly, findings from this study underline the importance of investigating electricity policies of developing countries from both techno-economic and environmental dimensions in the context of synergies and trade-offs around sustainable development goals (SDGs). Our results showed that achieving V30 in Nigeria would contribute to reaching sustainable development in expanding access to clean energy (SDG7) and lower environmental emissions (SDG 13). Specifically, V30 would improve nationwide grid stability, particularly in the northern region, through increased solar energy generation and a reduction in transmission losses. Similarly, realizing V30 would lead to a 12% reduction in CO_2 emissions by 2030 due to the increased deployment of low-carbon energy sources. However, it is also found that more investments and stronger political commitment are profoundly necessary to increase the share of renewables in the country. The most binding barriers to mobilizing on-grid renewable energy investments have been identified as lack of competitive electricity market, liquidity shortfall, policy uncertainty, stakeholder distrust, and lack of reliable infrastructure. For Nigeria to realize V30, we recommend the need for market reforms to ensure a competitive electricity market, cost-reflective tariff, robust policy and regulatory framework, and infrastructural upgrade. Failure to pursue some of the above policy proposals may make the dream of V30 become only a fantasy for Nigeria.

ACKNOWLEDGEMENT

This work was supported by a grant from the Konrad-Adenauer-Stiftung (KAS) foundation. Gratefully, we acknowledge Mr. Muhammad Wakil from the World Bank, Prof. Jimoh Boyi from Ahmadu Bello University (ABU), Zaria, and Engr. Shehu Abba-Aliyu from the Transmission Company of Nigeria (TCN) for sharing their expertise, comments, and feedback. We would also like to thank Tosin George from Mido Green Energy Services for proofreading the manuscript.

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Driving Policies through Research to Enhance Energy Management in Public Buildings in Nigeria

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Abstract

Buildings consume 40% of all energy worldwide. Within West Africa, only Nigeria and Ghana have standards and policies in place to guide energy consumption in public buildings. This work presents research project outcomes comprising survey results on the appliances and energy use habits of staff working in government buildings across Nigeria, at the local, state and national levels. The results show that 47.9% of building users would use electricity more efficiently if they were directly responsible for payment of bills, 62% do not have an energy manager in their organization, and 96.9% are willing to participate in awareness training programs annually. As part of the project outcomes, four 1-hour sessions on raising awareness on energy use in public buildings were also carried out with 91 public/government officers in attendance. The results show the importance of continuous awareness engagements with public officials, the creation of energy management policies for public organizations and the need to have an energy manager responsible for energy use in public and government buildings in Nigeria. This research work can be replicated in other West African countries to pave a pathway for regional energy management policies on public buildings for all ECOWAS countries.

KEYWORDS:
Energy management, public buildings, government buildings, policy, users, West Africa

1.0 INTRODUCTION

According to the European Commission EU buildings factsheet, non-residential buildings in Europe are on the average, 40% more energy-intensive than residential buildings [1]. Fortunately, energy consumption in residential buildings has been decreasing since 2008 due to energy efficiency improvements driven by various types of policy measures, higher energy prices and recession [2]. In Denmark, although energy for heating in buildings has also decreased due to effective legislation, there has also been an increase in electricity consumption from appliances and electronics not covered by energy efficiency legislative requirements [3]. In the United Kingdom, though buildings are responsible for nearly half of the UK's primary energy use and about 30% of national greenhouse gas emissions, the amount of electricity for other appliances increased by a factor of more than 5% in 2016 [4].

In Africa, the energy sector in Nigeria does have its own peculiar statistics too. According to a PwC report in 2017, the Nigerian power network faces the challenges of inadequate power supply, non-cost reflective electricity tariffs and liquidity constraints, limited transmission lines, operational inefficiencies, poor water management at hydropower plants, inadequate and obsolete distribution infrastructure and so forth [5]. While this is true, it is important to note that inefficient practices by energy customers and end users in terms of appliance use, equipment technology and behavior, is also a huge challenge. Energy use in appliances and buildings within Lagos and Abuja, the two cities with the highest number of federal and state government buildings, has a significant effect on the distribution companies operating in those areas – the Ikeja, and Abuja Electricity Distribution companies. According to the Nigerian Senate, Ikeja Electric (IE) Plc and Eko Electricity Distribution Company (EKEDC), alone are owed over N91.96 billion as outstanding debts by the federal government's ministries, departments and agencies (MDAs) [6]. Another probable reason is that the collection efficiency of these distribution companies also remains as low as 65.6% of total billings in these two locations [7]. Hence, Energy Management Systems (EnMS) are very vital to ensuring that the energy within a building envelope is used efficiently or managed through the use of certain standard measuring and verification tools such as meters, etc.

1.1 Statement of the problem

According to the Association of Nigeria Electricity Distributors (ANED) and a study by PwC, in 2017, the electricity distribution companies claimed that government ministries, departments and agencies owed N64.1b for electricity supplied to them over a period of three (3) years [7]. However, the Federal Executive Council approved the settlement of the debt only after authentication. The federal government and its agencies owed 38.6%, while the remaining was said to be owed by state governments, local governments and public international organizations. Several government ministries, departments and agencies have backlogs of huge electricity bills as a result of heavy energy consumption and related costs beyond their annual budget[7]. This has resulted in the distribution companies (DISCOs) operating at a loss within their coverage areas where these government institutions are located. It has also often resulted in court cases and outright disconnection of the public buildings. Government intervention is however the last resort, as the distribution companies still do not get full value for the service provided, despite the fact that some government agencies such as hospitals and research institutes are under the 'Special' tariff class and enjoy a slightly lower price per kWh of consumed electricity, compared to commercial, industrial consumers and some classes of residential consumers[8]. The electricity bills received within this special tariff class is also dependent on the tariff set by the particular distribution company for its consumers, and the quantity of energy consumed[9]. Thus, these heavy bills are caused by these factors, as well as the inefficient use of energy via inefficient appliances and lack of conservation on the part of the users. According to [10], it is common practice to find in government offices - refrigerators, air conditioners, television sets, photocopy machines, desktop computers, fans, electric kettles and incandescent bulbs, in many cases switched on at the same time. Their findings reveal most public officers do not pay for electricity in their official residences and many government buildings are not metered, thus making it difficult for occupants to be accountable. Since energy conserved at one point is energy consumed at the other end, the wastages resulting from the use of inefficient energy equipment and unethical behavioral practices limit the supply of energy to other end users [11]. Furthermore, since most public buildings operate between the hours of 8 a.m. to 4 p.m., policies that support energy conservation can make energy available to small and medium scale commercial businesses who operate in the evenings or nights. Consequently, this will support economic growth and create jobs. The intention of this research study, therefore, is to evaluate the effect of establishing Energy Management Systems on efficient use of energy in public buildings, with particular reference to how energy is used, types of appliances used, behavior of occupants and the ability to pay for energy bills.

1.2 Research questions

Research questions

1. What is the effect of carrying out compulsory energy audits for public buildings in Nigeria every two years, on energy use?
2. What is the effect of establishing an Energy management system in Public Buildings in Nigeria on energy use?
3. What is the effect of quarterly awareness creation campaigns on energy use in Nigeria's public sector?

Scope

This study is concerned with awareness creation and public enlightenment for users of existing public buildings, as well as building characteristics measurement, data gathering and analysis. The awareness creation was carried out via webinars open to government employees across the country for one month, as well as the administration of questionnaires (physical and electronic). It does not however focus on proposed buildings, financing of retrofits of public buildings or the enactment of the final draft policy to support energy management in public buildings. The survey and building characteristics measurement of two (2) buildings was done in four months, inclusive of when request letters were sent to the organizations in Lagos and Abuja. However, the COVID protocols and federal government's directive that only essential workers at government buildings come into the office had an impact on the distribution and number of the buildings used.

1.3 Policy relevance

Most policies in Nigeria have not put into consideration the importance of establishing energy management systems in the public and government sector. In the industrial sector, the adoption of energy management is mostly driven by competition and competitive prices in the market. In the residential and commercial sectors, by purchasing power and profit margins respectively[12]. This cannot be said for the public sector as individual officers are not directly responsible or do not pay from their pockets. This inadvertently leads to huge energy consumption, high electricity bills and the inability to pay the service provider. The significance of this proposed policy is that as government buildings significantly contribute to the energy consumption in the service sector, this policy will ensure that these buildings and its' occupants use energy efficient appliances and practice energy conservation habits. The policy will also establish the enactment of energy policies and setting of energy targets for each building. In addition, government through its public buildings, will take a leading role to showcase the possibility, practicability and benefits of imbibing energy efficiency and conservation, to all other sectors in the country.

1.4 Literature Review

Achieving energy efficiency in buildings, either residential, commercial or public, thrives on the availability of policies. Policies aimed at conducting energy audits, awareness creation on energy efficiency, procurement of energy efficient equipment, development of energy benchmarking for buildings, and so on will not only help in ensuring an increased

acceptance of energy efficient buildings, but also save energy cost while mitigating likely greenhouse gas emissions generated from the buildings' energy sources.
Energy audits in three residential building types were carried out by [13], followed by modelling, simulating and predicting the electrical energy consumption of these buildings using EnergyPlus. Their aim was to also identify energy-intensive equipment in the buildings, as these are important for energy management opportunities. It was observed in the analysis that though water heating systems account for almost one-fifth of the annual energy consumption, cooling loads were found to be more than five times the heating loads. The apartment style required the lowest annual energy consumption by 10 kWh/m^2 per person, followed by the duplex type with 13 kWh/m^2 per person, while the single-storey house comes with the highest energy consumption of 18 kWh/m^2 per person. These represent local power consumption of 69, 79, and 90 kWh/m^2, respectively[13].

Another residential building type, in this case a two-storey residence in the mid-west region of the United States of America was studied. The authors investigated various building material effects on the cooling load requirements with a view of reducing energy consumption in buildings[11]. Various building walls, lighting, window glazing, and insulations were used for simulation as single and combined cases. The return on investment from savings in the electrical load consumption against the materials cost was also investigated. It was found that the best single case savings and investments were for cases when lights were changed from incandescent lighting with 20 W/m^2 to efficient fluorescent bulbs, or when using double-skinned walls with 5 cm rock wool or expanded polystyrene insulation. Combined cases, combining more than one single change, offered more reductions in cooling loads but were associated with higher initial costs and thus, longer returns on investment. The best-case recommendation was for buildings with a 20cm hollow concrete block when combined with fluorescent lights and double pane heat-absorbing glazing for windows[11].

Annunziata et al.[14], in the study "Enhancing energy efficiency in public buildings: The role of local energy audit programs", used statistical analysis to investigate factors that influence the adoption of energy efficiency in municipal buildings. The results showed that capacity building through training courses and technical support provided by energy audits, positively affect the adoption of energy efficiency in municipal buildings. It was however observed in this study, that the size of the municipal authority, the setting of local energy policies for residential buildings and funding for energy audits had no correlation with energy efficiency in public buildings [14] . Similarly, [15] conducted a detailed energy audit with the aim of using the results generated to propagate awareness on energy saving potentials in Indian buildings. Based on the data collected, many energy-saving measures to be considered for implementation were in the air conditioning, lighting systems, UPSs, and in power factor improvement and installation of an Energy Management System (EnMS). The analysis revealed that a one-time investment of Rs. 27.5 Lakhs could result in an annual energy saving potential of 231,656 kWh, a cost saving of about Rs. 16.2 Lakhs and a payback period of 1.7 years[15].

In China, an investigation into public building energy consumption levels and influencing factors in Tianjin, was carried out. Forty public buildings consisting of twenty government office buildings, eleven hospital buildings and nine school buildings were considered and information such as the building details, form of cold and heat sources (HVAC), and energy consumption were collected and analyzed [16].The effect of other parameters such as building envelope, building function, and illuminating systems were also analyzed. From the study, the function of the building had an obvious effect on the energy consumption of unit building area, as the energy use index for hospitals was greater than that of government and school buildings. Also, for the building envelope, it was observed that using sealing materials, external wall insulation and shadings reduced infiltration, heat transfer across walls, and solar radiation respectively. The authors concluded that lighting energy consumption could be greatly reduced by using natural lighting, energy saving lighting lamps, zoning control and acoustic sensor intelligent control

Zhu et al.[17] also researched into the current situation of energy consumption of twenty (20) public buildings in China. The study predicated on strong advocacy for effective measure of energy saving management to reduce energy consumption and save resources. Having highlighted the reason for high energy consumption in large Chinese public buildings such as lack of national policy, insufficient building design, ineffective energy consumption monitoring platform, and shortage of energy savings management, the authors suggested solutions for overcoming the huge energy consumption of the country from the technical and management angle [17].

Cibinskiene et al. [18] posit that while energy efficiency is key in minimizing energy consumption and waste in public buildings, the role of energy conservation cannot be overlooked. It was affirmed in the study that human behavior in the office could contribute to the reduction of energy use and CO_2 emissions, and address a number of environmental issues. The work analyzed and compared the research performed on the topic of the determinants of sustainable energy consumption such as psychological and social; sociodemographic; and contextual determinants; and investigated their impacts on the behavior of employees in three public buildings in Greece. The questionnaire survey disclosed that, despite the organizations' paying the bill, the employees believe that saving energy at work was important. The results also showed that female employees felt more responsible for energy problems, such as the exhaustion of energy sources or global warming. Finally, a regression analysis affirmed that the willingness to save a substantial amount of energy at the workplace was greater when employees have higher personal norms, that is, they feel morally obliged to consider the environment and nature in their daily behavior [18].

Dias Pereira et al. [19] carried out an investigation into the energy performance of public schools in order to achieve a functional benchmarking, based on the real operation conditions of school buildings. The authors claimed that energy performance certificates in public buildings, particularly in schools, could drive into energy benchmark hypothesis (for heating and electricity needs), based upon reference building types, driven, on their turn, from average/typical consumption values or good practice. It could also help school facility managers compare how much energy a typical elementary, middle and high school in a specific geographic region should consume, assuming the same target indoor climate conditions. In addition, a survey to gather data on energy consumption in school buildings such as global energy consumption values, electrical energy consumption; fuel consumption for heating, energy data consumption of schools expressed in annual cost per unit of heated/cooled surface area ($/$m^2$) or per unit of heated/cooled volume ($/$m^3$) and the annual cost per student ($/student). The results of the survey stressed the importance of adhering to standard indoor environmental conditions for classrooms, ensuring electrical and heating consumption values are kept separately, and that different education levels present different energy consumption values [17].

In addition to buildings consuming a lot of energy, many existing buildings are also constrained by the superintendence for architectural, landscape, historical and artistic assets; therefore, becoming difficult to improve their energy performance. This was the work carried out by Marinosci et al.[20] where the authors proposed a simple methodology tailored to predict, starting by the knowledge of the billing data, the impact of retrofit actions on the building energy demand. In particular, three different retrofit actions were analyzed including: modification of the indoor temperatures in the heating season; replacement of the old actual boilers with condensation gas heaters; and substitution of the actual fenestration systems (only the single glass panes). The results of the energy analysis show an energy saving potential of about 15% with operations building management and over 30% with improvements of the heating system and the windows[20]. Similarly, Salvadori et al.[21] conducted an energy audit of the lighting systems in historical buildings, employing the case study of a historical building used as public offices in Pisa, Italy. The authors describe the possibility of obtaining significant energy savings with a refurbishment of the lighting system using seven interventions on indoor and outdoor lighting sub-systems. They were characteristically compatible with the historical and artistic value of the building and showed short payback times between 4 and 34 months, allowing a reduction of the electrical energy consumption for the artificial indoor and outdoor lighting within a range of 1.1 MWh/year to 39.0 MWh/year [21].

In the work of Sameeullah et al.[22], an attempt was made to analyze the energy consumption pattern in hostel buildings (National Institute of Technology, Kurukshetra) with major focus on lighting and fan loads. Having carried out a preliminary audit aimed at collecting and analyzing information on the electricity bill, types of loads connected and patterns of electricity use by different loads, the detailed audit sought to carry out the audit of lighting, cooling loads, appliances, laptops, and heating loads. The detailed energy audit data was used to find out the major areas of efficiency improvement for each of the loads audited. By implementing the suggested recommendations in the report, an average saving of 463 MWh, which would be about 21% energy saving was feasible. Also, reduction in carbon emission by 579 tons CO_2 equivalent would be achieved [22].

Following studies and audits carried out in buildings, the role of mandatory policy and program enforcement is seen as vital in achieving energy efficiency in government buildings. Zou et al. [23] posit that reducing the energy consumption in existing government buildings would help reduce the costs and environmental impacts, and also show governments' strong commitment towards the reduction of greenhouse gas emission. In the research, the energy efficiency policies/programs in five states in Australia: Victoria, New South Wales, South Australia, Western Australia, and Queensland, were reviewed in terms of respective policies and targets, implementation methods and current progress. Amongst other lessons, it was reported that having a properly enforced energy efficiency mandate with clear energy saving targets, establishing an expert facilitation team and implementing suitable financing and procurement methods were key factors for a successful government building energy retrofitting program[23].

2.0 DETAILED METHODOLOGY

The source of data and methodology used for this research study is divided into three (3) parts according to the components of the project – survey on energy use, energy audits, and online awareness program.

1. ***A survey on energy use in buildings***

For the survey on energy use in buildings, questionnaires were designed by the research team to capture the energy use patterns amongst respondents across Nigeria. The target respondents were civil/public officers and management staff across all levels of government in Nigeria. Due to the COVID-19 pandemic and the corresponding restrictions on movement for public officers below Grade level 12, which lasted for over a year, the questionnaires were administered mostly through Google forms and the others via hard/printed copies.

2. ***An energy audit of three selected government buildings***

According to [24], the Energy Conservation Act, 2001, defines energy audit as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

In a simpler form, an energy audit is an official scientific study of energy consumption of an organization's processes or equipment with the aim of reducing energy consumption without affecting productivity and comfort of the users[25].

The purpose of an energy audit is to understand and analyze how energy is used or wasted, find alternatives for reducing energy losses and improving overall performance, to work out the potential for energy savings, and then present a profitability calculation of different energy efficiency measures that can be implemented [26], [27].

Three (3) government buildings in Lagos and Abuja were selected for a walk-through energy audit exercise. Letters of collaboration/support were sent to the management of these organizations for their approval. The walk-through energy audit approach was utilized as it was the most feasible approach considering that most of the buildings were not fully occupied during the COVID-19 period. The walk-through energy audits were also carried out with the support of the technical/facility managers within these selected buildings.

At the time of writing the manuscript, 2 buildings were completely audited. The audit of the 3rd building was 75% complete due to the nature of the building, COVID-19 and the absence of some officers in individual office spaces.

3. *Online awareness/training program*

An online awareness creation program was developed titled "Awareness training on energy management in public/government buildings in Nigeria". The course content was developed by the team into a ~~44-slide~~ PowerPoint presentation covering all aspects of energy management in buildings – the envelope, the equipment and the energy user. The slides were also reviewed by the research supervisor to check for completeness and relevance to the target group.

In order to promote the training, a flier was designed and circulated by the team across the following social media platforms - Twitter, LinkedIn, Facebook and Instagram. The flier and other information for registration was also shared directly to government organizations, to different National Committees for Standards, and to the World Energy Council, where a considerable number of government officers and management staff belong to.
The registration process was conducted via a Google form. This enabled the team to know their audience ahead of the training, have access to their contact information for the training, and also for future correspondence.

The awareness training programme was carried out four times in the week of June 8th to June 12th 2021, with four (4) 1-hour sessions: Tuesday (10am – 11am), Thursday (3pm – 4pm), Saturday (11am – 12noon), and Saturday (4pm – 5pm) via the Zoom platform.

2.1 Barriers and limitations to the research

The following barriers and limitations were encountered during the implementation of the project

1. COVID-19 pandemic: The restrictions caused by the pandemic affected the response to letters. Most organizations had most staff below level 12 out of Office for months. Hence, it was difficult to get adequate attention to our requests.
2. Access to electricity distribution boards of public/ government buildings to place meters was a herculean task as there were only a few facility managers willing to provide access.
3. Face-to-face interviews were difficult to schedule due to the COVID-19 scare, for both the field researchers and the respondents.
4. Physical follow-up of respondents for the questionnaire was difficult due to COVID restrictions.

2.2 Data collection methods and instruments

The sampling design for the research study used two (2) probability sampling methods – random and stratified sampling method. The population sample was stratified into federal, state and local governments and then participants were randomly selected from each stratum across all employee grade levels. The same method was used for the selection of the buildings.

The following instruments were used to conduct the walk-through energy audit;
The Plug in Energy meter – It was used to measure the real time energy consumption of the appliances that have 13 Amp plugs. These include desktop computers, printer, microwave, photocopier, refrigerator, projector, electric kettle, scanner and other appliances with a 13A plug. It is shown in Figure 1.

Figure 1: Plug-in Energy meter

Carbon dioxide analyzer – This carbon dioxide analyzer shown in Figure 2, although primarily for carbon dioxide measurements, was also used to measure temperature and relative humidity, which are very important parameters when carrying out energy audits for buildings.

Figure 2: Carbon dioxide analyzer

Laser distance meter: This instrument, as shown in Figure 3, was used to measure distances with the aid of a laser embedded at the top. It can calculate automatically the area and volume of a space with the aid of a selection menu.

Figure 3: Laser distance meter

3.0 RESULTS

The result of the research study is presented in three (3) sections, in line with the three components previously mentioned. This section presents the outcomes of the online questionnaire, the energy audit of buildings and the awareness training sessions carried out.

3.1 Survey Questionnaire

The questionnaire had a total of twenty-eight (28) questions, inclusive of one (1) optional question for contact details – email address of the respondent if they would like to be contacted in the future. This section presents the results of each of the questions in charts with a brief analysis/ interpretation of the result.

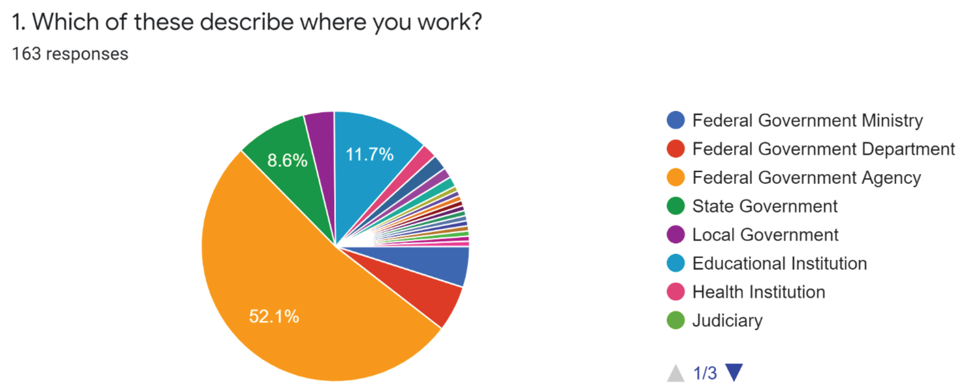

Figure 4: Type of government office of the respondents

Figure 4 shows the summary of the results of Question 1. The total number of respondents is one hundred and sixty-three (163). 82 (52.1%) of the respondents are staff of a federal government agency, 19 (11.7%) are of an educational institution, 14 (8.6%) in the state government, 6 (3.7%) from the local government, and 4.9% and 5.5% from the federal government ministry and department respectively.

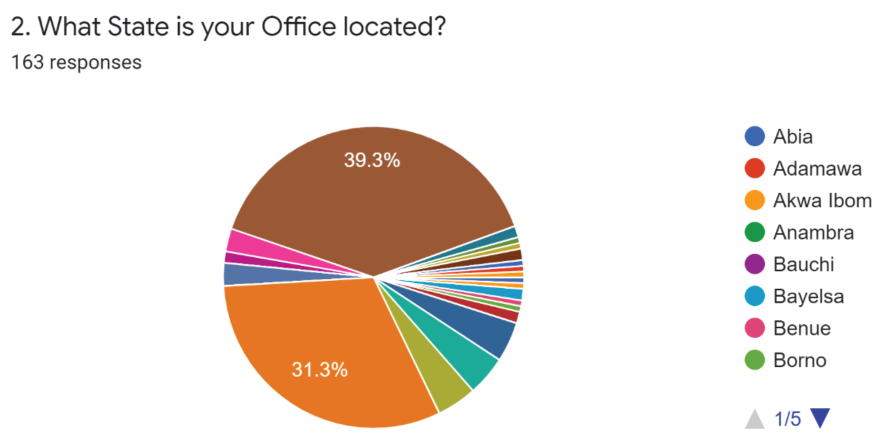

Figure 5: Location of respondents' offices, other than Lagos and Abuja

Out of 163 respondents, 64 (39.3%) work from a Lagos Office and 51 (31.3%) from Abuja. Thus, the remaining 29.4% of the respondents as shown in Figure 5, are spread across 19 states of Nigeria. This result shows that Lagos State and FCT Abuja have the highest number of public/government organizations/buildings in Nigeria. This implies that the focus on policies for energy management and the potential for energy savings are more in these two states.

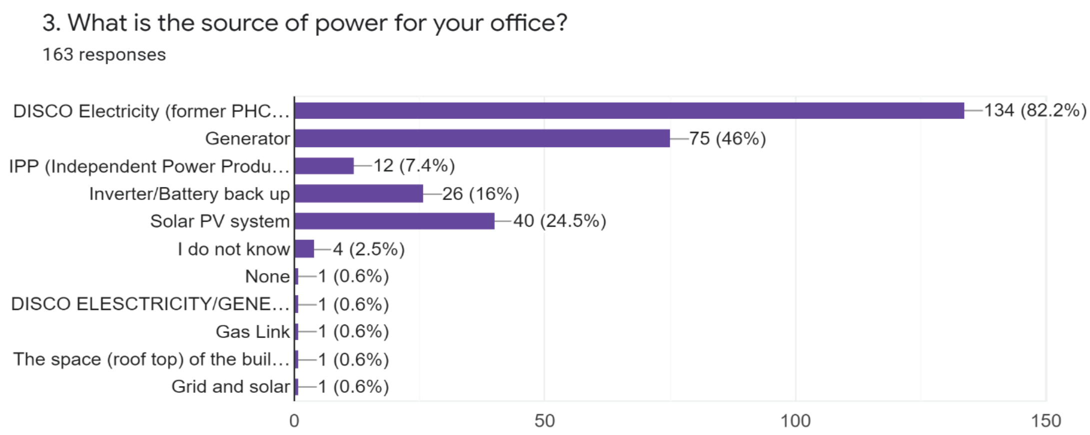

Figure 6: Source of electricity in public building

Figure 6 shows that 82.2% of the respondents' offices are powered from the national grid, through the distribution company. 46% of the respondents' offices are also powered by generators, 24.5% with solar PV system, 16% with inverter/battery back-up and 7.4% from an Independent Power Plant.

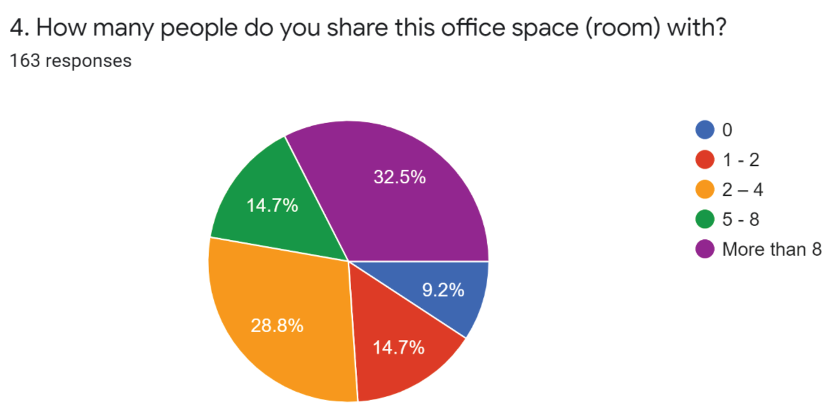

Figure 7: Number of persons per office space

Figure 7 presents the occupancy of office spaces of respondents. 90.8% of the respondents share the office space with at least one other person. 32.5% share office space with more than 8 persons. This indicates the high likelihood for high consumption of energy from a cumulative number of individual electrical appliances and gadgets (laptops, etc), but also the potential to appoint a person to be responsible for energy use and general energy conservation-related roles.

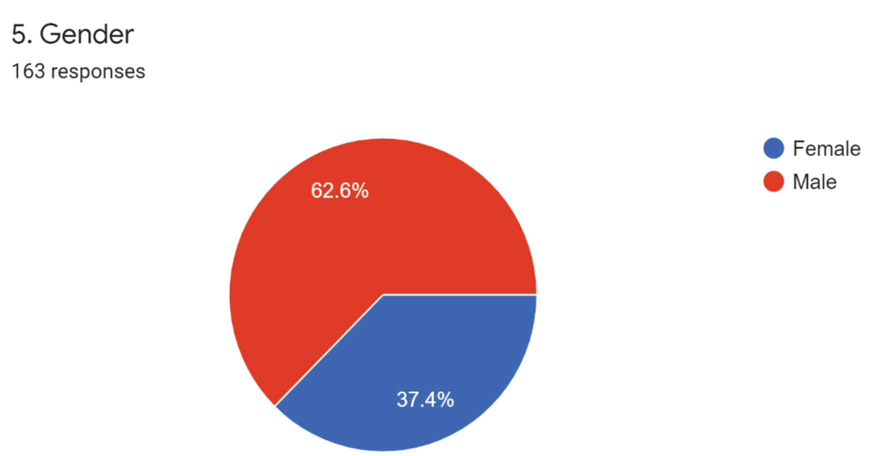

Figure 8: Gender of respondents

37.4% of the respondents are female as shown in Figure 8. This may indicate that within the office buildings, males are likely more responsible for energy related activities – use, maintenance and wastage. The chart also shows that energy is important to our daily lives irrespective of gender.

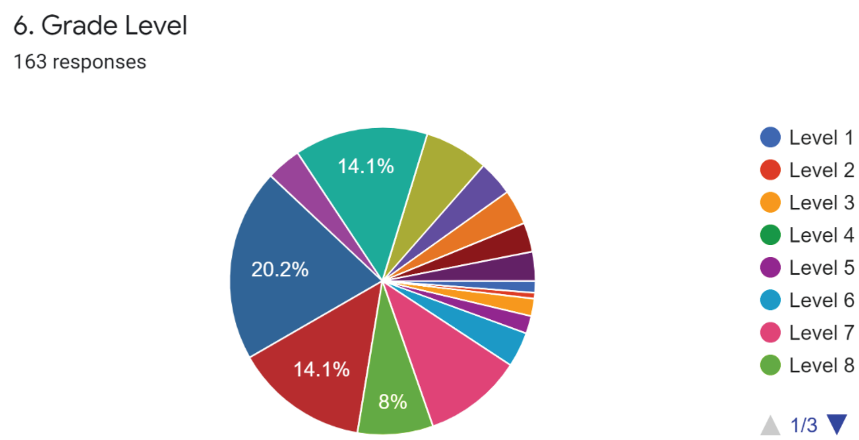

Figure 9: Grade level of respondents

From Figure 9, more than half (66.8%) of the responses were from officers at Grade Level 7, 8, 9, 10 and 12. This indicates clearly the most active and responsive grade levels within the public buildings in Nigeria. This may also indicate that these grade levels represent the most active energy users within the building.

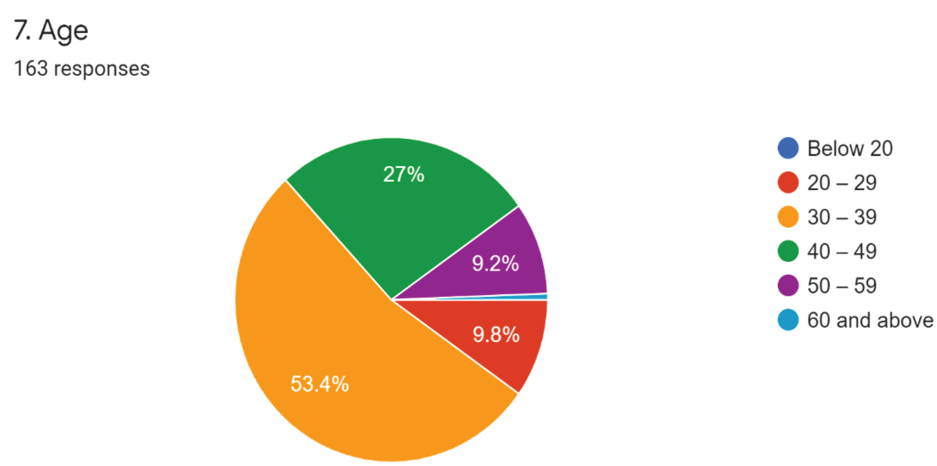

Figure 10: Age distribution

Figure 10 show the distribution of respondents by age. 53.4% of the respondents were in the age bracket 30- 39 years, followed by 40-49 which represents 27%. This represents to a large extent the active energy user within the public buildings are below 50 years old and still have some years of active service before retirement. Thus, encouraging changes in energy use habits can have a long-term effect on energy use in buildings.

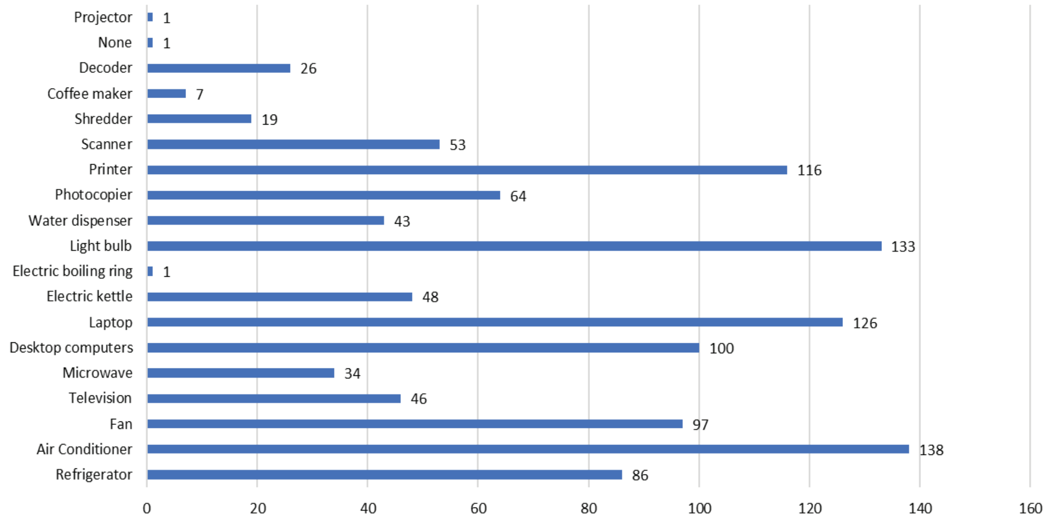

Figure 11: Appliances present in respondents' offices.

This bar chart in Figure 11 shows clearly the appliances that are present in offices in public buildings. 84.7% of the respondents indicate that they have air conditioners, representing the highest volume of all appliances in the chart. The top five (5) appliances in the office are air conditioners, light bulbs, laptops, printers and desktop computers. This result highlights where the potentials are for energy conservation and also energy efficiency. It is also important to note the percentage of high energy consuming appliances like electric kettles (29.4%) and microwaves (20.9%). This also shows the equipment for which quality, performance and energy standards may need to be developed, implemented and enforced. However, if the standards are already in place, they need to be domesticated.

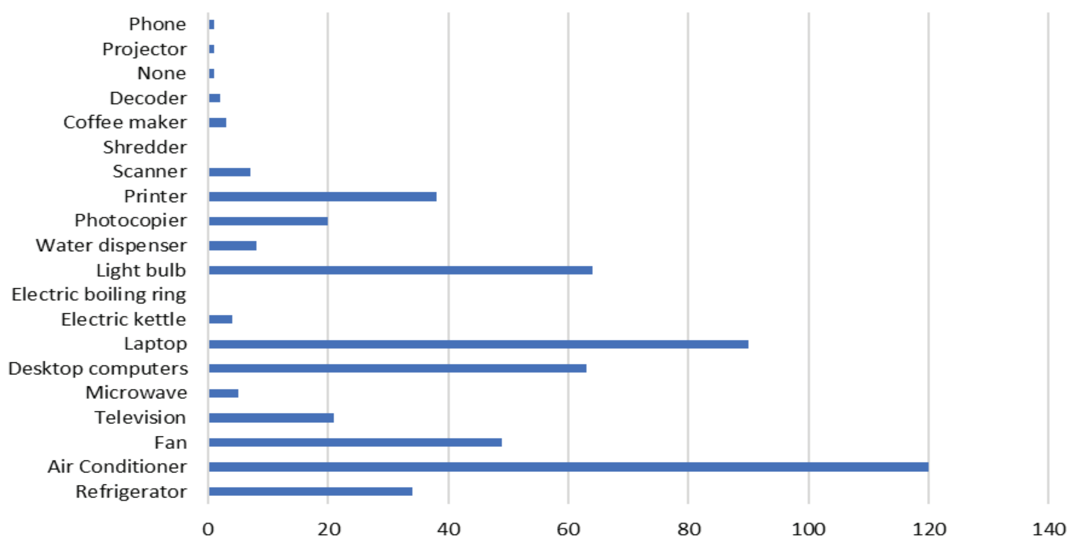

Figure 12: Top three appliances that are used most daily

The appliances which are used frequently within offices in public buildings in Nigeria are captured in Figure 12 above. The top three most used appliances on a daily basis in public buildings in Nigeria are air conditioners (73.6%), laptops (55.2%) and light bulbs (64%). This indicates that need for, or the importance of cooling and lighting in workspaces of public buildings. It also shows that in the procurement of office appliances, energy efficiency needs to be a compulsory consideration/requirement in order to cut down on energy consumption and the related carbon emissions.

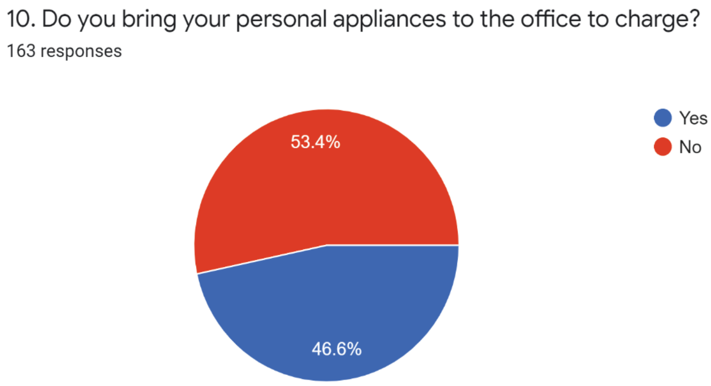

Figure 13: Charging of personal appliances

46.6% of the respondents take advantage of reliable energy supply within the public building to charge their appliances as shown in Figure 13. The questionnaire does not however extend its scope to what type of appliances. This highlights that other than the appliances in the building, which may be captured during an energy audit, considerations also need to be put in place to address the use of additional electrical loads which also contribute to the final monthly energy bills of public buildings.

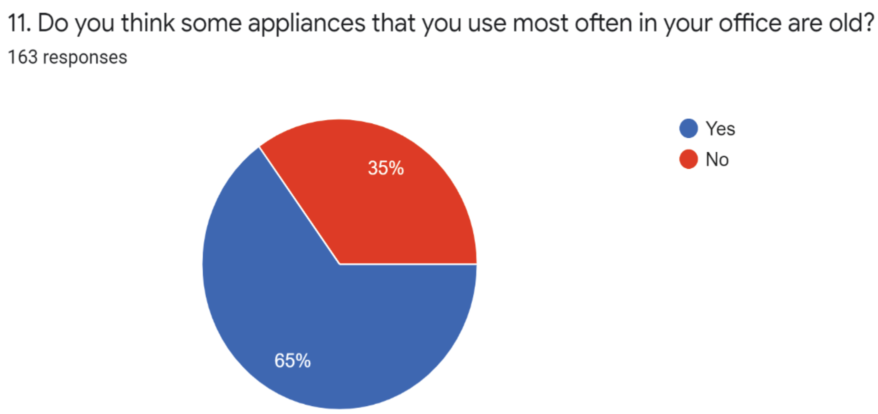

Figure 14: Old age of appliance used most often

Figure 14 shows that 65% of the respondents agree that the appliances that are in use in their offices are old. By inference, these are most likely to be inefficient in terms of energy consumption and performance. Recall, the top three most used appliances are air conditioners, light bulbs and laptops. The use of newer and more efficient air conditioners would contribute significantly to reduced energy consumption.

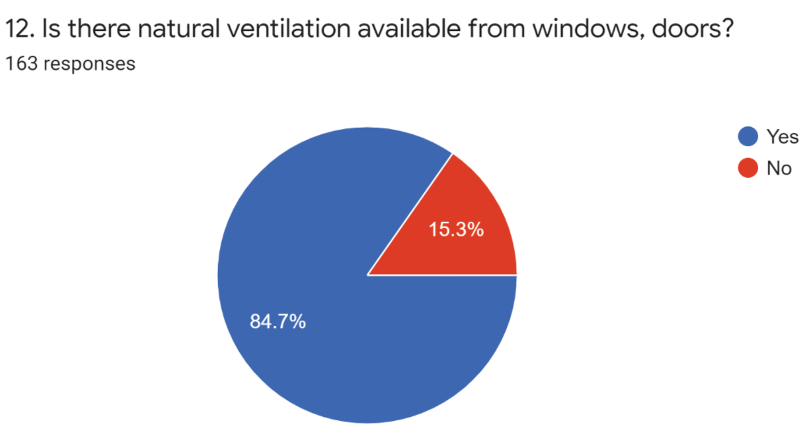

Figure 15: Availability of natural ventilation

Figure 15 presents that 84.7% of respondents have natural ventilation from windows and doors. This implies either a good building design or a good external environment in terms of weather conditions. It also indicates that huge energy savings can be made by exploring the use of natural ventilation over the use of air conditioners and fans.

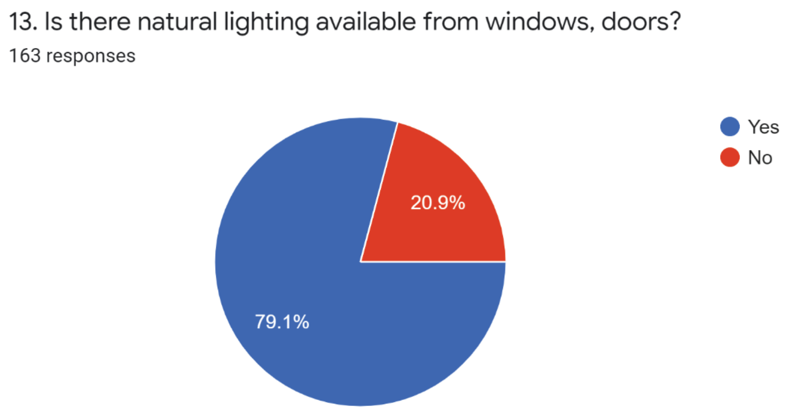

Figure 16: Availability of natural lighting

79.1% of the respondents also indicate that there is natural lighting available from windows and doors within their office buildings as depicted in Figure 16. Similarly, this implies that there can be a reduction in the use of artificial lighting where natural lighting is available and provides an adequate level of illumination.

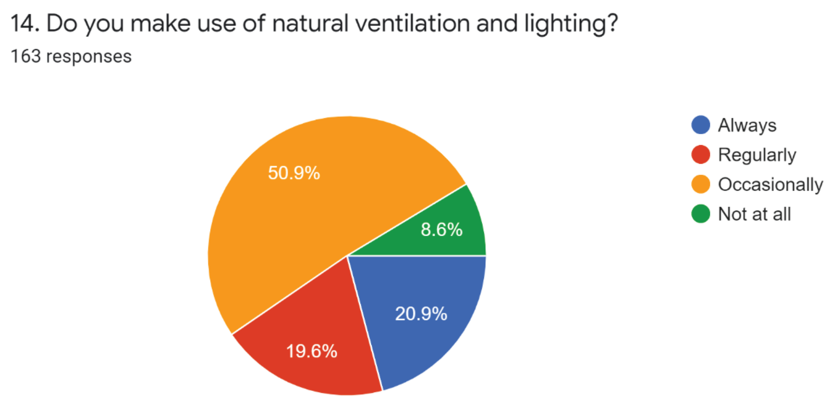

Figure 17: Use of natural ventilation and lighting

From Figure 17, 8.6% of the respondents do not use natural lighting and ventilation. 20.9% always use, 19.6% regularly use and 50.9% representing half of the respondents, occasionally use natural lighting and ventilation. This indicates to a large extent that the type of design most commonly used for public buildings in Nigeria put natural lighting and ventilation into consideration. On the contrary, the high use of natural ventilation and lighting may also indicate lack of reliable energy supply to power artificial cooling and lighting systems, which then necessitates the need for natural ventilation and lighting.

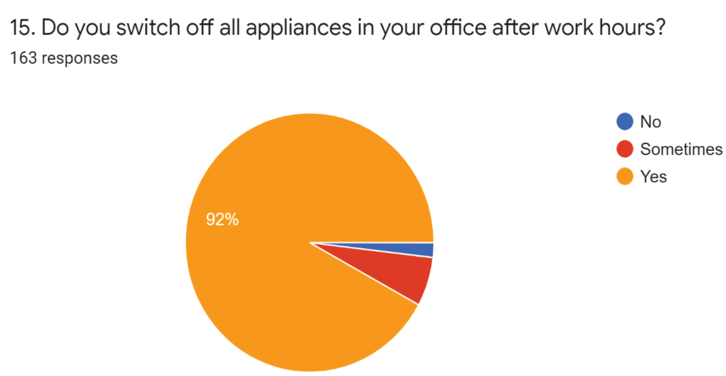

Figure 18: Respondents switching off appliances after work hours

92% of the respondents switch off all appliances after work hours which indicates good energy conservation habits, as shown in Figure 18 above.

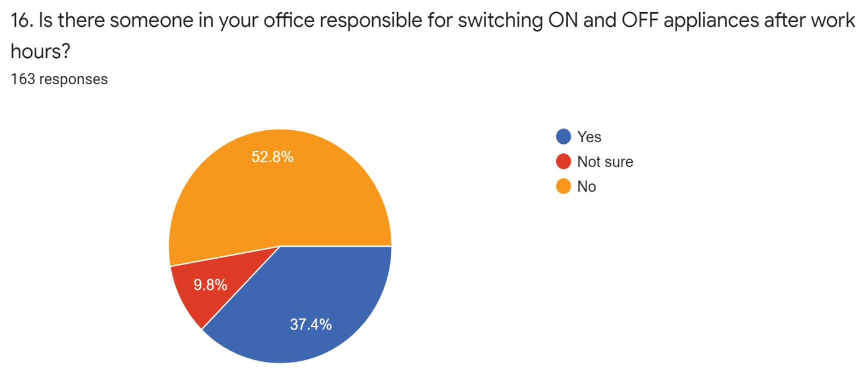

Figure 19: Is someone responsible for switching off appliances after work hours?

Figure 19 shows that 52.8% of respondents say that no one is responsible for switching off appliances after work hours. This may indicate that officers are personally responsible for this action within their offices/ buildings or that the appliances are left on or off at the discretion of the office occupants. It also shows however, the potential for the appointment of an energy manager in at least 52.8% of the respondents' office buildings.

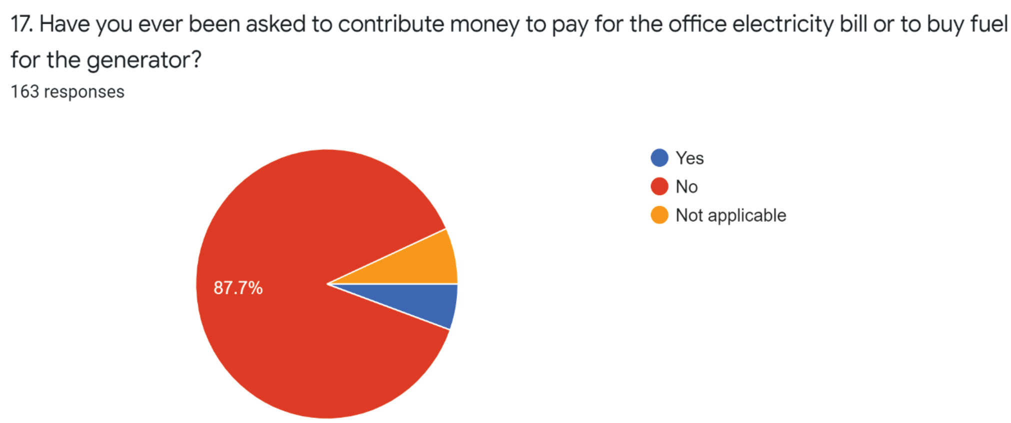

Figure 20: Do you contribute to the utility bill?

87.7% of the respondents, as shown in Figure 20, indicate that they are not directly responsible or asked to contribute to making payments of the electricity bills of their office buildings.

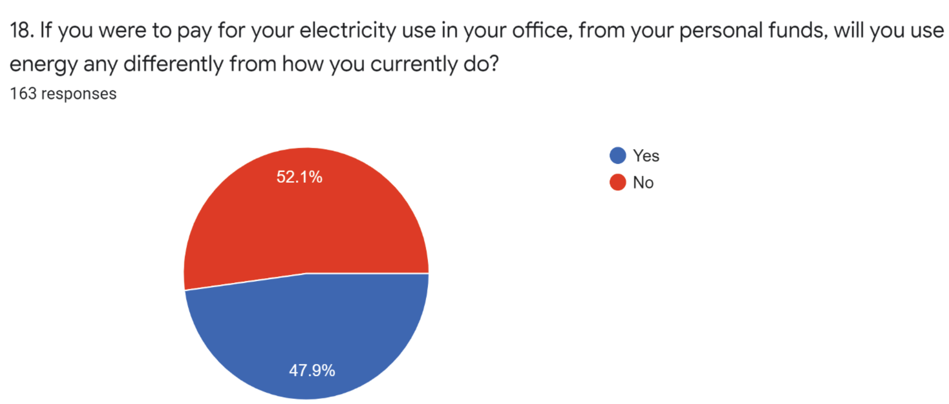

Figure 21: Will you use energy differently if you were paying for it?

When asked if the ways in which they use would be different if they paid for it, 52.1% of the respondents indicate that their energy use patterns will not change whether or not they are directly responsible, or asked to pay for their energy use. From the same Figure 21 however, 47.9% say they will use energy differently from how they currently do if they were to pay for the electricity from their personal funds. These 47.9% of the respondents that will use energy differently can be implied to mean that they are aware they can use energy better, but since they are not responsible for paying the costs of energy use, then using it efficiently does not matter to them. This shows the relationship between how energy is used and who is paying for it.

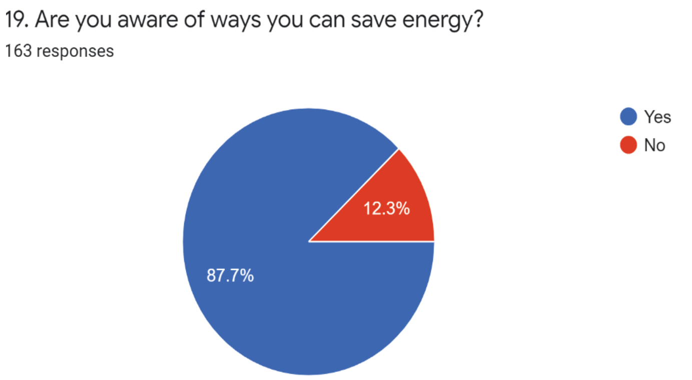

Figure 22: Energy saving awareness

87.7% of respondents are aware of ways they can save energy as presented in Figure 22. However, from Figure 18, it will only matter to 47.9% of these respondents if they are paying for the cost of energy from their personal funds.

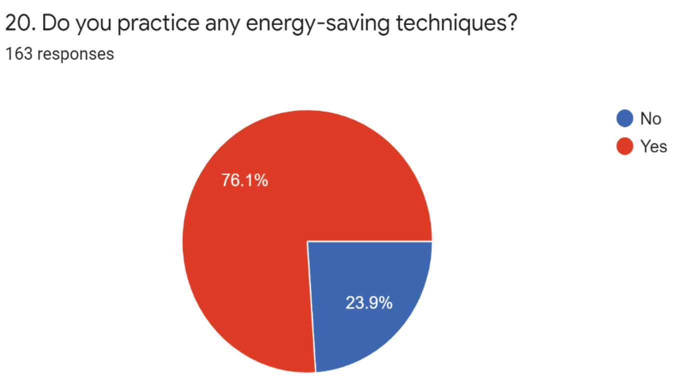

Figure 23: Energy saving practices

Figure 23 shows that 76.1% of the respondents practice energy saving techniques. The questionnaire does not cover in specific details what energy conservation techniques are practiced.

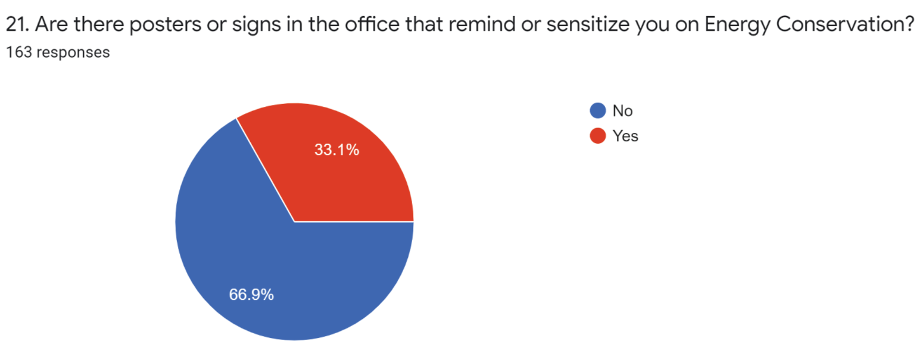

Figure 24: Energy saving posters or materials

66.9% of the respondents do not have signs or posters that encourage the building users to save energy, as shown in Figure 24. This presents an opportunity for increased energy conservation awareness programs and creation of educational materials to constantly sensitize the building users.

22. An energy audit involves finding out about the appliances and equipment and how they use energy when in operation. Has an energy audit been carried out in your Organisation?
163 responses

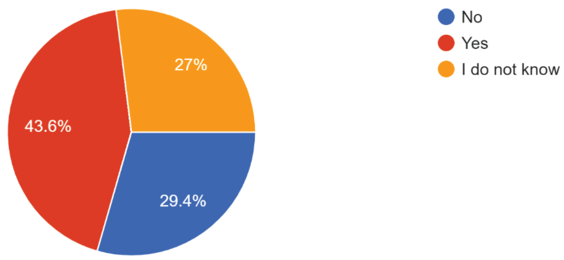

Figure 25: Energy audit exercise in the organisation

43.6% of the respondents have had an energy audit exercise for their buildings, as shown in Figure 25 above. This presents an opportunity for this to be extended to other public buildings in order to identify the energy saving opportunities that may exist.

23. If there was an energy meter in your office, would you use electricity differently?
163 responses

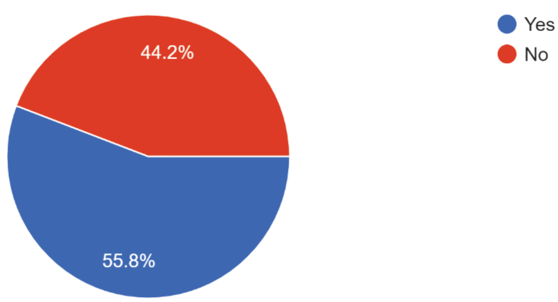

Figure 26: Energy meter and energy use

Figure 26 shows that visual or real time energy use data may impact positively on how energy is used in public buildings. 55.8% of respondents will use energy better or in a different way if they had an energy meter in their office that shows their energy use. However, 44.2% say that an energy meter will not influence their energy use or consumption patterns.

24. Is there an Energy Manager/ Champion in your Office?
163 responses

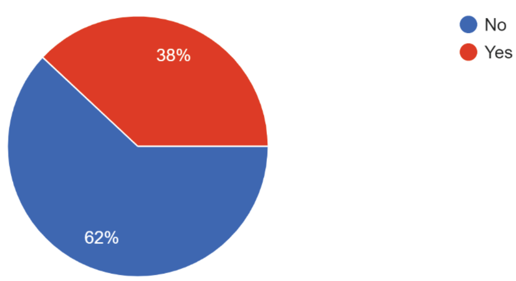

Figure 27: Availability of Energy Manager/Champion

Figure 27 above shows that 62% of the respondents do not have an energy manager or someone responsible for energy use within their buildings. This represents an opportunity to introduce an energy management system, which requires the appointment of an energy manager/champion.

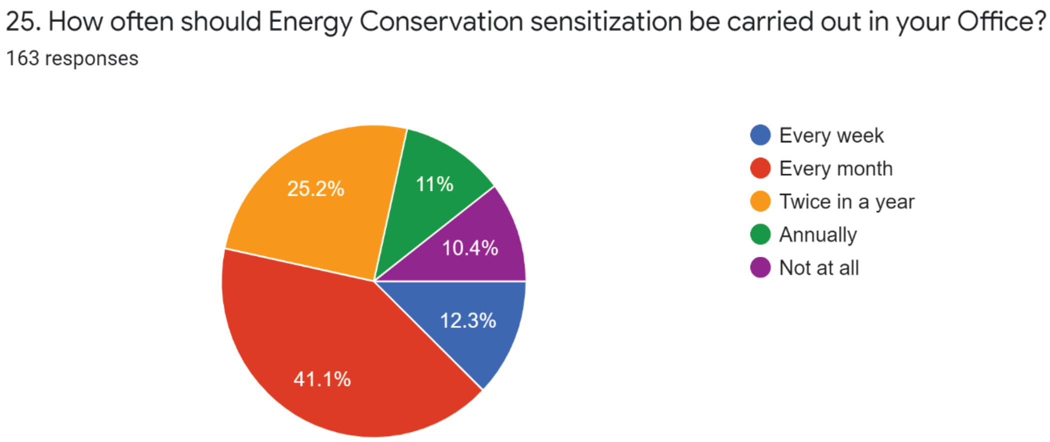

Figure 28: Proposed frequency of energy conservation sensitization

Majority (41.1%) of the respondents want energy conservation sensitization to be carried out every month, as shown in Figure 28. 10.4% of the respondents are not interested in energy conservation sensitization activities.

Figure 29: Annual training on energy management

96.9% of respondents are willing to participate in an annual training on energy management, according to the results presented in Figure 29. This may indicate that the respondents understand the importance of energy management in their office buildings.

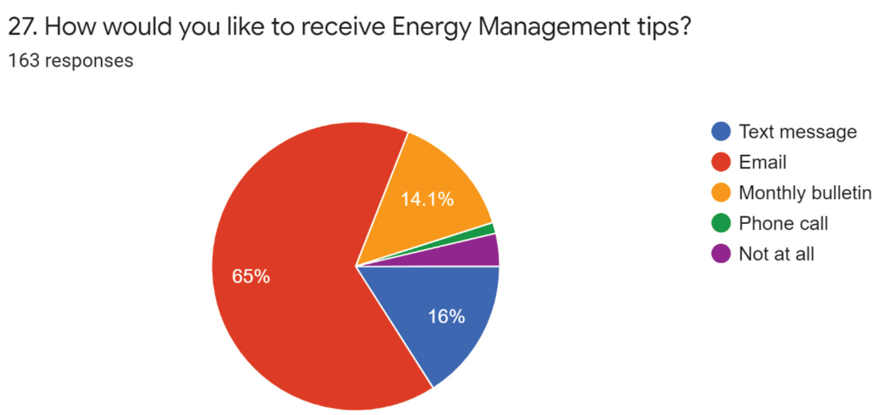

Figure 30: Energy management tips

Different communication methods for presenting energy management tips were presented to respondents. Figure 30 shows that 96.3% of the respondents want to receive an energy management tip. However, 65% will prefer to receive these energy management tips via email, and 16% prefer via text (SMS) messages.

3.2 Audit of buildings

The second part of this research work was on conducting energy audits in public buildings. Three public/government buildings in Lagos and Abuja were selected for the energy audit. However, due to constraints related to COVID-19 and access, only buildings in Lagos were audited. This section presents the findings from the walk-through energy audit for each of the buildings in Sections 3.2.1 and 3.2.2 respectively.

3.2.1 The Institute of Maritime Studies, University of Lagos

The Institute of Maritime Studies was established with the support of the Nigerian Maritime Administration and Safety Agency (NIMASA) in 2014. The Institute is dedicated to providing suitable manpower for contemporary maritime industry, through comprehensive theoretical and practical maritime training. The capacity development needs of the Nigerian maritime sub-sector of the economy received the needed attention with the establishment of Institute of Maritime Studies by the University of Lagos (Unilag), Lagos [28].

Figure 31: Institute of Maritime Studies

The scope of the walk-through audit was the entire building envelope, the equipment and the users. The building, as shown in Figure 31, has the following dedicated spaces – Director's office, lobby, male and female toilets, library, deputy director's office, administrative office and a laboratory. Table 1 below shows the results of the walk-through audit for each of these spaces.

Table 1: Energy audit (detailed) results for the Institute of Maritime Studies

Appliance	Wattage	Quantity	Total (Watt)	Other relevant details
DIRECTOR'S OFFICE				
Air conditioner	1492	1	1,492	Area of space - 5.046m X 2.961m
Lighting	17	6	102	CO_2 – 1279 ppm
	40	2	80	Humidity - 46.2%RH
Refrigerator	200	1	200	Temperature - 27.4C
Shredder	113	1	113	Illumination - 46 lux
Microwave oven	1250	1	1,250	Windows (2no) – 1.897m X 1.22m
Toilet	18	1	18	
Outside lighting	40	16	640	
Desktop computer	78	1	78	
Printer	221	1	221	
Satellite TV decoder	14	1	14	
51" LED television	69.7	1	69.7	
CCTV monitor	18	1	18	
			4,295.7	
ADMIN OFFICE				
Air conditioner	1492	1	1,492	Area of space - 5.05m X 2.58m
Refrigerator	64	1	64	Temperature – 24.9C
Photocopier	927	1	927	Illumination - 102 lux
Microwave oven	1,127	1	1,127	Humidity – 61.9%RH
Television	45	1	45	CO_2 – 1334 ppm
Printer	56	1	56	
Decoder	11	1	11	
Scanner	56	1	56	
Desktop computer	16	4	64	
Subtotal			**3,826**	
GMDSS				
Air conditioner	1492	4	5,968	Area of space – 7.93m X 6.01m
Lighting (LED)	18	18	324	CO_2 – 1002 ppm
Lighting (CFL)	40	4	160	Humidity - 52.7%RH
Projector	300	1	300	Temperature - 29.5C
Desktop computer		2	40	Illumination - 56 lux
Laptop		1	65	Windows (4no) – 1.795m X 1.258m
Subtotal			**6,857**	
DEPUTY DIRECTOR				
Air conditioner	1492	1	1,492	Area of space – 4.38m x 2.708m
Lighting	18	4	72	CO_2 – 850 ppm
Refrigerator	61.2	1	61.2	Temperature – 23.5C
				Illumination - 61 lux
				Window – 1.29m x 1.29m 2no - 1.259m x 0.94m
Subtotal			**1,625.2**	Humidity – 84.5%RH

LIBRARY				
Air Conditioner	1492	1	1,492	Area of space – 4.38m x 3.079m
Lighting	18	6	108	CO_2 – 914 ppm
				Temperature – 28.1C
				Humidity – 78%RH
				Illumination – 72 lux
Subtotal			**1,600**	Window – 1.244m x 1.292m
TOILETS (MALE AND FEMALE)				
Lighting	18	4	72	Area of space – 2.74m x 1.32m
Subtotal			**72**	Window – 0.94m x 0.74m
CORRIDOR				
Lighting	15	6	90	Area of space –
				CO_2 – 946ppm
				Temperature – 31.2C
Subtotal			**90**	Humidity – 68.9%RH
HALLWAY				
Lighting	18	4	72	Area of space – 0.862m x 13.591m
			72	
BOARD ROOM				
Air conditioner	1492	2	2,984	Area of space – 6.624m X 4.296m
Lighting	18	8	144	CO_2 – 609 ppm
	40	4	160	Humidity – 66.1%RH
Refrigerator	258	1	258	Temperature – 23.2C
Projector	300	1	300	Window (3no) – 1.23m X 1.26m
Kettle	1575	1	1575	
Television	202	1	202	
Subtotal			**5,623**	

The power consumption per room function in the building is plotted as shown in Figure 32. The GMDSS office, which also has the highest number of air conditioners installed, is the office with the highest power consumption.

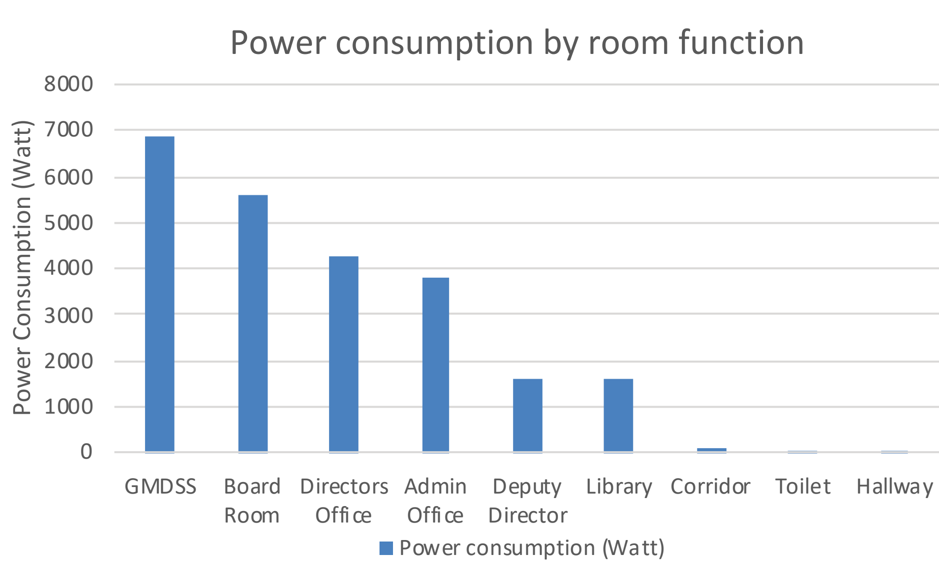

Figure 32: Power consumption by room function (Case study 1)

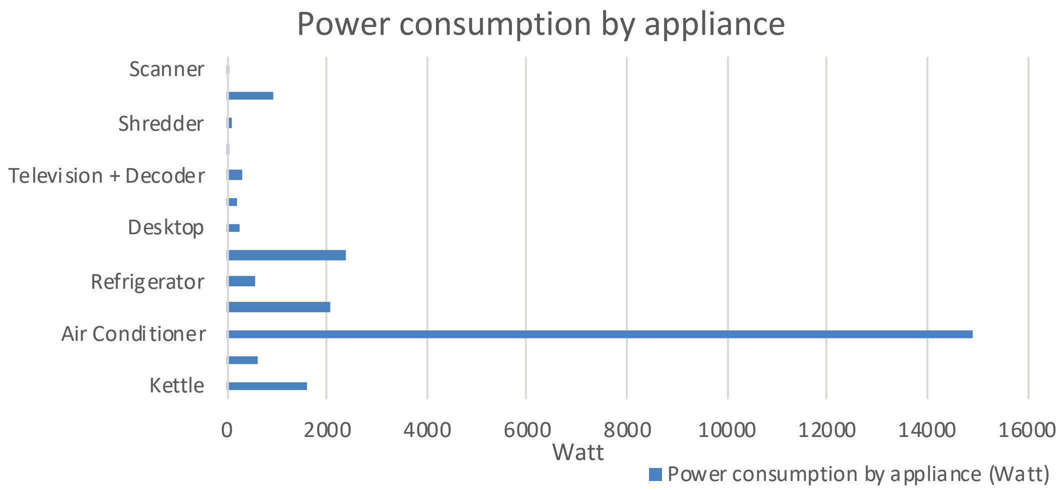

Figure 33: Power consumption by appliance (Case study 1)

Figure 33 shows the top three (3) equipment by power consumption in the Institute of Maritime Studies are air conditioners, microwave ovens and lighting. Air conditioners consume 62% of the total power consumption of the building (14.92 kW out of 24.06 kW). This implies that air conditioners are a Significant Energy User (SEU) and hence it is important their energy efficiency performance is prioritized.

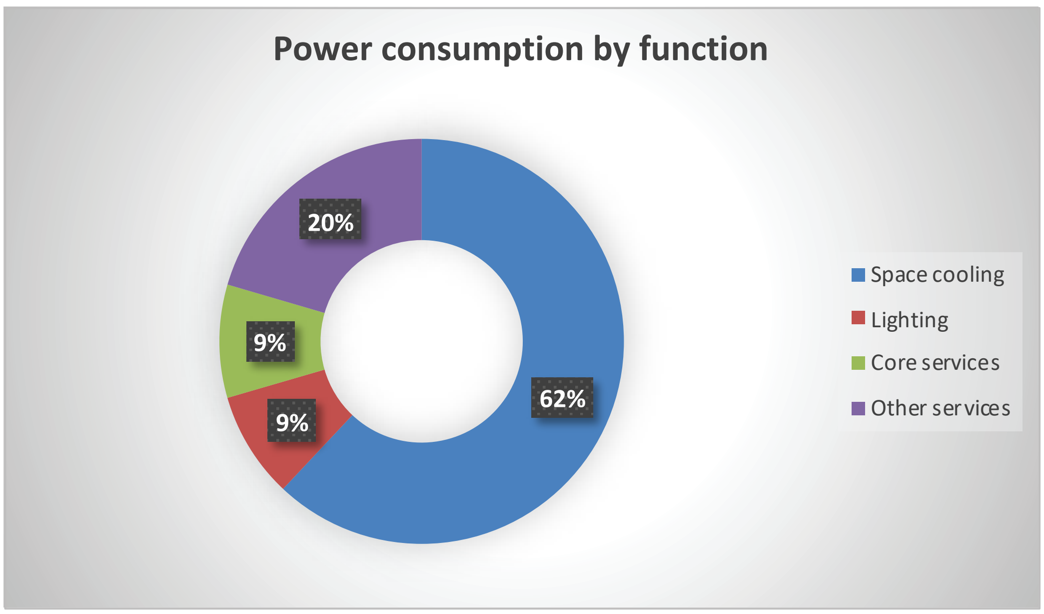

Figure 34: Power consumption by function (Case study 1)

Figure 34 shows the power requirement by function in the building. Space cooling takes the largest chunk at 62%, Lighting 9%, Core services 9% and other services 20%.

3.2.2 The Bursary Unit, UNILAG, Lagos.

The second building considered in this research was the Bursary Unit. The Bursary in its current form is managed by seasoned professional accountants whose varied experiences include investment, public sector accounting and finance, business assurances, taxation and tax management, systems processes and reviews, financial management and cost efficiency. The key activities of the Bursary unit are performed through the Bursar's Office and the Directorates. The Directorates are: Budget Planning and Control, Final Accounts and Treasury. Each Directorate is headed by a Director [29].

Figure 35: Bursary Department

The results of the walk-through audit carried out in the Bursary unit are as shown below in Table 2.

Table 2: Energy audit (detailed) results for Bursary Unit

Appliance	Wattage	Quantity	Total (Watt)	Other relevant details
GENERAL OFFICE				
Air Conditioner	2,800	2	5,600	Area of space – 6.942m X 10.724m
Lighting (CFL)	85	2	170	CO2 – 1074 ppm
Lighting (LED strip – 4ft)	20	10	200	Humidity – 65.9%RH
Refrigerator	180	1	180	Temperature - 27.2C
Fan	113	3	339	Illumination - 120 lux
Microwave oven	1,250	1	1,250	Window (2no) – 10.724m X 1.749m
Toilet	18	1	18	
Desktop computer	78	6	468	
Printer	221	3	663	
Satellite TV decoder	14	1	14	
LG TV 51”	69.7	1	69.7	
Photocopier	920	1	920	
Electric kettle	1,100	1	1,100	
Subtotal			**10,991.7**	
DIRECTOR’S OFFICE				
Air conditioner	1492	1	1492	Area of space – No access
Lighting (LED Strip – 4ft)	20	1	20	CO2 – No access
Refrigerator	200	1	200	Humidity – 65.9%RH
Desktop computer	78	1	78	Temperature - 27.2C
Printer	221	1	221	Illumination – No access
Subtotal			**2,011**	Window – No access

Figure 36 below shows the power consumption of each of the appliances within the Bursary Unit.

The top three consuming appliances are the air conditioners, microwave ovens and electric kettles. Air conditioners take a large share of 54.54% of the total power consumption (7.092 kW out of 13.002kW). This shows the huge significance of air Conditioners in public/government buildings and the potential for energy saving if energy-efficient air conditioners are used. The chart also shows the typical appliances that are in use.

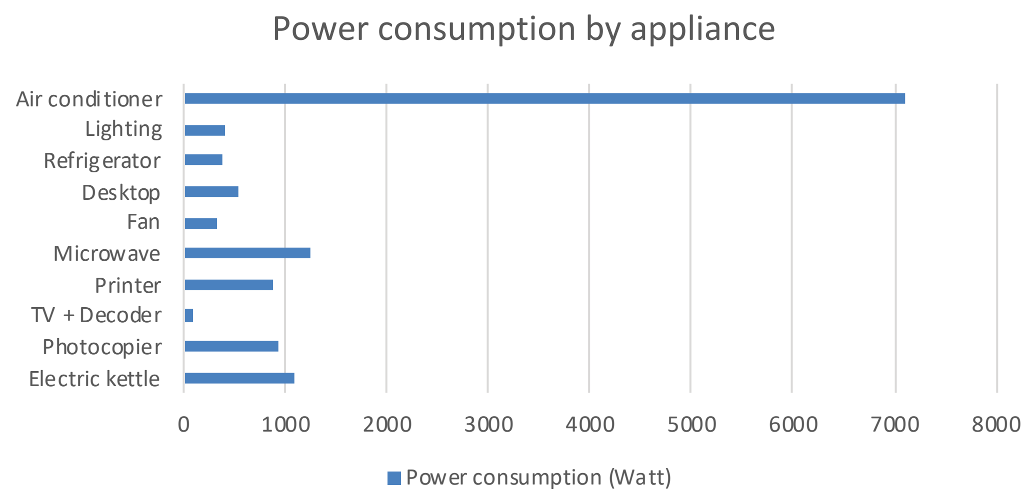

Figure 36: Power consumption by appliance (Case study 2)

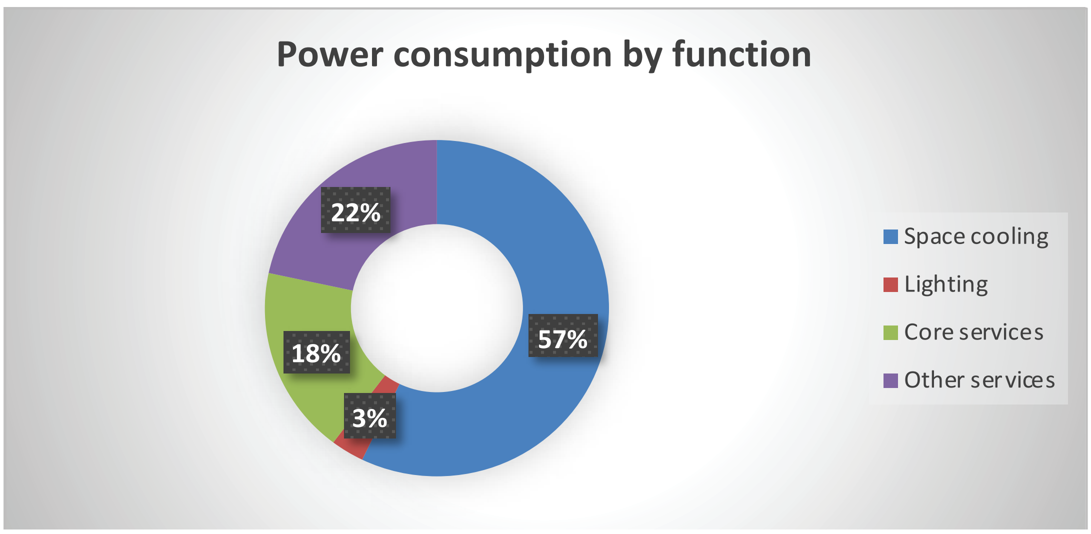

Figure 37: Power consumption by function (Case study 2)

The Figure 37 shows the power requirement by function in the building. Space cooling takes the largest chunk at 57%, Lighting 3%, Core services 18% and other services 22%.

3.3 Awareness sessions

A training session titled "Awareness training on energy management for public/government buildings in Nigeria" was organized for the public/government officials.

The training session was conducted online via the Zoom platform and had a total of 91 participants across the four (4) sessions. The main highlights of the presentation focused on the impact areas for energy consumption in buildings, which are the building envelope, the appliances within the building and the energy users. The presentation also aligned with the objectives of the project which is to carry out a survey to understand user perspectives and patterns, an energy audit of government owned buildings and a quarterly awareness training on energy management in public/government building.

One major highlight was the discussion around the Minimum Energy Performance Standards (MEPS) for end-use appliances. The relevant stakeholders from the Standards Organization of Nigeria, the Renewable Energy and Energy Efficiency Associations Alliance and the National Centre for Energy Efficiency and Conservation discussed around the reviewed MEPS for air conditioners and refrigerators and the importance of enforcing it as soon as it is approved in order to promote the use of these appliances in the Nigerian market.

Participants also indicated interest in quarterly and annual sensitization programs. Benue State University requested for an awareness training session to be carried out for its management staff. There is also ongoing conversation with officers of the Energy Commission of Nigeria – the government department responsible for energy related policy formulation, to take the recommendations of this research study to develop a draft policy document.

Twenty-four (24) awareness creation fliers were developed as part of the sensitization campaign and were widely circulated among the participating public/government officials. The fliers were also used as part of the training sessions. There is potential for future work in terms of replicating the designs and printed on hardware such as cups, laptops, doors, parking lots, billboards, etc. Further work may include using the awareness creation posters for adverts and programs on national TV, and other social and print media outlets.

4.0 DISCUSSION AND RECOMMENDATIONS

The research project points to the fact that energy management systems are increasingly becoming important in order for people, processes and buildings to use energy efficiently. On a more specific note, government buildings in Nigeria will highly benefit in terms of energy cost reduction and their contribution to the Nationally Determined Contributions, the Sustainable Development Goal agenda and Nigeria's commitment at the COP 26 to net zero by 2060.

The survey results indicate that there is a need for regular nation-wide awareness on energy conservation and energy efficiency measures for public/government officers. Figure 28 shows clearly that 41.1% of the respondents believe that the awareness program should be carried out monthly, contrary to the initial proposition of a quarterly awareness program. What is more interesting is that the study showed that energy champions/managers need to be appointed by top management in public/government organizations and buildings. This is shown in the more than half of the respondents who indicated that no one is responsible for energy use in their own government buildings.

The study also shows that special attention needs to be given to air conditioners, laptops and light bulbs especially in their procurement, technical and quality standard verification processes. This is validated by Tilwani et al. [15] that energy saving measures for air conditioning and lighting should be considered for implementation. Metering is also seen to have a significant influence on how the public officers behave towards and use energy.

It is recommended that an energy management policy document for public buildings be drafted that considers all the findings of this research project, and in consultation with all relevant stakeholders. The adoption and implementation of the final policy document is believed to have the potential to reduce energy wastages and their related cost, including reduction of CO_2 related emissions from diesel generators used widely in public buildings across Nigeria. This validates the position of Zhu et al.[17] that a national policy and an effective energy consumption monitoring platform are solutions to overcoming high energy consumption in public buildings.

The recommended activities are divided into different categories for easy adoption and implementation depending on the level of funding available to public/government buildings;

Recommended interventions with low or no investment:

1. Nationwide awareness campaign on energy use.
2. Quarterly awareness training on energy management.
3. Appointment of energy champions in every government organization/building.

Recommended interventions with moderate to high investment

1. Metering of all government buildings with prepaid meters, and where possible display boards indicating daily, weekly energy consumption for building users to see.
2. Retrofitting all inefficient cooling and lighting appliances/ equipment.

Policy recommendations based on the audit and survey outcomes.

1. Procurement processes of office appliances, equipment or material must have a mandatory provision for energy efficiency or energy performance standards.
2. All public buildings must use energy efficient cooling and lighting, according to the minimum energy performance standards for lighting and air conditioners, domesticated by Standards Organization of Nigeria.
3. All public buildings must have an energy manager appointed by the Director-General/CEO and enlisted in a database of energy managers for public buildings across Nigeria.

Further Research Areas

1. Economic analysis of retrofit exercise (replacing of inefficient appliances with efficient appliances) for public buildings
2. Comprehensive and investment grade audit of selected public buildings.
3. Design and prototype of a net zero energy public building.

5.0 CONCLUSION

This research work presented different facets of the importance of initiating and improving on energy management in public/government buildings. It focused on three sections, and each of these sections showed consistent outcomes in terms of what needs to be done if energy management is to improve in the public/government sector in Nigeria. The research work also shows the gaps present in energy use in public/government buildings, as well as the numerous opportunities for improvement in terms of energy use in this sector. There is indeed a lot of potential that spans beyond reduced energy bills, energy savings and improving energy access, but also in the achievement of the Sustainable Development Goals and cutting down on greenhouse gas emissions.

Due to the movement restrictions of the Covid-19 pandemic, some areas of research that can be addressed in subsequent work have been presented in the recommendations. In addition, further awareness sessions can be carried out regularly – live and virtually, to include target groups of staff such as management level staff and procurement staff, as well as using advertising media such as posters, billboards and souvenir items.

ACKNOWLEDGEMENT

The authors acknowledge the grant provided by the ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) and Konrad Adenauer Stiftung (KAS), under the Youth Leadership Development in Energy Initiative and the Research Grant program for policy research project.

The authors acknowledge the support of the National Centre for Energy Efficiency and Conservation in the use of some specialized equipment and personnel in the walk-through energy audit.

The authors acknowledge the contribution of team members – Jennifer Anya and Yewande Olatunde on the awareness training for energy management in public buildings targeted at public/government officers.

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The Impact of Climate Action on Energy Security in West Africa: Evidence from Burkina Faso, Ghana and Nigeria

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Abstract

Despite the good intentions of Nationally Determined Contributions (NDCs), implementing climate actions may adversely impact energy security if there is a lack of support for such an anticipated energy transition. The study investigates the impact of climate action on energy security in West Africa using an Autoregressive Distributed Lag Model and an Error Correction Model. Empirical results for Burkina Faso showed that total carbon emissions and climate finance improved energy security performance in the country in the short and long run, whiles capacity building and energy efficiency impaired energy security performance in the short run. In the long run, capacity-building efforts is estimated to improve energy security performance in Burkina Faso. For Ghana, empirical results showed that total carbon emissions improved energy security performance in Ghana whiles energy efficiency impaired energy security performance in the short run. Results for climate finance and capacity building are found to be insignificant and no long-run results are found for Ghana. Lastly, empirical results for Nigeria showed that total carbon emissions improved energy security performance in the long run. The short-run result for total carbon emissions and climate finance is found to be insignificant. Whiles capacity building and energy efficiency impaired energy security performance in the long and short run. Considering the need to reduce carbon emissions during full NDC implementation, policies should aim at decoupling carbon emissions from energy security by exploring options for low carbon energy development. The findings of the study provide key energy sector strategies that support NDC implementation and the energy transition by improving low carbon energy security.

Keywords

Energy, energy security, climate, emission, countries, ARDL, West Africa

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Abbreviations

ARDL	-	Autoregressive Distributed Lag
CO_2	-	Carbon Emissions
ECT	-	Error Correction Term
ETS	-	Emissions Trading schemes
FIT	-	Feed-in Tariff (FIT)
GDP	-	Gross Domestic Product
GHG	-	Greenhouse Gas Emissions
INDCs	-	Intended Nationally Determined Contributions
NDCs	-	Nationally Determined Contributions
ODA	-	Official Development Assistance
SPSS	–	Statistical Package for the Social Sciences
VECM	-	Vector Error Correction Model

1.0 INTRODUCTION

The idea of climate actions traces its roots from the United Nations (UN) Scientific Conference held in 1972 and has been sustained till the Kyoto protocol in 1990. The concern for climate action was re-emphasised in Millennium Development Goals (MDGs) in 2000 and prioritised during the Paris Agreement in 2015 (Loewe, 2015; UN, n.d.; UNEP, 1972). Key amongst the MDGs was seeking global collaboration for development through technical and liquidity support through Official Development Assistance (ODA), promoting environmental sustainability and improving education.

Climate finance is a critical component of promoting environmental sustainability. Most external climate finance support to low-income countries has been transferred as ODAs, to guarantee a stable support pool for climate adaptation and mitigation actions in low-income countries (Stewart, Kingsbury, & Rudyk, 2015). In this light, several studies establish a direct link between ODA allocation and increase in renewable energy investment, energy-efficient transfer of technology, climate mitigation and reduction in greenhouse gas emissions (Briggs, 1993; Kalirajan, Singh, Thangavelu, Anbumozhi, & Perera, 2012; Lee, Choi, Lee, & Jin, 2020).

For countries in West Africa, achieving climate actions as contained in Nationally Determined Contributions (NDCs) requires external climate finance support, technology transfer and capacity building. An analysis of 11 out of 16 NDCs of West African countries reveals that the energy sector leads in mitigation strategies (Antwi-Agyei, Dougill, Agyekum, & Stringer, 2018). Leveraging technology, renewable energy, energy efficiency, recycling materials, fuel switching are key to reducing anthropogenic greenhouse gas emission (GHG), particularly from the energy sector and may require fossil asset stranding (IISD, 2018). Despite the aforementioned emission mitigation strategies, the literature shows Sub-Saharan Africa's power generation mix is dominated by fossil fuels (73.3%) and hydropower (23%) while transport solely depends (100%) on fossils (Jingura & Kamusoko, 2017).

Regarding wood fuel consumption, empirical evidence shows the reliance on biomass is predicted to increase in the next 30 years (Sander, Haider, & Hyseni, 2011), but Article 5 of the Paris Agreement enjoins parties to reduce emissions from deforestation and forest degradation whiles promoting sustainable forest (UNFCCC, 2015). The enforcement of this provision will adversely impact rural dwellers in West Africa who rely on biomass in meeting their energy security needs.

The implementation of climate change mitigation strategies as contained in the countries' NDCs will mean reducing supply and dependence on fossil fuel and biomass and disincentivizing hydrocarbon resource and asset investments. But on the other hand, this will also trigger innovations in the energy sector, increase penetration of renewables and renewable energy finance, stimulate good governance and regulatory issues within the energy sector and require steps to use hydrocarbon resources and assets sustainably.

From the above premise, despite the good intention, implementing climate actions may adversely impact energy security if there is a lack of support for such an anticipated energy transition, which is yet relatively unknown. This work aims to assess the possible impacts of implementing climate actions on energy security in West Africa. We consider the results could contribute to assist the decision-making of NDC implementation in West Africa post the Paris Agreement.

Study outcomes are expected to be helpful for governments, energy planners, and analysts who can assess the relationships, determinants, synergies and tradeoffs between energy security and climate efforts. Moreover, understanding the climate action-energy security nexus is vital as it is the key to driving sustainable economic growth, sustainable energy production and consumption, consumer welfare and stabilizing national security (Jewell, 2013; United Nations, 2015). The rest of the paper is organized as follows: literature review, methodology, results, discussion, and conclusion.

2.0 LITERATURE REVIEW

A scoping background literature related to energy and climate change was reviewed to establish the problem regarding the impact of energy production and consumption on the climate. Next, related studies are cursorily reviewed. This is followed by a critical review of studies directly related to the research question "What are the impacts of implementing climate actions on energy security in developed and developing countries?"

"Energy security AND climate change, energy security AND nationally determined contributions AND developing countries, energy security AND nationally determined contributions AND developed countries" are the search strings used in google and google scholar for the search. The search was done from 29th May 2021-1st June 2021 and the literature constrained to the last 10 years. An initial review of the title and abstract was made and when the abstract was not relevant to the research question, the literature was discarded.

The nexus between climate action and energy security cannot be delinked. The energy sector contributes approximately two-thirds of all anthropogenic GHG emissions. Likewise, climate change threatens energy security in the sense of extreme weather events, water scarcity, damaged ecosystems that may affect energy production and system operations (Nyman, 2018; UNFCCC, IRENA, UN Environment, & European Commission, 2018)climate and security is vital both to the study of international relations and to ensure the continued survival of a world increasingly threatened by environmental change. Climate change is largely caused by burning fossil fuels for energy, but while discussions on the climate consider the role of energy, energy security debates largely overlook climate concerns. This article traces the separation between energy and climate through an analysis of US energy security discourse and policy. It shows that energy security is continually constructed as national security, which enables very particular policy choices and prioritises it above climate concerns. Thus, in many cases, policies undertaken in the name of energy security contribute directly to climate insecurity. The article argues that the failure to consider securing the climate as inherently linked to energy security is not just problematic, but, given global warming, potentially harmful. Consequently, any approach to dealing with climate change has to begin by rethinking energy security and security more broadly, as national (energy. Studies found that improving energy security and climate security are conflicting in some high-income countries like the United States and Australia (Ladislaw et al., 2009; Nettleton, 2016; Toke & Vezirgiannidou, 2013)

improving energy security and addressing climate change may seem irreconcilable goals: achieve an adequate, reliable, and afford- able energy supply for the United States, while at the same time reducing emissions of dangerous global warming gases into the atmosphere. After all, most of the world's energy comes from burning fossil fuels such as coal, oil, and natural gas – which are also major sources of greenhouse gases. Without scalable low-carbon replacements for these fuels, actions to reduce emissions could destabilize the current energy system. On the other hand, continued dependence on these fuels will jeopardize our climate. The hard truth is that the United States – and the world – must now figure out how to achieve energy security and protect Earth's climate. There is abundant evidence that the current energy system is unsustainable. Prices are volatile, supplies tight, and security threats – from supply disruptions to geopolitical tension – have become common- place. The expected environmental and social costs of climate change – sea-level rise, water scarcity, reduced food supplies, and damaged ecosystems – are rising. At the same time, the country is facing an economic crisis that strains public and private budgets, but also raises opportunities to stimulate the economy while building a cleaner and more reliable energy infrastructure in the process. Solutions to these problems are not always clear. While some strategies – such as energy efficiency measures – benefit climate change and energy security goals, other possible solu- tions for improving energy security – such as relying more on liquid fuels produced from domestic coal – could significantly worsen climate and other environmental problems. Similarly, some possible climate solutions – such as relying more on the sun or wind to make electricity – could reduce reliable and affordable energy supplies in the short term. This "roadmap" presents the results of a year-long effort by the Center for Strategic and International Studies (CSIS, an international policy and security-oriented think tank. In countries like China, improving energy security and climate security is reconcilable (Wu et al., 2012).

According to Toke & Vezirgiannidou, (2013) and Nettleton (2016), countries develop their energy security plans around locally endowed natural energy resources, like nuclear energy, biofuel, and fossil fuels, hence are of the view that at best climate actions and energy security should be pursued simultaneously, however, with priority for energy security because of the energy-intensive nature of their economies. On the other hand, Wu et al. (2012) postulate that energy security improves when climate protection measures, such as energy-saving and emission reduction measures, are implemented. Estimates by Bollen et al. (2010) indicate that when an integrated energy security climate policy is not pursued, global oil demand is reduced by 24% by 2150. Therefore, the study recommends an integrated energy security-climate policy to maximize the synergies between them.

Additionally, studies on climate action/NDC implementation have focused on energy use and related investments under NDC conditions. Study results from Tran et al., (2016) reveal that although NDC implementation is key to reaching emission reduction targets, deploying renewable energy forms such as solar PVs and biomass in power generation will lead to a marginal reduction in welfare and GDP. Similarly, Paroussos et al., (2020) and Wu et al., (2017)this paper uses a multi-regional computable general equilibrium (CGE estimate an increased investment in the energy sector due to retrofits in energy systems in an attempt to improve thermal integrity and energy efficiency. GDP losses are predicted by 2030 due to high energy production costs in the quest to shift entirely to clean energy. Vishwanathan & Garg (2020)NDC scenario, 2 °C scenarios (early and late actions study on energy system transformation and NDCs find that phasing out coal plants, shifting towards cleaner energies, decarbonization and installing super critical technologies are vital measures countries must deal with to meet NDCs. An investment of about US$6–8 trillion is needed in India between 2015 and 2030 to implement these measures.

A more comprehensive description of the effect of climate action on the energy sector is conducted amongst 38 developing member countries of the Asian Development Bank (ADB). The study finds that the bank's support for NDC implementation will plummet dependence on fossil fuels in general but coal in particular. This when done will see to the penetration of renewables, natural gas and nuclear energy. Despite this finding, coal, is estimated to dominate the energy mix whiles nuclear energy is to witness the highest growth in the region by 2030.It is estimated that an amount of $321 billion is required between 2016-2030 for each of the 38 member countries for power sector investments. The study notes that NDC implementation will reduce carbon emission significantly and GDP energy intensity by an average of about 29% and 22% respectively (Zhai, Mo, & Rawlins, 2018).

Similarly, positive effects of implementing INDCs is reported by Paroussos et al. (2020). The study notes that increased energy independence, reduction in emissions, reduction in energy import bills are some positive effects of implementing INDCs. Authors indicate that, the implementation of EU's INDCs will have a marginal adverse effect of 0.4% on EU's GDP by 2030 and 1% in 2050 due to the impact of a carbon pricing scheme, higher investment in retooling the countries energy systems and implementing the revenue recycling mechanism. Conversely, carbon mitigation scenarios are estimated to have a marginal positive effect on GDP. This is based on model assumptions that include a coal and natural gas-dominated energy mix with a reduction in oil by 2030. Carbon emission reductions are expected from the following interventions: increasing electricity access and increasing natural gas in the power and transport sector (Siagian, Yuwono, Fujimori, & Masui, 2017).

According to Wu et al., (2017) emissions trading schemes (ETS) and renewable energy policies are two important approaches to achieving NDC targets. However, the implementation of ETS will decrease 'China's emission cap by 0.3%. Implementing ETS and feed-in tariff (FIT) causes adverse effect on GDP welfare loss in Chinese regions and a decline in electricity supply although a decrease in CO_2 emissions is recorded by the implementation ETS and renewable energy policies. In a related study, conducted in three fossil fuel-rich middle-income countries, the nexus between energy security and sustainable growth is feeble and may involve opportunity costs because the tensity between the idea of asset standing of fossil fuels and the use of these assets in the domestic economy is strong. The concerns about energy security to meet national demand takes prominence in these countries than the call for climate action (Kuneman, Kamphof, & Van Schaik, 2017; Schaik, Tilburg, & Briscoe, 2016).

In West Africa, energy access, climate change adaptation and mitigation are identified as the three most crucial interrelated challenges to the energy system (ECREEE, 2013). West African countries depend largely on fossil fuels either through imports and (or) local exploitation of endowed fossil fuel resources. Without expansible low carbon substitutes for fossil fuels, climate actions will remain in limbo and could destabilise energy system (Ladislaw et al., 2009)improving energy security and addressing climate change may seem irreconcilable goals: achieve an adequate, reliable, and afford- able energy supply for the United States, while at the same time reducing emissions of dangerous global warming gases into the atmosphere. After all, most of the world's energy comes from burning fossil fuels such as coal, oil, and natural gas – which are also major sources of greenhouse gases. Without scalable low-carbon replacements for these fuels, actions to reduce emissions could destabilize the current energy system. On the other hand, continued dependence on these fuels will jeopardize our climate. The hard truth is that the United States – and the world – must now figure out how to achieve energy security and protect Earth's climate. There is abundant evidence that the current energy system is unsustainable.

Prices are volatile, supplies tight, and security threats – from supply disruptions to geopolitical tension – have become common- place. The expected environmental and social costs of climate change – sea-level rise, water scarcity, reduced food supplies, and damaged ecosystems – are rising. At the same time, the country is facing an economic crisis that strains public and private budgets, but also raises opportunities to stimulate the economy while building a cleaner and more reliable energy infrastructure in the process. Solutions to these problems are not always clear. While some strategies – such as energy efficiency measures – benefit climate change and energy security goals, other possible solutions for improving energy security – such as relying more on liquid fuels produced from domestic coal – could significantly worsen climate and other environmental problems. Similarly, some possible climate solutions – such as relying more on the sun or wind to make electricity – could reduce reliable and affordable energy supplies in the short term. This "roadmap" presents the results of a year-long effort by the Center for Strategic and International Studies (CSIS, an international policy and security-oriented think tank. The solutions to the problem are not always straightforward. To deal with the nexus problem, the Paris Agreement birthed NDCs and requires that high-income countries provide financial, technology transfer and capacity-building support for low-income countries to ensure that voluntary climate actions are achieved (UNFCCC, 2015).

Overall, quantitative and qualitative methods have been used in investigating the energy-climate nexus in the aforementioned studies. But the use of quantitative approaches has been dominant. Some of the quantitative approaches used in these studies include the Computable General Equilibrium model, GEM-E3 ,PRIMES model, Index, MERGE and Asia-Pacific Integrated Model, (e.g. Paroussos et al., 2020; Siagian et al., 2017; Vishwanathan & Garg, 2020; Zhai et al., 2018)NDC scenario, 2 °C scenarios (early and late actions.

The Asia-Pacific Integrated Model examines the interaction amongst variables such as GDP, carbon emissions, technology, final energy demand, extraction costs of fossil fuels, energy service demand by sector, availability and cost of renewable energy. Computable General Equilibrium models examine the interaction of behavioral factors (such as price and income elasticities), macroeconomic factors (such as GDP value-added) and economic policy data (such as taxes, tariffs and how it impacts price consumer welfare and energy production). Similarly, GEM-E3 models the interaction amongst energy, economic and environmental variables. Some of the economic variables include unemployment, labour, capital, import and export among others.

Qualitative approaches used in the study of the subject are comparative analysis of reports and political economy analysis (e.g. Kuneman et al., 2017; Nettleton, 2016; Schaik et al., 2016; Toke & Vezirgiannidou, 2013).
From the foregoing, this review has demonstrated a dearth of studies on the energy security -climate action nexus in Africa and West Africa. Secondly, studies that exist have focused on developed countries. Those that focus on developing countries have focused on countries in Asia (e.g. Kuneman et al., 2017; Siagian et al., 2017; Zhai et al., 2018).

The studies which exist on the subject have focused on; i. how energy security and climate concerns can be balanced either through internalising externalities through taxes, investments in energy systems or developing synergies via an integrated energy climate policy ii. investigating the interactions amongst various economic, environmental and energy variables.

This paper contributes to the dearth of studies in West Africa by investigating the interactions between energy security and climate action using different variables of interest in the current global energy-climate discourse. In an econometric model, the study models the impact of climate action (total carbon emissions, net official development assistance received, education expenditure and energy efficiency/technology) as regressors on energy security.

3.0 METHODOLOGY

3.1 Description and data

The regressors total carbon emissions, net official development assistance received, education expenditure, and energy efficiency/technology, consist of annual data from the Worldbank spanning 1970-2016. Energy security is used as the regress and is calculated as an index. Education expenditure and net official development assistance received are in US dollars, whiles carbon emissions are recorded in kilotons. Energy efficiency/technology is calculated as (total CO2/GDP) (EIA, 2020; Li, Wei, & Dong, 2020). Missing data for Burkina Faso on education is accounted for in SPSS using series means, linear interpolation and mean of nearby points. Using all three approaches produces similar results.

In the proposed model, the three key needs of successful climate action are represented, i.e., i. Capacity building ii. Technology transfer iii. Climate Finance. Education expenditure, CO_2 emission intensity and net official development assistance received are used as a crude way for representing capacity building, technology transfer and climate finance. The justification for using historical data is that most NDC_S were developed in 2016 thus data observations will be inadequate for econometric work. Hence guidance from historical data is vital to informing an effective NDC implementation (Jenkins & Quintana-Ascencio, 2020)

Table 1: Description of variables

Variable	Proxy	Expected Sign	Remarks
Energy security (LNES)	Energy security	Neutral	Energy security is a dependent variable
Carbon Dioxide (LNC02)	Greenhouse gas emissions	+	As energy security increases GHG emissions are expected to increase when the fossil fuel component in the electricity generation is large and energy efficiency is low. Second, rural folks use biomass and charcoal as energy sources.
Education expenditure (LNHC)	Education/ Capacity building	+	Capacity-building should improve the level of energy security due to a knowledgeable workforce and citizenry
Emission intensity (LNEMI)	Energy efficiency/ technology	+	Energy efficiency- a key energy demand-side approach should improve energy security
Official development assistance (LNODA)	Climate finance	+	Climate finance should improve energy security due to periodic allocations for energy sector investment

3.2 Index creation for energy security

The following steps are followed in creating an energy security index (Ang, Choong, & Ng, 2015; Nardo, Saisana, Saltelli, & Tarantola, 2005; Sovacool, 2013).

1. Normalizing 23 metrics[7] of energy security using the logarithmic transformation method to attain standard units to compare. These metrics represent governance, sustainability, reliability, affordability, energy sector investment, availability and security (Ofosu-Peasah, Antwi, & Blyth, 2021). Quantitative variables were not found for regional energy integration.
2. Making data unidirectional to ensure higher values predict better energy security performance.
3. Aggregating normalized indicators into an index using an additive aggregated method

3.3 Country selection

The countries are selected based on six criteria: i. data availability ii. electricity access rate iii. income status iv. (non) availability of locally endowed hydrocarbon resources v. Geographical location vi. electricity tariff structure. The countries selected are Ghana, Nigeria, and Burkina.

Based on electricity access rates reported by the International Energy Agency in its world energy outlook for the year 2020 (IEA, 2020), Ghana, Nigeria, and Burkina Faso have an electricity access rate of 85%, 62%, and 22%, respectively. This represents the top 30%, middle 30% and bottom 30% countries with electricity access rates. Ghana and Nigeria are of lower-middle-income status and are littoral countries, whiles Burkina Faso is of Low-income status and landlocked (World Bank, n.d.). Additionally, Nigeria is a major oil producer, Ghana a minor oil producer, and Burkina Faso does not produce oil.

Regarding electricity tariff structure, Burkina Faso deploys the fixed charge, capacity charge and electricity consumption charge (i.e., time of use charge, flat and block) regime. Other countries which use this kind of charge are Togo, Mali and Niger. Whereas Ghana deploys the same tariff regime albeit a flat and block electricity consumption charge. Other countries which use this kind of charge are Guinea, Benin and Carbo Verde. Also, Nigeria deploys the same tariff regime but a flat charge electricity consumption charge as in the case of Liberia (ERERA, 2019). The aforementioned selection criteria is important to identify the unique challenges and opportunities these countries face to achieve sustainable energy security so that inferences can be made to other West African countries with the same characteristics.

7 Metrics are transmission and distribution losses, electric power consumption ,system average interruption duration index, system average interruption frequency index, pump price for gasoline and gasoil ,population with access to clean fuels and technologies for cooking, GDP per capita, average end user tariff, oil rents ,renewable electricity output ,public investment in renewable energy ,nitrous oxide emissions in energy sector, electricity access ,investment in energy with private, participation, government effectiveness, voice and accountability, regulatory quality, corruption perception index ,length of time it takes new business and households to get electricity service, financial performance of utility company (current asset/current liability ratio),political stability and absence of violence/terrorism, state fragility

3.4 Unit Root Test

Due to structural breaks in data, the breakpoint unit root test is conducted for all variables to check variable stationarity and that no variable is integrated of order 2. The null hypothesis here is the "log of dependent and control variables has a unit root". The null hypothesis is rejected when $p < 0.05$.

3.5 Optimal lag length

To choose the optimal lag length for the model, the VAR lag order selection criterion is used to determine the optimal lags as much as possible. Guided by the Schwarz information criterion, the optimal lag length for each model is chosen.

3.6 Model Estimation

The ARDL model comprises lagged values of the explained and control variables. The lagged values of the control variables aid in estimating relations between variables in a time series structure. ARDL also helps in estimating short-run and long-run elasticities in the case of a small ***"t".*** The functional form is given as;

$$ES=f(GHG_{t}, HC_{t}, ODA_{t}, Tech_{t})$$

Where *ES* represents Energy Security and *t time*. *GHG*, *HC*, *ODA*, *Tech* represent Greenhouse gas emissions, capacity building/education, climate finance, and technology, respectively. Heteroscedasticity is reduced by converting all data to logarithms and using the log-log regression model.
A specified ARDL(p,q) model is given by

$$Y_t = \gamma_{oi} + \sum_{i=1}^{p} \delta_i Y_{t-i} + \sum_{i=0}^{q} \beta'_i X_{t-1} + \varepsilon_{it} \text{ ---------------------------- } equation\ 1$$

Where Y_t is a vector where Y_{t-l} is to be of $I(0)$ and $I(1)$ or both
β and δ are coefficients γ is the constant; i = 1,2,3..k : p, q are the lag values of the dependent and control variables respectively and ε_{it} is the vector of the error term which is serially uncorrelated and independent. The ARDL model follows a three-step approach namely test for stationarity; test for cointegration and test for causality.

3.6.1 The ARDL and ECM model

The ARDL (p, q_1, q_2, q_3, q_4) is stated as

$$\Delta lnESk_t = a_{01} + \Sigma_{i=1}^{p} a_{1i} \Delta lnESk_{t-i} + \Sigma_{i=1}^{q} a_{2i} \Delta lnGHGk_{t-1} + \Sigma_{i=1}^{q} a_{3i} \Delta lnHCk_{t-i} + \Sigma_{i=1}^{q} a_{4i} \Delta lnODAk_{t-i} + \Sigma_{i=1}^{q} a_{5i} \Delta lnTechk_{t-i} + e_{it} \text{ ---------------------------- } equation\ 2$$

When long-run relations exist among variables after an ARDL long run form and bounds test analysis, we specify the long run Error Correction Model as;

$$\Delta lnESk_t = a_0 + \Sigma_{i=1}^{p} a_{1i} \Delta lnESk_{t-1} + \Sigma_{i=1}^{q} a_{2i} \Delta lnGHGk_{t-1} + \Sigma_{i=1}^{q} a_{3i} \Delta lnHCk_{t-1} + \Sigma_{i=1}^{q} a_{4i} \Delta lnODAk_{t-1} + \Sigma_{i=1}^{q} a_{5i} \Delta lnTechk_{t-1} + \lambda ECT_{t-1} + e_{it} \text{ -----------------------} equation\ 3$$

Where k is a country.

Where λ is the adjustment co-efficient and a_{1i} , a_{2i}, a_{3i} , a_{4i} , a_{5i} are the short-run dynamic co-efficient of the model adjusted for the long-run

3.7 Bounds Test for Cointegration

To determine whether ARDL is suitable or not, we check for cointegration to determine if a long-run relationship exists between variables using the bounds test (Pesaran, Shin, & Smith, 2001)when it is not known with certainty whether the underlying regressors are trend-or first-difference stationary. The proposed tests are based on standard F-and t-statistics used to test the significance of the lagged levels of the variables in a univariate equilibrium correction mechanism. The asymptotic distributions of these statistics are non-standard under the null hypothesis that there exists no level relationship, irrespective of whether the regressors are I(0. There are three decision options to be taken after the bounds test for cointegration. First, if the F- statistic > the upper bound of I(1), Ho is rejected and the long run Error Correction Model is estimated. If the F- statistic < for the lower bound of I(0), we conclude that there is no co-integration and thus estimate a short-run ARDL. Lastly, if the F- statistic lies between the lower bound I(0) and the upper bound I(1), we conclude that the test is inconclusive. A conditional ARDL (p,q1,q2,q3,q4) model with five variables is specified where p is the lag of the dependent variable and q1..... q4 is the lag of the control variables

Hypotheses

H_0: $\beta_{1i} = \beta_{2i} =\ldots \beta_{5i} = 0$, i.e. . there is no cointegration (where *i*=1,2..5)
H_1: $\beta_{1i} \neq \beta_{2i} \neq\ldots \beta_{5i} \neq 0$ i.e.. H_1 is true
If H_0 is true, the short-run model is specified otherwise specification for VECM is made. See the bounds cointegration test below.

$$\Delta lnES_t = a_{01} + b_{11}ES_{t-1} + b_{21}GHG_{t-1} + b_{31}HC_{t-1} + b_{41}ODA_{t-1} + b_{51}Tech_{t-1} + \Sigma_{i=1}^{p} a_{1i}\beta lnES_{t-1} + \Sigma_{i=1}^{q} a_{2i}\beta lnGHG_{t-1} + \Sigma_{i=1}^{q} a_{3i}\beta lnHC_{t-1} + \Sigma_{i=1}^{q} a_{4i}\beta lnODA_{t-1} + \Sigma_{i=1}^{q} a_{5i}\beta lnTech_{t-1} + e_{it} \text{ --- equation 4}$$

$$\Delta GHG_t = a_{02} + b_{12}ES_{t-1} + b_{22}GHG_{t-1} + b_{32}HC_{t-1} + b_{42}ODA_{t-1} + b_{52}Tech_{t-1} + \Sigma_{i=1}^{p} a_{1i}\beta lnES_{t-1} + \Sigma_{i=1}^{q} a_{2i}\beta lnGHG_{t-1} + \Sigma_{i=1}^{q} a_{3i}\beta lnHC_{t-1} + \Sigma_{i=1}^{q} a_{4i}\beta lnODA_{t-1} + \Sigma_{i=1}^{q} a_{5i}\beta lnTech_{t-1} + e_{it} \text{ -- equation 5}$$

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$$\Delta lnTech_t = a_{06} + b_{16}ES_{t-1} + b_{26}GHG_{-1} + b_{36}HC_{t-1} + b_{46}ODA_{t-1} + b_{56}Tech_{t-1} + \Sigma_{i=1}^{p} a_{1i}\beta lnTech_{t-1} + \Sigma_{i=1}^{q} a_{2i}\beta lnES_{t-1} + \Sigma_{i=1}^{q} a_{3i}\beta ln\, GHG_{t-1} + \Sigma_{i=1}^{q} a_{4i}\beta lnHC_{t-1} + \Sigma_{i=1}^{q} a_{5i}\beta lnODA_{t-1} + e_{it} \text{---equation 8}$$

3.8. Diagnostic Test

To achieve a more robust model, diagnostic tests are performed on the estimated model. The goodness of fit test, normality, stability diagnostic, Breusch Godfrey serial correlation LM test, Breusch–Pagan Godfrey Heteroskedasticity test are used to investigate how robust the model is.

The adjusted R^2 predicts the estimating power of the regressors. The Durbin Watson must range between 1.5 and 2.5 to indicate the model is free from autocorrelation. Apart from the Durbin Watson test, the Breusch Godfrey LM test also helps detect serial correlation.

Jarque–Bera is used to testing for normality. For heteroskedasticity, the Breusch-Pagan-Godfrey test help to detect autocorrelation of errors of order ≥1. The chow test is used to check parameter stability and identify breakeven points. This approach is complemented with the CUSUM and CUSUMSQ test. The CUSUMSQ test helps detect regular instabilities. If the model is stable, the red line stays within the upper and lower limits.

4.0 RESULTS

4.1 Estimated model for Burkina Faso

Except for the log of energy security, which is stationary at levels, all other climate action regressors are stationary after the first difference (Table 1).

Table 1: Results of breakeven test-Burkina Faso

Variable	Break	T-statistic	Order
LNESBFA	1980	(-6.298)***	I(0)
LNCO2BF	1989	(-4.588)	
D(LNCO2BF)	1981	(-8.194)***	I(1)
LNEMIBF	2002	(-4.313)	
D(LNEMIBF)	1992	(-8.826)***	I(1)
LNHCBF	2000	(-3743)	
D(LNHCBF)	2013	(-8.742)***	I(1)
LNODABF	1995	(-3.729)	
D(LNODABF)	1974	(-8.219)***	I(1)

Source: Researchers calculation from Eviews 10

The optimal lag length via an unrestricted VAR and Schwaz information criterion (SC) for the model is 4. Additionally, the ARDL Long Run Form and Bounds Test indicate F-statistic 4.682 >I(1) at 5%. This signifies the existence of cointegration. Hence the results of the error corrected short-run model and long-run conditional error correction model are presented in table 2.

Table 2: Conditional Error Correction Regression of the Selected Model: ARDL(4, 3, 0, 4, 2)

Regressors	Estimated Coefficient	T-statistics
	Short Run	
D(LNEMIBF)**	-0.656	(-2.752)**
D(LNHCBF(-1))	-0.624	(-3.817)***
D(LNC02BF, 2)	0.761	(2.459)**
D(LNODABF(-3), 2)	0.254	(2.530)**
	Long Run ECM Regression	
D(LNC02BF, 2)	0.761	(3.545)***
D(LNODABF(-3), 2)	0.254	(3.152)***
D(LNHCBF(-1), 2)	0.489	(4.537)***
CointEq(-1)*	-0.432	(-5.242)***
Goodness of fit		P-value
R^2	0.941	
Adjusted R^2	0.910	

DW	1.832	
Jarque -Bera	2.539	0.2808
Prob(F-statistic)	0.000	
Stability Test		
CUSUM	Stable	
CUSUMSQ	Stable	
	Breusch-Godfrey	
Serial correlation- LM Test	0.536	0.764
Heteroscedasticity	12.232	0.835

Notes: t-statistics are in bracket whiles ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. No asterisk means its insignificant ie. >10%. LNESBFA,LNCo2BF, LNEMIBF,LNHCBF,LNODABF represent energy security, total carbon emissions, education/capacity building ,energy efficiency/ technology and climate finance.

From Table 2, all the regressors are significant at 5% or 1%. In the short run, a negative relationship exists between the first difference of LNEMIBF and LNESBFA. Likewise, a negative relationship exists between the first difference of the one-period lag of LNHCBF and LNESBFA. Albeit a positive relationship exists between the first difference of LNCo2BF and three periods lag of LNODABF and energy security. What this means is that "*ceteris paribus*" a 10% increase in the first difference of energy efficiency/technology will decrease energy security by 66% and a 10% increase in the first difference of the one-period lag of education/capacity building has a negative effect on the current level of energy security by 62%. Also, a 10% increase in carbon emissions increases energy security by 76% in the short and long run. Similarly, a 10% increase in the first difference of the one-period lag education (capacity building) has a negative significant effect on the current level of energy security in the short run.

In the long run, the impact of education (capacity building) on energy security is positive. The same is estimated for the first difference of the three-period lag of climate finance which has a positive effect on the current level of energy security in the short and long run, the impact of education (capacity building) on energy security is positive. In the long run, the effect of the first difference of carbon emissions, the first difference of the three-period lag of climate finance and the first difference of the one-period lag education (capacity building) is more significant a 1%.

According to results from the diagnostic test. The model is stable. This is confirmed by the CUSUM and CUSMSQ charts (See appendix B). Additionally, the model is homoscedastic, free from serial correlation and has normally distributed residuals. This is confirmed by the p-value >5% for the Jarque -Bera, Breusch-Godfrey serial Correlation LM Test and Breusch-Pagan-Godfrey Heteroscedasticity tests. The Adjusted R^2 of 91% indicates the estimating power of the regressors. The Error Correction Term (ECT) is negative and statistically significant at the 1% level indicating the existence of cointegration amongst variables. According to the ECT, the speed of adjustment from the previous 'year's disequilibrium in energy security added to the current 'year's equilibrium is 43%.

4.2 Estimated Model for Ghana

After a breakpoint unit root test, the log of energy efficiency (technology) and capacity building (education) are insignificant at levels and was significant after the first difference. But the remaining variables are significant at levels (Table 3). Results from the unrestricted VAR and Schwaz information criterion (SC) produce an optimal lag of 2 for Ghana.

Table 3: Results of breakeven test-Ghana

Variable	Break date	T-statistic	order
LNESGHA	1980	(-5.909)***	I(0)
LNC02GH	1978	(-4.692)*	I(0)
LNEMIGH	2002	(-3.875)	
D((LNEMIGH)	2002	(-9.275)***	I(I)
LNHCGH	1987	(-3.165)	
D(LNHCGH)	2014	(-7.016)***	I(I)
LNODAGH	1983	(-4.685)*	I(0)

Source: Researchers calculation from Eviews 10

The year 1992 is identified as a breakeven point for Ghana after an initial instability is detected in the model. This instability may be caused by the transition from military to democratic rule. In the year 1992, the country held a referendum on its first constitution and subsequently had its first election (Oquaye, 1995). A dummy variable is created to interact with regressors. After testing for a long-run relationship F-statistic< I(0) at 5%. The results of the estimated model is shown in Table 4.

Table 4: Estimated Model for Ghana

Regressors	Estimated Coefficient	T-statistics
	Short Run	
LNC02GH(-1)	0.959	(1.859)*
D(LNEMIGH(-1))	-0.536	(-2.258)**
D(LNHCGH)	0.143	(0.804)
LNODAGH	-0.197	(-1.392)
Goodness of fit		P-value
R^2	0.950	
Adjusted R^2	0.911	
DW	2.087	
Jarque -Bera	0.575	0.750
Prob(F-statistic)	0.000	
Stability Test		
CUSUM	Stable	
CUSUMSQ	Stable	
	Breusch-Godfrey	
Serial correlation- LM Test	1.086	0.580
Heteroscedasticity	27.221	0.099

Notes: t-statistics are in bracket whiles ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. No asterisk mean its insignificant ie >10%. LNESGHALNC02GH, LNEMIGH, LNHCGH,LNODAGH represent energy security, carbon emissions, education, energy efficiency/technology and climate finance.

From the model results in Table 4, the one period lag of Co_2 and lag of the first difference of LNEMIGH are found to be significant at 10% and 5% respectively. The first difference of LNHCGH and LNODAGH is positive but insignificant. Per the results a 10% increase in the one-period lag of carbon emissions has a positive effect on the current level of energy security i.e., increasing the current level of energy security by 95% and a 10% increase in the first difference of the one-period lag of energy efficiency (technology) decreases the current level of energy security by 54% "ceteris paribus". A long-run relationship amongst variables was not detected after the bounds test was performed. The F-statistics of 1.32 < I (0).

Based on a diagnosis of the model, it can be concluded that the model has a good fit. This is indicated by an adjusted R^2 of 91%. The model is stable, as both CUSUM and CUSUMSQ since chart lines between the 5 percent significance level. Additionally, the model is serially uncorrelated and homoscedastic and has normally distributed residuals (See appendix C). This is confirmed by an insignificant p-value of Breusch-Godfrey serial Correlation LM Test, Breusch-Pagan-Godfrey Heteroscedasticity test and Jarque -Bera.

4.3 Estimated model for Nigeria

After the breakpoint unit root test, the log of energy security, carbon emissions, energy efficiency(technology), capacity building (education) is significant at levels except for the log of climate finance (ODA) which is significant at first difference in the (Table 5).

Table 5: Results for breakeven test- Nigeria

Variable	Break	T-statistic	Order
LNESNGA	1980	(-5.692)***	I(0)
LNC02NG	1999	(-5.130)**	I(0)
LNEMING	2006	(-5.052)**	I(0)
LNHCNG	1985	(-6.926)***	I(0)
LNODANG	2003	(-4.452)	
D(LNODANG)	2003	(-8.483)***	I(1)

Source: Researchers calculation from Eviews 10

Additionally, after checking for the optimal lag length via an unrestricted VAR and Schwaz information criterion (SC) the optimal lag for Nigeria is 1.

A break-even point is identified in 1991 after a chow test hence a dummy variable is created to interact with regressors. The structural break may be attributed to gubernatorial elections under military rule and associated electoral fraud and violence which triggered the cancellation of the results from nine states by the military (Immigration and Refugee Board of Canada, 2013). After estimating the ARDL model, we check for cointegration using the Bounds Test approach and find a long-run relationship where F-statistic> I(1) at 5%. The speed of adjustment is CointEq(-1)* -1.351 and is significant at 1%. The result obtained are below;

Table 6: Conditional Error Correction Regression. Selected Model: ARDL(1, 1, 1, 1, 1)

Regressors	Estimated Coefficient	T-statistics
	Short Run	
D(LNC02NG)	0.520	(1.361)
D(LNEMING)	-0.525	(-2.222)**
D(LNHCNG)	-0.293	(-2.038)**
D(LNODANG, 2)	-0.035	(-0.588)
	Long Run ECM Regression. Case 3: Unrestricted Constant and No Trend	
D(LNC02NG)	0.520	(2.345)**
D(LNEMING)	-0.525	(-2.898)***
D(LNHCNG)	-0.293	(-2.684)**
D(LNODANG, 2)	-0.035	(-0.912)
CointEq(-1)*	-1.351	(-7.61)***
Goodness of fit		P-value
R^2	0.932	
Adjusted R^2	0.901	
DW	2.00	
Jarque -Bera	1.017	0.601
Prob(F-statistic)	0.000	
Stability Test		
CUSUM	Stable	
CUSUMSQ	Stable	
	Breusch-Godfrey	
Serial correlation- LM Test	0.949	0.621
Heteroscedasticity	19.697	0.140

Notes: t-statistics are in bracket whiles ***, ** and * indicate significance level at 1%, 5% and 10%, respectively. No asterisk mean its insignificant ie >10%. LNESBFA, LNCo2BF, LNEMIBF,LNHCBF,LNODABF represent energy security, carbon emissions, education,en ergy efficiency/technology and climate finance.

Table 6 shows that the first difference between LNEMING and LNHCNG is significant at 5%. The coefficient of (-0.525) shows that a 10% percent increase in the first difference of energy efficiency(technology) leads to a 53% decrease in energy security in the short run at a 5% level of significance whiles the coefficient of (-0.293) indicate that a 10% percent increase in the first difference of education (capacity building) leads to a 29% reduction in energy security in the short run at a 5% level of significance. This model indicates a negative relationship between the first difference of LNEMING and LNHCNG on LNESNGA. However, the first difference of LNCo2NG is has a positive relationship with LNESNGA and the first difference LNODANG has a negative relationship with LNESNGA but both are insignificant.

In the long run, the first difference LNCo2NG, LNEMING, LNHCNG become significant at 5% and 10%. Indicating that a 10% increase in the first difference LNCo2NG(total carbon dioxide) will lead to an increase in LNESNGA(energy security) by 52% "*ceteris paribus*" whiles the impact of the first difference LNEMING, LNHCNG on LNESNGA will not change.

The coefficient of the error correction term of -1.351 is negative and highly significant at a one percent level. This indicates the strong presence of long-run relationships amongst variables. But the speed of adjustment fluctuates along the long-run value before settling to equilibrium. However, once this process is complete, convergence to the equilibrium path is rapid. This may be attributed to the data frequency and presence of outliers(Narayan & Smyth, 2006).

Diagnostics checks indicate that the model has a good fit. This is indicated by an adjusted R^2 of 90%. Secondly, the Durbin Watson results lie between 1.5 and 2.5 range. The model suffers no problem of heteroskedasticity. This is confirmed by the heteroskedasticity Test: observed R^2 19.7 which is insignificant at 5%. Additionally, the p-value for Jarque -Bera, Serial correlation- LM Test and Heteroscedasticity are insignificant hence we conclude there is no serial correlation in the model and that the residuals are normally distributed.

5.0 DISCUSSION

The counter-intuitive nature of signs is not surprising in economic context. Counter intuitiveness is established in behavioral economics and justifies economics as a science studying complexities of human behavior and choice-making, justifying why policies may fail. Consumers may exhibit the following characteristics: i. profit maximizing, ii. have stable preferences, iii. willing to embark on a maximizing behavior, iv. take context or environmentally dependent decisions and sometimes ignore tradeoffs during decision-making, and v. may resist change or cannot predict the future (See Becker, 1976; Goldstein & Gigerenzer, 2002; Kahneman & Tversky, 1979; Thaler, 2008).

For Burkina Faso, the expected sign for energy efficiency (technology) and education (capacity building) is counter-intuitive; however, the expected sign for carbon emissions and climate finance (ODA) is intuitive. For Ghana, the expected sign for carbon emission is intuitive, but energy efficiency (technology) is counter-intuitive. For Nigeria, the expected sign for carbon emission is intuitive, whereas the expected sign for energy efficiency (technology) and education (capacity building in the short and long run differs from the expected sign in Table 1.

5.1 Energy efficiency (technology)

A negative relationship is presented between energy efficiency (technology) and energy security for the three countries in this study.

Energy efficiency programs have not yielded any results. This can be attributed to the rebound effect (Brockway et al., 2017; Diawuo, Sakah, de la Rue du Can, Baptista, & Silva, 2020; Sarr & Swanson, 2017). For instance, the penetration of energy-efficient machinery and appliances will mean cheaper energy costs. This is likely to trigger more energy consumption from various energy-intensive sectors. Those who could not afford energy services before will be more able to afford than expected. Hence the dividends from energy demand-side management will not be achieved. These findings are consistent with Sarr & Swanson (2017) study. They concluded that rebound effect is predominant in developing economies that aim at industrialization, thus typically have more intensive energy use, high economic growth rates, expensive energy costs, increasing energy access, and improving energy services. Similarly, according to Diawuo et al. (2020), the average hourly demand for electricity by the residential sector in Ghana increased by 8% due to unfavorable changes in consumer behavior that increased demand for energy services despite energy efficiency programs and energy demand-side management.

5.2 Education (capacity building)

No significant relationship between the education (capacity building) and energy security improvements was found for Ghana. In the long run, capacity building improved the level of energy security in Burkina Faso.

The negative relationship between education (capacity building) and energy security for Burkina Faso (the short-run results) and Nigeria implies that capacity-building efforts in the past have not focused on the need to produce and consume energy more sustainably. This finding is consistent with Virtič & Kovačič Lukman (2018)and Sendegeya & Chiguvare (2016). These studies highlight the essence of capacity building for energy efficiency, renewable energy, and sustainable energy development.

Sendegeya & Chiguvare (2016) identify the lack of knowledge by key stakeholders as a reason for the failure of energy efficiency and renewable energy penetration programs, hence preventing the implementation of sustainable energy solutions. Similarly, according to Martínez-Espiñeira et al. (2014) capacity building interventions that have no targets or no content on sustainable energy production fail to influence behaviours and investments to improve sustainable energy production and consumption. Similarly, capacity-building interventions that do not prioritize training of sustainable energy at a professional or academic level will be short-lived (Sendegeya & Chiguvare, 2016).

5.3 Total carbon emissions

The positive relationship in carbon emissions for Burkina Faso, Ghana and Nigeria implies an improvement in energy security where there is an increase in total carbon emissions. But this situation is undesirable under NDC implementation and will require energy efficiency, renewable energy and sustainable behavioral practices. These findings align with findings from Pakistan that oil intensity and oil use per capita increase due to the growth in energy demand and industrialization. Fossil fuel dominated the countries' energy mix (Lin & Raza, 2020).

In the case of Ghana, there is an increased share of fossil fuel and biomass in the energy mix, accounting for about 95% of the national energy production (Lin & Abudu, 2020). Ghana's primary energy supply is sourced from oil, natural gas, hydro, solar and biomass. Since 2000, the share of fossil fuels and biomass (charcoal and firewood) has dominated the primary energy supply mix by a percentage between 90 and 95%. Biogas and biofuels have been less than 1% over the years (Ghana Energy Commission, 2020).

5.4 Climate Finance

The impact of climate finance (ODA) on energy security is insignificant in Nigeria and Ghana. In Burkina Faso, Climate finance improves energy security in both short and long run. This indicates that the country and development partners have channeled a substantial amount of ODA in supporting energy investments. This may imply that fossil fuel scarce and low-income countries like Burkina Faso are more likely to maximize the impacts of climate finance for sustainable energy investment than fossil fuel rich lower-middle-income countries such as Ghana and Nigeria.

According to Briggs (1993), supporting sustainable energy development through ODA in developing countries is key to promoting sustainable development. Between 2008 to 2019, Burkina Faso receives about USD 150 million clean energy investment, making the country the 4th in rank amongst West African countries after Senegal, Sierra Leon and Mali (BloombergNEF, 2020).

5.5 Discussion Summary

Estimated results are summarized in Table 7. From the table, empirical results for Burkina Faso showed that climate finance improved the country's energy security performance in both short and long run, while capacity building and energy efficiency impaired energy security performance in a short run. In the long run, capacity-building efforts are estimated to improve energy security performance in Burkina Faso. Additionally, empirical results for Ghana showed that whenever there is an increase in carbon emissions, energy security performance improved energy security performance, whiles energy efficiency impaired energy security performance in the short run. Climate finance and capacity building are found to be insignificant, and no long-run results are found for Ghana. Also, empirical results for Nigeria showed that whenever there is an increase in carbon emissions, energy security performance improved in the long run. The short-run result for total carbon emissions and climate finance is found to be insignificant. Capacity building and energy efficiency impaired energy security performance in both long and short run.

Table 7: Summary of results

Regressor	Period	Burkina Faso	Ghana	Nigeria
CO_2	SR LR	(0.761)** (0.761)***	(0.959)*	0.520 (0.520)**
Capacity building	SR LR	(-0.624)*** (0.489)***	0.143	(-0.293)** (-0.293)**
Energy efficiency	SR LR	(-0.656)** -	(-0.536)**	(-0.525)** (-0.525)***
Climat finance	SR LR	(0.254)** 0.254)***	-0.197	-0.035 -0.035

Notes: SR-Short Run; LR-Long Run

6.0 CONCLUSION

The study sought to assess the impact of climate action on energy security in West Africa. This is done by investigating historical data on past efforts. The aim is to propose solutions to the convolutions around energy security and climate actions and gain lessons for informing NDC implementation in West Africa post the Paris Agreement.

The empirical results for Burkina Faso showed that climate finance improved the country's energy security performance in both short and long run. In the long run, capacity-building efforts are estimated to improve energy security performance in Burkina Faso. Additionally, empirical results for Burkina Faso, Ghana and Nigeria show that whenever there is an increase in carbon emissions, energy security performance improved energy security performance. Considering the need to reduce carbon emissions during full NDC implementation, policies should focus on decoupling carbon emissions from an improvement in energy security. Also, the adverse/limited impacts of capacity-building efforts, climate finance and energy efficiency must be corrected.

From the study results, it can be inferred that NDC implementation will have varying effects on oil and non-oil-producing countries. Oil-producing and lower-middle-income countries in West Africa such as Ghana and Nigeria will adversely be affected by NDC implementation "*ceteris paribus*". In contrast, low-income non-oil-producing countries such as Burkina Faso will experience limited adverse effects. To minimise the negative impacts of NDC implementation on energy security amongst West African economies, we propose the following recommendation:

i. Explore options for low carbon energy development.
ii. Implement targeted training programs on sustainable energy production and consumption in academic institutions and the workplace and influence human behaviour by implementing public awareness campaigns on energy conservation and efficiency.
iii. Climate finance should be used to enhance low carbon energy development, build capacity and promote public education campaigns.
iv. Incentivise energy efficiency and conservation to avert the rebound effect. Energy efficiency programs should not be delinked from public educational campaigns.

The findings of this study are useful to inform governments, energy planners, the private sectors and the donor community on key energy sector strategies for NDC implementation, as well as to tailor policy interventions and climate support via climate finance, technology transfer, and capacity building as per the article 9, 10, 11 of the Paris Agreement to deal with the convolutions around policymaking in the area of energy security and climate change.

Future research should examine relationships amongst variables using actual climate finance and climate/ energy related capacity building expenditure data other than the proxy ODA and total education expenditure on capacity building. Since climate finance originates from the 2015 Paris Agreement, it will require a minimum of 10 years of data for panel data analysis. In this case will be difficult to estimate the results for each country. Additionally, future research can consider increasing the number of countries when sampling West African countries for similar studies.

The challenge of accessing time series climate finance data and climate/ energy related capacity building expenditure data is a major limitation of this study and may have influenced study results. Several studies corroborate the non-availability or inadequacy of climate finance data to developing countries. There is either inconsistent or comprehensive data or lack of data or no standardized reporting. In some countries, the lack of data is attributed to data secrecy arising from lack of climate-related financial disclosure policy (See Clapp, Ellis, Benn, & Corfee-Morlot, 2012; Sinha, Jain, Padmanabhi, & Acharya, 2020) . Due to this case studies and (or) descriptive analysis of climate finance flows for a year or two or project level analysis is done (See Juergens et al., 2012; Odhengo et al., 2021). However, the limited/absence of data does not mean that related proxies and historic data cannot guide policy making.

ACKNOWLEDGEMENTS

My gratitude to the organisers of 44th UNEP/UNESCO/BMU International Postgraduate Course on Environmental Management for Developing Countries programme for providing the opportunity to present this work for feedback. Second to Dr. Serena Caucci and Dr. Lulu Zhang of UNU-FLORES for providing an initial review of this work. Lastly, to the ECOWAS Centre for Renewable Energy and Energy Efficiency for the financial support.

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APPENDIX

A -Preliminary analysis

Descriptive statistics for Burkina Faso

Burkina 'Faso's total carbon emission in kilotone ranges from143.01 to 3,417.64 kiloton (kt) of Co_2 over the study period. Over the period the average total carbon emission is 630 kt. Additionally, expenditure on capacity building (education) spans from USD 7.97 million to USD 517 million with the average spend on capacity building (education) been USD 66.25 million. Regarding climate funds (ODA) the amount received ranged from USD 21.99 million to USD 1.15 billion between 1970 and 2016 with the average amount being USD 458 million. Next, the energy security index calculated for Burkina Faso ranges from 11.07 to 44.78.

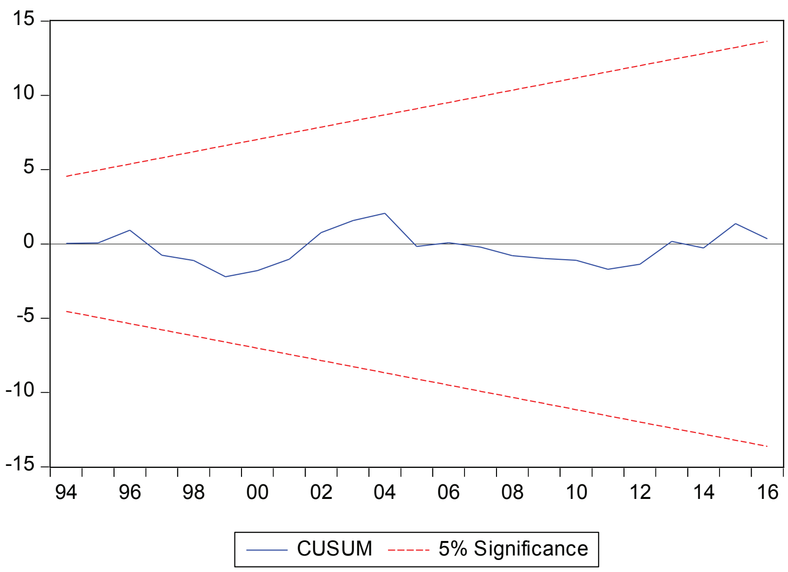
Descriptive statistics for Ghana

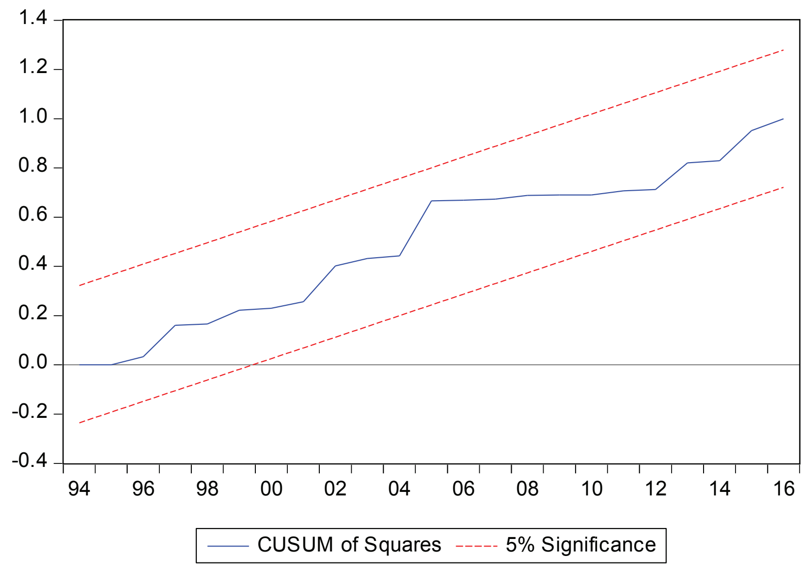
'Ghana's total carbon emission in kilotone of Co_2 ranges from 2,295.54 to 16,670.18 kiloton (kt) of Co_2. Over the period the average Co_2 is 6,123.26 kt. Additionally, expenditure on capacity building (education) spans from USD 61.10 million to USD 3.57 billion with the average capacity building (education) expenditure been USD 620 million. Regarding Climate funds (ODA) the amount received ranged from USD 36.32 million to USD 1.80 billion between 1970 and 2016 with the average amount being USD 677 million. Next, the energy security index calculated for Ghana ranges from 6 to 72.

Descriptive statistics for Nigeria

'Nigeria's carbon emission in kilotone of Co_2 ranges from 21,540 to 131,686 kiloton (kt) of Co_2. Over the period the average Co_2 is 70,412 kt. Additionally, expenditure on capacity building (education) spans from USD 128 million to USD 8.32 billion with the average capacity building (education) expenditure been USD 1.78 billion million. Regarding Climate funds, (ODA) the amount received ranged from USD 25.74 million to USD 1.10 billion between 1970 and 2016 with the average amount being USD 929 million. Next, the energy security index calculated for Ghana ranges from 6.55 to 70.41.

B Eviews output for Burkina Faso





Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.135768	Prob. F(2,21)	0.8738
Obs*R-squared	0.536140	Prob. Chi-Square(2)	0.7649

Test Equation:
Dependent Variable: RESID
Method: ARDL
Date: 05/24/21 Time: 21:38
Sample: 1975 2016
Included observations: 42
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNESBFA(-1)	-0.035993	0.169359	-0.212524	0.8337
LNESBFA(-2)	0.025139	0.185687	0.135382	0.8936
LNESBFA(-3)	0.028991	0.188569	0.153739	0.8793
LNESBFA(-4)	-0.022137	0.173615	-0.127504	0.8998
D(LNC02BF)	-0.010827	0.326120	-0.033199	0.9738
D(LNC02BF(-1))	0.004113	0.192110	0.021409	0.9831
D(LNC02BF(-2))	-0.000225	0.192599	-0.001169	0.9991
D(LNC02BF(-3))	0.016130	0.251920	0.064027	0.9496
D(LNEMIBF)	-0.009369	0.254198	-0.036859	0.9709
D(LNODABF)	0.008908	0.151071	0.058966	0.9535
D(LNODABF(-1))	0.013308	0.130657	0.101855	0.9198
D(LNODABF(-2))	-0.002296	0.120238	-0.019092	0.9849
D(LNODABF(-3))	0.006027	0.119282	0.050528	0.9602
D(LNODABF(-4))	-0.007534	0.105724	-0.071259	0.9439
D(LNHCBF)	0.003286	0.065807	0.049940	0.9606
D(LNHCBF(-1))	-0.004605	0.067993	-0.067722	0.9466
D(LNHCBF(-2))	0.001372	0.149335	0.009187	0.9928
C	0.002947	0.132194	0.022295	0.9824

@TREND	0.000260	0.009308	0.027922	0.9780
RESID(-1)	0.127134	0.273806	0.464320	0.6472
RESID(-2)	-0.079136	0.324588	-0.243805	0.8097

R-squared	0.012765	Mean dependent var	6.26E-16
Adjusted R-squared	-0.927458	S.D. dependent var	0.092419
S.E. of regression	0.128308	Akaike info criterion	-0.961909
Sum squared resid	0.345723	Schwarz criterion	-0.093074
Log likelihood	41.20009	Hannan-Quinn criter.	-0.643447
F-statistic	0.013577	Durbin-Watson stat	2.002313
Prob(F-statistic)	1.000000		

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.525089	Prob. F(18,23)	0.9165
Obs*R-squared	12.23260	Prob. Chi-Square(18)	0.8350
Scaled explained SS	4.369200	Prob. Chi-Square(18)	0.9996

Test Equation:

Dependent Variable: RESID^2

Method: Least Squares

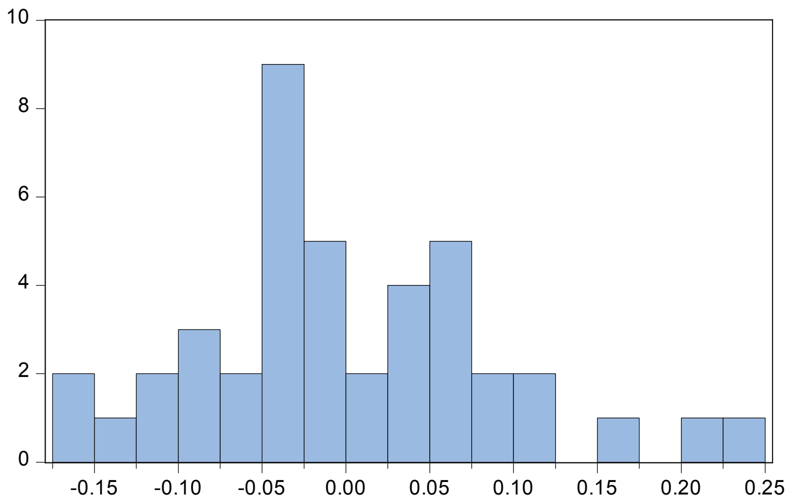
Date: 05/24/21 Time: 21:39

Sample: 1975 2016

Included observations: 42

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.011247	0.014074	0.799167	0.4324
LNESBFA(-1)	-0.004598	0.015411	-0.298373	0.7681
LNESBFA(-2)	-0.000606	0.015505	-0.039058	0.9692
LNESBFA(-3)	0.019784	0.018899	1.046863	0.3060
LNESBFA(-4)	-0.014370	0.017175	-0.836715	0.4114
D(LNC02BF)	0.025013	0.036732	0.680972	0.5027
D(LNC02BF(-1))	-0.027668	0.021831	-1.267365	0.2177
D(LNC02BF(-2))	-0.007133	0.021836	-0.326676	0.7469
D(LNC02BF(-3))	0.017336	0.028526	0.607726	0.5493
D(LNEMIBF)	-0.035645	0.028294	-1.259793	0.2204
D(LNODABF)	-0.026641	0.015837	-1.682194	0.1061
D(LNODABF(-1))	0.009994	0.014496	0.689402	0.4975
D(LNODABF(-2))	0.003757	0.013574	0.276819	0.7844
D(LNODABF(-3))	0.018635	0.012892	1.445400	0.1618
D(LNODABF(-4))	-0.001402	0.011927	-0.117527	0.9075
D(LNHCBF)	-0.001428	0.006799	-0.209976	0.8355
D(LNHCBF(-1))	0.002129	0.007336	0.290146	0.7743
D(LNHCBF(-2))	-0.017933	0.016910	-1.060502	0.2999

@TREND	-0.000172	0.000985	-0.174949	0.8627
R-squared	0.291252	Mean dependent var		0.008338
Adjusted R-squared	-0.263420	S.D. dependent var		0.013025
S.E. of regression	0.014640	Akaike info criterion		-5.307521
Sum squared resid	0.004930	Schwarz criterion		-4.521432
Log likelihood	130.4579	Hannan-Quinn criter.		-5.019388
F-statistic	0.525089	Durbin-Watson stat		2.373089
Prob(F-statistic)	0.916517			



Series: Residuals	
Sample 1975 2016	
Observations 42	
Mean	6.26e-16
Median	-0.016887
Maximum	0.249224
Minimum	-0.168332
Std. Dev.	0.092419
Skewness	0.571240
Kurtosis	3.382078
Jarque-Bera	2.539677
Probability	0.280877

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNESBFA)
Selected Model: ARDL(4, 3, 0, 4, 2)
Case 5: Unrestricted Constant and Unrestricted Trend
Date: 05/24/21 Time: 21:41
Sample: 1970 2016
Included observations: 42

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.430762	0.118619	3.631478	0.0014
@TREND	0.025128	0.008300	3.027471	0.0060
LNESBFA(-1)*	-0.432830	0.128090	-3.379102	0.0026
D(LNC02BF(-1))	1.618446	0.586970	2.757291	0.0112
D(LNEMIBF)**	-0.656340	0.238476	-2.752225	0.0113
D(LNODABF(-1))	0.333877	0.268208	1.244845	0.2257
D(LNHCBF(-1))	-0.624310	0.163544	-3.817376	0.0009
D(LNESBFA(-1))	-0.557617	0.157995	-3.529346	0.0018
D(LNESBFA(-2))	0.662683	0.190276	3.482751	0.0020
D(LNESBFA(-3))	0.803726	0.144757	5.552237	0.0000
D(LNC02BF, 2)	0.761449	0.309590	2.459540	0.0219
D(LNC02BF(-1), 2)	-0.981518	0.336986	-2.912635	0.0078
D(LNC02BF(-2), 2)	-0.670970	0.240432	-2.790684	0.0104
D(LNODABF, 2)	0.144035	0.133480	1.079070	0.2917
D(LNODABF(-1), 2)	0.208864	0.201173	1.038231	0.3100

D(LNODABF(-2), 2)	0.137010	0.144738	0.946607	0.3537
D(LNODABF(-3), 2)	0.254392	0.100526	2.530617	0.0187
D(LNHCBF, 2)	-0.184073	0.057308	-3.211985	0.0039
D(LNHCBF(-1), 2)	0.489905	0.142523	3.437378	0.0022

* p-value incompatible with t-Bounds distribution.

** Variable interpreted as Z = Z(-1) + D(Z).

Levels Equation

Case 5: Unrestricted Constant and Unrestricted Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNC02BF)	3.739218	1.075500	3.476727	0.0020
D(LNEMIBF)	-1.516391	0.524145	-2.893074	0.0082
D(LNODABF)	0.771382	0.603705	1.277747	0.2141
D(LNHCBF)	-1.442391	0.496669	-2.904127	0.0080

EC = LNESBFA - (3.7392*D(LNC02BF) -1.5164*D(LNEMIBF) + 0.7714 *D(LNODABF) -1.4424*D(LNHCBF))

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	4.682107	10%	3.03	4.06
k	4	5%	3.47	4.57
		2.5%	3.89	5.07
		1%	4.4	5.72
Actual Sample Size	42		Finite Sample: n=45	
		10%	3.298	4.378
		5%	3.89	5.104
		1%	5.224	6.696
			Finite Sample: n=40	
		10%	3.334	4.438
		5%	3.958	5.226
		1%	5.376	7.092

t-Bounds Test		Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-3.379102	10%	-3.13	-4.04
		5%	-3.41	-4.36
		2.5%	-3.65	-4.62
		1%	-3.96	-4.96

ARDL Error Correction Regression
Dependent Variable: D(LNESBFA)
Selected Model: ARDL(4, 3, 0, 4, 2)
Case 5: Unrestricted Constant and Unrestricted Trend
Date: 05/24/21 Time: 21:56
Sample: 1970 2016
Included observations: 42

ECM Regression
Case 5: Unrestricted Constant and Unrestricted Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.430762	0.078191	5.509080	0.0000
@TREND	0.025128	0.005385	4.666608	0.0001
D(LNESBFA(-1))	-0.557617	0.132805	-4.198774	0.0003
D(LNESBFA(-2))	0.662683	0.163982	4.041202	0.0005
D(LNESBFA(-3))	0.803726	0.127822	6.287867	0.0000
D(LNC02BF, 2)	0.761449	0.214762	3.545544	0.0017
D(LNC02BF(-1), 2)	-0.981518	0.227125	-4.321484	0.0003
D(LNC02BF(-2), 2)	-0.670970	0.182988	-3.666747	0.0013
D(LNODABF, 2)	0.144035	0.091233	1.578758	0.1280
D(LNODABF(-1), 2)	0.208864	0.127232	1.641596	0.1143
D(LNODABF(-2), 2)	0.137010	0.103644	1.321925	0.1992
D(LNODABF(-3), 2)	0.254392	0.080702	3.152238	0.0045
D(LNHCBF, 2)	-0.184073	0.049536	-3.715916	0.0011
D(LNHCBF(-1), 2)	0.489905	0.107964	4.537686	0.0001
CointEq(-1)*	-0.432830	0.082565	-5.242321	0.0000

R-squared	0.941358	Mean dependent var	0.045593
Adjusted R-squared	0.910951	S.D. dependent var	0.381643
S.E. of regression	0.113887	Akaike info criterion	-1.234776
Sum squared resid	0.350194	Schwarz criterion	-0.614179
Log likelihood	40.93029	Hannan-Quinn criter.	-1.007303
F-statistic	30.95861	Durbin-Watson stat	1.832192
Prob(F-statistic)	0.000000		

* p-value incompatible with t-Bounds distribution.

F-Bounds Test — Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)

F-statistic	4.682107	10%	3.03	4.06
k	4	5%	3.47	4.57
		2.5%	3.89	5.07
		1%	4.4	5.72

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-5.242321	10%	-3.13	-4.04
		5%	-3.41	-4.36
		2.5%	-3.65	-4.62
		1%	-3.96	-4.96

ARDL Error Correction Regression
Dependent Variable: D(LNESBFA)
Selected Model: ARDL(4, 3, 0, 4, 2)
Case 5: Unrestricted Constant and Unrestricted Trend
Date: 05/24/21 Time: 21:56
Sample: 1970 2016
Included observations: 42

ECM Regression
Case 5: Unrestricted Constant and Unrestricted Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.430762	0.078191	5.509080	0.0000
@TREND	0.025128	0.005385	4.666608	0.0001
D(LNESBFA(-1))	-0.557617	0.132805	-4.198774	0.0003
D(LNESBFA(-2))	0.662683	0.163982	4.041202	0.0005
D(LNESBFA(-3))	0.803726	0.127822	6.287867	0.0000
D(LNC02BF, 2)	0.761449	0.214762	3.545544	0.0017
D(LNC02BF(-1), 2)	-0.981518	0.227125	-4.321484	0.0003
D(LNC02BF(-2), 2)	-0.670970	0.182988	-3.666747	0.0013
D(LNODABF, 2)	0.144035	0.091233	1.578758	0.1280
D(LNODABF(-1), 2)	0.208864	0.127232	1.641596	0.1143
D(LNODABF(-2), 2)	0.137010	0.103644	1.321925	0.1992
D(LNODABF(-3), 2)	0.254392	0.080702	3.152238	0.0045
D(LNHCBF, 2)	-0.184073	0.049536	-3.715916	0.0011
D(LNHCBF(-1), 2)	0.489905	0.107964	4.537686	0.0001
CointEq(-1)*	-0.432830	0.082565	-5.242321	0.0000

R-squared	0.941358	Mean dependent var	0.045593
Adjusted R-squared	0.910951	S.D. dependent var	0.381643

S.E. of regression	0.113887	Akaike info criterion	-1.234776
Sum squared resid	0.350194	Schwarz criterion	-0.614179
Log likelihood	40.93029	Hannan-Quinn criter.	-1.007303
F-statistic	30.95861	Durbin-Watson stat	1.832192
Prob(F-statistic)	0.000000		

* p-value incompatible with t-Bounds distribution.

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	4.682107	10%	3.03	4.06
k	4	5%	3.47	4.57
		2.5%	3.89	5.07
		1%	4.4	5.72

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-5.242321	10%	-3.13	-4.04
		5%	-3.41	-4.36
		2.5%	-3.65	-4.62
		1%	-3.96	-4.96

C-Eviews output for GHANA

GHANA

Dependent Variable: LNESGHA

Method: ARDL

Date: 05/24/21 Time: 11:27

Sample (adjusted): 1973 2016

Included observations: 44 after adjustments

Dependent lags: 2 (Fixed)

Dynamic regressors (2 lags, fixed): LNC02GH D(LNEMIGH) D(LNHCGH) LNODAGH

Fixed regressors: DUMMY LNC02GHDUMMY LNEMIGHDUMMY LNHCGHDUMMY LNODAGHDUMMY C

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LNESGHA(-1)	0.142612	0.227091	0.627996	0.5359
LNESGHA(-2)	0.335766	0.200268	1.676580	0.1066
LNC02GH	0.010912	0.614003	0.017773	0.9860
LNC02GH(-1)	0.959477	0.516068	1.859206	0.0753
LNC02GH(-2)	-0.508792	0.399568	-1.273356	0.2151
D(LNEMIGH)	-0.087959	0.245578	-0.358171	0.7233
D(LNEMIGH(-1))	-0.536764	0.237643	-2.258697	0.0333
D(LNEMIGH(-2))	0.106224	0.249255	0.426164	0.6738
D(LNHCGH)	0.143206	0.177977	0.804635	0.4289
D(LNHCGH(-1))	0.085651	0.162636	0.526641	0.6033
D(LNHCGH(-2))	0.013467	0.150641	0.089399	0.9295
LNODAGH	-0.197513	0.141815	-1.392756	0.1765
LNODAGH(-1)	0.091548	0.125297	0.730648	0.4721
LNODAGH(-2)	0.131166	0.142912	0.917805	0.3679
DUMMY	-4.596148	7.317978	-0.628063	0.5359
LNC02GHDUMMY	0.026791	0.702349	0.038145	0.9699
LNEMIGHDUMMY	0.115209	0.225629	0.510612	0.6143
LNHCGHDUMMY	-0.143734	0.338299	-0.424873	0.6747
LNODAGHDUMMY	0.432074	0.352589	1.225433	0.2323
C	-2.736789	3.496436	-0.782737	0.4414
R-squared	0.950625	Mean dependent var		3.293731
Adjusted R-squared	0.911536	S.D. dependent var		0.637432
S.E. of regression	0.189590	Akaike info criterion		-0.184946
Sum squared resid	0.862669	Schwarz criterion		0.626049
Log likelihood	24.06882	Hannan-Quinn criter.		0.115810
F-statistic	24.31973	Durbin-Watson stat		2.087596
Prob(F-statistic)	0.000000			

*Note: p-values and any subsequent tests do not account for model selection.

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNESGHA)
Selected Model: ARDL(2, 2, 2, 2, 2)
Case 3: Unrestricted Constant and No Trend
Date: 05/24/21 Time: 12:17
Sample: 1970 2016
Included observations: 44

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-2.736789	3.496436	-0.782737	0.4414
LNESGHA(-1)*	-0.521622	0.319084	-1.634750	0.1152
LNC02GH(-1)	0.461598	0.642328	0.718632	0.4793

D(LNEMIGH(-1))	-0.518499	0.479570	-1.081176	0.2904
D(LNHCGH(-1))	0.242325	0.332092	0.729692	0.4726
LNODAGH(-1)	0.025201	0.097951	0.257279	0.7992
D(LNESGHA(-1))	-0.335766	0.200268	-1.676580	0.1066
D(LNC02GH)	0.010912	0.614003	0.017773	0.9860
D(LNC02GH(-1))	0.508792	0.399568	1.273356	0.2151
D(LNEMIGH, 2)	-0.087959	0.245578	-0.358171	0.7233
D(LNEMIGH(-1), 2)	-0.106224	0.249255	-0.426164	0.6738
D(LNHCGH, 2)	0.143206	0.177977	0.804635	0.4289
D(LNHCGH(-1), 2)	-0.013467	0.150641	-0.089399	0.9295
D(LNODAGH)	-0.197513	0.141815	-1.392756	0.1765
D(LNODAGH(-1))	-0.131166	0.142912	-0.917805	0.3679
DUMMY	-4.596148	7.317978	-0.628063	0.5359
LNC02GHDUMMY	0.026791	0.702349	0.038145	0.9699
LNEMIGHDUMMY	0.115209	0.225629	0.510612	0.6143
LNHCGHDUMMY	-0.143734	0.338299	-0.424873	0.6747
LNODAGHDUMMY	0.432074	0.352589	1.225433	0.2323

* p-value incompatible with t-Bounds distribution.

Levels Equation

Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNC02GH	0.884928	1.114920	0.793714	0.4351
D(LNEMIGH)	-0.994014	0.853551	-1.164563	0.2556
D(LNHCGH)	0.464560	0.745259	0.623354	0.5389
LNODAGH	0.048312	0.199617	0.242024	0.8108

EC = LNESGHA - (0.8849*LNC02GH -0.9940*D(LNEMIGH) + 0.4646 *D(LNHCGH) + 0.0483*LNODAGH)

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	1.325876	10%	2.45	3.52
k	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06
Actual Sample Size	44		Finite Sample: n=45	
		10%	2.638	3.772
		5%	3.178	4.45
		1%	4.394	5.914
			Finite Sample: n=40	
		10%	2.66	3.838

		5%	3.202	4.544
		1%	4.428	6.25

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-1.634750	10%	-2.57	-3.66
		5%	-2.86	-3.99
		2.5%	-3.13	-4.26
		1%	-3.43	-4.6

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	2.049286	Prob. F(19,24)	0.0489
Obs*R-squared	27.22117	Prob. Chi-Square(19)	0.0996
Scaled explained SS	6.186224	Prob. Chi-Square(19)	0.9974

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 05/24/21 Time: 12:02
Sample: 1973 2016
Included observations: 44

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.846561	0.373673	-2.265513	0.0328
LNESGHA(-1)	0.033893	0.024270	1.396513	0.1753
LNESGHA(-2)	-0.041851	0.021403	-1.955357	0.0623
LNC02GH	0.005362	0.065620	0.081713	0.9356
LNC02GH(-1)	0.107004	0.055154	1.940116	0.0642
LNC02GH(-2)	0.035019	0.042703	0.820060	0.4203
D(LNEMIGH)	0.022774	0.026246	0.867741	0.3941
D(LNEMIGH(-1))	-0.015377	0.025398	-0.605455	0.5506
D(LNEMIGH(-2))	-0.015614	0.026639	-0.586132	0.5633
D(LNHCGH)	0.024503	0.019021	1.288214	0.2100
D(LNHCGH(-1))	0.004110	0.017381	0.236459	0.8151
D(LNHCGH(-2))	-0.003063	0.016099	-0.190234	0.8507
LNODAGH	-0.012031	0.015156	-0.793832	0.4351
LNODAGH(-1)	0.006161	0.013391	0.460096	0.6496
LNODAGH(-2)	-0.010080	0.015273	-0.659971	0.5156
DUMMY	1.001358	0.782091	1.280361	0.2127
LNC02GHDUMMY	-0.089555	0.075062	-1.193089	0.2445
LNEMIGHDUMMY	-0.004197	0.024114	-0.174068	0.8633

LNHCGHDUMMY	-0.026180	0.036155	-0.724105	0.4760
LNODAGHDUMMY	0.008970	0.037682	0.238035	0.8139

R-squared	0.618663	Mean dependent var	0.019606
Adjusted R-squared	0.316771	S.D. dependent var	0.024513
S.E. of regression	0.020262	Akaike info criterion	-4.657183
Sum squared resid	0.009853	Schwarz criterion	-3.846188
Log likelihood	122.4580	Hannan-Quinn criter.	-4.356427
F-statistic	2.049286	Durbin-Watson stat	1.837691
Prob(F-statistic)	0.048931		

C-Eviews output for Nigeria

ARDL Long Run Form and Bounds Test
Dependent Variable: D(LNESNGA)
Selected Model: ARDL(1, 1, 1, 1, 1)
Case 3: Unrestricted Constant and No Trend
Date: 05/20/21 Time: 02:50
Sample: 1970 2016
Included observations: 45

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-3.400069	4.192100	-0.811066	0.4237
LNESNGA(-1)*	-1.351033	0.201927	-6.690697	0.0000
LNC02NG(-1)	0.678007	0.484078	1.400614	0.1716
LNEMING(-1)	-0.562604	0.281990	-1.995117	0.0552
LNHCNG(-1)	-0.385143	0.217273	-1.772626	0.0864
D(LNODANG(-1))	-0.009889	0.106790	-0.092605	0.9268
D(LNC02NG)	0.520259	0.382060	1.361720	0.1834
D(LNEMING)	-0.525224	0.236309	-2.222614	0.0339
D(LNHCNG)	-0.293012	0.143750	-2.038339	0.0504
D(LNODANG, 2)	-0.035205	0.059827	-0.588439	0.5606
DUMMY	-5.892287	16.52380	-0.356594	0.7239
LNC02NGDUMMY	0.992227	3.031836	0.327269	0.7457
LNEMINGDUMMY	-0.565867	3.221181	-0.175671	0.8617
LNHCNGDUMMY	-0.610788	3.046822	-0.200467	0.8425
LNODANGDUMMY	-0.002484	0.076939	-0.032286	0.9745

* p-value incompatible with t-Bounds distribution.

Levels Equation
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.

LNC02NG	0.501843	0.335669	1.495054	0.1453
LNEMING	-0.416425	0.193152	-2.155947	0.0392
LNHCNG	-0.285073	0.150434	-1.895006	0.0678
D(LNODANG)	-0.007320	0.078743	-0.092957	0.9266

EC = LNESNGA - (0.5018*LNC02NG -0.4164*LNEMING -0.2851*LNHCNG
-0.0073*D(LNODANG))

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
			Asymptotic: n=1000	
F-statistic	10.22787	10%	2.45	3.52
k	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06
			Finite	
Actual Sample Size	45		Sample: n=45	
		10%	2.638	3.772
		5%	3.178	4.45
		1%	4.394	5.914

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-6.690697	10%	-2.57	-3.66
		5%	-2.86	-3.99
		2.5%	-3.13	-4.26
		1%	-3.43	-4.6

ARDL Error Correction Regression
Dependent Variable: D(LNESNGA)
Selected Model: ARDL(1, 1, 1, 1, 1)
Case 3: Unrestricted Constant and No Trend

Date: 05/20/21 Time: 03:26
Sample: 1970 2016
Included observations: 45

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-3.400069	0.451029	-7.538475	0.0000
D(LNC02NG)	0.520259	0.221813	2.345483	0.0258
D(LNEMING)	-0.525224	0.181218	-2.898300	0.0069
D(LNHCNG)	-0.293012	0.109166	-2.684103	0.0117
D(LNODANG, 2)	-0.035205	0.038573	-0.912683	0.3687
DUMMY	-5.892287	13.20662	-0.446161	0.6587
LNC02NGDUMMY	0.992227	2.534694	0.391458	0.6982
LNEMINGDUMMY	-0.565867	2.679959	-0.211147	0.8342
LNHCNGDUMMY	-0.610788	2.583158	-0.236450	0.8147
LNODANGDUMMY	-0.002484	0.049062	-0.050631	0.9600
CointEq(-1)*	-1.351033	0.177464	-7.613011	0.0000

R-squared	0.705728	Mean dependent var	0.029195
Adjusted R-squared	0.619178	S.D. dependent var	0.265534
S.E. of regression	0.163863	Akaike info criterion	-0.570982
Sum squared resid	0.912940	Schwarz criterion	-0.129353
Log likelihood	23.84709	Hannan-Quinn criter.	-0.406347
F-statistic	8.153950	Durbin-Watson stat	2.006912
Prob(F-statistic)	0.000002		

* p-value incompatible with t-Bounds distribution.

F-Bounds Test   Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	10.22787	10%	2.45	3.52
k	4	5%	2.86	4.01
		2.5%	3.25	4.49
		1%	3.74	5.06

t-Bounds Test   Null Hypothesis: No levels relationship

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-7.613011	10%	-2.57	-3.66

5%	-2.86	-3.99
2.5%	-3.13	-4.26
1%	-3.43	-4.6

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.301900	Prob. F(2,28)	0.7418
Obs*R-squared	0.949907	Prob. Chi-Square(2)	0.6219

Test Equation:
Dependent Variable: RESID
Method: ARDL
Date: 05/20/21 Time: 03:29
Sample: 1972 2016
Included observations: 45
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNESNGA(-1)	0.252866	0.447436	0.565144	0.5765
LNC02NG	-0.048496	0.396664	-0.122259	0.9036
LNC02NG(-1)	-0.208856	0.436687	-0.478272	0.6362
LNEMING	0.015257	0.245441	0.062162	0.9509
LNEMING(-1)	0.123632	0.312461	0.395671	0.6953
LNHCNG	-0.000687	0.148193	-0.004633	0.9963
LNHCNG(-1)	0.103223	0.230912	0.447025	0.6583
D(LNODANG)	0.009857	0.062572	0.157526	0.8760
D(LNODANG(-1))	0.007273	0.079642	0.091322	0.9279
DUMMY	2.718224	17.47148	0.155581	0.8775
LNC02NGDUMMY	-0.610339	3.247683	-0.187931	0.8523
LNEMINGDUMMY	0.621998	3.450928	0.180241	0.8583
LNHCNGDUMMY	0.631829	3.279158	0.192680	0.8486
LNODANGDUMMY	-0.005353	0.079278	-0.067525	0.9466
C	1.883548	4.962237	0.379576	0.7071
RESID(-1)	-0.270941	0.454988	-0.595490	0.5563
RESID(-2)	0.199701	0.270911	0.737145	0.4672

R-squared	0.021109	Mean dependent var	-2.96E-15
Adjusted R-squared	-0.538257	S.D. dependent var	0.144044
S.E. of regression	0.178653	Akaike info criterion	-0.325650
Sum squared resid	0.893669	Schwarz criterion	0.356867
Log likelihood	24.32713	Hannan-Quinn criter.	-0.071215
F-statistic	0.037737	Durbin-Watson stat	1.998361
Prob(F-statistic)	1.000000		

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.668129	Prob. F(14,30)	0.1171
Obs*R-squared	19.69721	Prob. Chi-Square(14)	0.1400
Scaled explained SS	5.881983	Prob. Chi-Square(14)	0.9694

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 05/20/21 Time: 03:30
Sample: 1972 2016
Included observations: 45

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.021334	0.519027	0.041105	0.9675
LNESNGA(-1)	-0.014963	0.025001	-0.598491	0.5540
LNC02NG	-0.039659	0.047303	-0.838409	0.4084
LNC02NG(-1)	0.048029	0.038517	1.246948	0.2221
LNEMING	0.022295	0.029258	0.762028	0.4520
LNEMING(-1)	-0.010566	0.031770	-0.332587	0.7418
LNHCNG	0.021745	0.017798	1.221781	0.2313
LNHCNG(-1)	-0.017316	0.022148	-0.781802	0.4405
D(LNODANG)	0.002191	0.007407	0.295749	0.7695
D(LNODANG(-1))	0.016401	0.009548	1.717628	0.0962
DUMMY	-3.869363	2.045825	-1.891346	0.0683
LNC02NGDUMMY	0.744070	0.375374	1.982208	0.0567
LNEMINGDUMMY	-0.785600	0.398817	-1.969825	0.0582
LNHCNGDUMMY	-0.743271	0.377229	-1.970342	0.0581
LNODANGDUMMY	-0.014004	0.009526	-1.470099	0.1519

R-squared	0.437716	Mean dependent var	0.020288
Adjusted R-squared	0.175317	S.D. dependent var	0.023783
S.E. of regression	0.021598	Akaike info criterion	-4.571205
Sum squared resid	0.013995	Schwarz criterion	-3.968985
Log likelihood	117.8521	Hannan-Quinn criter.	-4.346704
F-statistic	1.668129	Durbin-Watson stat	2.370239
Prob(F-statistic)	0.117074		

Impact of COVID-19 on Electricity Supply-Demand in West-Africa

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Abstract

COVID-19 has been an unprecedented situation that disrupted the stability of many socio-economic dynamics all over the world and in particular on the energy sector in West-Africa. This study seeks to provide technical based analysis to inform policy decision-making and experts in the sector on how the pandemic impacted the countries in the region and actions to reduce vulnerability. This study analyses the impact of COVID-19 on Electricity Supply-Demand in Benin, Togo, Côte d'Ivoire, Senegal and Niger using both quantitative and qualitative data. The latter is based on semi-structured interviews targeting power utilities in these countries. A comparative assessment is conducted between the observed consumption and forecasted in 2020. Advanced forecasting methods with machine learning algorithms are explored including ARIMA, Prophet, ETS, TBATS, NNAR, GLMNET, Random Forest and hybrid ones which are regressed with climatic factors (temperature, humidity and solar radiation) and calendar effect (working days). The best models after the performance evaluation are the NNAR and GLMNET which show good measure compared to others. The assessment shows globally that despite the pandemic the demand has risen above forecast averaging 3.28%. Three distinct periods can be discerned from the time series: a pre-COVID where the demand rose in all countries, and slowed down as the pandemic intensified (in COVID period) and the post COVID period where the consumption rose up back as a result of the release of restriction measures (economic recovery). From one country to another, the recovery time can be longer or shorter.

Keywords:
COVID-19, time series forecasting, West-Africa, electricity, machine learning

1.0 INTRODUCTION

In December 2019, a cluster of pneumonia cases, caused by a newly identified β-coronavirus, occurred in Wuhan, China (Yan-Rong Guo et al., 2020). On 30th January 2020, the WHO (World Health Organisation) declared the Chinese outbreak of COVID-19 to be a Public Health Emergency of International Concern (WHO, 2020). Many measures such as quarantine, social distancing and lockdown have been set to mitigate the coronavirus infection (Rochelle P. Walensky & Carlos del Rio, 2020). This involved not only the forced quarantine of the population, closing of schools and churches, shops, bar, restaurants, retail shops, but also shut down of national and international flights, closure of non-essential ports and airports and non-essential firms and industries (Ghiani et al., 2020)in Italy, there is an ongoing pandemic of coronavirus disease 2019 (COVID-19. These changes in population activities have a direct impact on all sectors including energy consumption. According to the International Energy Agency (IEA) (2020), countries in full lockdown are experiencing an average 25% decline in energy demand per week and countries in partial lockdown an average 18% decline. The energy system has seen a rapid and steady decline in electricity demand; this situation is compared to an "extended Sunday" (IEA, 2020).

Energy plays a central role in responding to emergencies such as the COVID-19 pandemic, from ensuring adequate healthcare services to supporting households during lockdowns (Broto and Kirshner, 2020). According to the IEA, the residential sector accounts for over 25% of global electricity consumption. With the COVID-19 pandemic, most commercial and professional services are shifting to homes. While this shift impacts on lower electricity consumption in the commercial and public services sector, a shift in the location of such services to residences may have impacted on a surge in residential electricity use for various energy services (Edomah & Ndulue, 2020).

The power sector has a vital role to play in ensuring the resilience of societies in their response to COVID-19, in driving the recovery of economies and stimulating socio-economic development (Boulle & Dane, 2020). In the path toward meeting the Sustainable Development Goals (SDG) 7, learning from this unprecedented situation and building a resilient power system to an extreme period like this one, is a necessity for sustainable development. Therefore, a clear diagnosis of the response of power utilities of the region against this pandemic and its impacts will elucidate the difficulties elucidate the difficulties on one hand. And on the other hand, identify opportunities and help in formulating appropriate measures to address the situation.

Many studies have discussed the impact of the pandemic on the energy sector using multiple approaches like bottom-up and top-down analysis. The bottom-up research approach has been implemented by studying the effects of the pandemic on power systems in several countries, such as the United States (Agdas & Barooah, 2020), China (Norouzi et al., 2020), Italy (Ghiani et al., 2020), Spain (Santiago et al., 2021), Canada (Abu-Rayash & Dincer, 2020), India (Aruga et al., 2020), Sweden (Kanda & Kivimaa, 2020), and Finland (Navon et al., 2021). The top-down research efforts include new forecasting methods(Y. Chen et al., 2020), long-term business impacts (Paaso et al., 2020), the general effects of fast economic transitions (Kanda and Kivimaa, 2020), possible uses of machine-learning technologies (Wang et al., 2020), and the challenges related to the changing energy mix(Navon et al., 2021).In Africa, Andrade et al., (2020) explored the preliminary impacts caused by the COVID-19 pandemic in the South African electricity sector using seven weeks of data.

The results show the severe drops in electricity consumption and peak demand, which reached 28.1% and 20.2%, respectively. Another study done in Lagos, Nigeria by Edomah and Ndulue (2020) on the impact of COVID-19 electricity consumption on residential, commercial, and industrial sectors, shows that the industrial electricity consumption decreased by 24% and 18% under partial and total lockdown scenarios, respectively. The study of Edomah and Ndulue (2020) used a short time series data (five weeks during the lockdown period) to evaluate the impact of the COVID-19 on the electricity consumption, which is not robust to quantify the impact. In addition, their study is done at a local scale and not at national scale. An important question is how these disruptive shifts in the energy sector imposed by the COVID-19 pandemic will affect the West African region. Therefore, there is a need to provide information at national level for different West Africa countries using a large dataset with new approaches.

The paper aims to assess the impact of COVID-19 on the electricity consumption in five different countries namely Benin, Senegal, Niger, Cote d'Ivoire and Togo. We used a new machine learning algorithm to forecast the electricity consumption for different countries and compare with the electricity consumption during the year 2020. Moreover, the paper provides detailed information on the impacts of the COVID-19 on the balance of power supply-demand from different power utilities. The following section presents the data and mehtod used, while the results and discussions are in Section 3. The concluding remarks are presented in Section 4.

2.0 DATA AND METHODOLOGY

A comprehensive multi-approach was adopted in order to answer our research questions and infer the impact of COVID-19 on the power sector in the region. Given that, qualitative and quantitative data are collected. Quantitative data concerned electricity consumption and weather data to qualitatively assess the impact of the pandemic on a country's electricity consumption through time-series forecasting. Whereas qualitative data are semi structured interviews, helping to understand more in-country measures during the pandemic to meet the demand. This study was conducted in five countries namely Benin, Senegal, Côte d'Ivoire, Togo, and Niger in West-Africa countries with a direct interaction with countries main power utility.

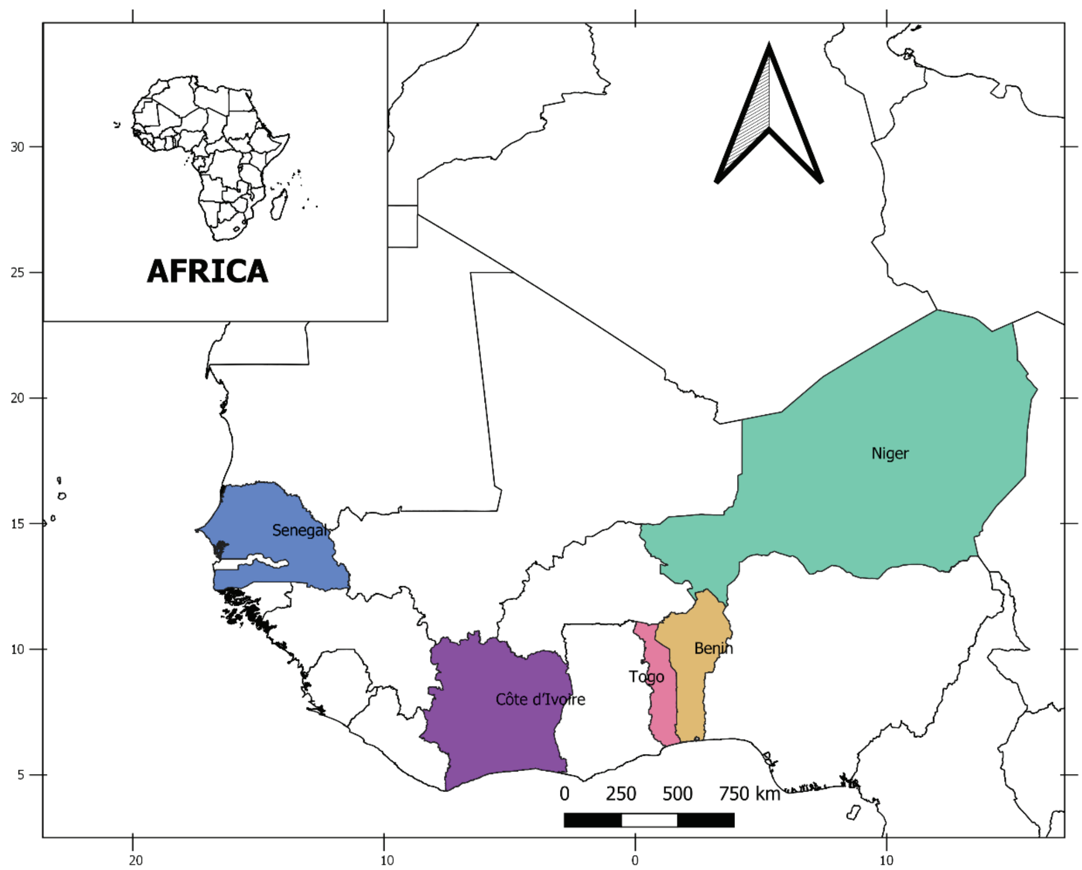

Figure 1: Study areas map: Countries of study highlighted

2.1 Data

Electricity demand is significantly affected by nonlinear factors and in electricity consumption forecasting the main factors that affect the accuracy of forecast are deterministic variables and weather variables. This includes climatic condition, calendar and other seasonality variables which have been widely reported in the literature (Chapagain et al., 2020; Chapagain & Kittipiyakul, 2018). Under West-Africa region and in literature as a whole, studies demonstrated that weather parameters such as: temperature, solar radiation and relative humidity have a considerable effect on the electricity consumption (Bonkaney, 2020; Friedrich & Afshari, 2015).

Given the sparse weather observation data over the region, spatial weather parameters data are retrieved from the latest climate reanalysis produced by European Centre for Medium-Range Weather Forecasts (ECMWF), the 5th generation of European ReAnalysis (ERA5). ERA5 is produced within the Copernicus Climate Change Service of the European Commission. It is widely used for many climate impact studies in West-Africa as they have demonstrated good performance to bridge data gaps (Danso et al., 2020; Sawadogo et al., 2020; Sterl et al., 2020)and knowing the best location for the implementation of solar and wind energy projects is important within this context. The purpose of this study is to assess the impact of climate change on solar and wind energy potential over Africa under low end (RCP2.6. ERA5 climate reanalysis, a numerical description of the recent climate by combining models with observations and are invaluable to numerous users around the world. It embodies a detailed record of the global atmosphere, land surface and ocean waves from 1950 onwards. ERA5 is based on the Integrated Forecasting System (IFS) Cy41r2 which was operational in 2016 (Hersbach et al., 2020)ECMWF is producing the ERA5 reanalysis which, once completed, will embody a detailed record of the global atmosphere, land surface and ocean waves from 1950 onwards. This new reanalysis replaces the ERA-Interim reanalysis (spanning 1979 onwards.

Calendar effects are captured by creating a dummy variable where special days such as holidays were considered as week-end. The dummy variable takes value 1 corresponding to "yes - normal working days" and 0 corresponding to "no-weekend or public holidays". Table 1 below summaries the data collected and sources.

Table 1: Weather and energy data collected

Type of data	Spatial Resolution	Time range	Temporal Resolution	Source
Weather parameters:				https://cds.climate.copernicus.eu/c
Solar radiation (RSDS)	Country wide	2017:2020	Hourly	
Relative Humidity (RH)	Country wide		Hourly	
Temperature (°C)	Country wide		Hourly	

Electricity consumption	Spatial Resolution	Time range	Temporal Resolution	Source
Load			Hourly	SBEE: Beninese Company of Electrical Energy
Load			Hourly	CEET: Togo Electric Energy Company
Electricity consumption	Country aggregation	2017:2020	Daily	SENELEC: National Electricity Company of Senegal
Electricity consumption			Daily	CIE: Ivorian Electricity Company
Load			Hourly	NIGELEC: Nigerien Electricity Company
Semi-structed interviews				SBEE, CEET, SENELEC, CIE, NIGELEC
Public Holidays (Wday)				Literature

The semi-structured interviews consists of a series of questions around four sections including Impacts, Challenges, Opportunities and Perspectives to better understand the response and strategies of West-African power companies during the early period of coronavirus (pre-vaccine).

2.2 Methodology

Electricity consumption forecasting implies the use of various approach ranging from simple regression to complex and modern ones where some are based on machine learning algorithm. In order to have the best model for each forecasting exercise per country, this paper tested the performance of nine models to predict historical electricity consumption regressed with climatic variables (air temperature, relative humidity, and solar radiation) and calendar effect. These models can be divided in three categories: automatic, Machine Learning and hybrid Machine Learning.

2.2.1 Automatic Models

2.2.1.1 ARIMA

Auto Regressive Moving Average (ARIMA) is an adaptation of time filtering methods developed in the 1930's — 1940's by electrical engineers. Later in the 1970's, two statisticians George Box and Gwilym Jenkins developed a systematic method for applying them in business and economic data. This model assumes that the time series is generated from a linear process. But in real world phenomena, systems are nonlinear pretty often (Benrhmach et al., 2020). These models predict time series' future values based on a linear combination of its previous values and disturbances (Kalimoldayev et al., 2020). The ARIMA model with parameters p (the autoregressive order or the lag of the model), d (the integration or differencing order), q (the moving average order) with additional regressors fit an equation:

$$\hat{y}_t - \varphi_1 y_{t\_1} - \dots - \varphi_p y_{t\_p} = \mu - \theta_1 e_{t\_1} - \dots - \theta_q e_{t\_q} + \beta^1(x^1_t - \varphi_1 x^1_{t-1} - \dots - \varphi_p x^1_{t-p}) + \dots + \beta^n(x^n_t - \varphi_1 x^n_{t-1} - \dots - \varphi_p x^n_{t-p}) \qquad \text{Eq. 1}$$

where ◂ is the constant, φk and θk are the AR and MA coefficients at lag k, and $y_t - k$ and $e_t - k = y_t - k - \hat{y}_t - k$ the values of the dependent variable and of the forecast error at lag k, respectively. N represents the number of exogenous variables, β^i is every constant and x^i_{t-k} is indicator i at lag k (Robert Nau, 2021).

2.2.1.2 TBATS

TBATS is an alternative to autoregressive approach developed by De Livera, H yndman, & Snyder (2011) which uses a combination of Fourier terms with an exponential smoothing state space model and a Box-Cox transformation, in a completely automated manner for univariate data. TBATS constitutes the following elements: Trigonometric terms for seasonality, B: Box-Cox transformations for heterogeneity, A: ARMA errors for short-term dynamics, T: Trend and S: Seasonal (including multiple and non-integer periods). The general representation of TBATS model Eq. 2, includes level Eq. 3, trend Eq. 4, seasonal Eq. 5, ARMA error term Eq. 6 :

$$y_t^{(w)} = l_{t-1} + \phi\, b_{t-1} + \sum_{i=1}^{T} s_t^{(i)} + d_t \quad \text{Eq. 2}$$

$$l_t = l_{t-1} + \phi b_{t-1} + \alpha d_t \quad \text{Eq. 3}$$

$$b_t = (1-\phi)b + \phi b_{t-1} + \beta dt \quad \text{Eq. 4}$$

$$s_t^{(i)} = s_{j,t-1}^{(i)} + \cos\lambda\, s_j^{(i)} \quad + \sin\lambda\, s_j^{(i)} + y_i\, d_t \quad \text{Eq. 5}$$

$$d_t = \sum_{p-1}^{p} \varphi_i\, d_{t-i} + \sum_{p-1}^{p} \theta_i\, \varepsilon_{t-i} + \varepsilon_t \quad \text{Eq. 6}$$

Here $y_t^{(w)}$ is Box-Cox transformed observations at time t with the parameter ω; l_t is the local level at time t; b is the long-run trend; b_t is the short-term trend at time t; seasonal periods; s_t^i isith seasonal component of the series at time t; d_t is an ARMA(p, q) error process; ε_t is the Gaussian white-noise process with zero mean and constant variance; α, β, γ_i are smoothing parameters; ϕ is damped parameter; $s_{j,t-1}^{(i)}$ is the stochastic level; k_i is the number of harmonics for the ith seasonal component, λs_j^i=2■j/mi where m_i is period of the ith seasonal cycles (Benrhmach et al., 2020; de Livera et al., 2011).

2.2.1.3 Multiple Seasonality Regression Models - Exponential Smoothing (ETS) Model

ETS refers to Error, Trend and Seasonal. ETS is an Exponential Smoothing Model technique based on the methods described by Hyndman et al. and is made available through the forecast package in the R software environment (Rob J. Hyndman & Yeasmin Khandakar, 2008). The seasonal component can be either which can be additive (A), multiplicative (M), or none (N). The optimum model method between the additive and multiplicative error models, was chosen based on either the minimum of Akaike information criterion (AIC), the corrected Akaike information criterion (AICc), or Bayesian information criterion (BIC) (Liu et al., 2020; Rob J. Hyndman & Yeasmin Khandakar, 2008). The general model involves a state vector and state space equations of the form

$$y_t = w(x_{(t-1)}) + r(x_{(t-1)})\varepsilon_t \quad \text{Ep 7}$$

$$x_t = f(x_{(t-1)}) + g(x_{(t-1)})\varepsilon_t \quad \text{Ep 8}$$

where $\{\varepsilon_t\}$ is a Gaussian white noise process with mean zero and variance σ^2, and ◂t = $w(x_{t-1})$. The model with additive errors has $r(x_{t-1}) = 1$, so that y_t = $◂_t + \varepsilon_t$. The model with multiplicative errors has $r(x_{t-1})$ = ◂t, so that yt = ◂t$(1 + \varepsilon_t)$. Thus, $\varepsilon_t = (y_t - ◂_t)/◂_t$ is the relative error for the multiplicative model. The models are not unique. Clearly, any value of $r(x_{t-1})$ will lead to identical point forecasts for y_t (Rob J. Hyndman & Yeasmin Khandakar, 2008).

2.2.1.4 Prophet Model

The Prophet Model implements a procedure for forecasting time series data based on an additive model where non-linear trends are fit with yearly, weekly, and daily seasonality, plus holiday effects. It works best with time series that have strong seasonal effects and several seasons of historical data. Prophet is robust to missing data and shifts in the trend, and typically handles outliers well (Taylor & Letham, 2018). It can be implemented in open source software such as Python and R, called Prophet. They are combined in the following equation:

$$y(t) = g(t) + s(t) + h(t) + \varepsilon_t. \quad \text{Eq. 9}$$

Here g(t) is the trend function which models non-periodic changes in the value of the time series, s(t) represents periodic changes (e.g., weekly and yearly seasonality), and h(t) represents the effects of holidays which occur on potentially irregular schedules over one or more days. The error term represents any idiosyncratic changes which are not accommodated by the model; later we will make the parametric assumption that is normally distributed (Taylor & Letham, 2018).

2.2.2 Machine Learning Models

2.2.2.1 NNAR

Neural networks are a kind of statistical model, popularly used in machine learning. The concept of Artificial Neural Network (ANN) is inspired from the biological neural network of the central nervous system (Panigrahi & Behera, 2017)a large literature has evolved to forecast time series using various linear, nonlinear and hybrid linear–nonlinear models. Recently, hybrid models by suitably combining linear models like autoregressive integrated moving average (ARIMA. Neural Network Auto Regressive (NNAR) is one kind of ANN's in which lagged values of the time series can be used as inputs to a neural network (Sena & Nagwani, 2016). In this article, we only consider feed-forward networks with one hidden layer, and we use the notation NNAR (p,k) to indicate there are p lagged inputs and k nodes in the hidden layer. A NNAR(p,0) model is equivalent to an ARIMA(p,0,0) model, but without the restrictions on the parameters to ensure stationarity. With seasonal data, it is useful to also add the last observed values from the same season as inputs. More generally, an $NNAR(p,P,k)_m$ model has inputs $(y_{t-1},y_{t-2},\ldots,y_{t-p},y_{t-m},y_{t-2m},\ldots,y_{t-Pm})$ and k neurons in the hidden layer. A $NNAR(p,P,0)_m$ model is equivalent to an $ARIMA(p,0,0)(P,0,0)_m$ model but without the restrictions on the parameters that ensure stationarity. For seasonal time series, the default values are P=1 and p is chosen from the optimal linear model fitted to the seasonally adjusted data. If k is not specified, it is set to k=(p+P+1)/2 (rounded to the nearest integer) (Rob J Hyndman and George Athanasopoulos, 2018). The NNETAR () function in R package forecast fits an $NNAR(p,P,k)_m$ model.

2.2.2.2 Generalized Linear Model Elastic Net (GLMNET)

The elastic net procedure is a form of regularized optimization for linear regression that provides a bridge between ridge regression and the lasso. The estimate that it produces can be viewed as a Bayesian posterior mode under a prior distribution implied by the form of the elastic net penalty (Hans, 2011). The Elastic Net (ENET) uses a mixture of the l1 (lasso) and l2 (ridge regression) penalties and can be formulated as:

$$\widehat{\boldsymbol{\beta}}(\text{ enet }) = \left(1+\frac{\lambda_2}{n}\right)\left\{\underset{\boldsymbol{\beta}}{\operatorname{argmin}} \parallel \mathbf{y}-\mathbf{X}\boldsymbol{\beta} \parallel_2^2 + \lambda_2 \parallel \boldsymbol{\beta} \parallel_2^2 + \lambda_1 \parallel \boldsymbol{\beta} \parallel_1\right\} \quad \text{Eq. 10}$$

On setting α=λ2/(λ1+λ2), the ENET estimator Eq. 7 is seen to be equivalent to the minimizer of:

$$\widehat{\boldsymbol{\beta}}(\text{ enet 2}) = \underset{\boldsymbol{\beta}}{\operatorname{argmin}} \parallel \mathbf{y}-\mathbf{X}\boldsymbol{\beta} \parallel_2^2 \text{ , subject to } P_\alpha(\boldsymbol{\beta}) = (1-\alpha) \parallel \boldsymbol{\beta} \parallel_1 + \alpha \parallel \boldsymbol{\beta} \parallel_2^2 \leq s,$$

for some where P α (β) is the Elastic Net penalty (Hans, 2011; Ogutu et al., 2012; Zou & Hastie, 2003).

2.2.2.3 Random Forest

Random Forest (RF) is a machine learning method for classification and regression. This modeling approach uses an ensemble of decision trees {h X_k (, , 1,... β_k) = } for mapping a relationship between a vector of predictors and dependent variables. For each tree, X is the input vector, βk is an independent stochastic variable which decides the growth of every tree (Jiang et al., 2019). Tree predictors such that each tree depends on the values of a random vector sampled independently and with the same distribution for all trees in the forest. The generalization error for forests converges to a limit as the number of trees in the forest becomes large. (BREIMAN, 2001). Statistically, Random Forests are appealing because of the additional features they provide such as measures of variable importance, differential class weighting, missing value imputation, visualization, outlier detection and unsupervised learning (Cutler et al., 2012).

2.2.3 Hybrid Models

We have included two hybrid models (arima_boost() and prophet_boost()) that combine both automated algorithms with the machine learning algorithm XGBoost. In the case of The Prophet Boost algorithm combines Prophet with XGBoost to get the best of both worlds. The algorithm works by firstly modeling the univariate series using Prophet and then using regressors supplied via the preprocessing recipe which generate new features, and regressing the Prophet Residuals with the XGBoost model. The model can be created using the fit() function using the following engines: "prophet_xgboost" (default) - Connects to prophet::prophet() and xgboost::xgb.train() which is implemented in the R package Modeltime (T. Chen et al., 2018; Dancho, 2021).

We used XGBoost, a gradient boosting framework, introduced back in 2014. XGBoost can be used as a forecasting technique for feature selection and load prediction of a time lag. From prediction to classification XGBoost has proved its worth in terms of performance (Barolli, 2019).

2.3. Evaluation metrics - Model Adequacy and forecast accuracy

Best of models per country was selected based on the one that minimized as much as possible the error and had an accurate forecast on testing period. Therefore, various metrics were computed including Root Mean Squared Error (RMSE), the Mean Absolute Error (MAE), Mean Absolute Scaled Error (MASE) and R-squared for model adequacy. The RMSE and MAE measures the average magnitude error between the model outputs and the observations. The RMSE value indicates larger differences, while the MAE does not introduce weighting and gives the sign of the error. The smaller the RMSE, the better the performance of the models (Rivera & Arnould, 2020).

Hyndman and Koehler (2006) recommend that the Mean Absolute Scaled Error (MASE) be the standard when comparing forecast accuracies in which the forecast error is scaled by the in-sample mean absolute error obtained using the naïve forecasting method. This new measure is also easily interpretable: values of MASE greater than one indicates that the forecasts are worse, on average, than in-sample one-step forecasts from the naïve method. For the model fit we need to check significance of the coefficients, overall model adequacy and stability, correspondence to the model assumptions: no serial correlation, homoscedasticity and normal distribution of residuals. The model adequacy is estimated on the basis of residual standard error (σ2), coefficient of determination (R^2) that refers to the percentage of target variable variance explained by the model (Kalimoldayev et al., 2020). The metrics equations are presented below:

$$MAE = \frac{1}{m}\sum_{i=1}^{m} |f(i) - y(i)| * 100\,\% \qquad \textit{Eq. 11}$$

$$RMSE = \sqrt{\frac{1}{M} + \sum_{i=1}^{m} (f(i) - y(i))^2} \qquad \textit{Eq. 12}$$

$$q_t = \frac{e_t}{\frac{1}{n-1}\sum_{i=2}^{n} |Y_i - Y_{i-1}|} \text{ and MASE = mean } (|q_t|) \qquad \textit{Eq. 13}$$

$$R^2 = \left[1 - \frac{\frac{1}{n}\sum_{i=1}^{n} (y_t - \hat{y}_t)^2}{\text{var}\,(y)}\right] \times 100 \qquad \textit{Eq. 14}$$

Let Y_t denote the observation at time t and F_t denote the forecast of Y_t. Then define the forecast error $e_t = Y_t - F_t$ (Hyndman & Koehler, 2006; Shaub, 2020).

To evaluate the prediction accuracy, the historical electricity consumption data were split into two. Models were trained over two years (2017-2018) and testing on 2019 respectively

(Figure 2). The performance metrics were calculated on the test set to get an unbiased estimation of the best model performance. The Tidymodels Extension for Time Series Modeling "Modeltime" package on its version 0.7.0 is used in R open source software for the data processing (Dancho, 2021).

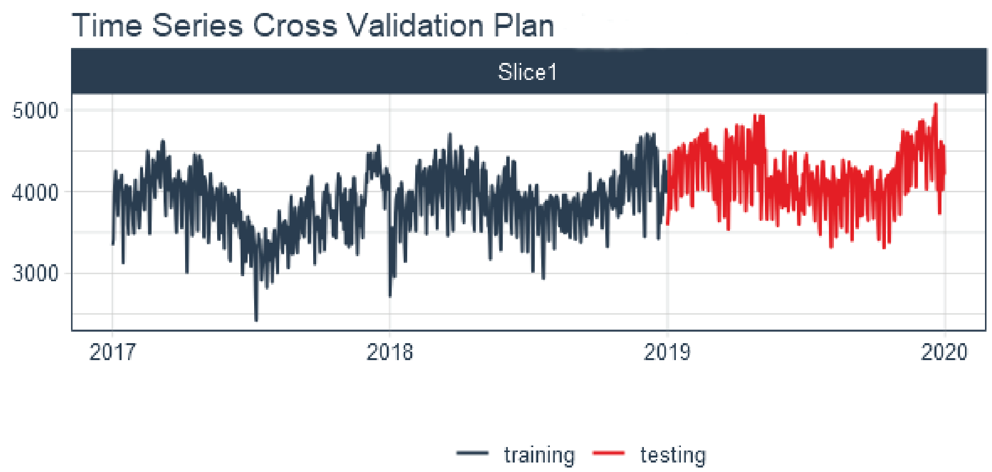

Figure 2: Time series cross validation - Training and testing period
Results and Discussions

Seasonal load profile is shown in Figure 4 for each of the countries over the years - a monthly average of three years data from 2017-2019 representing the training period. Daily energy electricity consumption is obtained by summing hourly load profiles.

Benin, Togo and Cote d'Ivoire had the same electricity consumption pattern. It was characterized by two peaks in the early period of the year during the month of March and later one during the month of December and lowest off-peak occurring during the month of August. The average daily energy consumption ranges respectively [2.87-5.1] GWh, [2.42 – 5.6] GWh and [17.37 – 32.27] GWh in Benin, Togo and Cote d'Ivoire. The seasonal pattern is consistent with the recent study of Kondi et al., (2019) on Weather Sensitivity of Electricity Demand in West African Megacities. This could be explained by the fact that Benin, Togo and Cote d'Ivoire share the same climatic zone (Figure 3) and therefore weather-based influence on electricity consumption of the population is the same. As a matter of fact, for the above countries, the temperature (TEMP), relative humidity (RH) and solar radiation (RSDS) follows the same pattern (Figure 5). In all cases, RH is an opposite of temperature whereas the RSDS has an opposite profile to RH in such a way that when RH is high, RSDS is low and reciprocally. Temperature range [25ﬄC-32ﬄC], the humidity [35 - 87] %, and solar radiation between [178 - 261] $W/m^2/day$. A perfect matching is found between the load consumption seasonal profile and the weather parameters positively for RSDS and temp or negatively for RH, correlation wise. RSDS and TEMP increases are followed by an increase of load while the opposite is observed for the relative humidity.

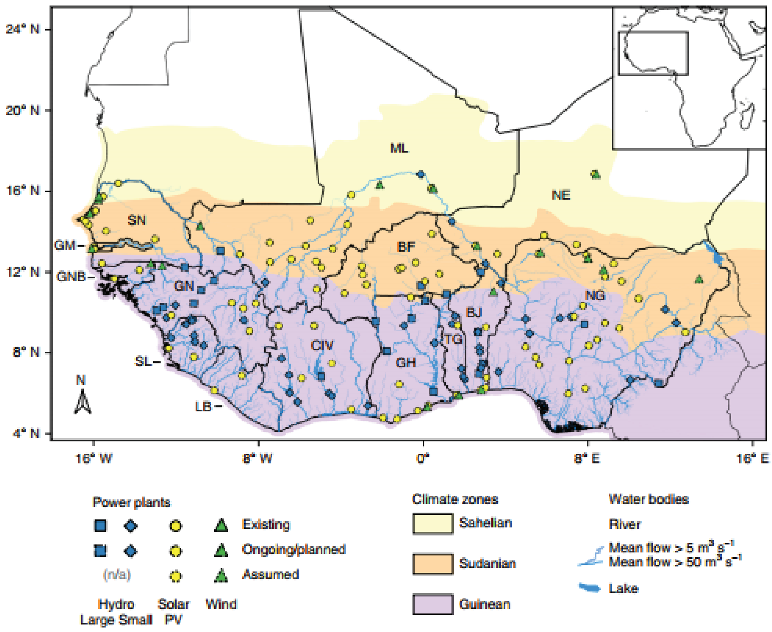

Figure 3:Climatic zones and power plants in West Africa, derived from (Sterl et al., 2020)

Niger and Senegal have distinct seasonal profiles compared to Benin, Cote d'Ivoire and Togo. Niger displays two peaks in its seasonal profile occurring respectively in May (2.79 GWh) and October (2.38 GWh) and the lowest in the months of December and January.

The temperature increases as we move northward to the Sahelian region. Hottest and coldest temperatures of all studied countries are observed in Niger ranging from 24.7 to 35.5 ﬄC (this value represent average mean temperature). The weather and electricity consumption pattern observed in the case of Niger match with the study of Bonkaney (2020)air temperature (T mean. In contrast, unlike the other countries of the study that depict two peaks, Senegal exhibits only one peak occurring in October with an average value of 13.56 GWh. The lowest consumption is observed in January with an average of 9.62 GWh.

As of the other countries, the same remark is observed for Niger and Senegal where the electricity consumption has positive correlation with temperature and radiation and negative correlation for the relative humidity.

Hence, for all the countries, the electricity consumption positively correlates with temperature and radiation and negatively with relative humidity. In a nutshell, we observed that load demand profile follows the weather seasonal trend and this trend varies depending on the climatic zone the countries mostly fall into. This explains why Benin, Cote d'Ivoire and Togo display the same seasonal pattern as they are in the same climatic zone (Guinea climatic zone) and Niger in Sahelian and Senegal in Soudanian zone have different pattern from those in Guinean Zone. See countries in their climatic zone (Figure 3).

As presented in the methodology, all the time-series forecasting models are multivariate and forced with regressors (RH, RSDS, TEMP and Wday) except for ETS and TBATS which are univariate models. The models are evaluated against each other on testing period (in the year 2019) and the best is selected based on the level of adequacy and forecast accuracy through minimizing error. The performance of regression models used differ from one country to the other.

Table 2 shows the results of the different performance metric computed for all the models. In Senegal, RF, Prophet, and GLMNET models are the best in fitting the electricity consumption and capturing as much as possible the variance on the observation with an R-squared of 81%,83% and 84% respectively. Except the ETS, TBATS and auto. ARIMA all the rest of models have a R-squared beyond 75%. Above all, the GLMNET model provides the least error with the lowest MASE of 1.82, which makes it the best model in forecasting 2020 electricity consumption without COVID-19 in Senegal.

In the case of Cote d'Ivoire, except the univariate based models which R-squared is below 25% the other models have reached a R-squared above 60%. Therefore, this shows that the considered predictors have significant impact on model estimation and explanation of the dependent variable. The GLMNET comes to be the best model while presenting the lowest error possible with MAE (37), RMSE (52) and best accuracy MASE (0.6) as shown in Table 2 compared to other models.

Regarding model's performance in capturing Niger electricity consumption in testing period, from Table 2, it can be observed that univariate models are under-performing with an R-squared nearly equal to 0 while the other have a good fitting above 0.85. NNAR, Prophet and GLMNET are the top models with an R-squared higher than 0.9. On the basis of the MAE, MASE and RMSE measures, NNAR Artificial intelligence model coefficients were low enough to outperform Prophet and GLMNET model with respectively 159.5, 1.34 and 195.13. Hence, the NNAR is used to model the electricity consumption in Niger with 10 neurons in the hidden layer with a weekly seasonality (NNAR (1,1,10) [7]).

In the case of Togo, regressed models outperformed univariate one (ETS and TBATS) with R-squared above 0.5 except NNAR of 0.43. As in Table 2 shows, in all cases, GLMNET model shows very good accuracy compared to others, as all the values are much lower in RMSE, MAE and MASE with an R-squared of 0.59. Finally, in the case of Benin, NNAR (1,1,10) [7] showed better performance both in predictive ability with highest R-squared of 0.67 and also in forecasting capabilities by minimizing the level of error.

From the above, it was found that for all the countries, the electricity consumption exhibits seasonality driven by climatic and calendar effects that have been taken into account in building the regressions models. Thus, the multivariate models outperform the univariate ones in west Africa. Furthermore, Generalized Linear Model Elastic Net (GLMNET) and Neural Network Auto-Regressive (NNAR) are the top models with good performances for forecasting electricity consumption in the countries considered. The seasonal profile difference and relative change between the observed and forecasted are shown in Figure 8 and Figure 9.

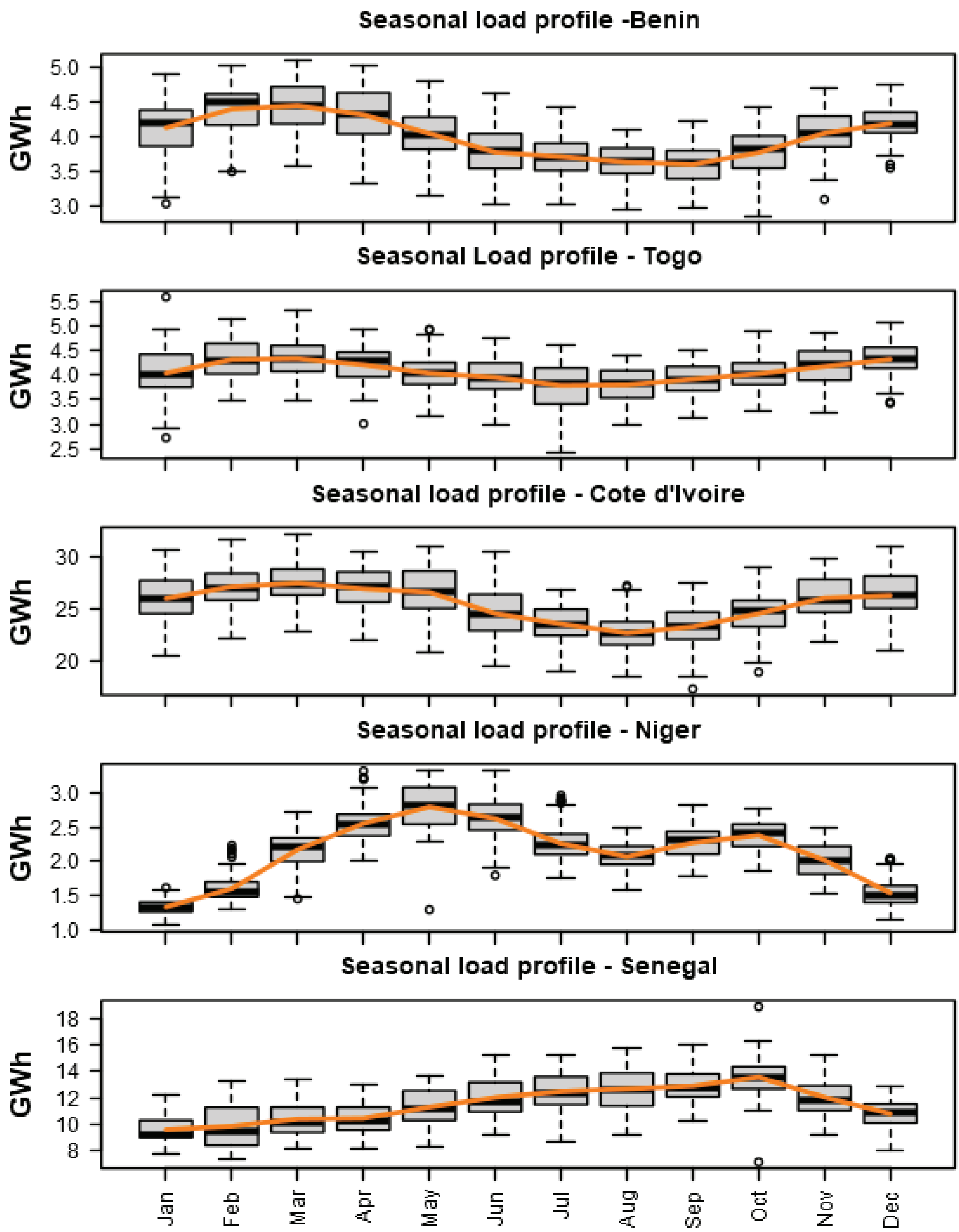

Figure 4: Seasonal daily energy load and consumption profile of countries

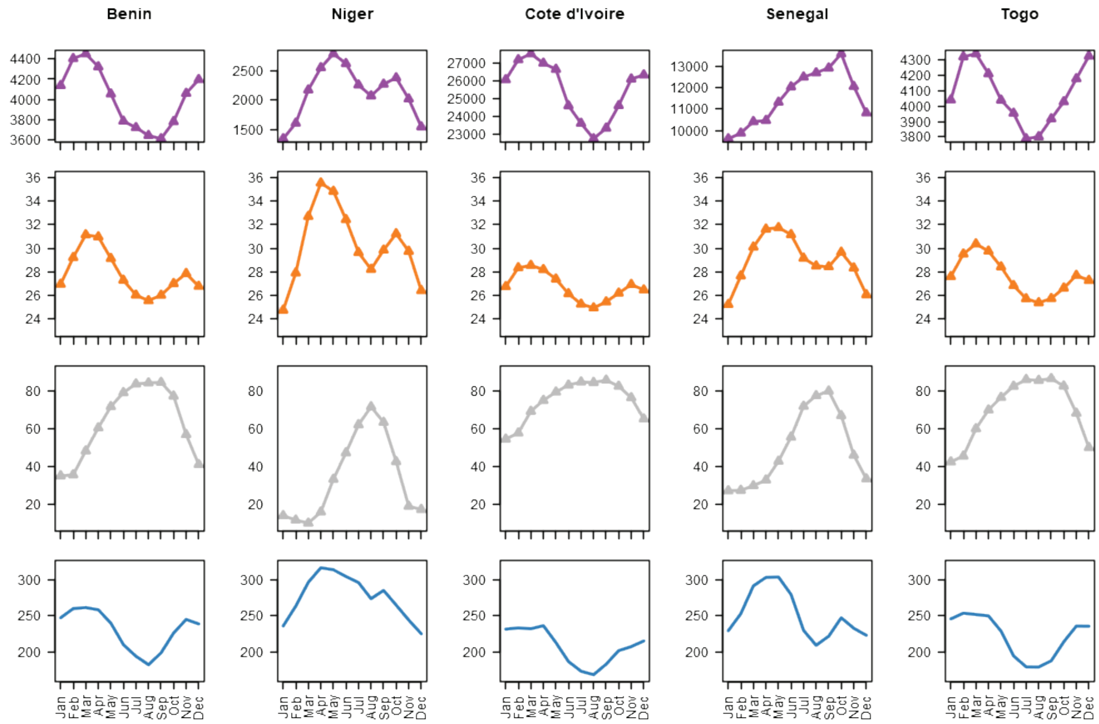

Figure 5: Seasonal electricity consumption profile against meteorological parameters, RSDS: surface downward solar radiation, TEMP: air mean temperature, RH: Relative Humidity. All parameters are monthly average from 2017-2019.

*Table 2: Accuracy table of model per country, * A part from Senegal which values are in kWh, for the other countries the statistical metrics are computed in MWh unit*

Accuracy table - SENEGAL *

.model_id	.model_desc	.type	mae	mase	rmse	rsq
1	REGRESSION WITH ARIMA(1,1,1)(1,0,1)[7] ERRORS	Test	2086417	3.96	2510997	0.03
2	PROPHET W/ REGRESSORS	Test	1491121	2.83	1604519	0.83
3	NNAR(1,1,10)[7]	Test	1442738	2.74	1603605	0.75
4	SEASONAL DECOMP: ETS(M,N,N)	Test	2012124	3.81	2415022	0.06
5	TBATS(0, {2,1}, -, {<7,3>})	Test	1927273	3.65	2334254	0.07
6	GLMNET	Test	957460.7	1.82	1065989	0.84
7	RANDOM FOREST	Test	1377272	2.61	1500802	0.81
8	PROPHET W/ XGBOOST ERRORS	Test	1238263	2.35	1368443	0.79
9	ARIMA(0,0,0) WITH NON-ZERO MEAN W/ XGBOOST ERRORS	Test	1353598	2.57	1494758	0.78

Accuracy table - Cote d'Ivoire

.model_id	.model_desc	.type	mae	mase	rmse	rsq
1	REGRESSION WITH ARIMA(3,1,2)(0,0,2)[7] ERRORS	Test	58.71	0.95	70.96	0.58
2	PROPHET W/ REGRESSORS	Test	44.6	0.72	57.81	0.77
3	NNAR(1,1,10)[7]	Test	76.8	1.24	86.18	0.77
4	SEASONAL DECOMP: ETS(M,N,N)	Test	83.21	1.35	97.37	0.2
5	TBATS(0, {2,1}, -, {<7,3>})	Test	84.17	1.36	98.68	0.22
6	GLMNET	Test	37.06	0.6	51.78	0.78
7	RANDOMFOREST	Test	70.38	1.14	81.48	0.72
8	PROPHET W/ XGBOOST ERRORS	Test	53.97	0.87	68.14	0.7

9	ARIMA(0,0,0) WITH NON-ZERO MEAN W/ XGBOOST ERRORS	Test	65.56	1.06	78.99	0.68
Accuracy table – Niger						
.model_id	.model_desc	.type	mae	mase	rmse	rsq
1	REGRESSION WITH ARIMA(1,0,2)(2,0,2)[7] ERRORS	Test	324.47	2.72	399.15	0.85
2	PROPHET W/ REGRESSORS	Test	352.95	2.96	394.73	0.92
3	NNAR (1,1,10)[7]	Test	159.5	1.34	195.13	0.96
4	SEASONAL DECOMP: ETS(M,N,N)	Test	879.29	7.37	1006.72	0.03
5	TBATS(0, {0,2}, 0.966, {<7,3>})	Test	965.79	8.1	1088.75	0
6	GLMNET	Test	217.97	1.83	250.14	0.94
7	RANDOMFOREST	Test	212.52	1.78	252.25	0.9
8	PROPHET W/ XGBOOST ERRORS	Test	288.4	2.42	322.53	0.89
9	ARIMA(0,0,0) WITH NON-ZERO MEAN W/ XGBOOST ERRORS	Test	214.26	1.8	254.35	0.89
Accuracy table – Togo						
.model_id	.model_desc	.type	mae	mase	rmse	rsq
1	REGRESSION WITH ARIMA(3,1,1)(2,0,0)[7] ERRORS	Test	199.68	0.74	254.94	0.51
2	PROPHET W/ REGRESSORS	Test	238.77	0.89	286.93	0.62
3	NNAR(1,1,10)[7]	Test	317.21	1.18	372.59	0.5
4	SEASONAL DECOMP: ETS(A,N,N)	Test	243.91	0.91	291.89	0.33
5	TBATS(1, {1,2}, -, {<7,3>})	Test	234.27	0.87	286.9	0.33
6	GLMNET	Test	197.2	0.73	241.83	0.59
7	RANDOMFOREST	Test	272.37	1.01	318.5	0.65
8	PROPHET W/ XGBOOST ERRORS	Test	263.26	0.98	317.41	0.56
9	ARIMA(0,0,0) WITH NON-ZERO MEAN W/ XGBOOST ERRORS	Test	219.18	0.81	275.31	0.6
Accuracy table – Benin						
.model_id	.model_desc	.type	mae	mase	rmse	rsq
1	REGRESSION WITH ARIMA(0,1,2)(0,0,2)[7] ERRORS	Test	494.85	2.13	584.43	0.57
2	PROPHET W/ REGRESSORS	Test	406.18	1.75	482.72	0.63
3	NNAR(1,1,10)[7]	Test	250.72	1.08	308.89	0.67
4	SEASONAL DECOMP: ETS (M,N,N)	Test	575.03	2.47	683.94	0.11
5	TBATS(1, {1,3}, -, {<7,3>})	Test	513.61	2.21	603.06	0.13
6	GLMNET	Test	378.06	1.63	453.4	0.63
7	RANDOMFOREST	Test	264.31	1.14	320.32	0.64
8	PROPHET W/ XGBOOST ERRORS	Test	376.33	1.62	457.38	0.52
9	ARIMA(0,0,0) WITH NON-ZERO MEAN W/ XGBOOST ERRORS	Test	266.22	1.14	327.34	0.64

Early cases of COVID-19 confirmed in 2020 were recorded in the beginning of February and start increasing to peak on the first wave in May and slow down a bit before taking an ascendant to peak in July (second wave of contamination) to reverse down through the end of year. This is due to the various restriction's measures put in place. As things are getting back to normal and the release of some restrictions, the contamination is peaking again in early 2021 and now experienced a decreasing rate in the mid-term part of 2021. Now with the new variant, the contamination is going up again (Figure 6). This sinusoidal pattern is also observed in overall confirmed cases in countries with some stagnant period of the year (Figure 7). Cote d'Ivoire and Senegal are the countries with the highest rate of cases confirmed followed by Togo, Benin and Niger on the last update of 23 July 2021 with 55861, 49386, 14970, 8324 and 5594 number of cases recorded respectively (Figure 7).

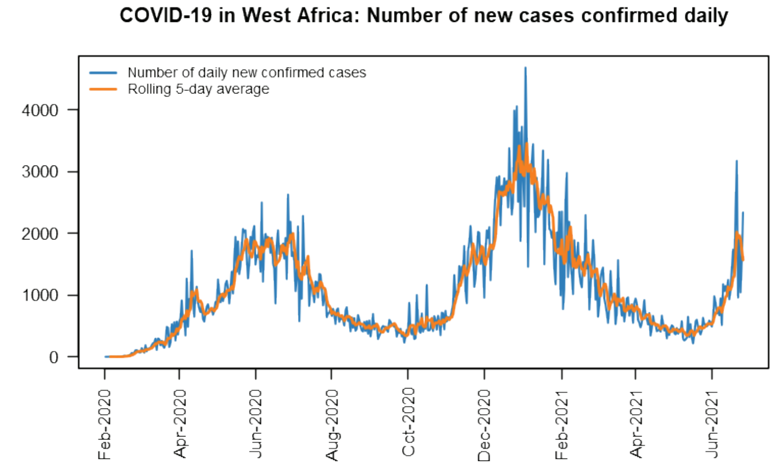

Figure 6: COVID-19 in West Africa, (Johns Hopkins University & Medicine, 2021)

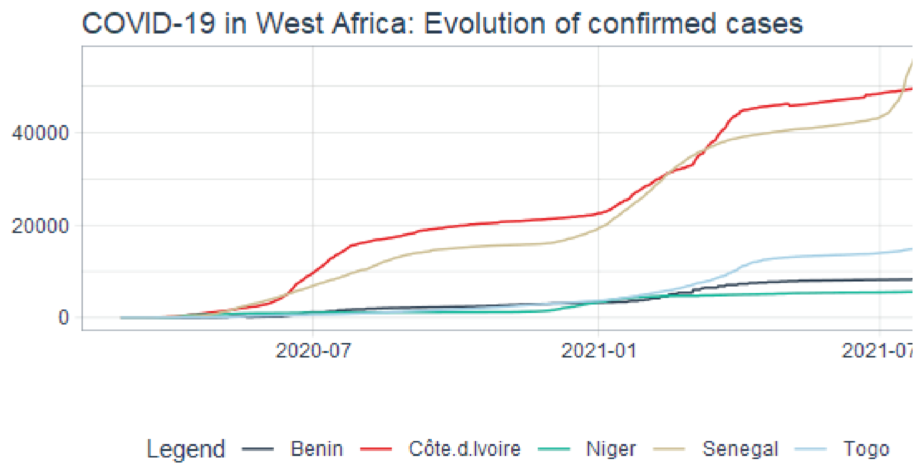

Figure 7: COVID-19 in West Africa: Evolution of confirmed cases (Johns Hopkins University & Medicine, 2021)

As a result of COVID-19 increase cases in West-African countries, this affected drastically the consumption pattern due to the restriction measures put in place. How this external factor affected the demand in the year 2020, is displayed in Figure 8 and Figure 9. The best model from the study above is used to forecast the electricity consumption for the year 2020 regressed with climatic and the calendar effect.

One general observation, that can be easily perceived from Figure 8 and Figure 9 is that prior COVID-19 cases being confirmed, all countries' demand rose, due to the economic progress that was being recorded in the region. Five out of the ten fastest-growing economies in 2019 were in West Africa: Côte d'Ivoire (the highest GDP growth rate: 7.3%), Ghana (7%), Benin (6.4%), Senegal (6.3%) and Niger (6.3%) (World Bank 2020).

It is worth noting that the seasonal pattern of consumption in all countries had not changed despite the pandemic, which follows the same path as described in Figure 4 (see Figure 4 against Figure 8 & Figure 9). However, as the covid-19 cases increase leading to various dynamics in the societies, the level of consumption changes compared to the normal (normal represents the forecasted consumption of 2020) which is different from one country to another.

In the case of Benin, three main time slots period can be observed. The pre-COVID, in-COVID and post-COVID in the year 2020. Table 3 gives the total consumption difference between the observed and forecasted consumption for 2020 and daily average.

The pre-COVID span from January to March where the demand rose with a total +11,096 MWh compared to the forecast for 2020 obtained from time series modeling above. During the in-COVID period (April-September) the demand decreased by about – 13,851.61 MWh (with a daily decrease of 76.52 MWh) in the period. As activities are getting back to normal post restriction measures the demand starts to increase with + 9,795.19 MWh (Table 3) during late September to December. Globally an increase in the consumption of about + 7040.45 MWh is noted despite the pandemic, which is about 0.46 % ± 6 of increase in overall compared to the normal (Table 4 and Figure 8, B2). The normal refers to the demand without COVID-19 as business as usual.

On the supply side the country was fortunate to finish his new plant on time the year before and that have played a critical role in helping the country meeting the demand as well as having a stable power importation as stated in the interview had with the SBEE Governance and Risk Management Department in the following "The efforts since 2019 with the construction of the MARIA-GLETA 2 Thermal Power Plant have not only reduced the country's import rate but also kept up with demand during the COVID-19 period. Imports from the suppliers (Ghana and Nigeria) were stable, which made it possible to avoid any additional production costs that would have required the rental of a reserve generator."

Among the countries studied Niger had the lowest COVID-19 confirmed cases and therefore was not subjected to the same pressure and socio-dynamic as the other countries (Figure 7). This low rate of contamination and economic progress recorded in 2019, could explain why they were not a significant decrease in consumption (Figure 8,NIG2) in 2020 in Niger. Over 2020, there was an increase of about 3777 MWh which represents an average increase of about 10.32% ± 8.20 compared to the forecasted consumption expected for the given year. The slight decrease below forecast at the end recorded could be due to the seasonal pattern. At the early period of contamination in March, the pandemic drives down consumption but still stay above the forecast, before resuming to an increasing trend.

Togo is a neighboring country of the Benin republic, and in term of relative change, the countries have similar trend. The pre-COVID, in-COVID and post-COVID periods are discernable as of Benin (Figure 6, B2 and Figure 6, TG2). Until a recent past till 2020, Benin and Togo shared a common body for electricity import for their country known as Communauté Electrique du Benin (CEB). This could be an underlying reason. During in-COVID period (April-September) the demand decreases by about -193 MWh and resumes back to an increasing trend for the last two months of year (post- COVID) with -8907.57 MWh (average 49.48 MWh). The pre- COVID total increase observed is about + 17, 030.75 MWh (average of 187.151 MWh). On average over the year the demand relative change shows an increase of 0.84% ± 5.54 (Table 4).

For the case of Cote d'Ivoire, the three periods were observed but the trend of consumption increase resumed quicker than other countries previously discussed after the in-COVID period. The in-COVID period (beginning of early cases confirmed of COVID-19) span from April to June where there is a slight decrease but still the consumption remains above forecast with +16802.34 MWh (averaging +161.56 MWh) surplus with regards to the normal (forecast) (Figure 8, CI1& CI2). The surplus from July to December is about 12, 0414.12MWh (averaging + 747.91 MWh) above forecast. Despite the context of COVID-19, the relative change is about 2.18% ± 3.52 (Table 4).

Cote d'Ivoire and Senegal experienced a quick recovery in consumption after a slow decrease during the first months after the recording of the first cases of COVID-19. In the case of Senegal, the early increase in consumption pre-COVID is observed from January (+35514.86 MWh) to March followed by a period of decrease spanning from April to May (- 5503.12 MWh) and the post-COVID from June to December (+ 95, 192.87 MWh) where consumption resume increasing above forecast (Figure 9, SN1 & SN2). The demand increased by 2.64 % ± 5.93 compared to the expected (Table 3).

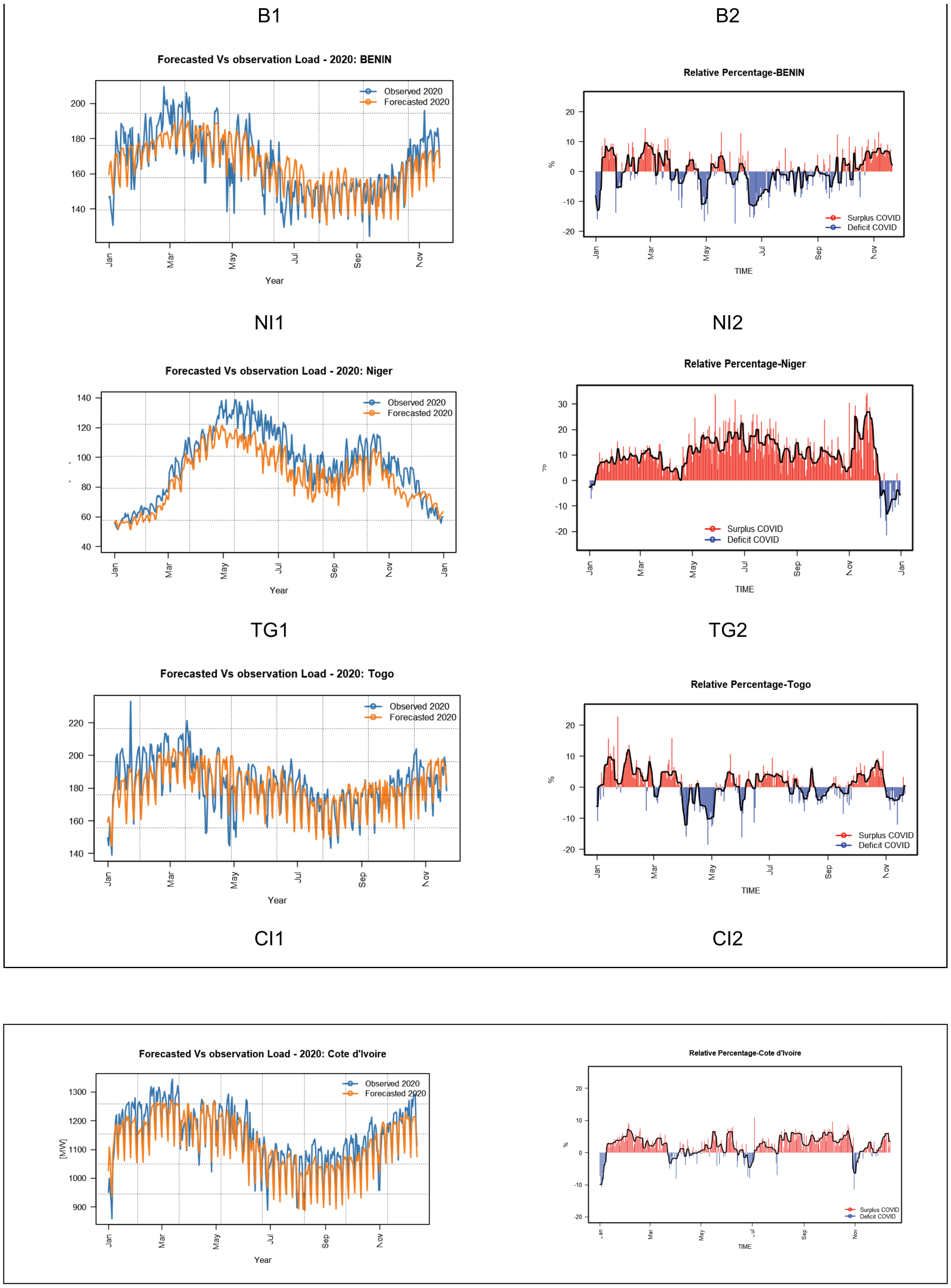

Figure 8: Time series forecasting of load without COVID and relative change: 100(Observed-forecast/forecast) in Benin, Togo, Niger and Cote d'Ivoire*

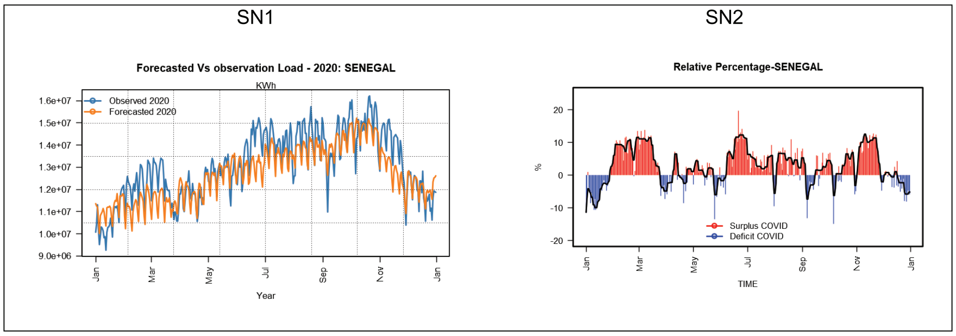

Figure 9: Time series forecasting of load without COVID and relative change: 100 (Observed-forecast/forecast) in Senegal*

Table 3: Total consumption and average daily consumption bias (observed – forecast) per COVID period.

COUNTRIES	TIME PERIOD	TOTAL CONSUMPTION (MWH)	DAILY AVERAGE (MWH)
COTE D'IVOIRE			
Pre-COVID	01/01/2020 - 3/22/2020	64636.59	788.25
In-COVID	3/23/2020 – 7/4/2020	16802.34	161.56
Post-COVID	7/4/2020 – 12/31/2020	120414.12	747.91
SENEGAL			
Pre-COVID	01/01/2020 - 3/24/2020	35514.86	422.79
In-COVID	3/25/2020 – 6/7/2020	-5503.12	-77.374
Post-COVID	6/8/2020 – 12/31/2020	95192.87	459.86
TOGO			
Pre-COVID	01/01/2021 - 3/31/2020	17030.75	187.151
In-COVID	4/1/2020 - 9/27/2020	-8907.57	-49.48
Post-COVID	9/28/2020 – 12/31/2020	3348.64	60.88
NIGER			
COVID year	01/01/2021 - 12/31/2020	81234.25	221.951
BENIN			
Pre-COVID	01/01/2021 - 3/23/2020	11096.87	133.69
In-COVID	3/24/2020 - 9/20/2020	-13851.61	-76.52
Post-covid	9/21/2020 – 12/31/2020	9795.19	157.98

Table 4: Descriptive statistics of observed and forecast

	mean	sd	min	max
BENIN				
Observed (MW)	3966.81	444.68	2984.25	5032.48
forecast (MW)	3945.21	328.51	3166.87	4573.65
Relative Bias (%)	0.46	6.17	-17.01	14.14
Observed - Forecast	21.60	116.17	-182.62	458.83
NIGER				
Observed (MW)	2300.86	539.96	1235.11	3327.34
forecast (MW)	2078.91	441.48	1226.56	2925.32
Relative Bias (%)	10.32	8.20	-21.20	34.06
Observed - Forecast	221.95	98.47	8.55	402.02
TOGO				

Observed (MW)	4360.08	378.13	3338.13	5592.69
forecast (MW)	4324.89	305.07	3468.69	4937.18
Relative Bias (%)	0.84	5.54	-18.64	22.73
Observed - Forecast	35.19	73.06	-130.56	655.51
		COTE D'IVOIRE		
Observed (MWh)	27409.49	2415.71	20616.66	32274.50
forecast (MWh)	26827.78	2229.21	21290.67	30553.74
Relative Bias (%)	2.18	3.52	-11.49	11.01
Observed - Forecast	581.71	186.50	-674.01	1720.76
		SENEGAL		
Observed (kWh)	13041887.36	1507418.68	9260175.30	16214307.00
forecast (kWh)	12699798.20	1214440.57	10017888.72	15212461.16
Relative Bias (%)	2.64	5.93	-14.83	19.77
Observed - Forecast	342089.17	740274.98	-2212620.63	2441785.68

4.0 CONCLUSIONS AND RECOMMENDATIONS

This study sought to understand the impact of COVID-19 on the electricty supply-demande side in selected countries in West-Africa (Benin, Togo, Cote d'Ivoire, Senegal). Several types of models were inventoried including Automated (Auto.ARIMA_REGRESSORS, PROPHET_REGRESSORS, NNAR, ETS, TBATS), machine learnings (GLMNET, RANDOMFOREST) and hybrid Model (PROPHET_XCGBOOST, ARIMA_XCGBOOST ERRORS) to explore the best of algorithm that have the highest predictive ability and forecasting accuracy electricity consumption per country of study. Various performance metrics are computed to assess models against each other. Mean air temperature, Solar radiation (RSDS), Relative Humidity (RH), Temperature (°C) and Workind days (Wday) are used as explenatory variables in multivariate models. We observed that the seasonal electricity consumption pattern was the same with the temperature, and solar radiation. As the temperature and RSDS increase, the electricity demand also increases while it decreases with increasing RH. Furthermore, it was also found that countries within the same climatic zones depicted the same seasonal pattern. This explains why the same seasonal pattern was observed between Cote d'Ivoire, Benin, and Togo on one hand Niger, and Senegal on the other hand. From the time-series modelling and model selection, we found that machine learning algorithms namely NNAR and the GLMNET were the best models that perform better in capturing variability and accuracy for forecasting. GLMNET was best for Senegal, Cote d'Ivoire and Benin while NNAR for Niger and Togo. These models are then used to forecast the electricity consumption for the year 2020 assuming no COVID-19 happened. On the observed consumption as regards to the pandemic, three main periods were detected namely pre-COVID, in-COVID and post-COVID period.

The pre-COVID is the first months before the recording of first cases of contamination and the results show that the electricity consumption was increasing above the forecast without COVID. This was explained by the economic progress noticed in the region. Then during the in-COVID period, as the cases are increasing and because of panic alert and rapid deployment of restriction measures, the consumption goes down in all countries. Nevertheless, in some countries the demand was much more pronounced like in Benin and Togo. The third period is the post-COVID which represents the period after the release of restrictions measures. It was a resurgence of rising demand in all countries. In overall, for all countries, during the 2020 as a result of COVID-19, the electricity consumption increased by about 0.46%, 10.32%, 0.84%, 2.18%, 2.64% respectively in Benin, Niger, Togo, Côte d'Ivoire, and Senegal with an average of 3.28%. Niger having the highest increase in consumption despite this special year could be explained by the evolution of the country and also that it had the least number of infected people of all countries. Therefore, the restriction measures were highly enforced as compared to the surrounding countries. This study was amongst the first of kind on forecasting electricity consumption in West-

Africa using advanced techniques and assessing the impact of the COVID-19 pandemic on supply-demand. Advanced modern techniques model is fitted on historical data and tested before being used for forecasting. However, this modelling practice requires high temporally scale and long historical data to produce accurate results. To promote more research and increase finding, it is highly recommendable that more effort is put into collecting and make available high-resolution electricity consumption data. This data is essential for proper demand analysis which can support proper power system planning.

Code availability

The R code is available upon request to the corresponding author. The analyses were performed in R Programming Language.

FUNDING

This research was supported by ECOWAS Centre for Renewable Energy and Energy Efficiency (ECREEE) is calling for proposals for its Research Grant Program, under the ECOWAS initiative on Youth Leadership Development in Energy.

ACKNOWLEDGEMENTS

We thank the power utilities of Benin, Togo, Senegal, Niger and Cote d'Ivoire for providing electricity consumption for given electricity consumption data and allowing conducting survey data.

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Development of a platform for the evaluation and technical-Financial Study of Solar Pumping Systems in the ECOWAS Region

Egas Sidney Mascarenhas, Patrício Fernandes Andrade, Yannick Andrade

Summary

Water is an essential natural resource for life. Nevertheless, in some regions of the Economic Community of West African States (ECOWAS) and particularly in remote areas, access to this essential resource is still a challenge. Limited access creates an obstacle to development that can lead to significant economic losses, since the survival of the population in these regions is very dependent on activities such as agriculture and livestock. However, an improvement in this sector would have a direct impact on local development, on sanitary conditions and, of course, the comfort of the population.

The main objective of this work is to develop a free web platform that allows the common user to easily verify the viability of accessing water. This platform will provide the results (technical and financial) for the implementation of a water pumping system, supported essentially by solar energy, considering the prospects of water consumption and the renewable potential at the pre-defined location.

Keywords :
water, solar energy, platform.

1.0 INTRODUCTION

The project goal is to create a web tool for evaluating solar pumping systems, with a focus on remote regions of ECOWAS to support the implementation of a water pumping system, supported by solar energy, considering the water consumption prospects and the renewable potential at the pre-defined location . The proposal intends to fill a gap and an important barrier to a greater use of solar energy to increase the availability of water for agriculture and consumption, especially in remote regions of ECOWAS and as a tool, of technical and economic simulation, it supports those interested in the implementation of specific projects, for pumping water in isolated communities in ECOWAS.

It is expected that this project can help the ECOWAS region improving the access to energy and water, in an environmentally sustainable way by betting on the use of solar energy.

Problem of water scarcity and renewable energy potential in the ECOWAS region

Water is a vital resource for survival and without access to this resource, no plant or animal species, including humans, could survive. In reality, few resources have such a decisive influence on human security as water. In the remote regions of ECOWAS, for example, its importance is not limited to domestic consumption, but also to other services such as irrigation and livestock. The economy of these regions is essentially based on activities such as agriculture (African Union Commission [AUC] / Organization for Economic Cooperation and Development [OECD], 2018).

In fact, the agricultural sector plays an important role in these regions, with a great impact on the maintenance and survival of a large number of families, whose livelihood and life organization are closely dependent on the exploitation of the land. It should be noted that this sector constitutes the important pillar of food and nutrition security. For Cunha and al. (2013), access to food and quality food are key issues for human development.

According to the report on Development Dynamics in Africa – Growth, Employment and Inequalities (2018), the agricultural sector is the main source of employment in ECOWAS. In the year 2000, for example, this sector represented between 33% (Gambia) and 77% (Niger) of jobs. In 2017, Guinea-Bissau had a high percentage of employees in agriculture, around 83%, followed by Niger and Cape Verde with around 75% and 67%, respectively. In this perspective, limited access to water creates an obstacle to the development that can lead to significant economic losses.

It is very common to use water supply infrastructure, such as conventional pumping stations, to exploit groundwater resources in remote regions. This technology is characterized by its low initial cost and easy operation, but also by its high dependence on fossil fuels, an expensive and polluting resource (Poompavai & Kausalya, 2019). There are also environmental and social issues, mainly due to the burning of fossil fuels in these operations and their effects on human health.

The geographical location of ECOWAS member countries is propitious to the development and growth of the use of Renewable Energy Sources (RES). According to the ECOWAS Renewable Energy Policy (EREP]) report (2012), there is great technical and economic viability for the development of renewable energy in West Africa. Resources such as wind and solar, for example, are generous and well distributed among countries. These advantages can be beneficial in more remote regions especially in photovoltaic pumping applications.

This technology has demonstrated over the years to be an alternative to supplying drinking water to off-grid regions, namely in agricultural applications, irrigation and livestock and in water supply for the population in general. For the case under study, it refers to submerged pumps, which are very common in public water supply systems, either in direct application in wells or as boosters, and their use is currently very diversified, also serving industrial water supply, rural and irrigation systems (Tedesco, 1997).

The correct dimensioning of the systems is important and implies adequate knowledge, not always available where the systems are most useful. Considering that the necessary data and calculations can be complicated for most stakeholders, the availability of an easy-to-use decision support system that provides results in a short time is an asset supporting the use of RES in pumping.

Benefits of using solar energy for water pumping

The use of RES in water pumping system in remote locations has several advantages, namely at the economic level, due to the reduction in imports expensive fuel and the decentralization of energy production. This technology is characterized by noise-free operation and no CO_2 emissions, with a low level of maintenance and completely independent of the fluctuation of fuel prices on the international market.

It is considered that the project demonstrates a high degree of innovation in the methodological/conceptual and operational approach view of the reality involved and the level of innovation factors, as well as the digital transformation in the energy sector nexus in the region ECOWAS.

The implementation of the proposed project will be marked as the first free web platform linked to this sector (Solar pumping) and characterized by its ease use and great power of analysis of the outputs, and presentation of accurate and assertive results.

Platform development

The platform was built using web development tools, using java script, html and python. These choices were made because these are open source and intuitive tools and still responded to all the prerequisites that were outlined at the beginning, allowing the content to be available on multiple devices.
The platform structure is constituted according to the following image:

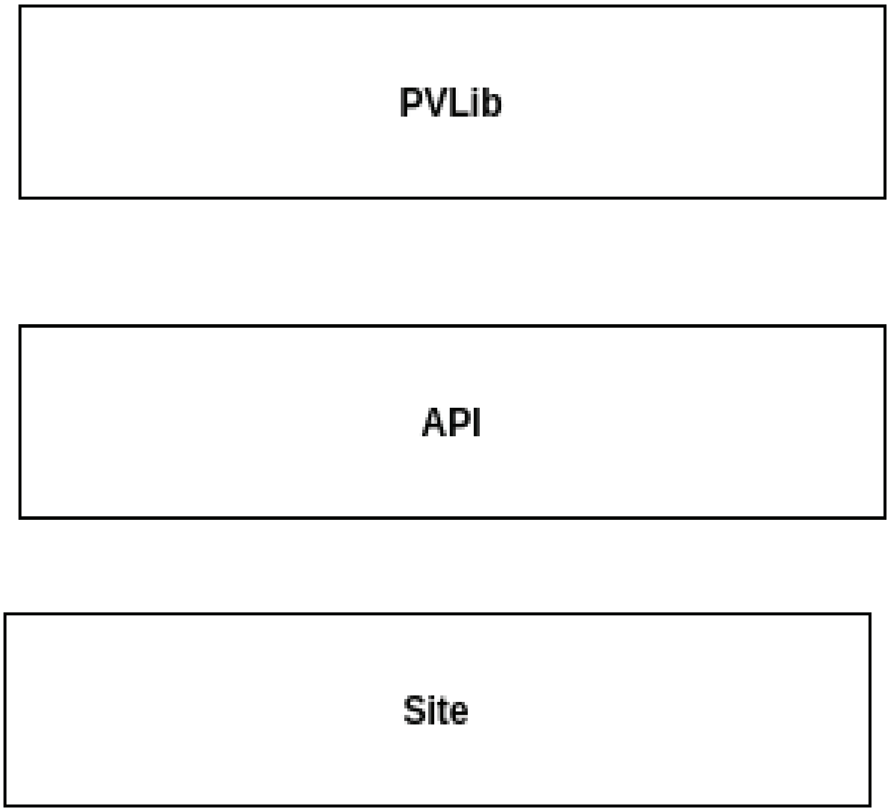

Figure 1: Platform deployment framework

Site : It is the client interface where the system's functions can be executed. It is developed in a very accessible way so that is possible to use it even with basic knowledge. The user only needs to select the location of the project execution and enter the input parameters.
API : This component feeds the website with information that it seeks in PVLib, which is a library that implements the procedures of the photovoltaic system. All the PV calculations are made in this component, and will be presented on the main site. These calculations are made taking into account the input parameters that are passed by the site on request.

PVLib : Library that implements models of photovoltaic systems. Through this library we were able to obtain solar radiation data that is used in the pump sizing.

Design

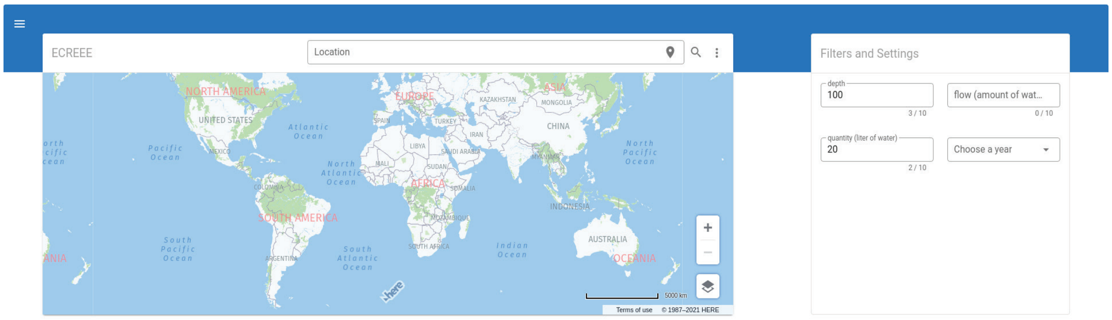

Figure 2: Main page of the site

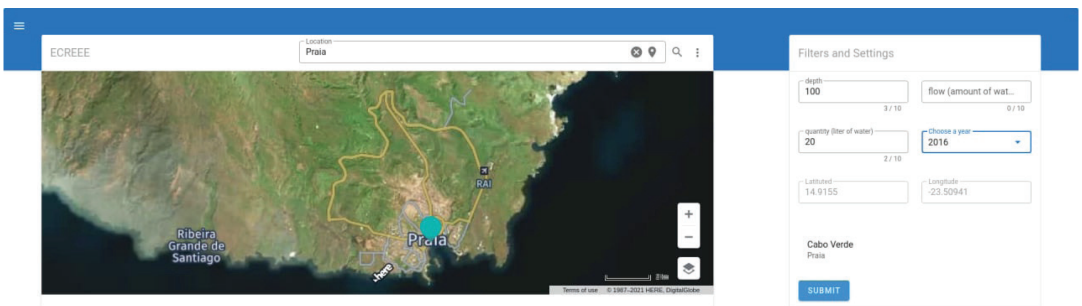

Figure 3: Input parameters

The user can choose the location, the depth of the hole and the amount of water to be extracted. Finally, it is necessary to submit the selected data to calculate the output parameters.

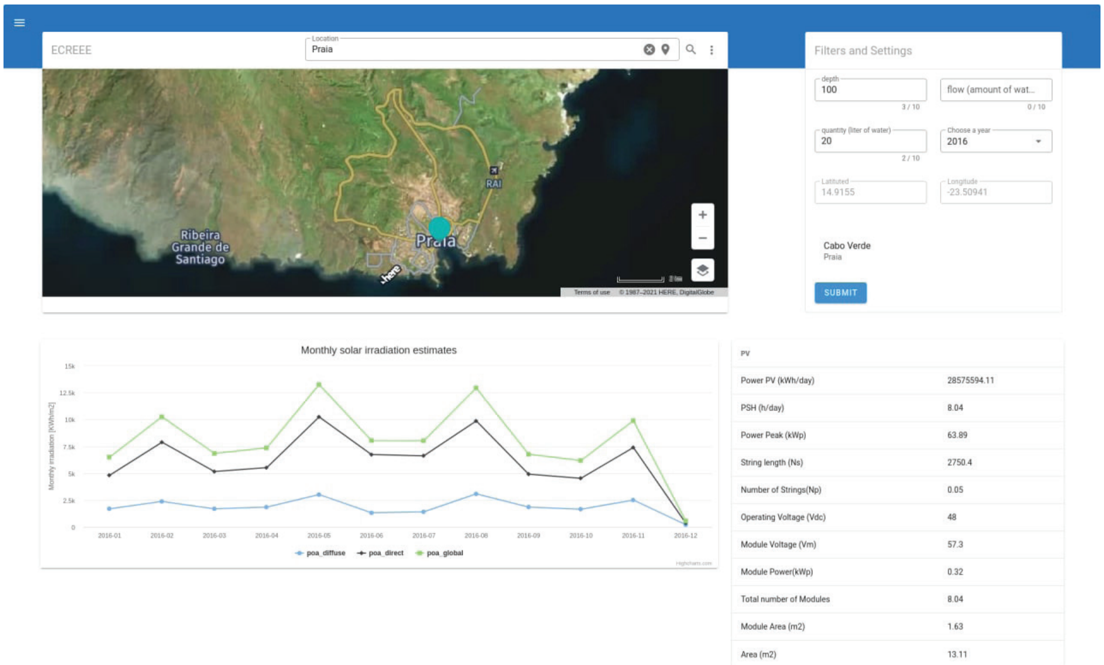

Figure 4: Result

After submitting the form, we have the simulation results, such as the solar power needed for the requested demand, as well as the number of panels needed, among other results.

Pump sizing and solar energy calculations

For the dimensioning of the system it is necessary to know some variables and operating conditions of the pump and the properties of the water itself. For each rotation N , the pump will provide a discharge Q , a manometric height Hm , providing an efficiency η . The useful power of a pump is a function of the specific mass in the liquid to be pumped, of the flow rate and the manometric height that this liquid must be subjected, according to the equation:

Pu=γ*Q * Hm*η [1]

Pu = Useful power in the pump (W);
γ = Specific weight of the liquid, in kgf /m^3;
Q = Flow, in L/s;
Hm = Manometric height, in meters;
η = pump efficiency,
γ - Ratio between specific weight and specific mass;

Solar energy

The main data needed to dimension the power is the solar irradiation map, the system performance and the panel area.

$E=\eta*A*G(1-p)$ [2]

η – Yield;
E – Annual energy produced (kWh);
G – Average solar irradiation (kWh/m2);
A – Module area (m2);
P – Associated losses;

With the total amount of energy that is needed during the day and using PVGIS, the daily available energy (Irradiance) was calculated. For the study site, the average irradiance value was chosen and, according to the following figure, it can be noted that the energy available at the site is sufficient to supply the previously defined energy needs.
Final considerations

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Renewable And Non-Renewable Energy and Economic Transformation of Developing Countries: Inward Approach to Sub-Saharan Africa

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Abstract

As demonstrated by recent studies, it is indisputable that energy is one of the impelling forces that boost industrial production and economic growth. However, the international communities remain resolute in the campaign for renewable energy consumption as last solution to the global CO2 emission. Studies on renewable energy-growth still remains controversial. This study examined the impact of renewable and non-renewable energy on economic development in Sub-Sahara Africa. The specific objectives are to examine: the impact of renewable and non-renewable and nonrenewable energy on economic growth; and the existence of sub-regional differences on renewable energy-growth nexus in the region. This study was rooted on Solow growth theory (1956) and energy-growth theory. Panel data on 29 SSA countries from 1990 to 2019 was sourced from World and African Development Indicator. The study employed Arellano-Bond version of Generalized Method of Moments estimation technique because of the inclusion of lagged of economic growth in the model. Findings from the study reveal that; renewable energy consumption does not contribute to economic growth in SSA region; nonrenewable energy consumption promotes economic growth; presence of domestic violence reduces economic growth in the region; and existence of sub-regional differences in the region. The Sargan test confirm the validity of instrument used, while confirm the absence of autocorrelation. An indication that the result of this study is void of spuriousness.

1.0 INTRODUCTION

Economic growth remains the central focus of all macroeconomic objective because it has strong bearing on all other objectives, especially unemployment, price stability and balance of payment equilibrium. Thus, it remains the target of policy makers, since it's a required condition for economic development. In developed economies, sustainable development remains the focus of government while developing economies focus on transformation from primitive to industrialization (Koçak & Sarkgünes, 2017). However, economic growth and environmental degradation nexus has showed positive relationship as found in several studies (Sinha, Shahbaz, & Sengupta, 2018; Zambrano- Monserrate & Fernandez, 2017). It implies that development tend to produce more CO_2 emission. Therefore, over the past three-decade economies across the world face dual challenges; economic growth and reducing environmental degradation. The economic performance of countries across the globe, among other factors, have been partly attributed to the quality of energy consumption and the policy strength of government to control its externalities, which is still problematic in most developing countries (Hanif, 2017).

The emergence of Asia miracle lends credence to this hypothesis. Thus, energy and transportation infrastructure remain an indispensable resource in the context of development economics. Access to energy determines the physical and socio-economic development in rural and urban settings. The importance of energy lies in other aspect of development - increase in improve balance of payment when energy products are exported, transfer of technology in the process of exploration, production and exchange; increase in employment in energy industries; improvement in infrastructure and socio-economic activities in the process of energy resource exploitation (Kim & Baek, 2011). Thus, in the quest for optimal development and efficient management of available energy resources, distribution and efficient operation can put the economy on the part of sustainable growth and development. Arising from this argument, adequate supply of energy thus becomes central to the radical transformation of the nation's economy.

Access to sustainable energy is therefore one of the leading factors that contributes to growth disparity between the developed and the developing countries. Due to the increased use of conventional sources of energy such as fossil fuels (oil, coal and gas) all over the world and the associated environmental impacts, efforts have been directed towards maximizing dependence on renewable resources by increasing renewable energy supply. Among the fundamental global issues are energy shortage and depletion, security of supply, energy price hike, and nonrenewable features of oil, natural gas, and coal as energy sources (Koçak & Sarkgünes, 2017). Since stable and sustainable energy for household and industries are key to welfare and economic development, countries and societies are compelled to find alternative energy sources to conventional energy sources (Kasperowicz, Pinczynski, & Khabdullin, 2017; Bilgili & Ozturk, 2015; Ozturk & Bilgili, 2015).

As reported in some studies most countries have an enormous potential for renewable energy production. However, for some reasons, the current renewable energy application in these countries is negligible compared to their potential (Apergis & Payne, 2010). For example, though India is rich in both renewable and conventional energy resources, coal has continued to be the dominant source of electricity due to its relatively low cost, availability, accessibility and suitability to the needs (Kasperowicz et al., 2017). Furthermore, rapid growth in urbanization and population, and subsequent increase in energy demand in the developing countries has led to emerging energy crisis which in effect increases people's dependence on non-renewable energy sources. Invariably, supply fails to catch-up with demand, and this informed the prevalent of consumption of dirty energy in most developing world.

Currently, Africa is undergoing economic transformation and diversification, coupled with rapid population and urbanization. The continent experienced unprecedented and sustained growth in the last decade. Prior to the advent of COVID-19 pandemic, Africa's economies were growing at an average rate of 4 percent annually. According to World Bank (2019), Sub-Sahara Africa has six of World's ten fastest growing economies over the last decade. Holding constant COVID-19's shock, if the projected growth trend is sustained, Africa's GDP growth was expected to increase 300 percent and 700 percent by 2030 and 2050 respectively. According to IRENA (2020) publication, by 2030, about 42 percent of Africans might still be without access to power with 56 percent without clean cooking facilities indicating that a large number of the African population will be deprived of quality wellbeing. When the projected scenarios are compared with that of 2010, when 57 percent and 68 percent were denied access to electricity and clean cooking energy respectively, the former scenario seemly better (IRENA, 2013).

Developing countries in West Africa have overtime increased their consumption of fossil fuels such as oil, coal, and gas. However, the multiplier effect of their inability to migrate to renewable and sustainable energy alternative have generated a number of challenges which has hampered economic growth and development in the region (Maji, Sulaiman & Abdul-Rahim, 2019). Although non-renewable energy consumption has managed to accelerate the economic growth in the region overtime, residues generated by the combustion of fossil fuels have had adverse impacts on the environment and on biological life across the whole region (Wolde-Rufael, 2009; Narayan & Smyth, 2005; Halicioglu, 2011). As developing countries gradually align to the reality of the paradigm shift towards renewable energy sources, only few countries in West Africa (Ghana and Nigeria) as well as from other regional blocs (Kenya and South Africa) in the region seemly have the political will and commitment of resources. It is pertinent to ascertain if the recent little efforts towards renewable energy source or large consumption of conventional energy have accounted for Sub-Saharan Africa (SSA) being among the fastest growing regions in the world (Olanrewaju, Olubusoye, Adenikinju & Akintande, 2019).

There is plethora of studies on energy consumption-growth nexus. Among these studies are Sadorsky (2009), Ozturk (2010), Apergis & Payne (2009), Payne (2010), Stern (2000), and Yildirim et al. (2012). Extensively, literature on energy-growth nexus focus on majorly on conventional energy source, less number of studies gave attention to the relationship between renewable and non-renewable energy consumption on economic growth. From the studies reviewed, energy consumption-economic growth nexus can be analyzed under four hypotheses. The growth hypothesis assumes energy as a major source of input into the growth process, and unidirectional causality exists from energy consumption to economic growth. In this scenario, energy conservation policies will have an inverse impact on economic growth. The conservation hypothesis implies that economic growth causes consumption of energy. Under this situation, conservation policy will not affect economic growth. The feedback hypothesis implies a bi-directional relationship between energy consumption and economic growth. This hypothesis suggests any change in energy consumption will affect economic growth with a reverse effect. The neutrality hypothesis indicates that energy consumption and economic growth are independent and do not affect each other. Most of the literature examines the relationship between electricity consumption and income, or the nexus of energy-income-emissions. The literature over the past decades has produced varied findings across countries under each of these hypotheses. No consensus has emerged from these studies on both renewable and non-renewable energy, hence, the importance of this study to show the relationship between both energy sources. We refrain from the voluminous literature here.

Against this backdrop, this study examines the impact of renewable and non-renewable energy consumption on economic growth in Sub Saharan Africa (SSA)

2.0 LITERATURE REVIEW

2.1 Energy-growth hypotheses

Empirical studies on energy-growth nexus is defined by four basic hypotheses, and each hypothesis has distinct implications for the direction of government policies towards regulation of energy consumption levels as a means of decreasing emission levels. This allow the government to understand the implication of their choice and the trade-off. Therefore, if energy consumption is taken to be a determinant factor for economic growth, policies that limit energy consumption to control environmental degradation could inadvertently lead to declines in incomes and worsen unemployment rates (Menyah & Wolde-Rufael, 2010).

2.2 Growth-induced hypothesis

The growth hypothesis states economic growth is a direct function of energy consumption. That is energy consumption plays prominent role in growth in output, just like labor and physical capital. This hypothesis holds if causality is found running from energy consumption to growth, but not from growth to energy consumption. The inference of this kind of unidirectional causality is that the strategies that limit energy consumption as a means of decreasing emissions will negatively impact economic growth (Tugcu, Ozturk, & Aslan, 2012). In this case, any government policy that reduces energy consumption will inevitably reduce economic growth.

2.3 Conservation hypothesis

This premise goes in the opposite direction of growth hypothesis. The conservation hypothesis states that economic growth is directly responsible for stimulating energy consumption. This hypothesis holds if causality runs from economic growth to energy consumption. It implies that changes in economic growth will affect energy consumption, but not the other way around. In this case, it is typical that economic growth leads to greater energy consumption. However, in certain cases, economic growth can lead to a decrease in energy consumption. This typically happens in growing economies as production shifts from primary industrial sectors to service sectors that are less energy intensive. The implication of this hypothesis is that government policy directed towards reduction in emission will not affect economic growth (Tugcu et al., 2012).

2.4 Feedback hypothesis

This hypothesis states both energy consumption and economic growth simultaneously affect each other. This hypothesis holds when evidence of bidirectional causality is found between energy consumption and economic growth. This implies that any government policy that affect any of the variable will equally influence the other variable. By implication, any policy employed to tackle emission through reduction in energy consumption will inevitably reduce economic growth. Also, fluctuations in growth will affect energy consumption (Tugcu et al., 2012).

2.5 Neutrality hypothesis

It states that there is zero relationship between economic growth and energy consumption. Evidence that found no causality between energy consumption and growth in either direction. This means that a change in GDP will not influence energy consumption, and that a change in energy consumption will not have an effect on GDP. By implication, just like conservative hypothesis, policies that limit energy consumption, will have no negative impact on economic growth (Tugcu et al., 2012).

2.6 Solow growth theory

According to Solow (1956) growth theory, beyond capital and labor which are paid, their marginal physical products, technology and population growth are important variable to output. Solow growth theory postulate that physical capital accumulation contributes to the growth in the short-run, but long run growth is totally determined by technological progress which is exogenous to the models so that there is no explicit role for knowledge and spill-overs (Stiroh, 2003). Solow growth theory takes the rate of saving, population growth and technological progress as exogenous.

2.7 Harrod-Domar model (1948, 1946)

Harrod-Domar model is a neo-classical model of economic growth mainly used in development economics to explain an economy's growth rate in term of saving and productivity of capital. According to the model, growth depends on the quantity of labor and capital, and as such more investment leads to more capital accumulation, which generates economic growth.

2.8 Empirical Review

According to Aguirre and Ibikunle (2014), politics, socio-economic and countries' peculiarity shape the consumption of renewable energy. The findings by Aguirre and Ibikunle (2014) showed that renewable energy sources are technically expensive to develop, while the conventional sources are far more economical. It is an indication that relatively capital driven renewable energy sources cannot survive the stiff competition with the conventional energy sources. With reference to this, several studies suggested reliable workable government policies to aid the adoption of renewable energy (Marques & Fuinhas, 2012; Kilinc-Ata, 2016; Stadelmann & Castro, 2014).

Panel studies on OEDC by Inglesi-Lotz (2016) and Bozkurt and Destek (2015), covering 1990-2010 and 1980-2012 respectively. They both found positive relationship between renewable energy and economic growth. Similar studies in Europe; panel studies on G-7 and 100 European countries by Tugcu et al. (2012) and Chontanawat, Hunt, and Pierse (2008) respectively, equally found positive nexus. A panel of study of top 38 European countries by in Bhattacharya, Paramati, Ozturk and Bhattacharya (2016), panel of 18 emerging countries by Sadorsky (2009a), a panel of developed countries in Europe by Okyay, Ebru, and Fatih (2014), a panel of 29 OIC countries by Anwar, Arshed, Nabeela and Kousar (2017), and a panel of 8 east-central European countries Alper, and Oguz (2016). They all found positive nexus. Also, Similar studies for the individual countries outside Africa and for different periods of time can be found for Turkey (Ocal, & Aslan, 2013), Saudi Arabia (Wada, 2017), for Brazil (Pao, & Fu, 2013), for Lithuania (Bobinaite, Juozapaviciene, & Konstantinaviciute, 2011), for China (Lin, & Moubarak, 2014), for U.S. (Stern, 2000; Yildirim, Sarac, & Aslan, 2012). They all point to positive nexus.

Khobai and Le Roux (2018) and Fotourehchi (2017) employed data 25years dataset (1999-2014) for South Africa and 23years dataset (1990-2012) for 42 developing countries respectively, to examine the renewable energy consumption-growth nexus. The former a long-term relationship, while both found a one-way causality relationship running from renewable energy consumption to economic growth. The empirical findings on energy consumption-growth nexus by Papiez and Smiech (2013), using 19years data (1993 to 2011) for nine post-communist countries. The findings aligned with positive energy-growth nexus hypothesis, much pronounce in Poland, Romania and Bulgaria. However, conventional energy (coal) played prominent role. Sasana and Ghozali (2017) studied five BRICS countries, using 20 years panel dataset (1995-2014). Consumption of renewable and fossil energy sources showed negative and positive impact on economic growth respectively. Similar to Papiez et al (2013), Smiech and Papie (2014) employed 19 years panel data (1993-2011) for European Union (EU) member states. The study found no causality relationship between two macroeconomic variables in 17 countries, but found bi-directional relationship in Latvia and Bulgaria.

Egbichi, Abuh, Okafor, Godwin and Adedoyin (2018) empirically examined the dynamic impact of energy consumption on the growth of Nigeria economy between 1986 and 2016. Using symmetrical ARDL lag model, the study electricity consumption in Nigeria had no significant impact on growth. This is largely attributed to power instability which over the decade account for decline in growth. Unsurprisingly, energy powered by petroleum products showed significant impact on economic growth. With respect to renewable energy sources, some studies found evidence of bi-directional relationship with economic growth (Neitzel, 2017 for 22 OECD countries; Apergis and Danuletiv, 2014 for 80 countries; Apergis and Payne, 2010a for 13 Eurasian countries; Apergis and Paynes, 2010b for 20 OECD countries; Apergis and Payne, 2012 for 6 Central American countries; Apergis and Payne, 2011 for 80 countries; Tugal et al., 2012 for G-7 countries; and Sadorsky, 2009b for selected emerging economies).

3.0 THEORETICAL FRAMEWORK AND MODEL SPECIFICATION

According to Solow growth theory (1956), beyond capital and labor which are paid their marginal physical products, technology and population growth are important variable to output. Solow growth theory postulate that physical capital accumulation contributes to the growth in the short-run, but long run growth is totally determined by technological progress which is exogenous to the models so that there is no explicit role for knowledge and spill-overs (Stiroh, 2003).

To ensure that the analysis is carried out extensively, data is collected for 29 countries chosen based on the availability of data and its geographical location in Sub-Sahara Africa. The countries considered in this study are Angola, Benin, Botswana, Cameroon, Comosoro, Congo Democratic, Congo Republic, Cote'divore, Equatorial Guinea, Ethiopia, Gabon, Ghana, Gambia, Guinea-Bissau, Kenya, Madagascar, Mozambique, Mauritius, Namibia, Niger, Nigeria, Rwanda, Senegal, Togo, Tanzania, Uganda, South Africa, Zambia and Zimbabwe. The 29 countries were chosen out of the 46 countries in Sub- Sahara Africa due to availability of data for these countries and their infrastructure development for renewable and non-renewable energy. The country selection is considered a bit biased to meet the research requirements.

Unbalanced secondary data for the 29 countries in the Sub-Sahara region were sourced from the world development indicators on World bank (2020) online database The database provided the data on GDP per capital of the countries, physical capital, growth rate of labor, non-renewable and renewable energy data. The table 1 below shows a conclusion of the variables used in the research analysis:

Table 1: Sources and Unit Measurement of Data.

Variables Notation	Definition	Measurement	Unit of measurement	Source of Data
GDPPC	GDP per capita	GDP at 2010 constant price	Dollars	World Bank Development Indicator
REN	Renewable energy	Total renewable energy consumed scaled by total energy consumed	Percentage	World Bank Development Indicator
NREN	Non-renewable energy	Total non-renewable energy consumed scaled by total energy consumed	Percentage	World Bank Development Indicator
L	Labor force	Growth in labor force	Percentage	World Bank Development Indicator
K	Physical capital	Total gross fixed capital formation	Absolute value	World Bank Development Indicator
INF	Inflation	Change in Consumer Price Index	Rate	World Bank Development Indicator

Source: Computed by the Author, 2020

3.1 Econometric model

To empirically calibrate the impact of renewable and non-renewable energy on economic growth, this study follows the work of Inglesi-Lotz (2016), Salih & Tugce, (2012), and Bhattacharya, Paramati, Ozturk and Bhattacharya (2016). Thus, it adapt the Neo-classical growth production function augmented with technical progress. The baseline model is the basic production function, stated as follows:

$$Y{=}AK_t^{\alpha}\ L_t^{\beta} \qquad (1)$$

Where is the GDP growth rate, is the physical capital, is labor and A is total factor productivity, α and β are the elasticities of physical capital and labor, respectively. Fang et al. (2011) particularly highlights the problem of omission of the technical progress term in equation (1), and suggests the augmentation of the traditional production function with measures of renewable energy.

The transformation of the variables into a natural logarithm provides efficient and consistent empirical results (Shahbaz, Loganathan, Zeshan & Zaman, 2015). Furthermore, Shahbaz, Raghutla, Song, Zameer and Jiao (2020) also suggested the use of a log-linear transformation for reliable empirical analysis. The log-linear conversion of the dataset is a more general approach, and all coefficients in the regression are interpreted as elasticities. The empirical equation of augmented production function is presented in log-linear form:

$$lnY_t{=}lnA_t{+}\alpha lnK_t{+}\beta lnL_t \qquad (2)$$

Following Mankiw, Romer and Weil (1992), the vector A0 is expanded to accommodate variables of interest. The core variables of interest are renewable and non-renewable energy sources. In addition, we also add control variables from conventional growth theory such as Interest rate and inflation.

$lnA_0=\psi lnRE_t+\varphi lnNRE_t+\delta lnINF_t$ ... (3)

Substitute equation 3 into 2

$lnY_t=\lambda lnK_t+\beta lnL_t+\psi InRE_t+\varphi lnNRE_t+\delta lnINF_t+\mu_t$... (4)

Transform equation 4 into dynamic panel form

$lnY_{it}=\Phi lnY_{it-1}+\lambda lnK_{it}+\beta lnL_{it}+\psi lnRE_{it}+\varphi lnNRE_{it}+\delta INF_t+\mu_{it}$...... (5)

Where is GDP per capital, is physical capital, is growth rate of labor, is renewable energy, is non-renewable energy and is the inflation rate.

4.0 PRESENTATION AND DISCUSSION

Table 2a below shows the descriptive statistics of the data. The number of observations used in the study shows that the data used is unbalanced data as the number of observations are not equal.

Table 2a: Descriptive Statistics

Variables	Obs.	Mean	Std. Dev.	Min	Max	Skew.
NREN	562	30.401	23.187	1.64	88.149	.935
GFCF	808	20.494	7.814	2	53.122	.565
REN	743	70.579	22.506	10.634	98.343	-.962
INF	758	55.728	882.7	-60.496	23773.13	25.804
LGDPPC	870	7.109	.966	5.102	9.388	.547
L	870	8850000	17679006	405678	59873566	
LL	870	15.2	1.462	11.455	17.908	-.509

NREN- Non-Renewal Energy, GFCF- gross fixed capital formation, REN-Renewable Energy, inflation (INF), total labor force (L), log of labor force (LL) and gross domestic product per capita (GDPPC)

4.1 Descriptive analysis

The study made use of unbalance panel data of 29 countries in Sub-Sahara Africa of which 8 are West Africa countries, covering 1990 to 2019. The descriptive statistics of renewable energy consumed (REN), non-renewable energy consumed (NREN), gross fixed capital formation (GFCF), inflation (INF), total labor force (LF) and gross domestic product per capita (GDPPC) are reported in Table 2a. Both labor force and economic growth are reported in their natural form, while other variables in rate. It can be seen from the results that labor force (LF) has the highest average value. Labor force consist of the active workforce in the population and consist of employed and unemployed. The data in this study shows that the labor force for the countries has an average labor force of 8850000. Surprisingly, 30 percent of total energy consumption in the region comes from conventional (nonrenewable) energy, with maximum of 88 percent, which is less than renewable energy of 70 percent (maximum of 98 percent). Also, the level of volatility depicts by the standard deviation shows that both forms of energy have similar dispersion. However, a close look at the results when both GDPPC and labor force are logged, reveals that both has the lowest volatility.

The region has an average interest rate of 9.1 percent, and a maximum of 80 percent. It equally has an average GFCF of 20 percent scaled by GDP, while a minimum and maximum of 2 and 53 percent respectively. Further, all the variables except REN are negatively skewed as indicated by the negative values of the skewness.

4.2 Unit root test

Table 2: Fisher-type unit root test (based on Phillips-Perron tests)

	With trend			Without trend		
Variables	Statistic	P-value	Remark	Statistic	P-value	Remark
LGDPPC	-2.8477	0.0025	ST	4.8646	1.0000	NST
NREN	-2.5723	0.0032	ST	-2.0117	0.011	ST
GFCF	-2.7304	0.0022	ST	-2.2111	0.0135	ST
LLF	-2.1267	0.0179	ST	-1.7011	0.0457	ST
REN	-2.9382	0.0021	ST	2.7818	0.9985	NST
INF	-10.794	0.0000	ST	-11.8536	0.0000	ST
INT	-2.1243	0.0177	ST	-1.7011	0.0457	ST

ST denotes significant while NST denotes not significant

Empirical studies show that the traditional unit root tests or cointegration tests method (e.g., ADF or residual-based co-integration tests) involves the low power problem for non-stationary data.

Empirical studies also show that panel data unit root tests have advantage over the conventional unit root tests, like ADF and Phillip Peron. One of these advantages lies in the additional information provided by pooled cross-section time series to increase test power. Thus, this study employs Fisher-type unit root test (based on Phillips-Perron tests). Fisher-type is preferred in this study because it accommodates as much heterogeneity as possible. Fisher-type unit root test considers with trend and without trend. As found in Table 2, all variables are found stationary (has no unit root) with trend, while without, REN and LGDPPC have unit root. Since the variables are stationary at level cointegration test is irrelevant.

4.3 GMM Regression

Table 3 presents the estimated results from Arellano-Bond dynamic panel data (Generalized Method of Moment). Model 1 captures all the explanatory variables in the study, while model 2 and 3 drop nonrenewable and renewable energy sources respectively. This is to allow the study find which of the energy source plays more impactful role on economic growth in the region. All the variables except renewable energy consumption were found significant. Estimated results in model 1 found renewable energy insignificant to the economic growth of SSA with negative sign, while nonrenewable (conventional) energy shows positive impact. As conventional energy consumption scaled by overall energy consumed increases by 1 percent economic growth in SSA increases by 0.001 percent. It shows that the impact of conventional energy suppressed that of the renewable.

Furthermore, renewable energy coefficient is found to be negative and statistically in model 2 when conventional energy is dropped. This finding contradicts growth-energy hypothesis as found in Apergis and Payne (2010 and 2011), Inglesi-Lotz (2016), Tugcu et al., 2012, Yazdi and Shakouri (2017), Kahia, Aïssa, and Lanouar, (2017) and Dees and Auktor (2018). However, it aligns with Taghvaee, Shirazi, Boutabba & Aloo, (2017). (2017). Conventional energy is found more significant in model 3 when renewable energy is dropped, than in model 1 when both are captured. It aligns with Papiez and Smiech (2013) and Sasana and Ghozali (2017). The behavior of both sources of energy on economic growth align with Sasana and Ghozali (2017); they found Consumption of renewable and fossil energy sources showed negative and positive impact on economic growth respectively. . However, the conclusion of Bhattacharya et al. (2016) showed that renewable energy consumption has different effects on economic growth across countries; positive in developed economies and has higher likelihood of being negative in developing economies. Perhaps, the findings of this study justify Bhattacharya et al (2016) findings since the countries examined are classified as developing economies.

The coefficient of the lagged values of GDPPC is found positive and significant across the three models. It means $1million increase in the lagged value of overall economic growth in Sub-Sahara Africa, on the average increases current output by $0.8530592 million, $0.8760199 and $0.8510318 million respectively, as found in the three models. This is an indication that the economic performance in the preceding year plays significant impact on the current performance in the region. This further justifies the dynamic specification of the model in this study. GFCF scaled by economic growth is found significant with negative sign in model 1 and 3. An indication that investment in overhead capital failed to produce significant positive impact on the economic growth of the region. This finding should constitute serious concern to the governments in the region.

The population of the labor force in SSA produced significant positive impact on the economic growth of the region. Across the three models estimated, on average, as the population of the work force in the region increases by 1 percent economic growth increases by 0.093 percent, 0.069 percent and 0.097 percent respectively. The contribution of labor force to economic growth in the region is an indication of less effective labor. Inflation and interest rate are found significant with negative sign. It shows that the economy of SSA contract as average inflation in the region increases the economy of SSA countries contract. However, the impact of inflation is less significant in the region.

Table 3: Arellano-Bond GMM Estimation

Variables	Model 1	Model 2	Model 3	Central Africa	East Africa	Southern Africa	West Africa
LGDP-PC_{t-1}	0.85306*** (0.02692)	0.87602*** (0.020475)	0.85103*** (0.02553)	0.86144*** (0.0360)	0.95161*** (0.0387)	0.67699*** (0.06677)	0.96233*** (0.32325)
GFCF	-0.00063*** (0.00023)	0.0001402 (0.00009)	-0.00059*** (0.00017)	0.00179*** (0.0006)	0.00037 0.00083)	-0.00053 (0.00101)	-0.00010 (0.00055)
LLF	0.09336*** (0.01151)	0.06997*** (0.00395)	0.09764*** (0.01247)	0.04385** (0.0227)	0.07458** (0.02964)	0.38366*** (0.06837)	0.05426 (0.29339)
INF	-0.00007** (0.00003)	0.00003 (0.00005)	-0.00007 (0.01247)	-0.00014*** (0.00005)	-0.00070 (0.00043)	-0.00065** (0.00027)	-0.00013 (0.00054)
REN	-0.0002556 (0.000491)	-0.00107*** (0.00027)	-	-0.00299** (0.00119)	-0.00018 (0.00180)	0.00436** (0.00182)	0.00011 (0.00147)
NREN	0.00104** (0.000401)	-	0.00125*** (0.00868)	-0.00043 (0.00093)	0.00004 (0.0025)	0.00046 (0.00185)	0.00364** (0.00160)
Constant	-0.36017 (0.192266)	-0.09432 (0.09244)	-0.43893* (0.21591)	-	-	-	-
Obs.	414	564	414	87	57	73	122
Group No	29	29	29	5	4	7	7
AR1	0.0080	0.0023	0.0078	0.0077	0.0116	0.0008	0.0000
AR2	0.3840	0.1701	0.3643	0.2411	0.2341	0.6203	0.2472
AR3	0.7324	0.4795	0.7375	0.5809	0.0931	0.5389	0.1526
Sargan test	0.8939	0.9182	0.8931	0.5809	0.4921	0.5453	0.0955

**** p<0.01, ** p<0.05, *p<0. The standard deviation is in parenthesis ()*

Across the four sub-regions in SSA, lagged of GDPPC positively affect its performance in subsequent year. Renewable energy consumption (REN) is found to be negatively and positively significant in central and Southern Africa respectively, but insignificant in East and West Africa sub-regions. Insignificant in West Africa because only 19% of rural population have access to renewable energy with 81% left without access (UNDP Dakar-Regional Energy Poverty Project, 2011). Nonrenewable energy consumption is found negative in Central Africa sub-region and positive in East, Southern and West Africa sub-regions, but found significant only in West Africa sub-region. Nonrenewable energy is positive and significant in West Africa because the sub-region is domicile to one of largest deposit of fossil fuels in the SSA region compared to other sub-regions.

The Sargan test of over identifying restriction Chi2 value of 18.351, 25.031 and 18.2668, with its corresponding p-value of 0.893, 0.918 and 0.893 respectively, shows that the null hypothesis of the instrument used in the study is valid. The P-value of AR2 and AR3 across the three models accept the null hypotheses of no autocorrelation.

5.0 POLICY IMPLICATION

The scenarios that play out in this study on energy-growth nexus contradict Apergis and Payne (2010; 2011). Nonrenewable energy crowd-in economic growth in Sub-Sahara Africa especially in West Africa, while renewable energy crowd-out economic growth. Given the fact that the region is endowed with renewable energy sources, switching from conventional source to renewable should not crowd-out growth. However, studies affirm and attribute the negative outcome to poor technology associated with the region. This study found conventional energy to have supported economic growth, while renewable energy crowd-out growth significantly. The region is going through economic transition period, and remains one of the fastest growing regions, coupled with rapid population and urbanization. Therefore, accessibility to energy is needed to support the transformation. In lieu of this, joining collective effort of international communities in promoting paradigm shift towards sustainable energy that are eco-friendly, governments in the region must be sensitive to the negative impact of the shift on their economies.

It is pertinent to take cognizance of the cross-sub-regional differences in the results of both renewable and non-renewable energy sources. For instance, only the result of West African countries found non-renewable source significant, while renewable source is found significant in central and Southern Africa. Differences in policies thrust and political will could have accounted for these variations. Therefore, governments in SSA could possibly explore the comparative advantage of the sub-regions, especially via technology transfer to promote use of renewable sources.

6.0 CONCLUSION

Energy sources remain one of the driving forces of modern economy. However, the international communities remain resolute on the campaign for renewable energy consumption as last solution to the global CO_2 emission. The international communities championing use of renewable energy are mostly developed nations that have made use of fossil fuels to develop infrastructures over the years. On the other hand, the countries in this study are still developing nations with a large range of non-renewable energy sources which have not been optimized. Due to this, the use of renewable energy in Sub-Sahara is not as important as it is in developed nations due to its high cost and the availability of unmaximized low-cost non-renewable energy sources.

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Soumission de Proposition de Recherche pour la Politique Energetique en Afrique de L'ouest

Theme : **Transition énergétique et transformation structurelle des économies de la CEDEAO**

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Résumé

Les pays en développement font face au défi de la transition énergétique et de la transformation structurelle de leurs économies. Cette étude analyse la relation entre la transition énergétique et la transformation structurelle dans six pays de l'Afrique de l'Ouest sur la période 1990-2019. A l'aide d'un modèle économétrique, cette étude examine l'évolution de la part de l'électricité dans la demande globale ainsi que l'intensité énergétique de la valeur ajoutée sectorielle et de l'emploi sectoriel. Les résultats montrent qu'une augmentation de la part de l'électricité dans la demande finale d'énergie affecte positivement la valeur ajoutée du secteur industriel et l'emploi dans le secteur des services. Les résultats indiquent également qu'une baisse de l'intensité énergétique influence positivement la valeur ajoutée du secteur industriel. L'effet sur l'emploi est mitigé selon les secteurs de l'économie. Ces résultats impliquent que les politiques énergétiques orientées vers la transition énergétique pourraient accélérer la transformation structurelle.

Abstract

Developing countries face the challenge of energy transition and the structural transformation of their economies. This paper analyzes the relationship between energy transition and structural transformation in six West African countries over the period 1990-2019. Using an econometric model, this study examines the effect of the share of electricity in final demand and of energy intensity on sectoral value added and sectoral employment. The results show that an increase in the share of electricity in final energy demand positively affects the added value of the industrial sector and employment in the service sector. The results also indicate that a decrease in energy intensity positively influences the added value of the industrial sector. The effect on employment is mixed on sectors of the economy. These results imply that energy policies geared towards energy transition could accelerate structural transformation.

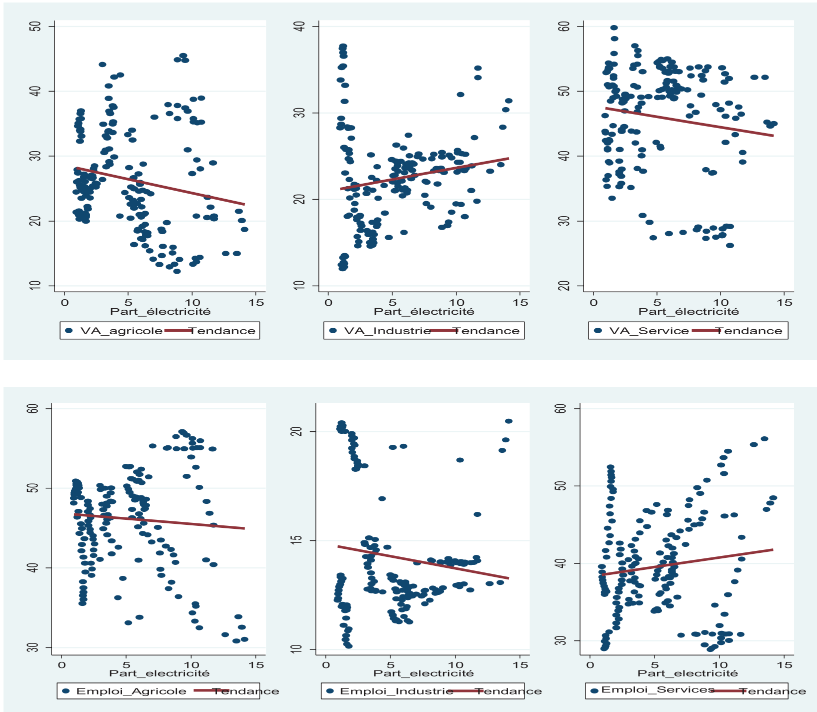
1.0 INTRODUCTION

L'accès à l'énergie moderne est fondamental pour la transformation structurelle des économies des pays en développement. Effectivement, une transition énergétique traduite par une modification structurelle profonde des modes de production et de consommation de l'énergie - c'est-à-dire de transiter depuis les énergies fossiles vers les énergies renouvelables- peut contribuer à une industrialisation durable, ainsi qu'à une réduction de la pauvreté. Le lien causal entre l'énergie et la croissance économique a été largement examiné par les économistes biophysiques et néoclassiques (Stern, 1993). De même, un vaste corpus de recherches empiriques a démontré qu'un meilleur accès à l'électricité affecte positivement l'emploi (Dinkelman, 2011 ; Murry et Nan, 1990), la production industrielle (Assunção et al., 2018 ; Allcott et al., 2016 ; Fisher-Vanden et al., 2015 ; Rud, 2012), le développement humain (Lipscomb et al., 2013 ; Lewis et Severnini, 2017), le revenu des ménages (Chakravorty et al., 2014) la réduction de la pauvreté (Diallo et Moussa, 2020 ; Okwanya et Abah, 2018 ; Bacon et Kojima, 2016 ; Yang, 2003), et la transformation structurelle de l'économie (Schäfer, 2005 ; Cao, 2017 ; Gaggl et al., 2020 ; Perez-Sebastian et al., 2020).

La transformation structurelle de l'économie se définit comme un processus graduel de réallocation des activités et facteurs de production des secteurs à faible productivité comme l'agriculture, vers des secteurs plus modernes et des services à forte productivité (McMillan et Rodrik, 2011). Selon la CNUCED (2012), pour promouvoir une transformation structurelle dans un contexte de développement durable en Afrique, il faudrait favoriser l'abandon des sources d'énergies non renouvelables, destructrices de l'environnement, au profit de sources d'énergies renouvelables, modernes et favorables à l'environnement. Cette transition vers un système énergétique basé sur des ressources renouvelables au détriment des énergies fossiles, traduit la transition énergétique.

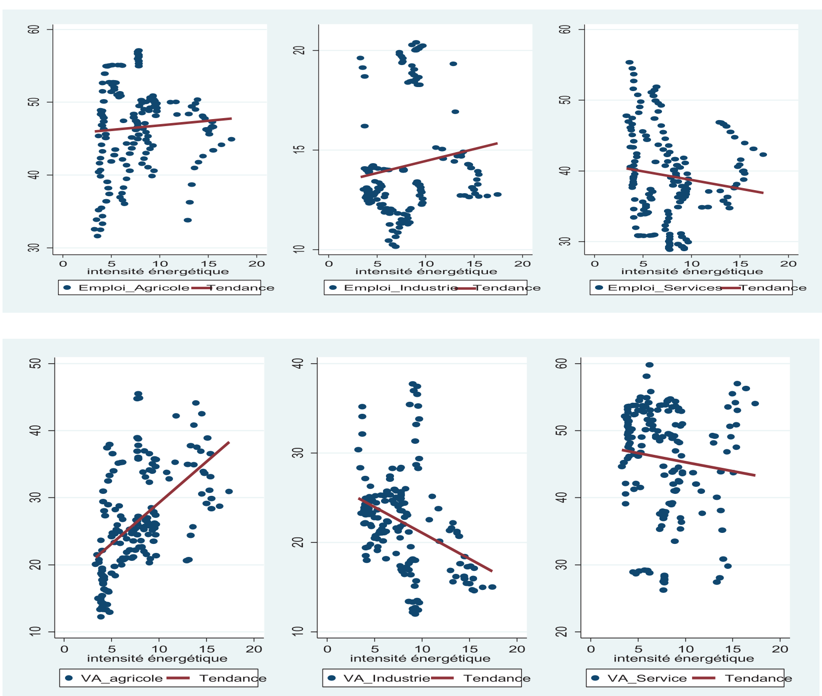
Un récent rapport de la CNUCED (2017) a montré le rôle de l'énergie dans la transformation structurelle des pays moins avancés. Il souligne que des services énergétiques modernes facilitent la transformation structurelle. Non seulement l'accès à des services énergétiques modernes influence la productivité d'autres secteurs, mais augmente également les revenus des populations, ce qui stimule la demande intérieure. Les pays de l'Afrique de l'Ouest sont sur le chemin de la transformation structurelle de leurs économies et de la transition énergétique. Les faits stylisés présentés par les graphiques ci-dessous montrent des liens entre la part de l'électricité et de l'intensité énergétique et la valeur ajoutée sectorielle ainsi que l'emploi sectoriel. Ces observations amènent à se poser la question de savoir si la transition énergétique est en train de favoriser la transformation structurelle dans les pays de la CEDEAO.

Graphique 1: Lien entre la part de l'électricité dans la demande finale d'énergie et valeur ajoutée sectorielle et emploi sectoriel



Source : Auteurs

Graphique 2: Lien entre intensité énergétique et valeur ajoutée sectorielle et emploi sectoriel



Source : Auteurs

Le principal objectif de cette étude est d'examiner la contribution de la transition énergétique à la transformation structurelle des économies de la CEDEAO. Plus précisément, cette étude veut : (i) Montrer la dynamique de la transition énergétique dans chaque pays tant au niveau de l'offre que de la demande ; (ii) Évaluer l'effet de la transition énergétique (mesuré par la part de l'électricité dans la demande finale d'énergie et de l'intensité énergétique) sur la valeur ajoutée sectorielle et l'emploi sectoriel. (iii) Analyser les implications pour le développement et la promotion de l'énergie durable.

La suite de cet article se structure de la façon suivante : la section 2 porte sur la revue de la littérature, la section 3 est un état des lieux de la transition énergétique et de la transformation structurelle, la section 4 présente la méthodologie, la section 5 est consacrée à la présentation des résultats ainsi que leur interprétation, la section 6 présente la conclusion.

2.0 REVUE DE LA LITTÉRATURE

Cette section présente les concepts de transition énergétique et de transformation structurelle, ainsi qu'une revue empirique du lien entre le changement de la structure énergétique et la transformation structurelle.

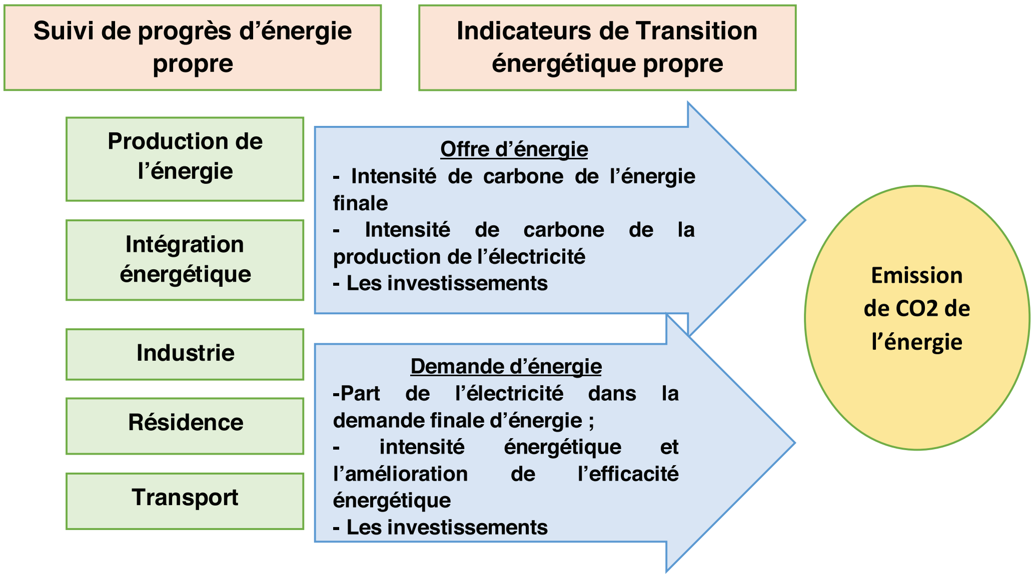
2.1 Concept de la transition énergétique

Selon l'Agence Internationale des Énergies Renouvelables (IRENA), la transition énergétique est la transformation du secteur énergétique mondial, vers une énergie fossile à zéro émission carbone d'ici la seconde moitié de ce siècle. Précisément, la transition énergétique fait référence au passage du secteur mondial de l'énergie, des systèmes de production et de consommation d'énergie fossiles - y compris le pétrole, le gaz naturel et le charbon - aux sources d'énergie renouvelables comme l'éolien et le solaire, ainsi que les batteries lithium-ion[5]. La transition énergétique vise à réduire les émissions de CO_2 liées à la production et à la consommation d'énergie pour limiter les effets du changement climatique. Au niveau mondial, le secteur de l'énergie compte pour 90% des émissions de CO_2.

Les émissions mondiales de CO_2 liées à l'énergie sont le produit de facteurs économiques, technologiques et démographiques (Agence Internationale de l'Energie, 2019). Cette agence fournit des indicateurs qui intègrent des informations sur les changements dans l'intensité énergétique de l'économie et l'intensité en carbone de l'approvisionnement énergétique dans les secteurs d'utilisation finale de l'industrie, du bâtiment et des transports. Ils permettent de suivre la décarbonisation de la production d'électricité ainsi que les progrès des technologies d'intégration énergétique. Des indicateurs intermédiaires sont proposés tant au niveau de l'offre que de la demande pour apprécier la transition énergétique propre. Du côté de l'offre, il s'agit de : (i) l'intensité de carbone dans l'énergie finale ; (ii) l'intensité de carbone dans la production de l'électricité et (iii) les investissements dans les infrastructures et technologies énergétiques à faible émission de CO_2. Du côté de la demande, on note : (i) la part de l'électricité dans la demande finale d'énergie ; (ii) l'intensité énergétique et l'amélioration de l'efficacité énergétique, et (ii) les décisions des choix d'investissements énergétiques.

5 S&P Global

Graphique 3: Indicateurs de la transition énergétique



Source : Agence Internationale de l'Energie

Les agences internationales et nationales de l'énergie sont toutes unanimes que les énergies renouvelables et l'amélioration de l'efficacité énergétique sont les principaux piliers de la transition énergétique, ce qui peut être rendu possible grâce aux technologies de l'information, les technologies intelligentes, les cadres politiques et les instruments de marché.

2.2 Concept de la transformation structurelle

La transformation structurelle est un processus qui fait référence au mouvement de la main-d'œuvre et d'autres ressources productives des secteurs traditionnels à faible productivité (comme l'agriculture traditionnelle) vers les secteurs modernes à forte productivité (comme les manufactures, les services modernes et les branches modernes de l'agriculture)6. Elle peut se définir comme l'ensemble des changements fondamentaux dans les structures économiques et sociales qui favorisent un développement équitable et durable (Commission Economique pour l'Afrique, 2018).

Selon cette définition, la transformation structurelle est un processus qui impose des changements dans la structure des économies et qui favorisent de bonnes performances économiques ainsi qu'une amélioration des conditions de vie des populations. Sur le plan économique, la transformation structurelle se caractérise par une modification de la répartition sectorielle des emplois et de la valeur ajoutée (De Brauw et al., 2014 ; Mama et Ongono, 2019, CNUCED, 2016).

La littérature théorique et empirique explique que la transformation structurelle est bénéfique dans les économies en développement, où les hétérogénéités structurelles sont plus prononcées. Le terme hétérogénéité structurelle fait référence à une structure de production hétérogène caractérisée par la coexistence de quelques industries hautement productives et d'une masse d'activités économiques à faible productivité. En raison de ces écarts de productivité, le mouvement de la main-d'œuvre des industries à faible productivité vers les industries à forte productivité stimule la productivité globale et la croissance économique.

6 The structural transformation process: trends, theory, and empirical findings, UNCTAD

La transformation structurelle d'une économie peut se manifester par plusieurs faits stylisés dont : (i) une réallocation des facteurs de production des secteurs d'activités moins productifs vers des secteurs d'activités plus productifs ; (ii) une création de richesse et d'emplois décents qui favorise l'émergence d'une classe moyenne ; (iii) un accroissement de la part des activités manufacturières et des services modernes à forte productivité dans le Produit Intérieur Brut (PIB), allant de pair avec une augmentation de la productivité et de la production agricole ; (iv) un redéploiement de l'activité économique des zones urbaines vers les zones rurales; (v) une transition démographique assurant le passage de taux de croissance et de mortalité élevés à de faibles taux de croissance et de mortalité ; (vi) une réduction des inégalités sociales et des disparités régionales ; et (vii) une urbanisation croissante.

2.3 Revue empirique

Des travaux ont mis en évidence la relation entre l'énergie et la transformation structurelle de l'économie en utilisant diverses méthodes. Un premier groupe s'est penché sur l'effet de la transformation structurelle sur la baisse de l'intensité énergétique, tandis qu'un autre groupe s'est orienté sur l'effet de l'électrification sur la transformation structurelle.

Farla et BlocK (2000) analyse l'efficacité énergétique et le changement structurel aux Pays-Bas sur la période 1980-1995. Par décomposition de l'indicateur de l'intensité énergétique, ils ont mis en évidence les effets liés à l'activité économique, à la transformation structurelle et l'effet réel de l'intensité énergétique. Ils ont trouvé que le taux global d'amélioration de l'efficacité énergétique était de 1,4 % par an sur la période 1980-1995. Ils ont observé qu'aucun changement substantiel n'a eu lieu au niveau des secteurs économiques de sorte que les changements dans la composition de l'économie, n'ont pas conduit à une diminution nette de l'intensité énergétique sur la période de l'étude.

Schäfer (2005) est parti de l'hypothèse que chacun des trois secteurs de l'économie (Agriculture, Industrie, Service) étant consommateur final d'énergie, le changement structurel illustré par le PIB sectoriel doit provoquer un changement sectoriel similaire dans le système énergétique. A partir de données historiques (1971-1998) de l'ensemble du système énergétique dans 11 régions du monde, il a montré comment le changement structurel du système énergétique induit par le changement structurel de l'économie a contribué à la baisse de la consommation énergétique finale. A l'aide d'un indicateur, il illustre l'évolution de l'intensité énergétique finale comme fonction des réductions d'intensité énergétique par secteur, des déplacements sectoriels de la valeur ajoutée dans l'économie et des réductions de l'intensité énergétique résidentielle (côté de de la demande). Les résultats de ces travaux ont indiqué dans les pays à faible revenu, la réduction de l'intensité énergétique finale est causée principalement par la réduction de l'intensité énergétique dans le secteur résidentiel et secondairement par la baisse de l'intensité énergétique dans le secteur industriel. Cependant, dans les pays à revenu élevé, la baisse de l'intensité énergétique finale est largement attribuée au secteur industriel et des services. Dans les régions en développement, il a trouvé que la baisse de l'intensité énergétique résidentielle contribue nettement moins à la baisse de l'intensité énergétique finale.

A l'aide d'un modèle de croissance économique et de simulation, Cao (2017) a exploré les mécanismes par lesquels les ajustements structurels influencent les changements d'intensité énergétique. En ajoutant le secteur de l'énergie aux modèle de croissance économique, il a trouvé que le changement d'intensité énergétique sectorielle est déterminé par les différences de technologies sectorielles et de production d'énergie. Les résultats de son modèle théorique et des simulations ont montré que le changement structurel influence les taux de croissance de l'intensité énergétique dans l'ensemble de l'économie.

Il a fait remarquer que cette influence dépend du taux de croissance technologique du seuil énergétique ; lorsque les taux de croissance technologique du seuil énergétique sont suffisamment élevés (ou faibles), l'intensité énergétique globale augmentera (ou diminuera). Toutefois, il souligne que l'introduction de variables de transition énergétique pourrait permettre de mieux appréhender le changement dans l'intensité énergétique à long terme.

Gaggl et al. (2020) ont analysé l'effet causal de l'électrification sur la transformation structurelle aux Etats-Unis. Précisément, les auteurs ont examiné l'extension du réseau électrique à haute tension et du potentiel hydroélectrique sur la structure de l'emploi. A l'aide d'un modèle économétrique de régression transversales, ils ont montré que l'électrification a entraîné une baisse de 0,7 point de pourcentage de l'emploi dans l'agriculture, associée à une augmentation de 0,5 point de pourcentage de celui dans le secteur manufacturier. Ils ont montré le rôle spécifique joué par l'électrification dans cette transition d'une économie à forte intensité agricole vers une économie à forte intensité manufacturière. De plus, ils ont constaté que l'accélération de l'électrification a affecté la structure de l'emploi, favorisant notamment la croissance des emplois opérationnels et affectant négativement les emplois des agriculteurs en milieu rural.

Perez-Sébastien (2020) propose un nouveau mécanisme du côté de l'offre, établissant un lien causal entre transformation structurelle économique et électrification du réseau. L'augmentation de la disponibilité de l'électricité affecte la réaffectation des intrants à des activités plus productives en générant des rendements plus élevés et en réduisant les coûts d'entrée dans les secteurs à plus forte intensité d'infrastructure. Les résultats de la modélisation et de l'analyse économétrique basés sur les données historiques du Brésil sur la période 1970-2006 confirment que le secteur manufacturier bénéficie le plus de ces deux dimensions, suivi des services et de l'agriculture. L'expansion des infrastructures électriques explique environ 17 % de ce processus et 32 % de l'augmentation observée du PIB par habitant. Des simulations d'un modèle de croissance néoclassique multisectoriel avec des entreprises hétérogènes permettent d'évaluer l'efficacité de différentes politiques d'électrification.

3.0 ÉTAT DES LIEUX DE LA TRANSITION ÉNERGÉTIQUE ET DE LA TRANSFORMATION STRUCTURELLE DANS LES PAYS DE L'AFRIQUE DE L'OUEST

Cette section fait un état des lieux de la transition énergétique et de la transformation structurelle dans les pays sélectionnés en présentant la dynamique de certains indicateurs.

3.1 Indicateurs de la transition énergétique

Les indicateurs de transition énergétique développés par l'Agence Internationale de l'Énergie sont présentés ci-dessous. Ces indicateurs sont classés selon les aspects de l'offre de l'énergie et de la demande de l'énergie. Du côté de l'offre, l'analyse porte sur l'intensité carbone dans la demande finale et l'intensité carbone dans la production d'énergie électrique. Du côté de la demande, l'analyse concerne l'intensité énergétique et la part de l'électricité dans la demande finale d'énergie. Les données ne sont pas disponibles sur les investissements.

3.1.1 Côté offre d'énergie

Intensité carbone de l'énergie finale

L'intensité carbone de l'énergie finale est définie comme la teneur en carbone de toutes les formes d'énergie finale divisée par la consommation totale d'énergie finale. Il est mesuré en grammes (g) équivalent CO2 par Mégajoule (MJ) d'énergie finale. Le graphique 1 présente l'évolution de l'intensité de carbone de l'énergie finale sur la période 1990-2019. L'intensité carbone de l'énergie finale dans le monde stagne autour de 80 g CO2/MJ. En dessous de 80 g CO2/MJ dans la décennie 1990, elle a connu une hausse dans la décennie 2000 avant de connaître une baisse depuis le début de la décennie 2010.

Dans les pays sélectionnés de la CEDEAO, l'intensité de carbone de l'énergie finale connaît une tendance d'allure ascendante mais elle a été toujours en deçà du niveau mondial. Parmi ces pays, Le Sénégal reste jusqu'à ce jour le pays ayant l'intensité la plus élevée. D'ailleurs, en 2017, valant 78 gCO2/MJ son niveau était proche du niveau mondial de 81,1 gCO2/MJ. Le Bénin et le Ghana, qui avaient les intensités les plus faibles dans les années 90, dépassent à présent la Côte d'Ivoire, le Nigeria et le Togo dans la dernière décennie. En moyenne, le Nigeria sur ces trois décennies connaît l'intensité carbone la plus stable. Fluctuant entre 10 et 15t sur les 3 dernières décennies, ce faible niveau d'intensité carbone reflète la grande part que détient la biomasse traditionnelle dans le mix-énergétique nigérian (Climate Transparency Report, 2020). Cependant, cela ne fait pas de lui le moins pollueur car son niveau d'émissions s'élevait à 104 millions de tonnes en 2018 suivi du Ghana (14 millions de tonnes). En fait, la consommation finale d'énergie du Nigeria est largement supérieure à celle des autres pays. Par exemple, celle du Togo lui vaut à peine 1,6%. De plus, le Nigeria fait partir des six pays au monde où la consommation d'énergie renouvelable est supérieure à la moyenne et essentiellement dictée par une consommation traditionnelle de la biomasse (AIE, 2019)7.

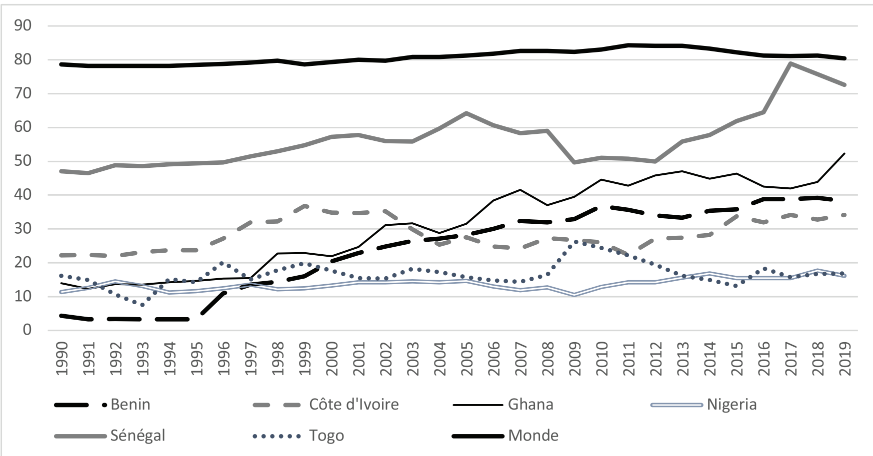
Les variations de l'intensité carbone dans la demande d'énergie finale sont intuitivement liées à la composition de la consommation d'énergie finale. Lorsque cette dernière est dominée par l'utilisation de combustibles fossiles, l'intensité carbone augmente. La

7 AIE (2019)

plupart du temps, la part des énergies non-renouvelables dans la consommation d'énergie (notamment nucléaire), le prix du pétrole et du transport, causent un effet de substitution résultant de l'augmentation des prix de l'électricité (qui entraîne une baisse d'intensité énergétique) et d'une augmentation de l'utilisation d'énergies primaires qui déterminent la hauteur de cette intensité.

L'année 2018 enregistre la plus grande valeur d'intensité carbone soit 28,79 g CO2/MJ tandis que la valeur minimum sur la période 1990-2018 s'établit à 9,22 g CO2/MJ et est observée en 1993. En moyenne, l'intensité carbone dans la demande d'énergie finale dans la zone CEDEAO sur la période 1990-2018 s'élève à 21,10 g CO2/MJ. Le Bénin est le pays qui enregistre le plus faible niveau avec environ 10,94 g CO2 /MJ tandis que le Sénégal présente le niveau le plus élevé, 55,04 g CO2 /MJ.

Graphique 4: Évolution de l'intensité de carbone de l'énergie finale



Source : Auteurs à partir des données de l'Agence Internationale de l'Énergie

Intensité carbone de la production d'électricité

L'intensité carbone dans la production d'électricité représente le niveau d'émissions de carbone par unité de production d'électricité. Elle est définie ici comme le rapport entre le niveau d'émissions issu du secteur de l'électricité et la production totale d'électricité comme proposé par Ang et Su (2016).

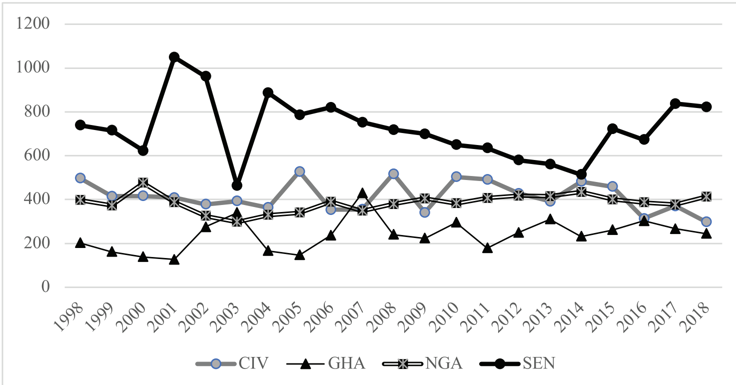
Sur le graphique 2 présentant l'évolution de l'intensité carbone dans la production d'électricité de 4 pays8, on remarque que cette évolution est instable pour tous les pays. Sur toute la période et en moyenne, le Sénégal et la Côte d'Ivoire sont les moins efficaces en termes de CO2 issus de la production d'électricité. Ils engendrent respectivement 697,26 et 403,64 gCO2. Cependant, sur la période 2006-2014, cette intensité présente une tendance à la baisse au Sénégal, passant de 820 gCO2/kWh à 513,74 gCO2/kWh. Ceci s'explique par la coïncidence de cette période avec celle de la crise énergétique sénégalaise liée à la crise pétrolière mondiale de 2008 (AFD, 2017) et des tumultes politiques dans la gestion du secteur de l'électricité. Le rationnement du système d'approvisionnement énergétique qui en a suivi était décrit par une pénurie dans la distribution des carburants, du gaz butane et de l'électricité (Ba, 2018).

Sur la dernière décennie, l'intensité carbone de la production d'électricité est la plus faible au Ghana. En effet, pour un kWh produit, le Ghana émet 250,047 gCO2. De tous les pays, il est celui dont la part d'énergie non fossile dans le mix électrique est la plus élevée, 60% environ. C'est le premier Etat de la CEDEAO à avoir établi un tarif de rachat

8 Les données pour le Togo et le Bénin sont indisponibles.

pour les énergies renouvelables en 2011 avec un soutien prononcé pour l'énergie solaire photovoltaïque à raison de 0,15 dollar/kWh (REN, 2014). Le Ghana et le Nigeria sont des pays, qui en plus d'avoir définit des objectifs pour les énergies renouvelables, ont adopté aussi bien des politiques réglementaires, des incitations fiscales et des financements publics. Le Nigeria quant à lui a connu une baisse marginale de 3% de son intensité dû à la légère baisse du gaz comme productible dans son mix (Climate Transparency Report, 2020). Elle vaut en moyenne sur cette période 403,3 gCO2/kWh.

Graphique 5 : Evolution de l'intensité carbone dans la production d'électricité pour 4 pays de la zone CEDEAO



Source : Auteurs à partir des données de IEA (2020)

3.1.2 Côté demande d'énergie

Intensité énergétique

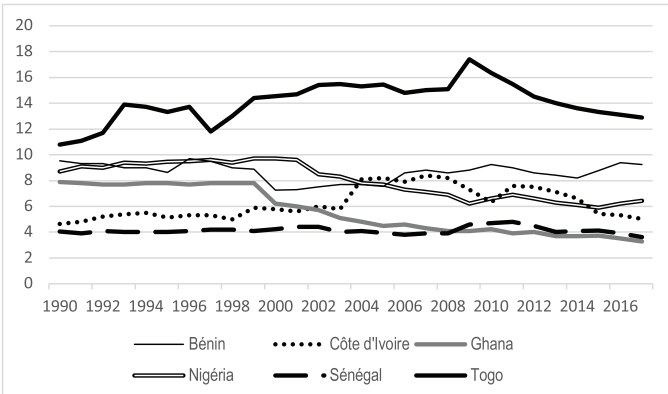
L'intensité énergétique est un indicateur qui désigne le rapport entre la consommation d'énergie primaire et le PIB. Il est utilisé afin d'évaluer l'évolution de l'efficacité énergétique (IEA, 2020). C'est ici le lieu de rappeler que l'efficacité énergétique s'améliore lorsqu'un niveau de service donné est fourni au moyen de quantité réduite d'intrants énergétiques ou lorsque ce service est amélioré pour une quantité donnée d'intrants énergétiques. Selon AIE (2012), l'efficacité énergétique pourrait permettre des gains considérables pour la sécurité énergétique, la croissance économique et l'environnement. Une série de données a été recueillie sur cet indice pour les 6 pays de la CEDEAO sélectionnés afin d'apprécier son évolution.

D'après le graphique 2, l'intensité énergétique à une allure baissière dans la majeure partie des pays, l'efficacité énergétique s'est améliorée ces dernières années. Cela s'explique par la mise en place de la politique de la CEDEAO en matière d'efficacité énergétique qui a vu l'implication de tous les pays dès son adoption en 2012. L'implémentation s'est faite pour chacun de ces pays selon leurs réalités propres. Cependant, elle a pour la plupart concerné l'éclairage, la distribution électrique, la cuisson et les normes et étiquetage (REN, 2014).
Par exemple, le Bénin, la Côte d'Ivoire, le Sénégal et le Togo ont tous mis sur pied des programmes d'électrification rurale fondés précisément sur les technologies d'énergies renouvelables en vue d'améliorer l'accès à l'électricité. Au Sénégal, le gouvernement a levé toute taxe sur les achats de matériels ou d'équipements destinés à la consommation domestique d'énergies renouvelables.

Le Ghana a créé un fond national de l'énergie qui est partiellement financé par la taxe fixe de 0,06 dollar/litre s'appliquant à l'essence, à l'huile de paraffine et aux carburants diesel produits dans le pays. La recherche et le développement ainsi que la promotion des énergies renouvelables sont financés in fine par ces revenus. Dans le cadre de son Programme

national de la biomasse, le Sénégal a permis une subvention destinée à financer 25 % des coûts d'investissement des digesteurs de biogaz (REN, 2014).
D'un point de vue général, la désindustrialisation, les importations couplées aux investissements directs étrangers, la flambée des prix de l'énergie et la structure du commerce sont autant de facteurs qui influenceraient l'évolution de l'intensité énergétique (Adom, 2015).

Graphique 6 : Evolution de l'intensité énergétique par pays



Source : Auteurs à partir des données de IEA (2020)

Le Sénégal a l'intensité énergétique la plus appréciable sur toute la période (4,125 MJ/$ en moyenne) soit une différence très considérable de 10 MJ/$ avec le Togo qui arrive en dernière place du classement. Ceci est principalement dû au fait que le PIB sénégalais supplante largement celui du Togo vis-à-vis de leur consommation d'énergie primaire. En effet, sur la dernière décennie, l'écart-moyen entre ces deux pays pour le niveau de consommation d'énergie primaire est de 204,22 ktep. En revanche, cet écart (en faveur du Sénégal) du PIB est très élevé et estimé à 3,186 milliards de dollars US. Pour Kpemoua (2016), l'intensité énergétique au Togo demeure à la hausse car le niveau de consommation d'énergie croit plus que proportionnellement par rapport à celui du PIB. Aboua et Touré (2018) qui ont également démontré que le Sénégal était énergétiquement plus efficace que le Togo expliquait que cette différence entre les pays s'explique par une obsolescence et un dysfonctionnement des infrastructures énergétiques ainsi qu'un faible approvisionnement en énergie comme c'est le cas pour le Togo (SIE,2019 ; Ntagungira, 2015). En plus, la politique de promotion d'efficacité énergétique semble être plus efficace au Sénégal où des résultats tangibles peuvent être observés. Le Programme de Mise à Niveau des Entreprises (PMNE) a, par exemple, permis de réduire les coûts de facteurs dans l'industrie de l'acier de 26,5%, d'améliorer l'utilisation des matières premières et de réduire les déchets de 50% dans les activités d'impression et de blanchisserie.

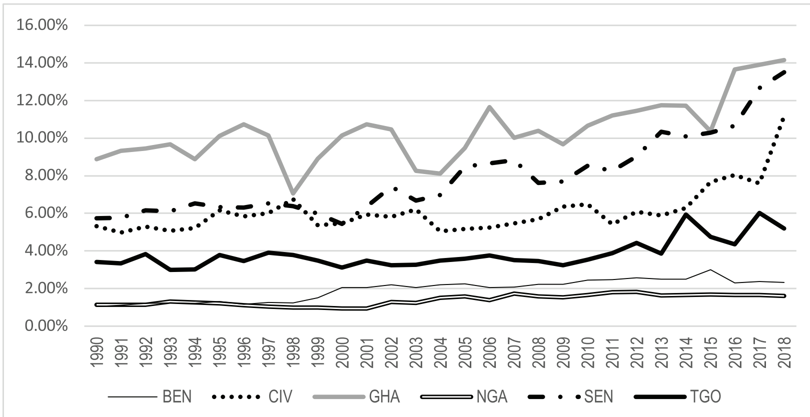
Par ailleurs, Le Bénin et le Togo présentent une évolution très instable avec des écarts-types respectifs de 0,71 et 1,54.

En Côte d'ivoire et au Sénégal, après une longue période d'évolution similaire, on a une conjonction de la baisse de la consommation d'énergie finale primaire et de la hausse de la croissance économique. Cette baisse de la consommation d'énergie s'explique par l'urbanisation en lien avec une utilisation d'appareils électriques de plus en plus efficaces et un délaissement des combustibles fossiles pour les besoins de cuisson (Djezou, 2009). Pour le Nigeria, entre 2000 et 2010, le taux de croissance du PIB supplante celui de la consommation d'énergie finale et entraîne une baisse de l'intensité énergétique. Mais depuis 2015, celle-ci connaît une croissance puisque qu'on observe une baisse du PIB jumelée à une hausse de la consommation d'énergie.

Part de l'électricité dans la demande finale d'énergie

Généralement, ce sont les changements des habitudes de consommation, l'urbanisation, la croissance du secteur tertiaire dominé par les Nouvelles Technologies de l'Information et de la Communication (NTIC), les périodes de canicule, l'utilisation des pompes à chaleur, le prix de l'électricité et la compétitivité des coûts des équipements électriques qui déterminent la part de l'électricité dans la demande finale d'énergie (Enerdata, 2020[9] ; Académie des technologies, 2015).

Graphique 7 : Évolution de la part d'électricité dans la demande finale d'énergie de 6 pays de la zone CEDEAO



Source : Auteurs à partir des données de IEA (2020)

Le graphique 4 présente l'évolution de la part d'électricité dans la demande finale d'énergie des 6 pays sélectionnés. Toutefois, cette part évaluée en moyenne à 3,01% sur la période est encore trop faible par rapport aux autres régions du monde (tableau 1). Cela montre qu'être connecté à un réseau formel d'électricité est encore aujourd'hui un luxe accessible à peu de ménages dans la zone CEDEAO.

Tableau 1. Part moyenne d'électricité dans la demande finale d'énergie dans le monde

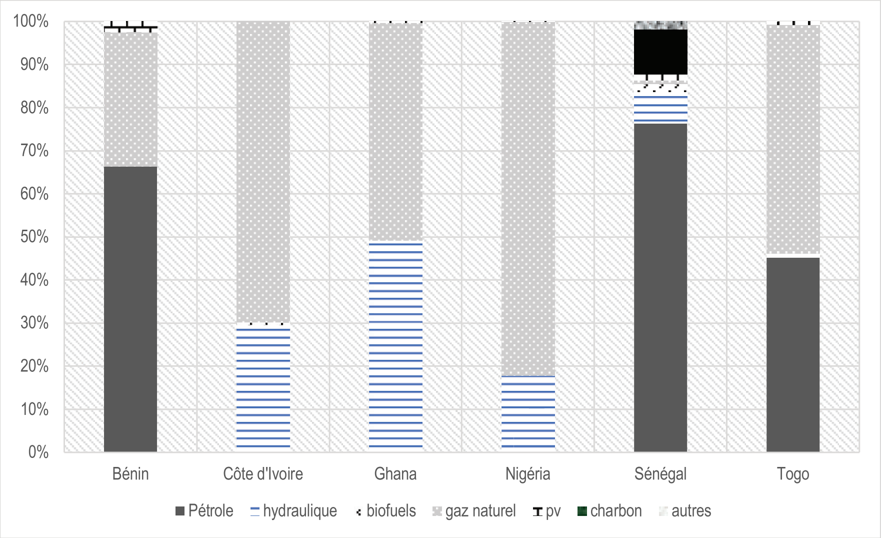
Zone géographique	Part d'électricité dans la demande finale d'énergie (%)
Afrique du Sud	25,4
France	21,65
Etats-Unis	19,9
Allemagne	18,42
Monde	16,13
Chine	12,19

Le Sénégal, le Ghana et la Côte d'Ivoire connaissent les évolutions les moins régulières avec des écarts types respectifs de 0,0209 ; 0,0165 et 0,0125. Le Nigeria, le Bénin, et le Togo ont des fluctuations plus stables avec respectivement 0,0028 ; 0,0056 et 0,0077 d'écarts-types. Cependant, la part d'électricité dans la demande d'énergie finale est la plus faible dans ces trois pays voisins, précisément moins de 6% en 2018. En fait, à la différence du Sénégal, du Ghana et de la Côte d'Ivoire, l'on constate que le Bénin et le Togo ne produisent qu'une faible partie de l'électricité qu'ils consomment et restent tributaires de leurs importations. Pour preuve, d'après le Rapport SIE[10]-2019, leurs taux de dépendance électrique moyen sont respectivement de 84,69% et 75,18% durant la dernière décennie. Le Togo, longtemps importateur net d'électricité a l'un des taux d'accès à l'électricité les plus faibles en Afrique

9 https://www.enerdata.fr/publications/breves-energie/electrification-decarbonation-mondiale.html
10 Système d'Information Energétique

de l'Ouest. Cela se justifie par le fait que le coût du branchement formel y est relativement élevé (Ntagungira, 2015). De plus, la consommation moyenne par habitant et par an d'énergie électrique au Togo est de 118 kWh contre 149 kWh au Nigeria, 212 kWh en Côte d'Ivoire, 344 au Ghana et 535 pour la moyenne des pays d'Afrique subsaharienne (Ntagungira, 2015). Le Nigeria a certes une production d'électricité supérieure à celle des autres pays11 mais cette offre ne répond pas à la demande forte et croissante causée par sa dense population (IEA, 2017). Il est d'ailleurs classé parmi les 20 pays du monde représentant le plus grand déficit sur la période 2010-2017 selon le rapport intérimaire sur l'énergie (AIE12 et al., 2019).

Graphique 8 : Composition du mix-électrique de 6 pays de la zone CEDEAO, année : 2018



Source : Auteurs à partir des données de IEA (2020)

L'observation du mix énergétique (graphique 6) nous permet de constater que la Côte d'Ivoire, le Ghana, et le Nigeria ont une configuration semblable tout comme le Bénin et le Togo. Le Sénégal contrairement aux autres pays a le mix le plus diversifié avec une part du pétrole comme productible évalué à 76,3%. L'hydraulique est pratiquement la seule technologie d'énergie renouvelable dans la production d'électricité dans tous les pays. Au Ghana, elle représente près de la moitié du mix.

Malheureusement, le solaire et la biomasse n'ont qu'une infime contribution en moyenne (inférieure à 3% et 1% respectivement). L'énergie fossile fortement représentée par le gaz naturel et le pétrole demeure encore en forte prédominance (environ 79,80% en moyenne).

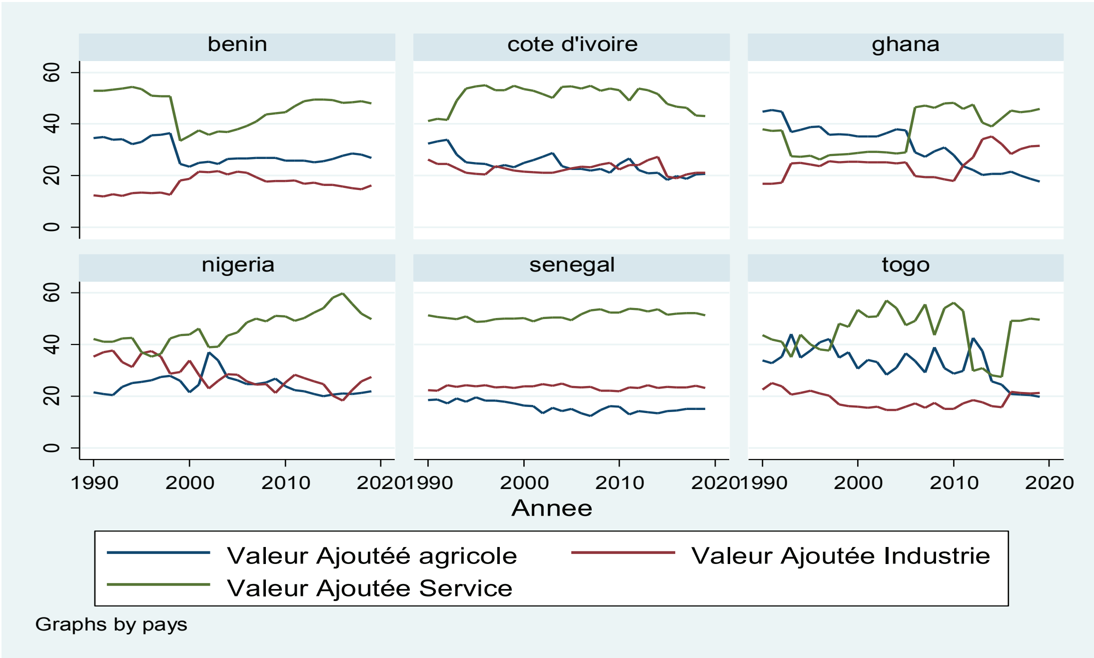
3.2 Transformation structurelle dans les pays de l'Afrique de l'Ouest

Les trajectoires d'évolutions des parts des valeurs ajoutées sectorielles à prix courant du Bénin, de la Côte d'Ivoire, du Ghana, du Nigeria, du Sénégal et du Togo, sont présentées par le graphique 9. Il ressort de l'analyse du graphique que globalement le secteur des services est le secteur dominant des activités économiques du Bénin, de la Côte d'Ivoire, du Nigeria, du Sénégal et du Togo. Tandis que la dynamique de ce secteur au Ghana, est ponctuée par des hausses et des baisses, et est devient le secteur dominant à partir de l'année 1989 jusqu'à l'année 2019.

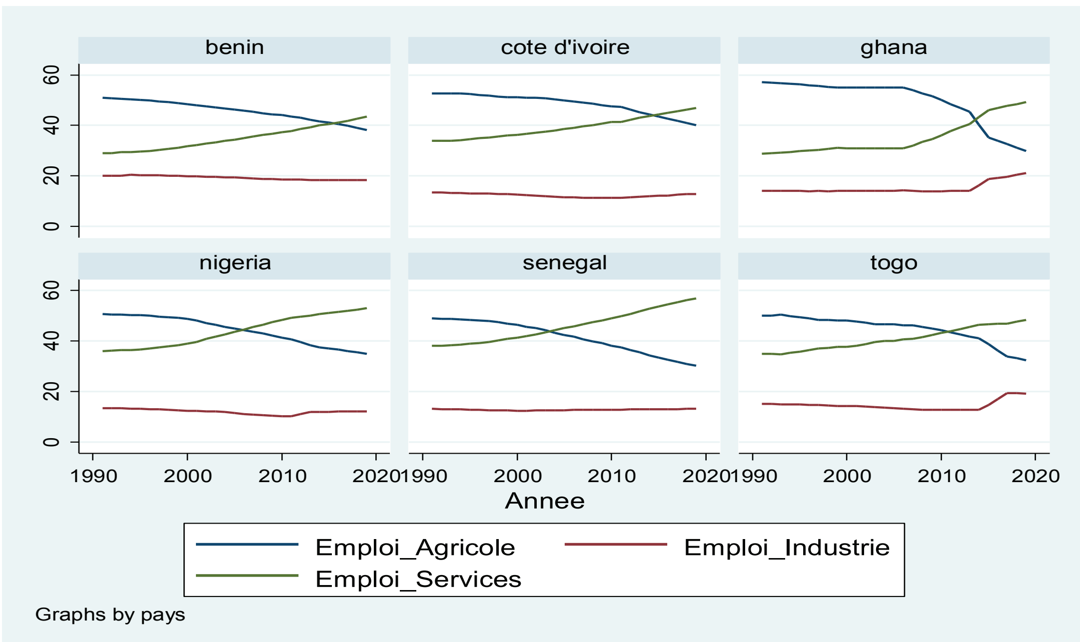
11 36277 GWh (NIGERIA), 12262 GWh (GHANA), 10092 GWh (COTE D'IVOIRE), 4861 GWh (SENEGAL) en 2018 www.iea.org consulté le 05/06/2021
12 Agence Internationale de l'Energie

Le graphique 10 ci-après montre la dynamique de l'emploi dans les secteurs de l'agriculture, l'industrie et des services, du Bénin, de la Côte d'Ivoire, du Ghana, du Nigeria, du Sénégal et du Togo sur la période 1991 à 2019. Il révèle que les emplois dans le secteur de l'agriculture connaissent une baisse généralisée sur la période pour chacun des pays, tandis que ceux des services connaissent une hausse globale pour ceux-ci.

Graphique 9: Evolution des parts des valeurs ajoutées sectorielles



Graphique 9: Evolution des parts de l'emploi sectoriel



4.0 MÉTHODOLOGIE

4.1 Modèle

Les évaluations ont été effectuées à l'aide de modèle de régressions apparemment liées (SUR13). Ce type de modélisation offre l'avantage d'obtenir des estimateurs pour l'ensemble des individus du panel, de même que des estimateurs pour chaque individu du panel isolé des autres. Dans une situation où le nombre d'individus du panel est faible et inférieur au nombre d'observations - comme dans notre cas - , Pesaran (1999) suggère l'utilisation du modèle de régressions apparemment non liées de Zellner (1962).

Le modèle de base

Notre modèle de base SUR est celui proposé par Zellner (1962) et se présente comme suit :

Équation 1

$Yi=X_iB_i+U_i$ (1)

Ce modèle décrit la i-ème équation d'un système d'équations (équation 2) de régressions où Yi est un vecteur d'observations de la i-ème variable dépendante. Xi et Bi représentent respectivement le vecteur des variables explicatives et celui des coefficients de la régression. Les valeurs des coefficients Bi traduisent l'effet des variables Xi sur les variables Yi . Ui est vecteur regroupant les termes d'erreurs liés à chacune des équations constituant le système.

Équation 2

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_I \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \dots & 0 \\ 0 & X_2 & \dots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & \dots & X_I \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_I \end{bmatrix} + \begin{bmatrix} U_1 \\ U_2 \\ \vdots \\ U_I \end{bmatrix}$$

Le modèle est en général estimé par la méthode des moindres carrés généralisés (MCG) qui permet un gain d'efficacité. Cependant, pour le cas où les facteurs de régression dans les différentes équations sont identiques, une estimation équation par équation par la méthode des Moindres Carrés Ordinaires (MCO) conduiraient à des résultats semblables (Greene, 2012).

Ces équations sont dites apparemment indépendantes du fait qu'elles semblent être des estimations conjointes de plusieurs modèles de régression, chacun ayant son propre terme d'erreur. Elles sont donc en réalité liées parce que les erreurs contemporaines associées aux variables dépendantes peuvent être corrélées (Cameron et Trivedi, 2010).

L'application du test du multiplicateur de Lagrange (Breusch et Pagan, 1980) sur la matrice de corrélation des résidus des différentes équations est utilisée afin de valider le choix de la spécification SUR. La statistique du KHI-2 fournit par ce test permet alors de porter un jugement sur l'objectivité du choix de la spécification SUR du modèle. L'hypothèse nulle selon laquelle les régressions apparemment indépendantes sont en fait indépendantes est rejetée si la statistique du Khi-2 est supérieure à sa valeur critique tabulée. Elle est acceptée dans le cas contraire.

13 Seemingly Unrelated Regression, Zellner(1962)

Le modèle empirique

Nous considérons un système d'équations de fonctions de productions sectorielles (valeurs ajoutées) proche de celui de Rahman et al. (2016) en utilisant la méthode SUR (Zellner, 2016) avec quelques adaptations. Ainsi, notre modèle empirique est représenté par le système d'équations comprenant les équations 3, 4 et 5.

$\text{val\_agric}(t) = a_0 + a_{1i}\,\text{parelec}(t) + a_{2i}\,\text{ide\_agric}(t)_+\, a_{3i}\,\text{credit\_agric}(t)_+\, a_{4i}\,\text{dep\_agric}(t)_+\, a_{5i}\,\text{terre\_agric}(t)_+\, a_{6i}\,\text{vc\_temp}(t)_+\, a_{7i}\,\text{vc\_precip}(t)_+\, e(t)$ (3)

$\text{val\_indus}(t) = b0 + b1i\,\text{parelec}(t) + b2i\; i{=}\text{fbcf}(t) + b3i\,\text{ide}(t) + b4i\,\text{credit}(t) + b5i\,\text{pib}(t) + b6i\,\text{ouvcom}(t) + v(t)$ (4)

$\text{val\_services}(t) = c_0 + c_{1i}\,\text{parelec}(t) + c_{2i}\; i{=}\text{fbcf}(t) + c_{3i}\,\text{ide}(t) + c_{4i}\,\text{credit}(t)_+\, c_{5i}\,\text{pib}(t) + c_{6i}\,\text{ouvcom}(t) + w(t)$ (4)

4.2 Données

Les données utilisées pour mener à bien cette analyse proviennent de diverses bases de données internationales. Elles concernent 6 pays de la zone CEDEAO qui ont les données sur l'énergie disponible sur la période 1990-2019. Il s'agit notamment du Bénin, de la Côte d'Ivoire, du Ghana, du Nigeria, du Sénégal et du Togo. Le tableau renferme les informations sur les variables, mesures ainsi que les sources de données.

Tableau 1 : Données de l'analyse

Variables	Codes	Mesures	Sources
Industrialisation	Val_ind	Valeur ajoutée du secteur industriel (% du PIB)	World Development Indicators
	Val_agric	Valeur ajoutée du secteur agricole (% du PIB)	
	val_servic	Valeur ajoutée du secteur des services	
PIB par tête	pibhab	Ratio du PIB / population totale (dollars US)	
Ouverture commerciale	ouvcom	Taux d'ouverture (% PIB)	
Main d'œuvre	Emploi_agric	Nombre d'employés dans le secteur agricole	International Labor Organization Database (2020)
	Emploi_indus	Nombre d'employés dans le secteur industriel	
	Emploi_service	Nombre d'employés dans le secteur des services	

Intensité de carbone dans la production d'électricité	incarel	Emissions de CO_2 du secteur de l'électricité / Production totale d'électricité	Agence Internationale de l'énergie (2020)
Part de l'électricité dans la demande finale de l'énergie	eledfe	Consommation d'électricité (% consommation totale d'énergie)	
Intensité énergétique	intene	Rapport entre la consommation d'énergie primaire et le PIB (MJ/USD)	
Consommation d'énergie dans le secteur industriel	Cenind	Consommation d'énergie dans le secteur industriel (TJ)	
Intensité de carbone de la consommation de l'Energie dans le secteur industriel	carben	Emissions de CO_2 issues du secteur industriel / Production industrielle	
Intensité carbone de la demande d'énergie finale	-	Ratio émissions de CO_2 / Consommation totale d'énergie	
Investissements	fbcf	Formation Brute du Capital Fixe	World Development Indicators

Source : Auteurs

5.0 RÉSULTATS

L'effet de la part de l'électricité dans la demande finale de l'énergie sur la valeur ajoutée sectorielle et l'emploi sectoriel

	VA Agricole	VA industrie	VA Services	VA Agricole	VA industrie	VA Services
Part électricité	-0,427*** (0,16)	0,267** (0,11)	-0,322* (0,174)	-0,460** (0.227)	0,475*** (0,127)	-0,011 (0,223)
IDE Agricole				-1.265*** (0.453)		
Crédit Agricole				-1.789*** (0.458)		
Dépenses publique agricole				-0.013** (0.006)		
Terres Agricoles				.048*** (0.768)		
Variabilité Température				63.649 (60.562)		
Variabilité précipitation				-18,22*** (2.766)		
Investissement					3,878*** (0,824)	-6,447*** (0,000)
IDE					-0,856** (0,471)	1,930*** (0,827)
Crédit à l'économie					-0,213*** (0,065)	0,366*** (0,114)
Ouverture commerciale					0,013 (0,051)	-0,497*** (0,089)
PIB par tête					-0,002 (0,289)	0,01*** (0,004)

constante	28,592*** (1,04)	20,955*** (0,72)	47,691*** (1,097)	73,3*** (4,663)	-53,997 (15,184)	172,462 (26,85)
Chi-2 p-value	83,118*** 0,0000			24,785*** 0,000		

	Emploi Agricole	Emploi industrie	Emploi Services	Emploi Agricole	Emploi industrie	Emploi Services
Part électricité	-0,133 (0,135)	-0,111* (0,06)	0,245* (0,145)	-0 ,966*** (0,114)	-0,059 (0,073)	0,163 (0,120)
IDE Agricole				-0,712*** (0,239)		
Crédit Agricole				-3,019*** (0,230)		
Dépenses publiques agricoles				-0,001 (0,003)		
Terres Agricoles				2,768*** (0,374)		
Variabilité Température				-30,076 (27,24)		
Variabilité précipitation				4,498*** (1,345)		
Investissement					-0,523 (0 ,464)	0,170 (0,744)
IDE					-0,150*** (0,037)	0,147 (0,443)
Crédit à l'économie					-0,150*** (0,037)	0,669*** (0,06)
Ouverture commerciale					-0,042 (0,029)	-0,238*** (0,047)
PIB par tête					-0,003*** (0,001)	0,0004*** (0,002)
constante	46,85*** (0,858) 14,84*** (0,389) 38 ,30*** (0,9189)			27,632		
Chi-2 p-value	160,769 0,000					47,355 (0,000)

L'effet de l'intensité énergétique sur la valeur ajoutée sectorielle et l'emploi sectoriel

	VA Agricole	VA industrie	VA Services	VA Agricole	VA industrie	VA Services
Intensité Energétique	1,221*** (0,146)	-0,579*** (0,111)	-0,271 (0,182)	0,830*** 0.204	-0,256** (0,122)	0,124 (0.20)
IDE Agricole				-1,385*** 0,445		
Crédit Agricole				-1,517*** (0,431)		
Dépenses publique agricole				-0.006 (0,006)		
Terres Agricoles				2,881*** (0,693)		
Variabilité Température				10,306 (58,037)		
Variabilité Précipitation				-11,422*** (3,071)		

Investissement					3,220*** (0,833)	-6,759*** (1,431)
IDE					-0,565 (0,496)	1,938** (0,830)
Crédit à l'économie					-0,199*** (0,066)	0,352*** (0,113)
Ouverture commerciale					0,090* (0,049)	-0,509*** (0,082)
PIB par tête					-0,001 (0,002)	0,012*** (0,004)
constante	17,041*** (1,242)	26,84*** (0,948)	48,01*** (0,000)	50,841*** (5,798)	-40,601 (15,362)	177,40*** (26,378)
Chi-2 p-value		74,475*** (0,000)		30,497 (0,000)		

	Emploi Agricole	Emploi industrie	Emploi Services	Emploi Agricole	Emploi industrie	Emploi Services
Intensité Energétique	0,1244 (0,131)	0,12* (0,06)	-0,245* (0,144)	-0,377*** (0,132)	-0,125* (0,066)	0,109 (0,111)
IDE Agricole				-0,792*** (0,295)		
Crédit Agricole				-2,661*** (0,281)		
Dépenses publique agricole				-0,025*** (0,004)		
Terres Agricoles				3,986 (0,453)		
Variabilité Température				-22,688 (36,806)		
Variabilité précipitation				-8,323*** (1,954)		
Investissement					-0,458 (0,460)	-0,387 (0,752)
IDE			-0.233	0.044	0,454* (0,269)	0,157 (0,450)
Crédit à l'économie					-0,161*** (0,036)	0,648*** (0,060)
Ouverture commerciale					-0,050* (0,027)	-0,233*** (0,044)
PIB par tête					-0,004*** (0,001)	0,006*** (0,002)
constante	45,58*** (1,119)	13,24*** (0,527)	41,16*** (1,229)	74,995 (3,784)	31,269*** (8,487)	37,334*** (13,856)
Chi-2 p-value		160,108*** 0,000			38,239 (0,000)	

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ISBN 978-3-98574-112-0