A Review of Planning of Integrated Energy System in Nigeria

2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON) | 978-1-6654-7978-3/22/$31.00 ©2022 IEEE | DOI: 10.1109/NIGERCON54645.2022.9803125

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***Abstract*—The recent global concerns on traditional energy depletion, intermittency of renewable energy, and goal towards carbon neutrality has led to the emergence of multiple energy generation systems to satisfy multiple loads via conversion and distribution devices. This new power system is known as the Integrated Energy System (IES). Studies on planning and operation of IES have received great attention in developed nations for energy security and efficiency. However, in developing countries such as Nigeria, it is still at infancy and rarely explored despite its many benefits and the energy challenges in the country. In this study, review of the status of IES development in Nigeria is presented. The barriers to IES studies and possible strategies to its planning and operation in Nigeria are expounded as well. At the end of this paper, it is concluded that Nigeria must create and promote new energy policies while investing in infrastructures to support IES planning and operation in the country.**

Keywords*— *integrated energy system, planning and operation, sustainable development

I. INTRODUCTION

Recently, Integrated Energy System (IES) has gained more popularity over the traditional centralized power system in United States of America, United Kingdom, Denmark, and Germany to ensure sustainable development by increasing energy access and minimizing carbon emissions [1]. Unlike the traditional power system which is characterized by a single form of generation transmitted over a long distance to the distribution system, the IES eliminates the inefficiency of energy equipment through effective design combination and coordination of sub-systems. Also, it increases the efficiency of renewable energy sources caused by their intermittent nature and allows for self-sufficiency while minimizing carbon emissions and enhancing energy security. The IES uses advanced technologies to generate electricity, heat, and cold demand from multiple resources such as natural gas, solar, wind, geothermal, and biomass. This increases consumers' choices and energy efficiency which is a driver to sustainable development [2]. Planning and operation are the major aspect of IES for economy benefits, net-zero carbon and reliability [3].

However, most developing countries especially countries in Sub-Saharan Africa (SSA) have not been able to fully adopt and take advantage of the potentials of IES to solve the myriad of existing global energy challenges [4].

For instance, Nigeria, a country situated in Sub-Saharan Africa (SSA) and referred to as the giant of Africa has a population of about 240 million citizens but only a total generating capacity of about 13,000 MW with a primary source from natural gas and water (hydro) [5]. The majority of its population either has no access to electricity or is faced with an unstable power supply due to the increasing demand of the growing population, insufficient energy generation, transmission, and operational limits [6]. Though the government has put in place a governing body: the Nigerian Electricity Regulatory Commission started March 2005 to oversee the operation of the Power Holding Company of Nigeria (PHCN) which consists of six (6) generation companies with twenty-three (23) grid-connected plants; the transmission system is exclusively owned by the government with a transmission capacity of 7,500MW and the eleven privatized distribution system [6], [7]. Nigeria has an enormous amount of hydro and solar energy [8]–[10]. Despite the potentials and government policies like disco privatization, creation of the regulatory agency, providing funds seasonally for power infrastructures; the power generated in the country is insufficient for half of the demand due to inadequate infrastructure investment, regulatory uncertainty, gas pipeline vandalization, etc. [11].

Given the above background, this study presents an analysis of the existing IES planning in Nigeria, the challenges encountered and recommended solutions for IES penetration in the country. This paper is structured as follows:

The definition, component, types, and benefits of IES is introduced in section II. Analysis of IES planning studies in Nigeria is presented in section III highlighting a comparison between the year of study, energy resources, objective, modeling tool, and limitation. Section IV discusses the findings from the carried out in section III, alongside possible solutions/strategies to IES development in the country. In section V, conclusion and future work is provided.

II. OVERVIEW OF INTEGRATED ENERGY SYSTEMS

An IES involves the organized planning and operation of the power system in such a way that the benefits of each energy source in the system are efficiently maximized to satisfy multiple demands. Different sources of energy are coupled using sophisticated technologies to generate the demand for electricity, heating, and cooling [12].

A typical IES as shown in Fig. 1 consists of several elements compounded in four sub-systems for energy supply, coupling, storage, and consumption [13]. The multiple energy supply system is made up of a combination of different energy resources which can either be traditional or renewable for

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Hohai University Scholarship, Nanjing under the recommendation of IEEE Women in Power (WIP).

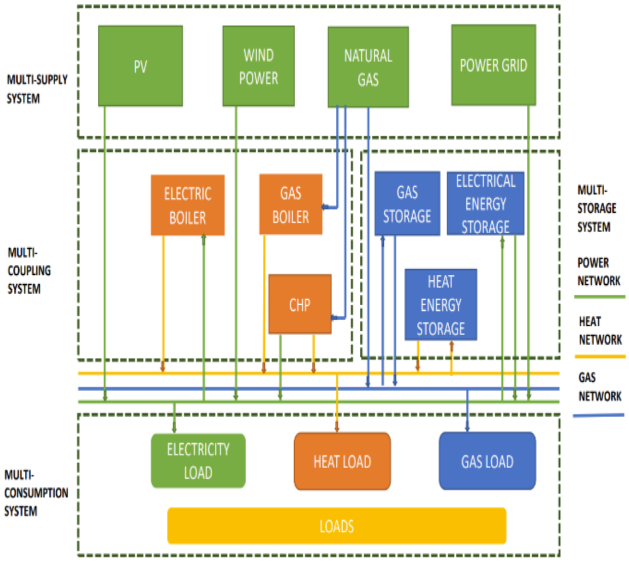

Fig. 1. Typical Integrated Energy System Configuration

generation, transmission, and distribution networks. These include natural gas sources, power grids, photovoltaic (PV), and wind. On the other hand, the energy coupling sub-system includes Combined Heat and Power (CHP) units, gas and electric boilers while the multi-storage system consists of electric, gas, and heat energy storage devices. The electrical load, heat and gas loads are in the multi-consumption system [14], [15].

Generally, IES is a unified system for generating, converting, storing and consuming energy through the connection of electric-gas and cold-electric system for high efficiency and sustainability [16].

IES can be categorized based on their geographical size and energy features into building, regional, and cross-regional IES [17]. The building category of IES comprises of multiple energies of buildings or consumers in different forms and varying characteristics are coordinated and complemented using technologies such as demand response, load forecasting, network, and storage.

The regional IES (RIES) connects and coordinates various energy systems to achieve a balanced multi-energy system for an efficient and sustainable power system. The basic technologies in RIES for strong coupling between the energy systems include the hybrid energy storage system, conversion systems, and active distribution networks. RIES, which is common and usually located on the distribution side of the power network to meet the electric and thermal demands of users in the region and to be able to absorb the distributed energy resources. On the other hand, cross-regional IES (CRIES) fundamental technologies include power electronics, transmission systems, energy routers for deep coupling of the energy systems management, transmission, and operation between the different regions [18], [19].

Systematic planning of IES is very important to ensure reliability, economic, and environmental benefits. This is due to its complexity over the traditional centralized power system as it couples various energy systems such as renewable energy sources that are intermittent. Also, energy market deregulation and the occurrence of a fault in a device or coupling link might affect the whole configuration; hence subsequent instability in the power system [20]–[22]. The planning and design include multiple energy resource identification, capacity planning, multi-energy network modeling, and coupling analysis.

The two types of modeling for a complete analysis of IES were discussed in [23]. The physical model which is the most used among researchers involves the coupling analysis of each component and its energy features in a system. The coupling system which allows a bidirectional flow of energy between power and gas is known as the power to gas coupling system while the connection between electricity and thermal energy via electric boilers, heat pumps, and cogeneration systems is termed the power to thermal coupling system. However, a typical IES combines the electricity, gas, and thermal network, which is analyzed by modeling each of the energy networks and coupling conversion equipment. Different modeling studies of IES have been carried out and presented in literature. Most of these models focus on two main objectives: economic benefits and environmental protection while ensuring energy efficiency and security [24]–[28]. However, the details of the modeling studies carried out in each country in SSA were not explicitly discussed. Hence, the analysis of integrated energy systems modeling studies for Nigeria is presented in section III. The specific limitations to its development and expansion are presented and possible solutions are subsequently discussed.

III. OVERVIEW OF PLANNING AND DESIGN OF IES STUDY IN NIGERIA

The planning and operation of IES in Nigeria has not been extensively studied as only few research and projects have been conducted and reported in the country.

In 2010, [29] presented a study on Nigeria's capacity expansion plan through economic and environmental evaluation of its present and future energy system in a period of 27 years (2003-2030). An IES was modeled under four categories and scenario analysis using two life cycle assessment (LCA) modeling tools: Global Emission Model for Integrated Systems (GEMIS) for preliminary LCA and economic analysis of its energy system, and SimaPro for environmental impact evaluation. The first category which was termed primary data modeled the exact current installed capacity, energy generated and associated technologies, fuel cost, and efficiencies from the national grid. In the absence of definite data such as emissions, generation cost, the second category called generic data was modeled based on data from the modeling tools databases which reflects or are like the Nigeria settings. While the third category, secondary data combines the primary and generic data with an addition of operating hours and fuel consumption, the last category, scenario data included data from the government's grid expansion plan. The scenario analysis of each category was developed according to the corresponding four time periods starting with 2003 as the base-year and installed capacity made up of gas, hydro, and diesel systems. Furthermore, the 2010 scenario combined gas, hydro, coal, and a small amount of diesel; while 2020 increased the generation capacity by integrating purely renewable energy technologies: hydro, gas, biomass, solar PV, and solar thermal. Lastly, the 2020-2030 scenario was dependent on 70% renewable and 30% traditional systems with the addition of wind energy technologies to increase the generation capacity. In conclusion, the result of the model shows an increase in greenhouse gas emissions which signifies that the environmental protection objective of the proposed IES not met. However, the economic evaluation presented shows that a huge amount of investment in solar, wind, and biomass energy sources is needed to satisfy system objective. A study on Nigeria's energy production potential expansion and environmental ramification plan was conducted in 2013 by [30]. The total current and committed generation output of the various combination of energy resources and their technologies (IES), their corresponding forecasted energy demand under three scenarios were simulated in Long-Range Energy Alternative and Planning (LEAP) system for 20 years period (2010-2030). In the first scenario, hydro and natural gas are the major source of energy considered for simulation at the start period of 2010 and by 2020, generation capacity increased with the addition of coal, wind, and solar as input in the second scenario of the model. However, in 2022, nuclear energy was introduced to start the third scenario with a gradual increase in the size of coal, solar, hydro, natural gas, and nuclear energy as it ends in 2030. The objectives of this modeling study were to plan and design a system that proffers possible solutions to the country's electricity crisis through analysis of its 2010 existing system and future expansion and the mitigation of greenhouse gas emissions. For the latter part, the possible effects of nuclear power plants on the environment were investigated using the AERMOD modeling system while the study concluded that natural gas and nuclear would help in fulfilling the development of generation capacity to satisfy the rising need.

In 2018, an IES study was conducted by the authors in [31] to explore the possibility of a fully sustainable power supply in Nigeria. Two objectives were considered in this study: economic (annual energy cost minimization) and environmental (carbon reduction) based on the country's policy and zero-emission targets to determine the optimal investment and power supply technology combination (power, gas, and desalination). A linear optimization in the LUT Energy System Transition modeling tool was used to simulate the Nigeria power system under current scenarios and best scenarios for a long period of 35 years at an interval of 5 years. In the starting year, 2015, the existing fossil fuels were simulated based on hourly resolution yearly with a gradual introduction of new energy resources. This resulted in the installation of gas turbines, complete extinction of fossil fuels and use of purely renewables in the period leading to 2050; subsequently enabling lower carbon emission, increase efficiency, and use of sustainable energy resources. The model input: generation profiles, electricity demand, renewable energy capacities, and storage capacities were compiled in MATLAB while the sum of annual cost of each technology capacity, power generation cost, and ramping cost were optimized in MOSEK. The study also highlighted the impact of carbon emission cost and coupling link and concluded that renewable energy-based IES for energy sustainability can be achieved in Nigeria by 2050 through support and commitment from the government, well-designed structures, and the right policies.

Similarly, in 2018, an IES study presented in [32] employ the Long-Range Energy Alternative Planning (LEAP) modeling tool to simulate the Nigeria power system for future energy generation and demand projection under three scenarios considering for 30 years. The objectives considered for the three scenarios were environmental impacts and economic costs. Total energy consumptions, energy resources (hydro, nuclear, biomass, wind), fuel cost, equipment cost, generation cost, and carbon emission were considered. In the Business as Usual (BAU) scenario, all the data used in the model, for example, transmission and losses, generation technologies, and efficiencies were assumed to follow the past trend that generation and demand policies continue in the future. The Energy Conservation (EC) scenario was analyzed based on data from the country's policies such as Renewable Energy Master Plan while the third scenario, Renewable Energy (REN) considered the introduction of renewable energy sources without new gas plants. After a comparison between the three scenarios, the authors concluded that investment cost would be minimized in EC scenarios due to reduced energy demand, losses, and increase energy efficiency.

Additionally, Nigeria has been mentioned in other IES modeling studies conducted for SSA. For instance, studies by authors in [33]–[36] involve the planning of IES for sustainable development in Africa while a comprehensive review of similar studies was also been presented in [25], [37], [38].

A comparative analysis of IES planning and design studies for Nigeria is given in Table I.

IV. DISCUSSION BARRIERS AND POSSIBLE SOLUTIONS TO IES DEVELOPMENT

The review of studies in section III shows that there have only been a few studies conducted on the planning and design of IES for Nigeria. Among 10 studies in which Nigeria was mentioned, only 4 study has been solely carried out for the country. Each of these studies as seen in Table 1 also has its limitation and hence do not fully capture the elements of an IES. For instance, the study carried out in 2010 has been the most comprehensive and combines the evaluation of both economic cost and environmental impact. However, the model study resulted in a trade-off of one of these objectives while demand forecast, and energy storage system were not also considered. The other three studies were focused on a single objective and hence had their limitations.

Also, the study shows that for universal energy access and environmental protection target in Nigeria, the incorporation of various renewables in the IES is required. Though the nation has solar energy in abundance and can take advantage of its complementary benefits in combination with other renewables such as wind and geothermal, however the existing enabling infrastructures in the country are dilapidated. This is due to ageing infrastructures, poor maintenance culture, lack of investment on new power infrastructures and policies. Therefore, it is important to carry out more research on the planning and design of IES in Nigeria to stimulate operation, energy access that meets its growing demand and minimizes carbon emission. The studies should consider the country's power system features and capacities, reflect all aspects of IES: multiple supplies, multiply demand, and new technologies as applied in developed countries and presented in works of literature. This would eventually end energy poverty in the country and promote the realization of global sustainable development goals towards cheap and clean energy for all and zero-carbon targets.

Hence, we recommend that the following be considered for future planning studies for the country:

1. A comprehensive integrated model study that considers the optimization of each IES component and the mutual coupling relationship between electricity, gas, cold, and heating network.

TABLE I. COMPARATIVE ANALYSIS OF EXISTING IES STUDY IN NIGERIA

Year	***Objective***	***Modeling Tool***	***Traditional Energy Source***	***Renewable Energy Source***	***Time-Period***	***Limitation***
2018	Economic & Environmental	LEAP	Coal, Natural gas, Nuclear	Hydro, Solar, PV, Biomass, Wind	30 years (2010-2040)	No consideration of energy storage system
2018	Economic & Enviromental	LUT MATLAB & MOSEK	Coal, Oil, Gas Turbines (Open cycle &Combine cycle) Nuclear	Wind, Solar, Hydro, Biomass Geothermal, Energy storage systems	35 years (2015-2050	No analysis of constraints such as transmission network and other parameters such as ramp rates, spinning reserves
2013	Generation Capacity Expansion & Environmental Protection	LEAP AERMOD	Coal, Natural gas	Hydro, Wind, Solar, Nuclear	20 years (2010-2030)	No cost analysis of energy generation and technologies such as storage system
2010	Economic & Environmental	GEMIS SimaPro	Coal, Oil (Diesel), Natural gas	Solar PV, Solar-Thermal, Biomass, Wind Hydro	27 years (2003-2030)	Limited to either economic profits or aid environmental safety, no energy demand forecast, and storage system was considered

2. An IES planning study that not only considers the techno-economic factors of Nigeria but covers themes such as demand response, energy efficiency, storage, and electricity trading should be investigated. The impact of increase in the use of renewables and storage devices in terms of cost should be studied as most of the existing model studies are dependent on renewable energy.
3. A model that considers the cost of new infrastructures, maximum load, spinning reserves, ramping costs, peak loads, storage system, and reserve margin of the country's power grid, and their effect on long-term generation costs should be developed.
4. An optimal IES planning study for short, medium, and long time-period plan into states or intra-regional analysis to allow for a comprehensive and efficient study with the use of new simulation tools such as GAMS, GUROBI, AIMMS, etc. is also recommended.
5. Cross-regional IES allows energy exchange between neighboring locations thereby enhancing energy security. Therefore, IES cross-regional planning study for future expansion, support and technology exchange, and sustainability.

V. CONCLUSION

The efficient planning and coordination of IES can increase energy supply by reducing inefficiency of power equipment and carbon emission as well as maximizing the potential of renewables and overall system stability.

In this study, the review of planning of IES in Nigeria was presented and result shows that the country is yet to make significant progress in the development of IES. The nation's energy system must grow rapidly in proportion to demand as this is fundamental to achieving universal energy access and net-zero carbon targets.

In addition, this paper provides an outlook for other researchers especially from Nigeria to conduct research that addresses the highlighted gaps and proffer new solutions or modifications to the limitations of existing studies.

REFERENCES

[1] W. Li, W. Tang, J. Zheng, and Q. H. Wu, "Reliability modeling and assessment for integrated energy system: a review of the research status and future prospects," iSPEC 2020 - Proc. IEEE Sustain. Power Energy Conf. Energy Transit. Energy Internet, no. 202008190000098, pp. 1234–1241, 2020.

[2] Y. Zhong, D. Xie, M. Zhou, Y. Wang, Y. Hou, and Y. Sun, "Hierarchical optimal operation for integrated energy system based on energy hub," 2nd IEEE Conf. Energy Internet Energy Syst. Integr. EI2 2018 - Proc., no. 61673161, pp. 5–10.

[3] J. Huan, J. Zhao, C. Zeng, Y. Sui, and X. Zhang, "Capacities optimizing of region-level integrated energy systems based on random model," 3rd IEEE Conf. Energy Internet Energy Syst. Integr. Ubiquitous Energy Netw. Connect. Everything, EI2 2019, pp. 1258–1262.

[4] P. A. Trotter, M. C. Mcmanus, and R. Maconachie, "Electricity planning and implementation in sub-saharan Africa : a systematic review," Renew. Sustain. Energy Rev., vol. 74, pp. 1189–1209, Dec. 2016 .

[5] A. I. Adekitan, A. A. Olajube, and I. A. Samuel, "Data-based analysis of power generation and transmission losses in Nigeria," IEEE PES/IAS PowerAfrica Conf. Power Econ. Energy Innov. Africa, PowerAfrica 2019, pp. 746–751.

[6] O. J. Ayamolowo, E. Buraimoh, A. O. Salau, and J. O. Dada, "Nigeria electricity power supply system: the past, present and the future," IEEE PES/IAS PowerAfrica Conf. Power Econ. Energy Innov. Africa, PowerAfrica 2019, pp. 64–69.

[7] O. Ogunrinde, E. Shittu, M. Bello, and I. E. Davidson, "Exploring the demand-supply gap of electricity in nigeria: locational evaluation for capacity expansions," IEEE PES/IAS PowerAfrica Conf. Power Econ. Energy Innov. Africa, PowerAfrica 2019, pp. 587–592.

[8] C. Onyeka, O. Taylan, and D. K. Baker, “Solar energy potentials in strategically located cities in Nigeria : review , resource assessment and pv system design,” Renew. Sustain. Energy Rev., vol. 55, pp. 550–566, 2016.

[9] Y. S. Mohammed, V. Kiray, B. Saka, E. A. Aja, and I. I. Dalhatu, “Application of solar energy technologies in nigeria: synopsis of significant issues and challenges,” IEEE PES/IAS PowerAfrica, PowerAfrica 2020, pp. 16–20.

[10] M. O. Dioha and A. Kumar, “Exploring the energy system impacts of Nigeria’s nationally determined contributions and low-carbon transition to mid-century,” Energy Policy, vol. 144, p. 111703, April 2020.

[11] T. Company, “Transmission Company of Nigeria(TCN) Independent System Operator (ISO) generation adequacy report,” no. July, 2017.

[12] C. Jiang and X. Ai, “Study on optimal operation of integrated energy system considering new energy incentive mechanism,” 3rd IEEE Conference on Energy Internet and Energy System Integration: Ubiquitous Energy Network Connecting Everything, EI2 2019 , pp. 301–306, 2019.

[13] Y. Wang, Y. Wang, Y.Huang, F. Li, M.Zeng, J. Li, X. Wang and F.Zhang, “Planning and operation method of the regional integrated energy system considering economy and environment,” Energy, vol. 171, pp. 731–750, 2019.

[14] J. Zhai, X. Wu, S. Zhu, B. Yang and H. Liu, “Optimization of integrated energy system considering photovoltaic uncertainty and multi-energy network,” vol. 8, pp. 141558-141568, August 2020.

[15] B. M. Azar, R. Kazemzadeh, and M. A. Baherifard, “Energy hub: modeling and technology - a review,” 2020 28th Iran. Conf. Electr. Eng. ICEE 2020.

[16] C. Jiang and X. Ai, “Study on optimal operation of integrated energy system considering new energy incentive mechanism,”3rd IEEE Conf. Energy Internet Energy Syst. Integr. Ubiquitous Energy Netw. Connect. Everything, EI2 2019, no. 3182037, pp. 301–306, 2019.

[17] D. Wang, L. Liu, H. Jia, W. Wang, Y. Zhi, Z. Meng and B. Zhou, “Review of key problems related to integrated energy distribution systems,” CSEE Journal of Power and Energy, vol. 4, no. 2, pp. 130–145, June 2018.

[18] X. U. Zhu, J. U. N. Yang, Y. Liu, and C. Liu, “Optimal scheduling method for a regional integrated energy system considering joint virtual energy storage,” IEEE Access, vol. 7, pp. 138260–138272, 2019.

[19] C. Wei, X. Xu, Y. Zhang, and X. Li, “A survey on optimal control and operation of integrated energy systems,” Hindawi Complexity, vol. 2019, pp. 1-14.

[20] L. Liu, D. Wang, K. Hou, H. Jia, and S. Li, “Region model and application of regional integrated energy system security analysis,” Appl. Energy, vol. 260, p. 114268, Dec. 2019.

[21] A. Mirakyan and R. De Guio, “Modelling and uncertainties in integrated energy planning,” Renew. Sustain. Energy Rev., vol. 46, pp. 62–69, 2015.

[22] W. Lip, J. Shiun, W. Shin, H. Hashim, and C. Tin, “Review of distributed generation system planning and optimisation techniques : comparison of numerical and mathematical modelling methods,” Renew. Sustain. Energy Rev., vol. 67, pp. 531–573, 2017.

[23] W. Zhang, J. Lou, J. Wang, X. Chang, C. Wang, Q. Yu and Y. Liang “Review and prospect of modeling and optimization of integrated energy system,” IEEE Student Conf. Electr. Mach. Syst. SCEMS 2020, pp. 888–896.

[24] N. Voropai and K. Suslov, “Simulation approach to integrated energy systems study based on energy hub concept,” IEEE Milan PowerTech, pp. 1–5, 2019.

[25] X. S. Musonye, B. Daviosdottir, R. Kristjansson, E. I. Asgeirsson and H. Stefansson, “Integrated energy systems ’ modeling studies for sub-Saharan Africa : a scoping review,” vol. 128, pp. 1-12, May, 2020.

[26] C. Eyisi, A. S. Al-Sumaiti, K. Turitsyn, and Q. Li, “Mathematical models for optimization of grid-integrated energy storage systems: a review,” 51st North Am. Power Symp. NAPS 2019.

[27] Y. Qin, L. Wu, J. Zheng, Z. Jing, Q. H. Wu, X. Zhou and F. Wei, “Optimal operation of integrated energy systems subject to coupled demand constraints of electricity and natural gas,” CSEE J. Power Energy Syst., vol. 6, no. 2, pp. 444–457, June 2020.

[28] S. Wu, P. Wang, Y. Lie, Z. Li, and O. Min, “Review on interdependency modeling of integrated energy system,” IEEE Explor.,2017.

[29] H. Gujba, Y. Mulugetta, and A. Azapagic, “Environmental and economic appraisal of power generation capacity expansion plan in Nigeria,” Energy Policy, vol. 38, no. 10, pp. 5636–5652, 2010.

[30] A. S. Aliyu, A. T. Ramli, and M. A. Saleh, “Nigeria electricity crisis: power generation capacity expansion and environmental ramifications,” Energy, vol. 61, pp. 354–367, 2013.

[31] A. S. Oyewo, A. Aghahosseini, D. Bogdanov, and C. Breyer, “Pathways to a fully sustainable electricity supply for Nigeria in the mid-term future,” Energy Convers. Manag., vol. 178, pp. 44–64, August 2018.

[32] H. Ibrahim and G. Kirkil, “Electricity demand and supply scenario analysis for Nigeria using long range energy alternatives planning (LEAP),” J. Sci. Res. Reports, vol. 19, no. 2, pp. 1–12, 2018.

[33] A. Sanoh, A. S. Kocaman, S. Kocal, S. Sherpa, and V. Modi, “The economics of clean energy resource development and grid interconnection in Africa,” Renew. Energy, vol. 62, pp. 598–609, 2014.

[34] S. Szabó, K. Bódis, T. Huld, and M. Moner-Girona, “Sustainable energy planning: leapfrogging the energy poverty gap in Africa,” Renew. Sustain. Energy Rev., vol. 28, pp. 500–509, Dec. 2013.

[35] C. Taliotis, A. Shivakumar, E. Ramos, M. Howells, D. Mentis, V. Sridharan, O. Broad and L. Mofor, “An indicative analysis of investment opportunities in the African electricity supply sector - Using TEMBA (The Electricity Model Base for Africa),” Energy Sustain. Dev., vol. 31, pp. 50–66, 2016.

[36] B. van der Zwaan, T. Kober, F. D. Longa, A. van der Laan, and G. Jan Kramer, “An integrated assessment of pathways for low-carbon development in Africa,” Energy Policy, vol. 117, pp. 387–395, March 2018.

[37] S. Gri, “A review and assessment of energy policy in the middle east and north Africa region,” Energy Policy, vol. 102, pp. 249–269, 2017.

[38] P. L. Lucas, J. Nielsen, K. Calvin, D. L. McCollum, G. Marangoni, J. Strefler, B.C.CC van der Zwaan and D. P. van Vuuren, “Future energy system challenges for Africa : insights from integrated assessment models,” Energy Policy, vol. 86, pp. 705–717, 2015.