

Optimization of Power Generation in South-South, Nigeria Using Leap Model

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Abstract:

This study aims to evaluate the most efficient power generation methods for Nigeria's South-South region. The analysis utilized the Low Emissions Analysis Program and constructed four scenarios based on key factors from existing research. These scenarios include the Base case, Modest Renewable Energy Technology (RET) scenario, High RET scenario, and varying degrees of Renewable Energy Transition scenarios. The study found that integrating renewable energy technologies offers substantial benefits, with potential advantages ranging from 0.5% to 13.23% over a 30-year period depending on cost improvements. Implementing renewable energy transitions can lead to significant economic and environmental gains. Therefore, the recommended energy strategy for Nigeria involves improving energy efficiency while addressing distribution and transmission losses.

Keywords — **Generation, Leap Model, Renewable energy, NEMO tool**

I. INTRODUCTION

The economy of the South-South region experiences significant adverse effects due to an insufficient and unreliable power supply. Hence, it is incumbent upon the researcher to offer viable answers. The electrical power system primarily consists of producing stations, transmission stations, distribution stations, and load centers. The power sector in Nigeria has been a challenging and extensive endeavor for both the government and its inhabitants, characterized by difficulties, demands, hardships, and significant consequences. The presence of a population of 170 million individuals, wherein over 50% lack access to electricity, poses significant challenges to the economic and social advancement of Nigeria and its citizens. The liberalization of electrical sectors in Nigeria has prompted a need to explore alternative energy sources in order to enhance power generation, improve dependability, and ensure availability. This

encompasses the transition towards generating electricity at the distribution level, rather than relying solely on centrally supplied power. The notion of the embedded generation is a relatively recent development in terms of its actual implementation, and it presents promising alternatives to traditional centrally generated electricity. Niger State is a region located in the central part of Nigeria (Sadat, 2013).

Nigeria encompasses a land area of 356,667 square miles (923,768 square kilometers). Out of the total area, the greatest portion comprises 351,649 square miles (910,771 square kilometers), which accounts for 98.6% of the whole. Nigeria is comprised of the Federal Capital Territory (FCT), six Geo-political Zones, and 36 states. The country has a diverse range of land topography, vegetation, and physical features, encompassing a variety of terrains such as expansive flat savannahs and densely populated rain forests. Additionally, the presence of rivers, lakes, and mountains further contribute to the

overall landscape. The intersection of national geography and politics is a significant obstacle in effectively addressing the entirety of a nation's energy requirements. In order to attain industrialization and ensure sufficient power production, Nigeria needs undertake three essential activities.

It is imperative for the country to generate an ample amount of power and thereafter distribute this energy to every geographical area. Ultimately, the effective distribution of electricity to its users is vital (Perwez et al., 2015). The effective management of these three duties necessitates an inventive and sensible approach, given the dynamic nature of population and development across nations. In order to prosper, it is imperative for each nation to possess a sufficient and reliable source of electrical power. The sectors engaged in the generation, transmission, distribution, and administration of electricity exhibit a significant reliance on capital investment, necessitating substantial financial resources and expertise. In light of the prevailing scarcity of funding, there is a pressing need for novel and inventive approaches to tackle the issue of electricity deficiency in Nigeria.

Over the course of the last four decades, Nigerian citizens have been engaged in the generation of electrical power through the utilization of various fuel sources. Hydroelectric plants and gas-fired plants are widely regarded as prominent choices within the energy generation sector (Abido, 2012). It is well acknowledged that the sources of fuel for power plants, including coal, oil, water, and gas, are readily accessible. The coal reserves in Nigeria, which are believed to be approximately 2 billion tonnes, are of significant magnitude. The majority of Nigerian coal, over 95%, is mostly utilized within the country for various purposes such as railway transportation, cement manufacture, and industrial heating. Nigeria possesses natural-gas deposits that have been estimated to be approximately 176 trillion cubic feet, placing it inside the top 10 countries globally in terms of natural-gas reserves. Additionally, they hold the distinction of being the largest in Africa. Natural gas is a naturally occurring blend of hydrocarbon gases that is found

underground in reserves. The predominant constituent of the substance is methane, constituting approximately 70 to 95 percent. The combination additionally comprises minute quantities of heavier hydrocarbons, namely ethane, propane, butane, and pentane, among other impurities such as carbon dioxide, water, Sulphur, and so forth (Ibrahim & Kirkil, 2018). The utilization of Nigerian gas extends beyond its potential for exportation, encompassing its application in meeting the energy demands of local industries such as power generation, cement production, and iron & steel manufacturing. The Power Holding Company of Nigeria (PHCN) represents the foremost consumer of natural gas in Nigeria, accounting for approximately 70% of the gas consumption required to operate the electricity-generating gas plants located in Afam, Ughelli, Sapele, and Egbin.

Despite the rapid advancement of power optimization mathematical techniques, conventional methods have yet to offer dependable and expeditious real-time solutions for power system applications. It is of utmost significance to use caution and vigilance in order to circumvent certain mathematical challenges, including issues related to convergence and ill-conditioning. The field of artificial intelligence significantly relies on the phrasing of problems in a precise manner and the acquisition of subject-matter expertise (Cie, 2013). The ES system, which operates on a knowledge-based framework, exhibits a limited capacity to adapt or acquire new knowledge in response to changing conditions. The implementation of a knowledge-based system has the potential to enhance the functionalities of a power system. Artificial neural networks (ANNs) acquire knowledge through adaptive training and the ability to generalize. The development and implementation of ANNs and fuzzy models require the expertise of a singular individual. Furthermore, their proficiency in formal model theory or mathematical rigor is lacking (Acha, 2014). This renders individuals susceptible to the knowledge and skills possessed by specialists. Further investigation is warranted regarding ANNs and fuzzy theories due to their capacity to accurately depict power system issues and offer adaptive

training and universal applicability. In contrast, Genetic Algorithms (GA) employ existing models to attain a comprehensive comprehension of complex issues. The likelihood of achieving success in the study of power systems is higher when employing the use of GA. GA is a recent addition to the field of Artificial Intelligence (AI). The comprehension of GA is enhanced when considering its application in computational tasks and its characteristics related to convergence. Hybrid systems represent a novel advancement in the field of power system analysis, with promising prospects for future development.

The task of power optimization, also known as MOOP (Multi-Objective Optimization Problem), presents challenges due to the presence of discontinuous, nonlinear, and nonconvex components. The optimization of reactive power regulation is commonly achieved through the utilization of the Newton approach or the standard interior-point strategy. The methodological approach entails the conversion of the Multi-Objective Problem (MOP) into a single-objective solution with linear weighting, employing the following techniques. According to Gaing (2013), it is not feasible for a multi-objective optimization problem (MOP) to possess a control system that is reasonably optimal. In the context of a complex multi-objective reactive energy optimization problem, the utilization of an evolutionary multi-objective algorithm (MOEA) that operates on the principles of the Pareto front (PF) would offer greater utility. The outputs of the Multi-Objective Evolutionary Algorithm (MOEA) are more readily comprehensible. Numerous studies have been conducted to investigate the optimization of reactive power across several areas

II. METHODOLOGY

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A. Materials

The following tool will be used to model this study;

- LEAP modelling tool.

- NEMO modelling tool.

B. Methods.

1. Data Collection

The secondary data used for the research modelling was computed data extrapolated from information secured from data sources (mainly the World Bank, United Nations and National Control Centre, Osogbo, Nigeria). Additionally, capacity data for technology and renewable energy systems was used to calculate the capacity information for future energy systems inputted into the model.

2. Methods of Data Collection / Instrumentation

The data collection was conducted through the internet platforms, encompassing evaluations, downloads, and correspondences. The sole reason for the visit to the Osogbo National Control Centre, located in Oyo State, Nigeria, was due to the absence of digitalization in their system. In accordance with established conventions, proper citations have been provided for all data sources referenced in this study.

The LEAP tool was thereafter employed for the analysis of the gathered data. The methodology employed in this analysis is shown in Figure 1.

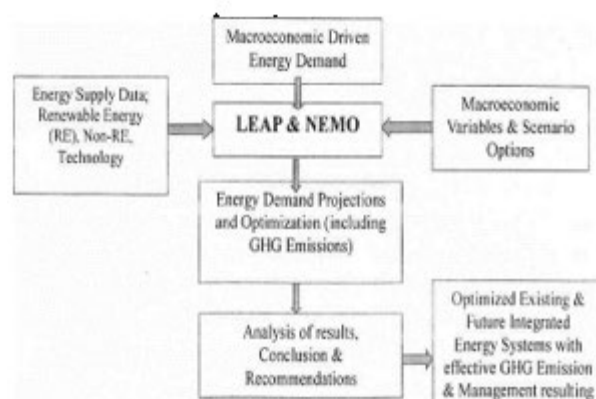


Figure 1: Methodology Flowchart

3. Methods of Data Analysis

The data analysis involved the utilisation of graphs, charts, and tables to represent the results obtained from the LEAP / NEMO Optimisation Model. Through this analysis, trends, profiles, and changes

were examined, and deductions were made, which were afterwards categorised as conclusions. The analysis of the findings is subsequently conducted within the framework of the project's objectives, resulting in the formulation of conclusions. The aforementioned conclusions are further examined in the context of the requirements specific to emerging economies, with the aim of offering recommendations that, if put into practise, will result in enhancements in the energy capacity and reduction of greenhouse gas emissions in integrated energy systems.

C. LEAP Design

The NEMO, a component of the Low Emissions Analysis Programme (LEAP), was employed to optimize and simulate the integrated energy systems of Nigeria. The model also assessed the aspect of environmental sustainability, specifically focusing on greenhouse gas (GHG) emissions and their impact on climate. Subsequently, it was employed to facilitate the advancement of a supply system characterized by reduced carbon emissions. The LEAP programme, which is an integrated energy modelling tool, is utilized for the purpose of simulating energy resources, generation, transmission, distribution, as well as consumption and utilization patterns in various sectors such as home, commercial, and industrial. This modelling is conducted at several scales, including states, countries, and regions, encompassing both developed and emerging economies. This particular tool is often utilized inside the sector. One notable advantage of this application is its extensive database, enabling it to operate well even in situations where the necessary data is not readily accessible. Leap, an accounting framework, may be effectively utilized for both short-term and long-term planning and modelling purposes.

The SEI LEAP model, established in 2009 by the Stockholm Environment Institute and the University of Boston USA, is a notable model in the field. Originally, this tool was employed for the purpose of simulating energy systems and conducting assessments on future demand, taking into consideration environmental concerns. These

analyses were based on a range of macro and microeconomic indicators, including population dynamics, growth rates, and other relevant variables. The software is well-suited for the modelling of technologies and adaptations, both of which play a crucial role in the contemporary energy systems model.

The LEAP application has been developed by Charlie Heaps. The system has undergone multiple updates and upgrades in order to increase and optimize its efficiency. Following the completion and release of the latest upgrade in the first half of 2020, the nomenclature of the system previously known as the "Long Range Energy Alternatives Planning System" was modified to the "Low Emissions Analysis Programme," a term that aligns more well with its purpose. Furthermore, the aforementioned development resulted in the successful deployment and assimilation of NEMO, a software application that offers a comprehensive framework for the purpose of robust optimization. The LEAP Mathematical Modelling Framework is dependent on the energy consumption study conducted by LEAP. This analysis is summarized through the utilization of the equations provided by Feng et al. (2012).

Based on the algorithm for the energy consumption calculation and carbon emissions, the total final energy consumption is computed with the following equation:

$$EC_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \quad (1)$$

where:

EC is the aggregate energy consumption of a given sector, AL is the activity level, EI is the energy intensity, n is the fuel type, i is the sector, and j is the device.

This suggests that the overall energy consumption within a specific sector is determined by the integration of the activity level within that sector, which is aggregated across various devices and fuel types, as well as the intensity level of the energy utilized. The present concept bears resemblance to the vector equations employed for the consolidation of energy employed at a central location, with the

hub being analogous to the observed sector.

The net energy consumption for transformation is computed with the following equation:

$$ET_s = \sum_m \sum_n ETP_{m,n} \times \left[\frac{1}{f_{n,j,i}} - 1 \right] \quad (2)$$

Where ET is the net energy consumption for transformation, ETP is the energy transformation product, f is the energy transformation efficiency, s is the type of primary energy, m is the equipment, and t is the type of secondary energy.

This states that the total energy consumption for a particular energy transformation process, is a product of the integration of the energy transformation product (output) and the transformation efficiency, aggregated across equipment type and the secondary energy type. Again, this is similar to the hub transformation equation where the transformation coefficient is equivalent to the “coupling matrix”.

The Carbon emission from final energy consumption is computed with the following equation;

$$CEC = \sum_i \sum_j \sum_n AL_{n,j,i} \times EI_{n,j,i} \times EF_{n,j,i} \quad (3)$$

Where: CEC is the carbon emission, and $EF_{n,j,i}$ is the carbon emission factor from fuel type ‘ n ’ for equipment ‘ j ’ from sector ‘ i ’.

This implies that the amount of carbon emission associated with an energy consumption process is computed as the integration of the activity level, energy intensity and carbon emission factor, aggregated over the fuel type, equipment type and energy sector in view. Once again this reveals a similarity of the computation structure with the hub system, in this case, with the carbon emission factor serving as the coupling matrix.

The carbon emission from the energy transformation process is computed with the following equation;

$$CET = \sum_s \sum_m \sum_t ETP_{t,m} \times 1/f_{t,m,s} \times EF_{t,m,s} \quad (4)$$

Where CET is the carbon emission from transformation, ETP is the energy transformation product, f is the energy transformation efficiency, and $EF_{t,m,s}$ is the emission factor from one unit of primary fuel type ‘ s ’ consumed for producing secondary fuel type ‘ f ’ through equipment ‘ m ’.

It may be inferred that the overall carbon emissions resulting from the energy transformation process can be calculated by multiplying the integral of the energy transformation product (output) with the aggregated transformation efficiency across primary and secondary fuels and equipment types, and the emission factor. The hub equation remains same, with the exception that the coupling matrix serves as the factor for transformation efficiency.

The literature research reveals a commonality in the integration and aggregating methodology employed by LEAP and hub processes. However, this pertains solely to energy sectors rather than specific categories. The NEMO, which was designed using the Julia programming language, is founded on principles of optimizing energy supply and demand, minimizing costs, and including energy storage capabilities. The storage of data occurs within a publicly accessible database, facilitating convenient access to the obtained results (SEI, 2020). This study aimed to establish a comprehensive framework for an integrated energy network that caters to the needs of a rapidly expanding economy, taking into account both present and future energy resources and systems. The purpose of this action was to ensure the tool's feasibility in its application within developing economies. The tool has been modified for implementation in Nigeria through the utilization of zero-parametric assignment. The tool was subsequently modified for use in Nigeria by deactivating elements that were not relevant, employing zero parametric assignment. Subsequently, the data was uploaded to the model. The integration of energy was facilitated through the development and subsequent implementation of a scenario within the model.

III. RESULTS AND DISCUSSION

LEAP interface is structured under seven different views by means of graphical icons: Analysis, Results, Energy balance, Summaries,

Overviews, Technology database (TED) and the Notes views used for the analysis are shown in Figure 3.

A. Energy Demand: Past and forecast

In South-South Nigeria, it is assumed that energy demands are uniform across all local governments. As a result, electrical appliances, such as refrigerators and air-conditioners, are less used during raining seasons than they are in the dry. To accommodate the fluctuation in temperature, a seasonal variation of 20% has been taken into account. As a result, a household's daily energy requirement is estimated at 6,64 kWh/da. In the HOMER platform, the house load data is shown in Figure 2.

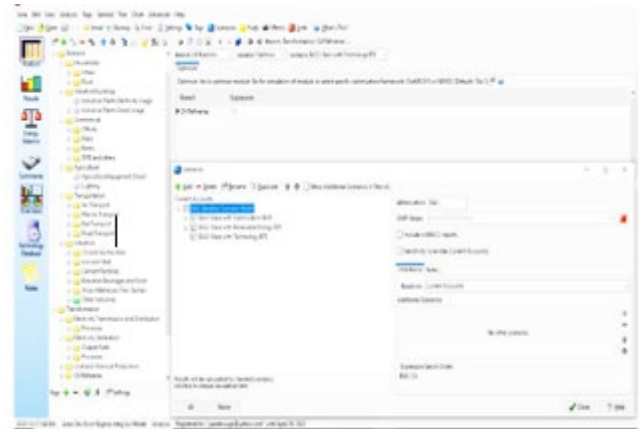


Figure 3: LEAP demand forecast model of South-South, Nigeria

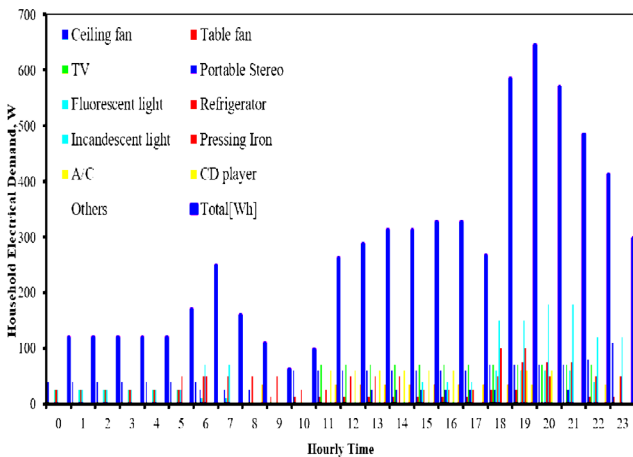


Figure 2: Typical household daily electrical energy demand

The Bottom-Up demand model approach in LEAP was adopted for modelling the future energy demand and energy optimization in this research.

Energy consumption data was collected by the Energy Commission (Halkos) in 2010. In Figure 4, the projection of South-South Nigeria's energy consumption from 2010-2040 is predicted. The utilization of the LEAP Energy Demand Model was employed to demonstrate. The findings indicate that there will be an increase in energy use in the future. The average growth rate for the periods 2010-2020 and 2020-2030 is 9% each. The rates of growth mentioned align with previous state demand and official load estimated (Nojedehi, et. al., 2016). According to estimates, the region of South-South Nigeria is projected to exhibit a cumulative energy consumption of 118.88 megawatt hours (MWh) by the year 2025. The anticipated outcome of the study suggests that the energy consumption will rise to 200.5 megawatt hours upon its completion. In order to adequately address the projected increase in energy demand within the nation, it will be imperative to augment the existing installed capacity of 80.19 MW to 200.0 MW first, followed by a subsequent increase to 260 MW by either 2020 or 2040. To adequately address forthcoming energy requirements, it is imperative to conduct a comprehensive assessment of available energy sources within one's jurisdiction. In the context of this thesis, it is imperative to consider the potential for real demand to surpass projected estimates. The potential for this disparity arises from the reliance on historical data and GDP estimates in making projections. This phenomenon might be attributed to

Demand (TWh)

the insufficient generation capacity and limited electrification rates, particularly in rural areas. The utilisation of the back casting methodology provides a more precise means of ascertaining demand. The occurrence of energy crises in 2007 coincided with a decline in demand growth. This observation underscores a strong positive association between the official forecast of demand and the ability to meet it. The objective of this thesis is to investigate several strategies that can be employed to attain sustainable energy generation in the South-South Region of Nigeria. The study will additionally offer a comprehensive examination of the economic and environmental consequences associated with various scenarios. This will be applicable to all conceivable scenarios.

B. Scenario Description

The scenarios developed for this study fall under four main classes: reference expansion plan (Base case), Plan with coal (Coal); expansion plan with implementation of various renewable energy policies and strategies (Modest RET and High RET scenarios) and optimum scenario developed by LEAP.

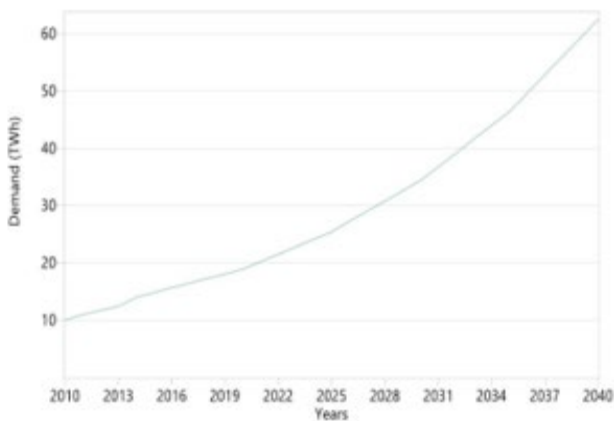


Figure 4: Electricity demand forecast for South-South, Nigeria

The scenarios developed for this study fall under four main classes: reference expansion plan (Base case), Plan with coal (Coal); expansion plan with implementation of various renewable energy

policies and strategies (Modest RET and High RET scenarios) and optimum scenario developed by LEAP.

1. Base Case Scenario

The reference scenario, also known as the Base Case scenario, is derived from the optimisation plans of the government of South-South, Nigeria on energy capacity and the recommended options for mitigation.

The present augmentation of generation capacity in the South-South region of Nigeria exhibits a notable growth in thermal power generation, mostly reliant on natural gas (NG) and crude oil (oil).

2. Modest RET Scenario

The Modest-RET scenario places emphasis on the advancement of renewable energy technologies that provide substantial potential. Therefore, photovoltaic (PV), wind, small hydro, wave, biomass, and municipal solid waste (MSW) are incorporated in moderate quantities with the objective of augmenting the renewable energy capacity to approximately 20% by the year 2030.

3. High RET Scenario

The High RET-RET Scenario aims to comprehensively examine and exploit the maximum capabilities of renewable energy technologies (RETs). Therefore, there is a strong focus on the implementation of renewable energy technologies that are supported by verified domestic capabilities. This scenario posits a policy shift aimed at promoting the extensive development of low emission technologies while concurrently reducing reliance on fossil fuel generation.

4. Technical Results

Figures 5–9, presents the generational perspective of South South, Nigeria, as influenced by several policy directions outlined in the scenarios. Based on the data presented in Figure 4, it can be inferred that in order to adequately fulfil the demand and maintain the necessary reserved margin, it is imperative to optimise the installed capacity of South-South, Nigeria to a minimum of 200 MW.

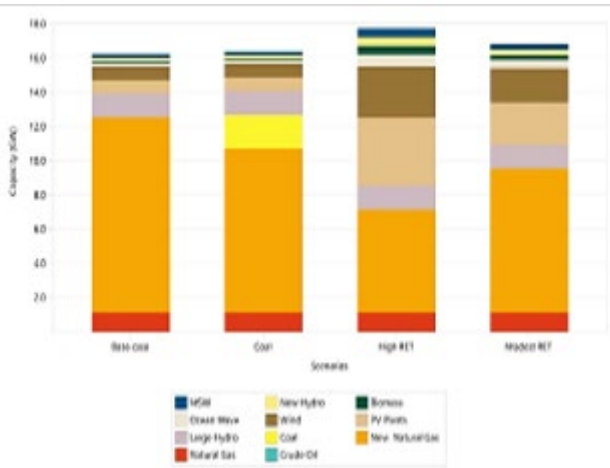


Figure 5: Installed capacities of Scenario at the end of the study period (2040)

RETs scenarios necessitate a rise in the installed capacity. The limited credit capacity of renewable energies in comparison to traditional thermal plants accounts for this phenomenon. According to Reddy (2013), a greater capacity of RET was required to meet an equivalent level of demand compared to that of thermal power plants. The implementation of additional RETs will enhance the variety in electricity generation and reduce the proportion of thermal power sources. Based on the provided predictions, it is anticipated that the implementation of a high renewable energy goal will provide a renewable share of 57 percent, whilst a mild RET scenario is expected to result in a renewable share of 38 percent. The initial scenario results in a renewable energy share of barely 18 percent.

5. Technical Results of Base Case Scenario

The outcome of the increase of the system's generation in the base-case scenario is illustrated in Figure 6. In order to cater to the needs of the entire nation, the capacity of the system has been augmented from 152.50MW to 220.50MW. The insufficiency of the 2014 capacity was attributable to the high demand from the States. However, the present situation was simulated in such a way that the Low Emission Alternative Pathway (LEAP) may internally generate an increase in new natural gas plants with a capacity of 60 MW in order to fulfil the

overall demand. The underlying premise of this model was predicated on the assumption that a continuous supply of fuel would be accessible during the whole planning process. To adhere to the prevailing policy, the preexisting thermal plants have been transitioned to operate only on natural gas (NG) commencing in 2030 (Kemausuor, 2011).

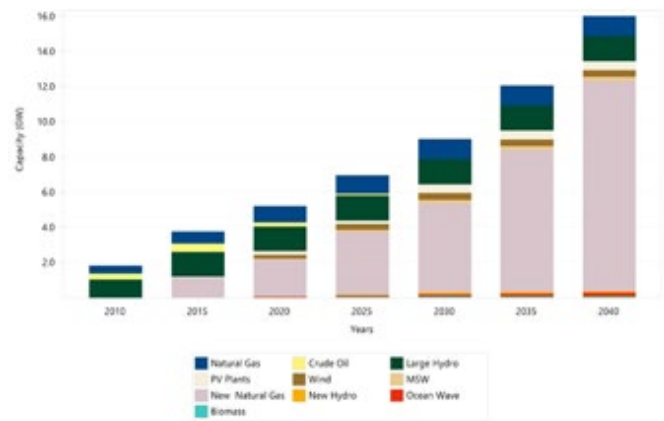


Figure 6: Electricity generation capacity by plant type for base case

Based on the statistics presented in Figure 7, it is evident that in order to meet the state's generation demand by 2040, there would be a need to augment the installed capacity to roughly 200 MW. There has been a substantial increase of over 300% when comparing the current capacity to the documented capacity in 2015. This prediction was generated based on the prevailing demand. The presented data indicates that hydroelectric plants own a relatively lesser share of the overall capacity. Hydroelectricity has had a notable reduction, with its capacity dropping from 57.6% in 2010 to 20% in 2020, and is projected to further decrease to 9% by the year 2040. The decline in hydroelectric power supplies is thought to have resulted in a significant rise in the utilization of thermal technologies for electricity generation. Over the recent years, the incorporation of external factors has facilitated the expansion of Non-Renewable Energy Technologies inside the prevailing framework. The proportion experienced a notable increase, rising from an initial value of 0.1% at the commencement of the study to almost 13% by

the year 2020. The aggregate energy generation during the initial year of analysis amounted to 13 megawatt hours (MWh). Hydroelectric power made a significant contribution of 64.4% to the overall power output, but solar power accounted for a minimal proportion of only 0.1%. A little fraction of the energy was produced by the utilization of natural gas and crude light oil in thermal power units. The model's estimation of generation for the basic case indicates a little increase in hydroelectric generation in 2018 as a result of the introduction of technologies such as tidal-wave generation and small hydro systems. According to the model's projections, it is anticipated that by the year 2040, there will be a shift in the primary energy source from hydroelectricity to natural gas.

the study. Within the energy composition, it is observed that a proportion of 14% is derived from the generation of energy through big hydroelectric power plants. The energy that remains is sourced from non-renewable technologies (NRET).

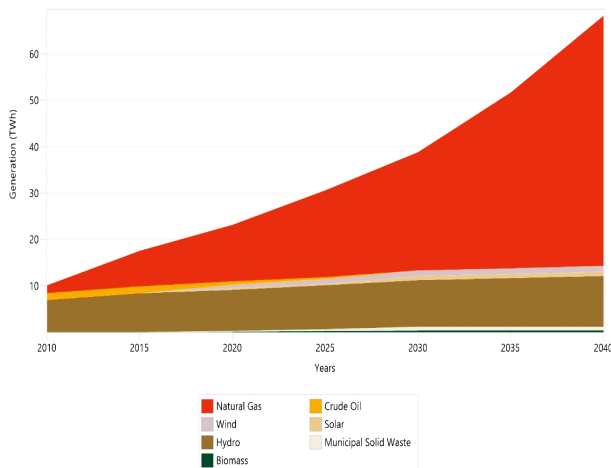


Figure 7: Electricity generation by source in base case

Figure 8, presents the percentage distribution according to generation. Figure 8 illustrates the prevailing dominance of natural gas-fuelled thermal power generation across the whole state. In the year 2020, thermal generating accounted for 54% of the total energy production. The projected proportion is anticipated to increase to 65% by the year 2030, and further rise to 79% by 2040. The demand for increased electricity has resulted in a rise in thermal generating. The implementation of this expansion strategy has yielded a decline in the generation of renewable energy, ultimately resulting in a projected share of 21% for renewables upon the conclusion of

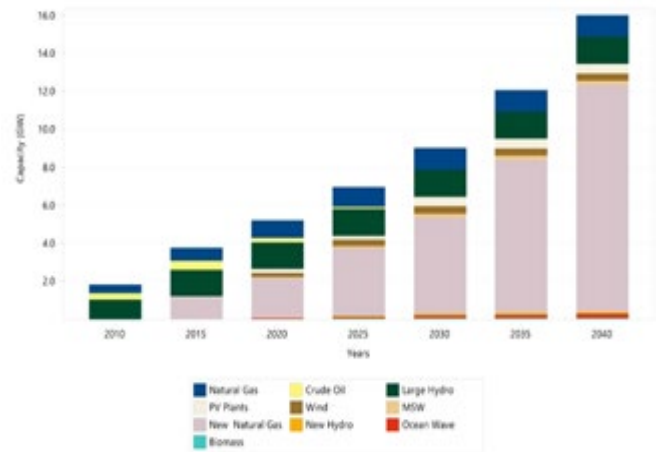


Figure 8: Electricity generation capacity by plant type for base case

Figure 9 highlights the increased significance of NRETs in fulfilling the energy requirements outlined in the base-case scenario. The proportion of NRET generation in the base scenario has exhibited substantial growth, rising from less than 0.1% in 2013 to exceeding 10% by the year 2030. The region of South-South in Nigeria has recently revised its official aim for renewable energy. This aligns with the observed rise. The primary contribution of NRET is derived from wind power, accounting for 3% in 2020 and 2% in 2040. This scenario posits a greater prevalence of photovoltaic (PV) plants in comparison to non-renewable technologies. The constrained accessibility of PV plants restricts the magnitude of power generated by such facilities.

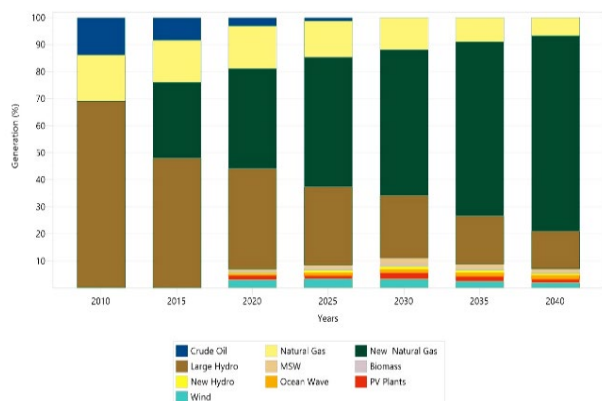


Figure 9: Percentage of generation by source in base case scenario

IV. CONCLUSION

This study evaluates the competitiveness of NRET in various scenarios and highlights a decline in RET costs. It discusses strategies by the South-South Nigeria government to address energy deficiency, including incentives for consistent power providers, which currently favour fossil fuel plants. The study emphasizes RET's potential in the region, showcasing scenarios with high RET targets leading to reduced greenhouse gas emissions and cost savings. It suggests that South-South Nigeria could benefit from carbon trading under the Kyoto Protocol by enhancing its energy infrastructure with RET. Financial constraints hinder RET implementation, but diversification in the energy system, especially with wind and small hydro technologies, could reduce fossil fuel dependence and improve energy security. Natural gas is highlighted as an economically efficient and environmentally sustainable alternative amongst fossil fuels. The study concludes that optimizing energy strategies in South-South Nigeria involves improving energy efficiency and integrating renewable sources to reduce infrastructure investment needs.

V. RECOMMENDATIONS

Based on the findings of the study, the study recommends that:

1. Renewables along with the distributed generation should be promoted in the country to reduce generation costs and environmental emissions.
2. Indigenous coal should be promoted for energy security and diversity of generation technologies but with abated emissions.
3. South-South, Nigeria is surrounded by water therefore, hydro power sources should be tapped.

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