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Energy modelling as a tool for curbing energy crisis and enhancing transition to sustainable energy system in Nigeria

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ABSTRACT

The relevance of energy in the growth and development process necessitates giving serious attention to the planning, production and consumption of energy. Energy modelling carried out in recent years using sophisticated and computerized models has become an important tool in planning and analysis of energy systems. These models rely heavily on future assumptions regarding the expected economic conditions in consideration to the current and unfolding situations of the economies in question. However, due to uncertainty of the future economic conditions, informality of especially developing economies and too much reliance on technical expertise of development/collaboration partners, these assumptions are mostly not well formed, hence found untenable to adequately capture the evolving events. This is more evident if one looks at the alternative energy projections made by different organizations using different understandings and assumptions. This study compares the best energy demand and supply projections of NECAL2050 as the best and most recent energy model in Nigeria with other alternatives projections and previous Energy Commission of Nigeria - ECN's model to showcase the discrepancies and their economic consequences. It is found that in most cases of energy planning collaboration, modeling assumptions do not well capture the current and future economic realities of the assisted nations, resulting in misleading projections. Policy implications and recommendations are discussed at the end.

Keywords:

Energy modelling;
NECAL2050;
MAED;
MESSAGE;
Projections;
Electricity

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1. Introduction/Background

The transition to sustainable energy system at city, state, region, country and the world at large is crucial to achieving the goals of the global development agenda 2030 and Paris Climate Agreement [1, 2, 3, 4 & 5]. Effective transition to renewable energy system will directly depend on the comprehensiveness of energy planning [6, 7 & 5] including the analysis and projections of energy demand and supply as well as the targeted level of economic activities being envisaged for a given nations [8]. Several methods and approaches to energy planning have been evolving over the years and computer-based energy modelling [9] has become the order of the day in modern energy planning [10, 11, 6, 12 & 13]. Energy modelling relies heavily on huge amount of economic data and some economic assumptions regarding the future expected conditions of the economy whose energy demand and supply is being modelled. On the other hand, the economic data are mostly unreliable in developing countries, the future assumptions are not always perfect in the continuously dynamic world with a lot of unforeseen changes [14 & 15]. Estimations with accuracy that stand the test of time are very difficult to arrive at leading to poor energy

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planning that results in energy (electricity) crisis in most of the developing world particularly Africa [16, 17 & 45]. This fault is not limited to African developing countries as noted in a report by Oxfam International on the eve of 22nd Conference of the Parties to the Kyoto Protocol at Morocco in 2016. The report claimed that "a year after the Paris Climate Deal, most vulnerable are still not getting financial support they need" and also the "amount of net financial assistance going to help developing countries fight climate change has been miscounted by tens of billions of dollars" [18].

These errors, as recently studied and confirmed by [19], whether by developing countries or their advanced development partners have a dimension in creating serious economic imbalances. One such imbalance this paper intends to study is in the area of the persistence of energy crisis in Nigeria despite the presence of modern energy modelling tools and their continuous upgradation. The failures of these models to adequately capture the local and changing conditions of the economies [14] they are intended for has been understood to be the root of the problems [20, 21, 22, 6]. Nigeria is not only the largest economy in Africa, it is also the most populous and having amongst the largest growth in populations and energy demand. In the estimates of The Economist in 2015, Nigeria will have the third largest population in the world by the year 2050 after India and China [23]. The combined effects of rapid population growth and urbanization in the developing world, particularly Africa [17], on the growth of energy demand are unimaginably undermining climate action. This is even more important in Africa with high energy intensity in GDP [24, 46] and low access to clean energy, that the share of people without access to is growing [25]. This is true because, the current energy crisis in Africa – being either the result of poor energy planning or wrong estimates and assumptions – is a testimony to the fact that, unless something is done, the same result will be recorded for climate action in the continent, despite their long standing advanced development partners. One possible area of intervention is in improving energy planning by improving the relationship between energy projections and actual energy production and consumption as well as their effects on the economies [7].

This paper intends to use the case of Nigeria Energy Calculator 2050 – NECAL2050 to showcase the evidence of these gaps by comparing its best projections with other projections from the local and some renowned international energy organizations for the same economy (Nigeria). The paper, after highlighting the best energy projections of NECAL2050, carries out a small comparative analysis of the electricity demand and supply from the model and other alternative projections estimated using similar or different assumptions for Nigeria. Policy implications and recommendations are discussed at the end, before which an overview of energy planning (modelling), Nigeria's modelling experience and brief review of NECAL2050's features and weaknesses is given.

2. Understanding Energy Modelling

Before dwelling on energy modelling, it will be good to take a look at the concept of modelling generally, its nature and associated terminologies. Modelling is a method of studying or solving problems through a simplified systemic representation that enables system analysis and prediction from the observed and recorded behavior in a simulation of the original system. It involves evaluating and understanding the interaction of the components of a real or theoretical system by designing its representation (model) and executing it in real time. A model in this case is defined by Singh and Singh [11] as a simplified representation of a real or theoretical system at some particular point in time or space intended to provide understanding of the system. Energy model is then a simplified representation of a real or theoretical energy system designed and run at a particular point in time or space with the aim of getting as much information and understanding as possible regarding the present or future energy variables of the replicated system [26]. Energy modelling is the method of evaluating and understanding the interaction between the different components of a real or theoretical energy system through designing its simplified representation and executing it.

Modelling is important in that it enables one to choose and invest wisely by testing every aspect of the proposed changes or additions without committing resources [26 & 47]. It allows for compression and expansion of time, provides team training as it gives clear understanding of system behaviors or an aspect of it by allowing problem diagnoses, enables exploration of possibilities, identification of constraints, allows visualization of plans and systems as well as its requirement specification. On the other hand, it should be understood that, modelling is difficult and requires special and continuous training as the real life systems being modelled are constantly dynamic especially in the area of energy and related dynamic economic variables that serve as inputs into the models. It is difficult for energy planners in developing countries with little to no training/experience to keep up with the changing situations. And so, the generated results mostly appear random, not in agreement with the current changing realities. As such, sometimes the process becomes time consuming, as is modelling generally, but even more without the right inputs and outputs. It is therefore expensive and the results are used inappropriately in generating energy policies that will not serve their own purposes.

2.1. Historical Evolution of Energy Modelling

Bhattacharyya and Timilsina [21] observed that, the World Dynamics of Jay Forrester and its application in Meadows et al. (1972)'s Limit to Growth, despite their infamous and limited representation, was traced as the pioneering efforts towards global large-scale energy modelling as well as most of the national modelling initiatives. Other key factors in this list are the collective effort of the US EIA and International Institute for Applied System Analysis in the 1977 Workshop on Alternative Energy Sources and the high prices of oil in the 1970s. One of the earliest approaches to energy analysis and modelling is the energy accounting framework that is used in generating energy balance as the most simplified energy system representations [22]. Its comprehensive and consistent nature has been enjoyed as early as the 1950s in the USA [27] and is still popular in 21st century modelling practices and models [21, 22]. Reference energy system framework, by Hoffman, is an expansion of the accounting/energy balance approach that focuses on the actions involved in the entire supply chain. This is done by taking the technological characteristics as well as all possibilities of future technological improvements of the system into account thereby facilitating analysis of different energy scenarios, hence setting a new line of energy system modelling tradition.

With the complexities brought by pictorial presentations and the associated optimization techniques benefits, linear programming has been an integral part of reference energy system leading to several models being developed for many purposes and with different capabilities over the years including most Electricity related models and the Brookhaven Energy System Optimization (BESOM). Other methods that followed it include the more generic and dynamic or multi-period Market Allocation (MARKAL) model as the best of its days, the Mexico's ENERGETICOS and The Energy Research Institute – TERI Energy Economy Environment Simulation Evaluation model for India as the two national specific models developed based on the BESOM model [28]. Other country level models developed in France are Modele d'Evolution de la Demande d'energe (MEDEE)/Model for Energy Analysis and Energy Flow Optimization Model (EFOM).

The econometric approach of linking growth to inter-industry models with endogenously determined inter-industry input-output coefficients was pioneered by [29] in the United States. In 1978 Wien Automatic System Planning (WASP) was developed by International Atomic Energy Agency as a response to calls for and attention given to integrated planning and coordinated modelling efforts, which was extensively used and modified over the years. In the 1980s focus shifted to energy-environment linkages to cater for environmental concerns, while in the 1990s other climate change related issues were further added to the modelling efforts. This new change required very long-term (100 years or more) understanding, making efforts looking beyond (normal 20-30) 100 to 200 years to cause the validity of assumptions to be complex due to high risks and uncertainty. The incorporation of the probabilistic risk analysis made the development of Very Long-term Energy Environment Model initiative of the European Union possible. Along with these are models like Asian-Pacific Model (AIM), Second Generation Model (SGM), Regional Air Pollution Information and Simulation (RAINS)-Asia Model, Global 2100, Dynamic Integrated Model of Climate and the Economy, Poles etc. Existing models like MARKAL are also expanded, while Long-range Energy Alternative Planning – LEAP system became national communications standard for UNFCCC reporting.

These developments also witnessed the divergence of views between bottom-up (focusing on energy sector's technical characteristics) and top-bottom (stressed on the price and markets) model builders that failed to be settled. [21, 22] further reviewed the categorization of energy models in the works of [27] based on modelling approach, [10] based on paradigm, space, sector and time, while [30] uses modelling approach and Meta-Net approach. Within all the categorizations, models are found based on linear programming-based method, input-output approach, econometric method, process models, system dynamics and game theory, (top-down and bottom-up) methodology, partial equilibrium, general equilibrium or hybrid, modelling technology (optimization, econometric or accounting) and the spatial dimension (national, regional and global), sectoral coverage, time horizon and spatial focus.

However with this long history, developments and all these differences, it will be interesting to know where Nigeria stands as far as energy modelling is concerned. This is covered in the next section.

3. Energy Planning (Modelling) in Nigeria

Energy modelling in Nigeria is part of the mandate of the ECN as the government's strategic planner and coordinator of national policies in the field of energy and all its ramifications [31]. In fulfilling this mandate, the commission has over the years been utilizing many computer based tools of energy modelling, planning and analysis including;

- Model for Analysis of Energy Demand – MAED,
- Energy and Power Evaluation Program – ENPEP,
- Wien Automatic System Planning – WASP for electricity,
- Model for Energy Supply Strategy Alternative and the General Environmental Impacts – MESSEGE for strategizing energy supplies,
- Simplified Approach for Estimating Environmental Impacts of Electricity – SIMPACTS for projects and plants financial viability assessment
- Energy Forecasting Framework and Emission Consensus Tools – EFFECT

The recent development of NECAL2050 is another milestone in this journey and addition to the suite of tools of energy analysis at its disposal as according to [32], it is still keenly utilizing MESSAGE and MAED. Thus NECAL2050 is currently the best and most advanced energy modelling tools at the disposal of ECN because it has all the features of the two and even more as captured in Table 1 as adopted from ECN's NECAL2050 documentation.

Nigeria stands to benefit from these tools, as energy supply mechanism for any country has to look for the ways to provide for all categories of energy demand in the economy. The process of doing begins with energy modelling, but as iterated by numerous modelling and development studies, the needed skills & expertise are lacking or inadequate in the developing countries, hence the need for technical assistance. The business of international technical assistance is at the center of most interactions between developed and the developing countries and also mostly shapes the nature and conditions of bilateral, multilateral and international private, public as well as private public partnership-PPP collaborations. Under normal conditions, the nature of these collaborations needs to take into account the mutual interests of both collaborators or partners to produce a win-win situation that promotes both partners, an ideal hardly met [20, 21, 22, 6]. This is because, solutions built while depending on the assistance of developed nations are mostly based partly on the realities and experiences of the developed nation helping to set it up. The usual issues faced are: down the road there will be mismatch between the solutions offered by the model and the realities on ground and the trained staff may not be able to effectively use it or address problems it may develop. At the end its overall purpose may be defeated in the sense that it may further complicate issues for the developing nation and the locally trained staff on what way to go about it. The model, despite its high level of capabilities compared to the previous models may just be there without achieving its target as is mostly the case.

One typical example of such a recent collaboration is in the development of the newest and the best among the Nigeria's suite of energy modelling tools. The Nigeria

Table 1: Comparing NECAL2050, MESSAGE and MAED, ***Source: [32]***

S/No.	MAED	MESSAGE	NECAL2050
1.	Excel-based energy demand modelling framework or modelling tool.	Energy Supply Modelling framework based on dynamic linear programming.	Integrated energy demand and supply mode; Excel and Web-based.
2.	Simulation modelling framework.	Optimization model.	Both demand supply are simulation models
3.	MAED does not calculate emissions.	Calculates up to maximum five user defined emission types on the supply side based on input demand.	Calculates the emissions on the demand side for fuels (e.g. gas, petrol, fuelwood, etc.); calculates emissions from electricity at the supply side on the supply.
4.	Takes a very long time to run a single scenario.	Takes a very long time to run a single scenario.	Can run several scenarios within a very short time.

Energy Calculator 2050 (NECAL2050) model is typical of the story line above in the sense that it did quite try to capture the urban sector of the economy, but as far as the Nigeria's rural sector is concerned, the model has not done its job well. One may not be right to this claim, given that, the developers of NECAL2050 were so honest and open to some of its fundamental weaknesses, all of which are discussed in the next section.

4. Overview of NECAL2050

NECAL2050 is an integrated model of energy, emissions and land use in Nigeria and aims to identify energy secure pathways for supply and demand of energy between now and 2050 [32]. It was developed by the Nigeria Energy Commission with the assistance of United Kingdom Department of Energy and Climate Change (based on the UK 2050 Calculator) through the British High Commission, Abuja and launched in the year 2015 with the following three key objectives;

i. To offer a platform to facilitate academic and policy debate about the possible future pathways for the Nigeria's energy sector and enable prioritizing some policy interventions for deeper analysis.
ii. To help users (individuals, businesses and government) understand the wide range of possible energy pathways available to the country from highly pessimistic to highly optimistic scenarios.
iii. To provide indicative numbers for demand and supply, for each scenario in the range of possibilities, and potential implications on issues such as import dependence, cost and land requirement.

As stated earlier, it would do justice to the developers of NECAL2050 to hail their honesty and openness in terms of some of its weaknesses they mentioned, which are summarized as follows:

i. The model does not capture potential positive and negative feedback impacts on the economy from the levels of effort implied by the pathways.
ii. It focuses on identifying the least-cost pathway to meet Nigeria's energy demand in a reduced emission manner up to year 2050, but in some cases questionable assumptions are used (e.g., unrealistically low cost of coal at some stage of the considered timeframe).
iii. The NECAL2050 demonstrates the scales that are likely to be required for Nigeria to make transition to a low carbon economy, as well as the choices available for clean modern energy access for all. The Calculator is helpful in exploring a range of available pathways. However, it misses to point out the optimal one, which would instead be needed to allow policy makers to take the right decision promptly. This is of vital importance for an economy in a serious energy crisis that coincided with lack or inadequacy of energy modelling expertise, hence having an optimal option will reduce delays that would be caused by debates as to which of the available pathways to follow.
iv. The model has been developed by focusing exclusively on Nigeria and its options for GHG emissions reduction and energy security.
v. The analysis under the model looks at what might be possible to deliver in the coming years up to 2050, but does not propose or identify the required policy decisions to ensure this future. In other words, the Nigeria Energy 2050 Calculator does not provide a detailed policy framework and the trajectories should not be considered as projections based on policy decisions.
vi. The NECALS2050 platform does not 'recommend' or 'prefer' any one scenario or pathways over the others. It merely provides the user a way to understand the realm of possible scenarios and their implications and post their preferences and choices as a contribution to the debate on sustainable energy development for Nigeria.

NECAL2050 is the best energy modelling tool Nigeria has gotten till date, it is by far the most up-to-date equipped with energy and emission analysis tools. However, the weaknesses do not stop at those clearly stated in the model documentation as other key issues are neglected in its global economic assumptions on Nigeria. Key amongst which are:

i. A major issue of consideration that was missed by NECAL2050 developers is the future role of agriculture not only in Nigeria but in the whole region as contained in the Agenda 2063 of the African Union. The place of agriculture in the NECAL2050 was not explicit despite the fact that agriculture provides almost 18% of Nigeria's GDP and over 30% of employment as at 2015, the year the model was launched. The sector is being transformed by commercialization at the small, medium and large-scale enterprise levels that is evident by a significant simultaneous expansion and mechanization. The key role of Agricultural energy demand in the largest African economy's energy model cannot be overemphasized and the omission of which would be an unforgivable miscalculation.

ii. Undermining the Nigeria's capacity in the use renewable energies by including and capitalizing on a scenario where the current trend of refine petroleum products importation is extended to include electricity from sources out of the country. This is despite the estimations of the renewable potentials of before and recently after the model like [4].

iii. The recent developments in the international market for renewables was neither anticipated nor provided for while developing the NECAL2050, which would give us better scenarios than those projected in the model.

iv. Cooling energy demand especially in the household sector is overemphasized as the number of household that actually have cooling system and as such need energy for cooling is not that significant from the perspective of the overall population with majority below poverty line.

These are important issues to the economy particularly with regards to sources and extent of energy demand and the renewable energy capability as well as potentials. Wrong energy projections may result from such omissions further leading to underestimating the capabilities of existing infrastructure and some possibilities of technological improvements. The effect may also undermine the role of the available energy reserves and potentials of resources, existing and changing energy policy and regulatory environment and energy investment. This is also true for their combined effects on the production and consumption of energy and its market conditions as well as ultimately growth and development of the economy. It is observable in most future energy projections in both developed and developing countries, that while highlighting the current challenges and the unwanted results of inaction or right kind of action, they are explicit as to the highest positive outcomes that may follow the best course of action [26, 35, 36, 37, 38 & 39].

5. Best NECAL2050 Energy Scenario/Projection

It is interesting to know that there are four levels of trajectories built-in on the model namely; least, determined, aggressive and heroic efforts scenarios that users can select from in using the model. These trajectories have different levels of potential implementation in energy technology improvement, behavioral, structural, lifestyle as well as fuel choices that affect the overall volume of energy demand and supply in the economy. Among these levels of efforts, level four (4), which is termed as the 'Heroic Effort' scenario attempts the most highly laudable, elaborate and ambitious alteration of the energy system towards the highest physical and technical limits possible within the prevailing economic conditions. The results from this scenario are graphically portrayed in Figure 1 showing the level of energy demand and supply possible as far as the models' understanding and assumptions about the economy of Nigeria including GDP, population and their growth rates, speed of urbanization etc. The graphical results of NECAL2050 (Web Version) best (Heroic Effort) scenario show selection of best possible options in all variables and assumptions as well as the final energy demand, primary energy supply and greenhouse gas emissions. Tables 2 and 3 give similar best scenario results from the Excel Version of NECAL2050 that clearly and categorically shows the volume of the energy demand and supply on the five year intervals from 2010 to 2050. The tables also show the volume of energy demand and supply from various renewable and non-renewable energy sources and the totals of each of the five (5) year intervals. The percentages of the same are also given in the lower segment of each of the tables to show the relative significance of each source or vector of energy.

Nigeria's energy projections from the best (Heroic Effort) scenario are presented in table 2 where it is clear that there is a steady overall increase in energy demand from 870TWh in 2010 to 1448TWh in 2050 (equivalent to 166.4% increase in total energy demand). It is interesting to see that this energy demand increase trend is not shared by all vectors in Nigeria as transport, cooling, lighting and appliances recorded increase while decline is registered by industry and cooling vectors. The highest increase is recorded by lighting and appliances vector from 31TWh to 679TWh equivalent to almost 43.3% change in the share of the country's energy demand. While the least increase is by transport

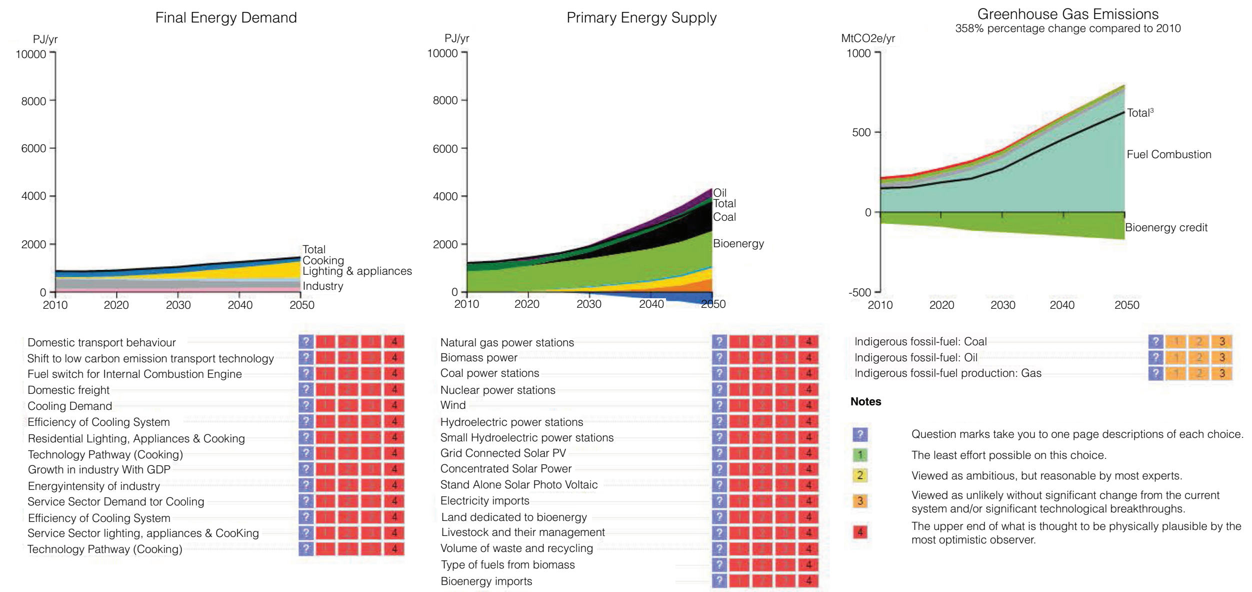

Figure 1: Best NECAL2050 Energy Scenario/Projection using Web Version NECAL2050 Model

Table 2: Best NECAL2050 Energy Demand Scenario

Final energy demand									**TWh**
Vector	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Transport	128	143	149	151	153	164	172	180	189
Industry	419	395	371	350	328	310	295	283	276
Cooling	46	54	65	78	89	104	115	126	137
Lighting & appliances	31	37	69	144	225	335	439	553	679
Cooking	245	238	249	258	253	254	232	204	167
Total	870	866	903	980	1048	1166	1253	1347	1448

Final energy demand%									**TWh%**
Vector	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Transport	14.8	16.5	16.5	15.4	14.6	14.0	13.7	13.4	13.1
Industry	48.2	45.6	41.1	35.7	31.3	26.6	23.5	21.0	19.1
Cooling	5.3	6.2	7.2	7.9	8.5	8.9	9.2	9.3	9.4
Lighting & appliances	3.6	4.2	7.7	14.7	21.4	28.7	35.0	41.1	46.9
Cooking	28.1	27.5	27.6	26.3	24.2	21.7	18.6	15.2	11.6
	100	100	100	100	100	100	100	100	100

from 128 TWh to 189 TWh corresponding to 1.7% change in the share of energy demand. It is ironic – though it may comply with the then Nigeria's economic conditions – that, the industrial demand for energy showed the highest and steady decline from 419 TWh to 276 TWh (a 29.1% decrease in the share of the total Nigeria's energy demand) over the period of the projections. This is contrary to the recent developments in the country in terms of industrialization and agricultural transformation that stand to be a major source of energy demand.

From the energy supply side as shown in table 3, up till 2050 the bioenergy will be the dominant source of energy in Nigeria with over 70% and over 38% shares of Nigeria's energy supply in 2010 and 2050 respectively. The relevance of oil, over 24% in 2010 will be reduced to a little over 5% in 2050, while coal currently relying on imports will become the second dominant source of energy in Nigeria to the tune of over 33% in 2050, the year at which the world is ironically targeting carbon neutrality. Gas share will be increased from 4.1% to 10% between 2010 and 2050 while nuclear fission will start

Table 3: Best NECAL2050 Energy Supply Scenario

Primary energy supply									**TWh**
Vector	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Nuclear fission	0	0	0	21	41	79	152	294	568
Solar	0	1	48	97	154	228	285	354	436
Wind	0	0	4	7	11	15	15	18	22
Hydro	10	10	17	29	38	47	56	65	75
Electricity oversupply (imports)	–1	–1	–1	–6	–69	–177	–277	–426	– 601
Bioenergy	855	919	1016	1098	1156	1230	1295	1369	1441
Coal	–2	–3	20	117	277	507	752	994	1237
Oil	301	309	221	188	191	198	198	196	192
Gas	50	44	108	64	96	171	243	309	375
Total	1214	1279	1435	1616	1893	2299	2719	3174	3743

Primary energy supply%									**TWh%**
Vector	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Nuclear fission	0.0	0.0	0.0	1.3	2.2	3.4	5.6	9.2	15.2
Solar	0.0	0.1	3.4	6.0	8.1	9.9	10.5	11.2	11.6
Wind	0.0	0.0	0.3	0.5	0.6	0.6	0.5	0.6	0.6
Hydro	0.8	0.8	1.2	1.8	2.0	2.0	2.1	2.1	2.0
Electricity oversupply (imports)	0.0	0.0	0.0	–0.4	–3.7	–7.7	–10.2	–13.4	–16.1
Bioenergy	70.5	71.8	70.8	68.0	61.0	53.5	47.6	43.1	38.5
Coal	–0.2	–0.2	1.4	7.2	14.6	22.1	27.6	31.3	33.1
Oil	24.8	24.2	15.4	11.7	10.1	8.6	7.3	6.2	5.1
Gas	4.1	3.4	7.6	4.0	5.1	7.4	9.0	9.7	10.0
Total	100	100	100	100	100	100	100	100	100

from 2025 at 25TWh to reach 568TWh by 2050 representing 1.3% and over 15% respectively. Hydro, solar and wind combine currently supplying less than 1% of Nigeria's energy are expected to supply 2%, almost 12% and 0.6% respectively by 2050. The shortage of power supply in Nigeria according to the projections is expected to continue and even increase to heavily rely on electricity imports from other countries to the tune of over 600TWh by 2050 corresponding to over 16% of the total energy demand in the country. The overall energy supply will grow from 1214TWh in 2010 to 3743TWh in 2050, almost 310% increase over the period of the projections.

Key observation from Tables 2 and 3 generally is the excess of energy supply over demand and simultaneously excess electricity demand over local supply due to low envisaged generation even in the most heroic effort of the NECAL2050's scenarios leaving no option but the importation of electricity into Nigeria. This is despite the fact that there exists a huge excess of energy supply 3743TWh over demand 1448TWh in 2050 coupled with massive renewable energy potentials and growing fossil energy reserves that are slowly being developed. One may not be wrong to argue that, from the projections of NECAL2050, electricity is one of the most important energy issues in Nigeria and as reflected in the estimations of the model. Demand for electricity in lighting and appliances (46.9% of total energy demand) have the highest and dominant share of the country's energy demand. Hence the focus of our analysis here will be narrowed down to electricity demand and supply projections, where a comparison will be made between NECAL2050 and other three alternative projections to see the level of agreement or otherwise. This analysis is carried out in the next section.

6. Alternative Electricity Projections for Nigeria

The closeness of the NECAL2050 projections to the realities in Nigeria can be gauged by looking at other projections that focus on the same issues and used similar or different assumptions. This analysis will be useful in such a way that, where there is an agreement of focus or assumptions the two projections will be compared to see first, which is the best reflection of changing conditions in Nigeria and second, which is better for Nigeria's future energy system. The scope of the analysis here is narrowed down to electricity as one of the energy vectors that regarded to have the least development in Nigeria leading it to rely on imports to the tune of 16% of the total energy supply. Three projections were analyzed in comparison to the NECAL2050 best electricity demand and supply projections, one from demand side, the second from supply side and another from demand and supply sides.

6.1. Comparison of Electricity Demand Projections

With the aim of determining the nature of electricity load demand for the purpose of planning future expansions of current network and also determine load distribution on the existing generating plants, [40] analyzed past load demand and estimated the future load till 2030. This was done using the forecasting method of stochastic/probabilistic extrapolation based on time series analysis of past load demand curve and straight line graph/curve to make decisions for improving the power system balance to ensure more quality and reliability of power supply and its network. The Nigeria's demand load data for the years between 2000 and 2012 was used as the basis for the estimations to project load demand up-to 2030. The figures as shown in table 4 appear quite different from those in NECAL2050, however, the basic observations is that there is a symmetry of pattern in the growth of demand over the period that the two estimations cover equally. That is from 2015 to 2030, the growth of cooling, lighting and appliances energy demand, which is usually provided using electricity, in NECAL2050 is about 245% and power demand growth is a little above 27% for [40]. The difference can be attributed to time, methods and economic assumptions of estimations, but overall they both indicated an ever growing demand for energy and the need for increased generation. However, while [40] projections were silent about the way and manner the excess demand over supply of electricity can be met, NECAL2050 predicted the import of electricity into Nigeria.

6.2. Comparison of Electricity Supply Projections

From the supply side, this study considered the work of PwC on the future of electricity in Nigeria. The PwC's projection targets increasing the generation capacity to

Table 4: Electricity Demand Projections based on real Load Demand data, Source: [40]

Year	2013	2014	2015	2020	2025	2030
Predicted Load Demand (MW)	14,812	15,093	15,373	16,774	18,175	19,576

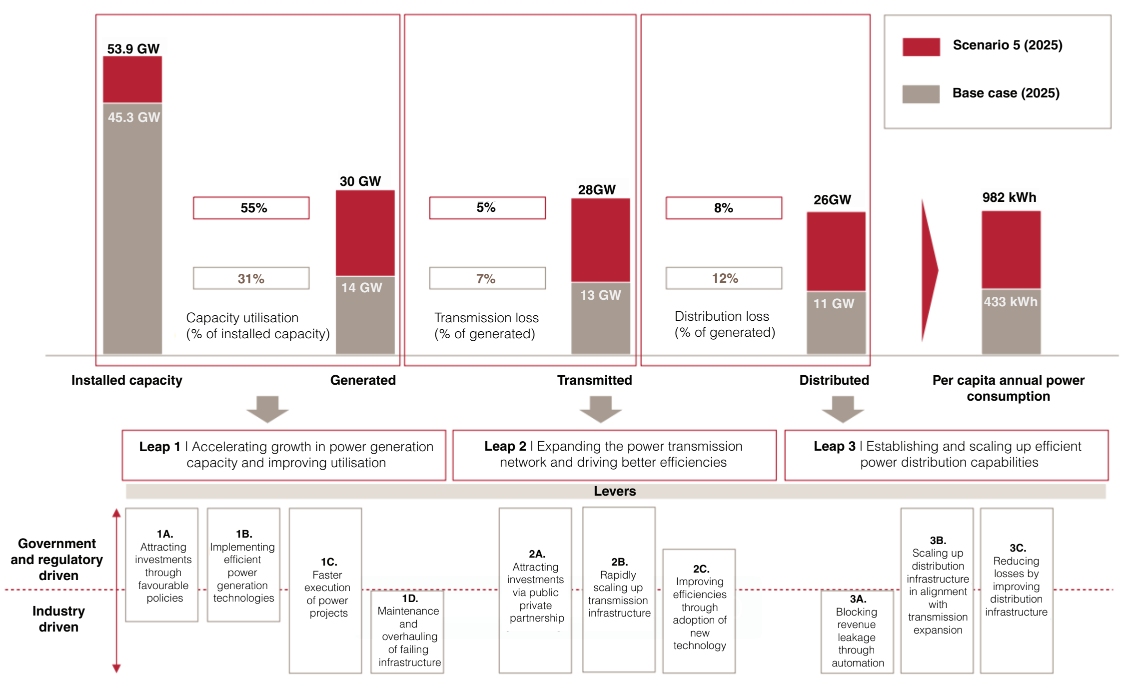

Figure 2: PwC's Future Electricity Roadmap to 2025 (Scenario 5) Source: [41]

53.9 GW with 55% capacity utilization, 13% transmission and distribution (T&D) losses and about 1000 kWh annual per capita of electricity by 2025. Their projections are divided into 5 scenarios in 3 leaps strategy based on 10 transformation levers to be driven by industry, government and its regulatory bodies. The best scenario (no. 5) is considered here for comparison with the electricity supply side of the best energy projections of NECAL2050, but limited to 2015 to 2025 figures as in the case of demand side comparison. Unlike NECAL2050, the PwC projections saw the possibility of expanding of generation capacity, reducing T&D losses as the way of achieving higher energy access and consumption per capita. While NECAL2050 is not explicit about per capita kWh consumption in the country, the PwC projections factored that in relation to population growth to the year 2025. Therefore, contrary to the case of electricity demand, the best NECAL2050 electricity supply and by implication all other energy projections may not be regarded as the true representation of the best future energy system of Nigeria. The claim made in the NECAL2050 documentation that, the model tries to show the "scales of what are possible" by "exploring a range of available pathways" is not adequately achieved in the model's best, and possibly true with all other projections. The fact that, [41] showcased a better power projection for Nigeria in demand, supply and sustainability or environmental concerns is a clear testimony to this.

6.3 Combined Energy Supply and Demand from other Models (MAED/MESSAGE)

To have a clearer view of the electricity projections from NECAL2050, the projections from previous models used by ECN were analyzed and compared with them. These models were secured through the International Atomic Energy Agency's Sustainable Energy Development for Sub-Saharan Africa as suite of energy analysis and planning tools. Model for the Analysis of Energy Demand (MAED) and Model for the Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) are specific to the role they play in energy planning. MAED is for energy demand while MESSAGE is for energy supply and the associated alternative strategies and environmental issues. The two models were used in combination by [42] to generate the electricity demand and supply projections for Nigeria till the year 2030. Four scenarios used to generate the projections are discussed in details in [42] in addition to other energy analysis related

Table 5: Electricity Projections from MAED and MESSAGE Source: [42]

Demand						**MW**
Scenario	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Reference (7%)	5,746	15,730	28,360	50,820	77,450	119,200
High Growth (10%)	5,746	15,920	30,210	58,180	107,220	192,000
Optimistic I (11.5%)	5,746	16,000	31,240	70,760	137,370	250,000
Optimistic II (13%)	5,746	33,250	64,200	107,600	172,900	297,900

Supply						**MW**
Scenario	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
Reference (7%)	6440	15668	28356	50817	77450	136879
High Growth (10%)	6440	15861	30531	54275	107217	192079
Optimistic I (11.5%)	6440	15998	31235	71964	177371	276229

Fuel Type (%)	**2010**	**2015**	**2020**	**2025**	**2030**
Coal	0.0	9.9	13.8	15.3	15.6
Gas	78.6	48.5	53.5	53.0	59.0
Hydro	21.3	18.9	13.6	10.7	8.6
Nuclear	0.0	9.4	5.3	8.3	6.7
Solar	0.1	13.1	11.0	10.4	8.3
Wind	0.0	0.1	2.9	2.3	1.8

information specific to Nigeria and the models. The focus here is on the projected numbers generated using these models and how they compare with the figures in NECAL2050, as superficial observation showed the symmetric pattern of the trends in Nigeria's electricity demand from both projections. However, when attention is turned to the energy balance of the [42] projections, it is obvious that in all the scenarios, except Optimistic I, there is excess of electricity demand over supply till around 2025. Optimistic I achieved excess supply in 2020 while the supply side did not feature the Optimistic II scenario thereby making the analysis incomplete. However, while we will not be computing and comparing the exact volume of electricity between the two projections, the shares of different vectors or fuels will give insight to another more important dimension of the analysis – sustainability of the energy system.

It is obvious that the share of coal in the primary energy supply by 2030 will be only 1% less in the NECAL2050 compared to its almost a decade old predecessors' share in electricity supply. Over all, the general concern raised in NECAL2050 of relying on electricity imports in Nigeria is not there as far as the previous models are concerned. Above that, the models are even showing that the excess of demand over supply will disappear by 2020 in the Optimistic I scenario and 2025 in the High Growth and Reference scenarios. It will be misleading to pass judgements on the level of sustainability of the electricity systems between the two projections, but if we take all figures on pro-rata basis, the MESSAGE projections are more sustainable for Nigeria than the NECAL2050. This is because, putting aside bioenergy, the shares of modern renewables of solar, wind and hydro by 2030 are higher in MESSAGE with 8.3%, 8.6% and 1.8% than in NECAL2050 with 8.1%, 2% and 0.6% respectively. On this considerations, while NECAL2050 is the most modern and advanced tool of energy analysis in Nigeria, some of the economic assumptions its best projections derived from are not in the best sustainability interest of the Nigerian economy. The following table summarized the differences between the three projections and that of NECAL2050.

It is obvious that the units in the tables (2, 3, 4 & 5) of the projections are quite different, specifically NECAL2050's values are in energy units while others are in power. However, the focus of our analysis is on electricity projections in the models and their assumptions of the potential capacity of the energy system to adequately supply the needed power with considerable share of renewables. Quantitative summary is attempted though may appear superficial as far as NECAL2015 is concerned because similar analysis is needed for other energy vectors to fully cover the model. NECAL2050 projections report over 66% growth of energy demand between 2010 and 2050 and 78% within similar period with other projections (2015-2030). Power demand growth is 364% for Sambo-2030, 27% for Ezennaya-2030. On the other hand growth of energy supply for NECAL2050 is above 208% (2010–2050) and about 48% (2015-2030), while power supply growth is about 784% for Sambo-2030 & little above 331% for PwC–2025.

The shares of renewables (hydro, solar and wind) in the supply side are also different specifically in the projections of Sambo-2030 showing a decline from 32.1% to 18.7% between 2015 and 2030. This can mainly be due to the focus of then government in developing gas power plants as reflected by the projected rapid growth of the gas share of electricity supply from 48.5% to 59% within the same period. On the NECAL2050's projections, there is also a steady projected growth of the same renewables' share from 0.9% to 10% of the primary energy to be consumed within the same period, which is incomparable with that of Sambo-2030 (that is on electricity generation only).

Table 6: Comparison of the four models

Differences in	**NECAL2050**	**Ezennaya-2030**	**PwC-2025**	**Sambo-2030**
Timing	**2015 (35 years)**	**2014 (17 years)**	**2016 (14 Years)**	**2008 (22 Years)**
Objectives	Integrated energy demand and supply projections with detailed fuel sources and emissions	Power demand projection based predicted load	Power supply projection with a targeted per capita kWh consumption	Combined power demand and supply projections with fuels sources.
Results	Steady growth of power demand, under capacity electricity generation and relying on power imports.	Steady growth of power demand.	Steady growth of power demand with ways to meet and improve upon the current situation.	Steady growth of power demand and supply, and the needed investment in generation without recourse to imports.

However, this would be highly appreciated, from sustainability viewpoint, if not for the presence of concurrent projected growth of coal's share in the primary energy supply from –0.2 to 14.6% (surpassing the renewables) despite the global campaigns on climate action. Though the units are different between the projections, the level of optimism shown in the supply potentials of the Nigeria's energy system is higher in other projections than those of NECAL2050. Therefore, from these findings one may conclude that NECAL2050 projections as considered in this study may bring higher energy access to Nigerians but not in a sustainable manner as compared to its previous as well as subsequent counterpart projections. Hence, there is the need for improving some of its basic assumptions, particularly those regarding the changing local economic realities in building its scenarios, so that they will reflect the sustainable and self-reliant direction of the global and local development efforts.

7. Conclusion: Policy implications & Recommendations

The paper aimed at reviewing the conceptual and historical evolution of energy modelling and the Nigeria's modelling experience over the years with most important models in Nigeria currently being MAED, MESSAGE and the latest NECAL2050. It is established in both literature and experience that most energy models do not capture the features and issues of developing countries. The study further analyzed the best energy projections of NECAL2050 with the view to finding out whether the model fully reflects the realities of the Nigeria's economy and that of similar developing economies in facilitating the transition to intensive renewable energy use in their development journey.

Based on the analysis carried out in this paper, it can be concluded that often at times, while trying to solve problems, more are created with even more complexities that further compound the situation. In this case, while trying to help countries solve their energy issues, more problems are created and compounded by developing models that do not pit their circumstances. The NECAL2050 is a good model that failed to cover some of the most important requirements of the Nigerian economy. Undermining the electricity generation capability of Nigeria as well as the role of renewable energy in the energy system at the best scenario of the model are the pronounced flaws identified in the NECAL2050. That is to say, the problem is more with the modelling assumptions as the same model will produce far better projections than the current ones if the current and future conditions are well captured. Similar projections are carried out for developed and developing countries alike in both medium and long term ranges with somewhat good results as can be seen in [6, 12, 2, 8, 43 & 44] with even more complex systemic challenges than simple electricity generation. It should however be in mind that, this work of ensuring the right assumptions are used rest more with the developing countries being helped than those assisting them. Therefore the need for a better understanding as well as inclusion of these local conditions is the best way to go about, not only for energy modelling for developing countries but also for all other works that involve interactions between developed and developing countries. One way of doing that is introducing into the model the reflection of the local, regional, national and international policies, programmes and initiatives. Another issue is increasing the role of renewable energy in the Nigeria's Energy Mix, particularly with the recent development of renewables in the global market that is forcing the parity of the renewables in an unprecedented manner.

With these considerations, a more comprehensive modelling nature of NECAL2050 which includes growth, development and environmental concerns, will be much more appreciated in the energy modelling journey of developing countries, not only Nigeria. The real impact of these suggestions will be much clearer in the new energy projections that result when they are applied to the model and run. This is however not achieved in this work; perhaps it provides an avenue for further studies that will be of special interest to researchers in the energy future of developing countries, particularly those in Africa.

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