Modelling the Nigeria's Electric Power System to Evaluate its Long-Term Performance

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Abstract

The study presents a System Dynamic model of the Nigeria electric power system. The model was developed with a view to using it to evaluate the long-term performance of the system. Both primary and secondary sources were employed to collect the system's baseline information. Results from this formed input to develop a four-sector-model in Vensim software for the long-term evaluation of the NEPS. Leverage points in the model were identified from the validated model using data from 2005 to 2009 in the Base Run. The system behaviour, based on two other scenarios (Scenario 1 representing improved basic level of consumption and Scenario 2 representing industrialization target), was then evaluated on a timeframe of 30 years starting from 2009. The study concluded that Compounded Annual Growth Rate (CAGR) and Economic Growth Rate (EGR) were the most critical policy leverage intervention points for NEPS improvement within the next 30 years.

Keywords: System Dynamics, Electric power system, VENSIM, Model, Nigeria

Background

The Nigeria Electric Power Sector Reform (EPSR) Act was enacted into law in March 2005 (FGN, 2005). This Act represents the legal and regulatory framework which guides the holistic operations in the sector. With this Act as a legal and regulatory framework, it is hoped that Nigeria electric power system (NEPS), would be moved away from state-dominated systems to that with a greater role for market forces (Joskow, 2003) - resulting in more efficiency of operations to the supplier and more reliable, adequate and efficient supply to the consumers. In summary, the Act was supposed to have created (Biobaku & Co, 2010):

- an electric power sector that encourages investment and ultimately competition in generation and distribution;
- allows for efficient and effective dispatch of generated electricity;
- an electric power market that meets current and future demand efficiently and economically; and
- an even playing field that will attract private investors.

These objectives were in anticipation that key stakeholders in the Electricity Supply Industry (ESI) would be attracted into the sector for new investment decisions, particularly with participation in the competitive segments of the industry. To achieve a level playing field for all new entrants as well as those already operating in the market, the Act made provision for Nigeria Electricity Regulatory Commission (NERC), an independent regulator. The goals of the objectives as enunciated in EPRI (2003) are succinctly captured as follows:

- Lower the cost of reliable, safe, clean electric service
- Attract capital for infrastructure development
- Enable greater consumer choice
- Greater economic efficiency
- Level the competitive playing field

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To appreciate improvements made in the system through reforms, whether these goals are achieved would be weighed against current realities of:

- Higher cost and lower reliability
- Reduced investment confidence and incentive
- Loss of accountability to consumers
- Greater financial risk
- Market volatility

However, unexpected anomalies in the global performance of liberalized electric power systems necessitated a rethink towards the issue of reorganizing the electricity sector. The flagship of these is the case of California power market, which suffered sustained shortage of generation capacity, and this led to an energy and price crisis in the summer of 2000 and 2001 (Olsina, 2005, Besant-Jones and Tenebaum, 2001). Other things noticed in some other markets are inefficiencies in resource allocation as a consequence of excess capacity in their systems. United Kingdom and Argentina power markets have registered low unprofitable prices due to massive entry of combined cycle gas turbine (CCGT) based capacity. In the US markets, signal of overinvestment is what is currently exhibited (Olsina, 2005). A combination of these anomalies had made some observers argue in the one hand that deregulation should be scrapped/decommissioned, while others argue on the other hand that deregulation is a noble endeavour and that these problems can be solved with structural adjustments to the markets (EIA, 2000). The concept of this study agrees with the latter school of thought that the problem of electric power system can be solved through structural adjustment of the system. It is important however to state that dealing with the problems of electric power system, (in fact all energy system as recent unfolding events in Nigeria shows), is notoriously difficult, and the results of conventional solutions are often poor enough to create discouragement about the prospects of ever addressing them (Aronson, 1998).

In order to gain significant insight into structure and long-term performance of Nigeria electric power system, a simulation model based on Systems Thinking (Frasser and Brettner, 2002, Forrester, 1968), making use of *System Dynamics* principles was employed for this study, to evaluate the entire system from policy making to service delivery. This is with the aim of using the computer to reproduce the structure of the NEPS and the relationships that exist among its components in order to simulate its long-term performance. The approach included dynamic framework to enhance its usefulness for decision makers (Smith and Ackere, 2002). Thus the objective of the study is to present a SD model to forecast the long-term performance of the NEPS.

Significance of study

The importance of the electricity sector cannot be overemphasized in many economy. It is over 25 years since the advocacy for reorganizing the electricity sector began worldwide. It is also about a decade since the California electricity crisis and the collapse of Enron occurred (Joskow, 2008). Presently, there are two government documents related to improving Nigeria’s electricity sector. These documents are namely, Vision 2020 Energy Report and Roadmap for power sector reform. These two documents were taken into consideration in evaluating government targets of achieving improvement in the electric power sector.

The electric power industry is a closed, feedback dominated, non-linear system featuring time delays as in capacity approval, capacity construction, scrapping/decommissioning and response of price to change in demand – (Olsina, 2005; Ventosa et al., 2005; Oladeji, 2005; Ford, 1997). Mathematical representation of many situations in electric power system is difficult due to its stochastic nature. Further, the electricity system is characterized by incomplete information, uncertainty and distributed decision-making with the implication that it is imperative to incorporate the bounded rationality of the actors into modelling. It is also essential that any evaluation of the system should be able to take into consideration the soft but important variables of the system (e.g.

the effect of maintenance on extending plant reliability, labour issues/staff welfare) to enhance validity of the analysis.

Electric power industry exhibit major dynamics with respect to management, technology progress, consumer behaviour, industry configuration and government policy (Dyner et al., 2003). In addition, ill-defined policy assessment or company mismanagement which impacts significantly on performance or outcome of the system raises related questions. Thus, with the benefit of hindsight, it can be argued that in all circumstances some evaluation tool with capacity to incorporate feedback for analysis in the system would be helpful. Such is the System Dynamics (SD) modelling tool. SD modelling has underlying bases for dynamic features that display consistent high intuitive pattern of behaviour. Further, SD modelling has need of fewer details, contains fewer equations, and cost less to develop and run than other detailed models. Accordingly, this study focuses on the scope of SD principles for evaluation of the NEPS. This helped to highlight how feedback-evaluated system can take an important role in "learning environments" as well as form a support tool for decision-making and policy assessment.

The available data in the system were collated and described in compatible statistical database to simulate the long-term performance of the NEPS. It also integrated conventional micro-economic principles into the SD framework. This is with the aim of offering readily accessible and analytical guidance to policy makers on the dynamic implications of policy as they affect decision making. The key insight of this approach is to yield numerical estimates of the *paths* that could be taken by key policy variables, as well as present any equilibrium to which they might converge particularly as they relate to the Nigerian process of reforming and restructuring her electric power industry.

Methodology

Conceptual framework: the Nigeria electric power system

The conceptual framework for this study was developed from the canonical form of feedback system in control system (Dorf, 1976). Its application to model the Nigeria electric power system (NEPS) is as presented in Figure 1. Each of the variables, namely, R(s), G(s), C(s), and H(s) in the system is explained.

R(s) in the system is the input which is the desired national electricity consumption level. This has usually been given by policy pronouncements as targets by the government as a level to be attained for economic development and growth. These policy pronouncements become backed by either laws or decrees (depending on the kind of government in power at that time). These policies usually generate regulations and rules (bureaucracy) demanding organizational structures such as regulators (NERC), investors (Independent Power Producers - IPPs) and government involvement (Federal Ministry of Power - FMP and Energy Commission of Nigeria - ECN) for implementation.

G(s) had earlier been defined as the aggregation of the supply side of the system under study which consists of generation, transmission, distribution system operation and retail trading. G(s) is thus the aggregation of the supply side, which includes generation, transmission/system operations and distribution as well as the human resource available in the NEPS. Also, the output is C(s) is described as the performance of the utility as measured by the electric power demand met measured in GWh through the generation capacity measured in MW. H(s) represents stakeholders' response to performance.

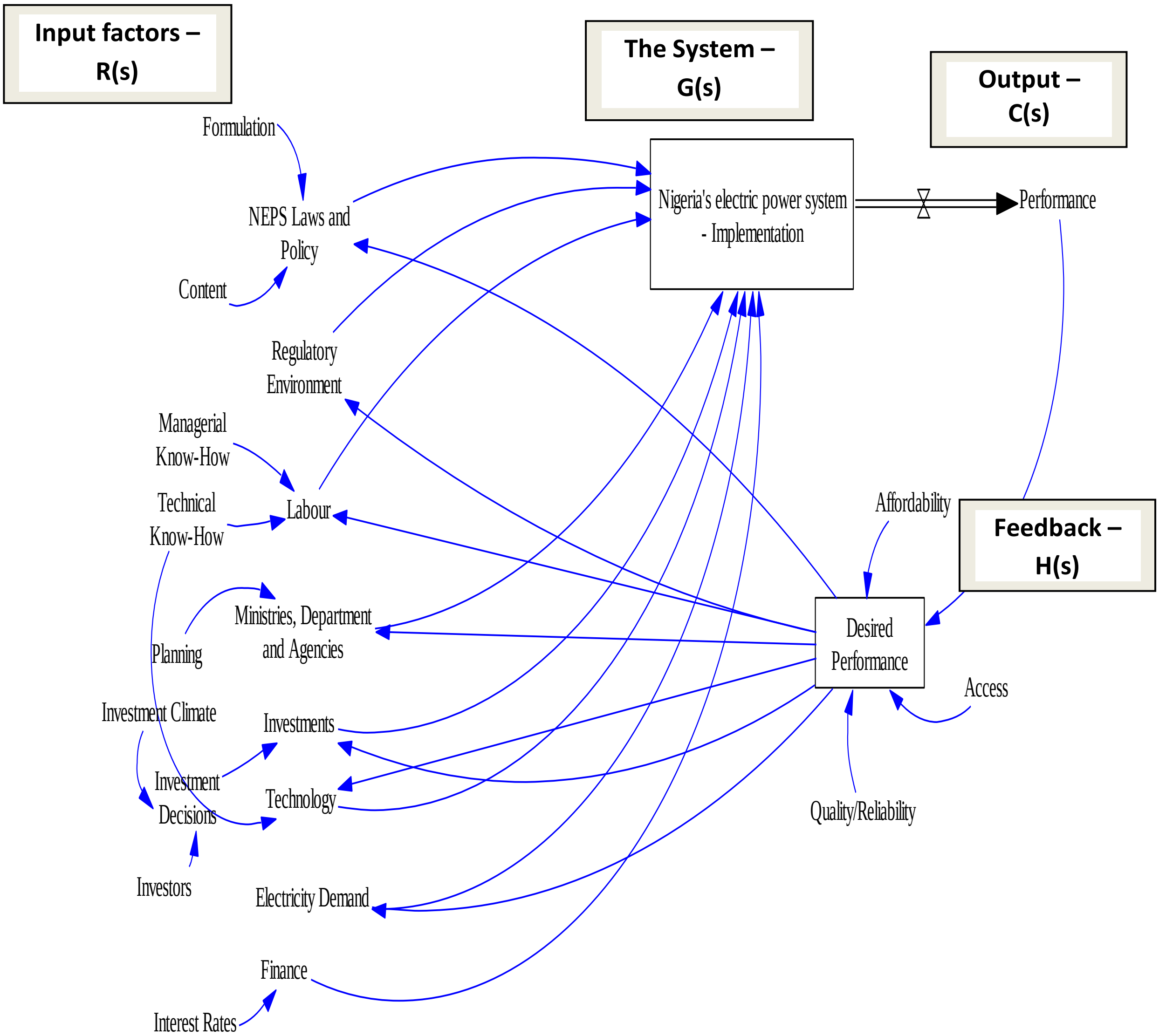

Figure 1 **Conceptual framework for applying system dynamics for decision making in NEPS** (*Drawn with Vensim® PLE*)

Study design and scope of work

The study covers the planning and management procedure of the NEPS running through the generation, transmission, distribution, retail and marketing sub-sectors of the system. In evaluating its long-term performance, access (influenced by availability and adequacy) to electricity in the system, affordability of electricity prices (usually meaning economical and cost reflective tariffs) and power quality (meaning security and reliability) of the system are examined against the backdrop of the EPSR Act 2005 goals of providing reliable supply, secured service, economic efficiency, attracting new capital investments and providing level playing field. The performance indicators were also viewed with regards to energy sector of the Vision 2020 Report (2010) and the Power Sector Reform Roadmap (2010). These were also bench-marked against some countries (USA, Egypt, Libya and South Africa) power system operations.

System boundary and general research approach

The electric power system can be characterized as a structural model (Olsina, 2005), having a bottom-up approach, since the long-run development of the power market is determined by modelling the variables having direct influence on long-term movements of supply and demand. Figure 2 presents a simple description of the Nigeria electric power market showing the competitive and regulated segments. The competitive segment is made up of the generation and retail sectors as depicted by the 6 generation companies, 4 independent power producers (2 of which are for state governments) and 11 distribution companies to also include the customers while the regulated segment is made up of the ‘wired’ sector namely the transmission and distribution networks. Regulation in the ‘wired segment of the NEPS is achieved under the aegis of the Market/System Operator that handles the power exchange (in Nigeria’s case, the National Control Centre, Osogbo). It must however be pointed out that the codes for operating this segment falls under the purview of the NERC.

In order to demonstrate the simulation focus, the required inputs, and the system boundary of the research approach, a bull’s eye diagram of the model as adapted from Kilanc and Or (2008) is presented in Figure 3. In the bull’s eye diagram, endogenous variables are placed in the center of the bull’s eye; exogenous variables are placed in the outer frame. Excluded variables are placed outside the outer frame. The bull’s eye diagram is a convenient way to show the relative balance between required inputs (exogenous variables) and endogenous variables. If endogenous variables are more, this is a good sign indicating that ‘‘*model generates interesting dynamic behaviour from within the system*’’ (Ford, 1999). If a variable appears somewhere in a feedback loop, or it is influenced by another variable that it is in a feedback loop, then the related variable is said to be an endogenous variable in the model.

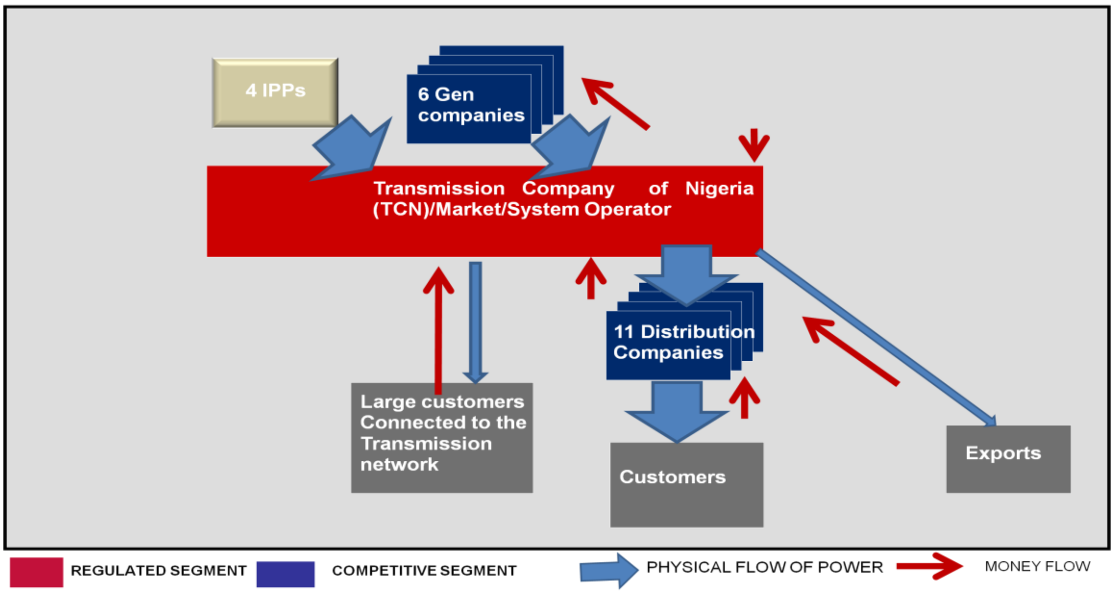

Figure 2 Simple flow chart of the competitive and regulated segments of the Nigeria Electric Power System (NEPS) as described by the EPSR Act 2005

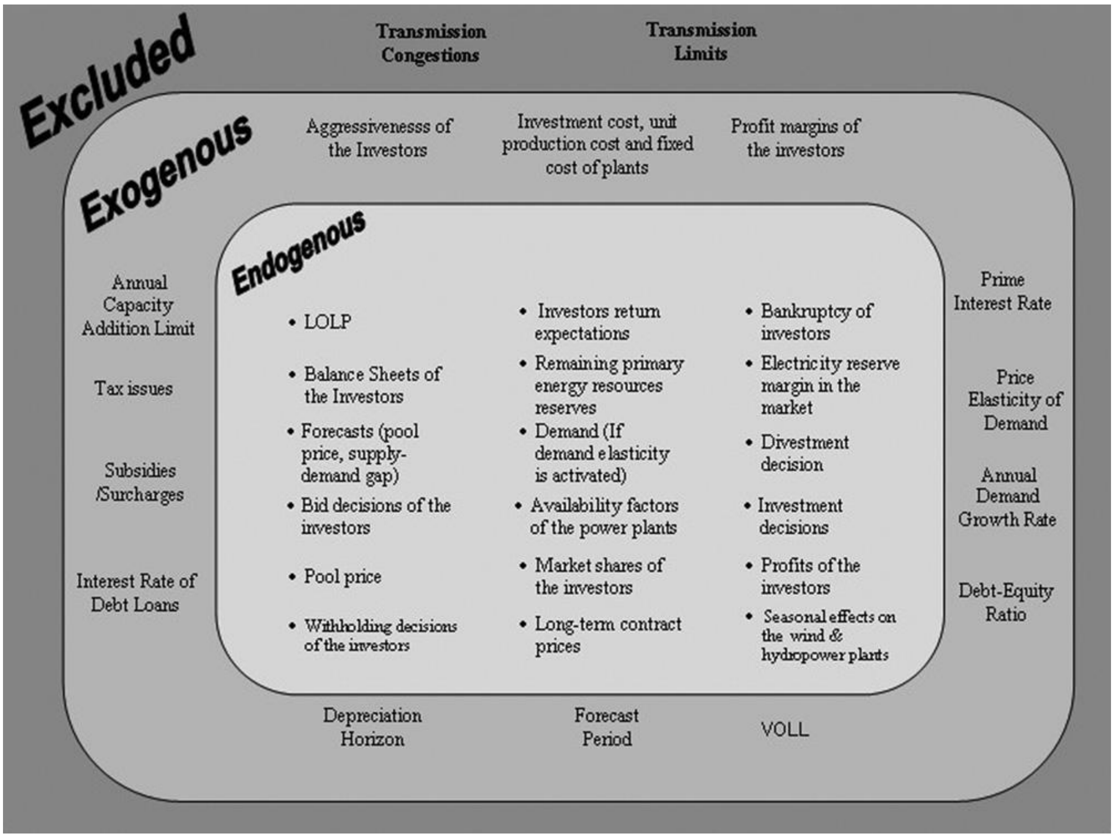

Figure 3 Bull's eye diagram of the model (adapted from Kilanc and Or, 2008)

In addition to the bull's eye diagram, to provide a snapshot picture of the extension of the model, the major factors under consideration are grouped under eight categories namely, laws and policy, regulation, labour, implementation, investments, technology, electricity demand and finance. The categories are represented in loose form in the Table 1.

Table 1 Factors and measurements of scales for the Nigeria's Electric Power System

No	Factors/variables
i.	• Examine laws/decrees/policy establishing NEPS • Examine regulations for daily operations of NEPS • Quantify assets in NEPS • Plant/generation related ○ Availability factor (as changes throughout the simulation run depending on aging) ○ Remaining primary energy resources reserve ○ Seasonal effects on availability of wind and hydropower plants ○ Construction times ○ Cost times ○ Age of the already installed and operational power plants ○ Capacity factors ○ Length of forecast period ○ Initial power plant portfolio (installed and under construction) • Transmission + Distribution facilities • Benchmarking above (3) against internationally accepted standards
ii.	• Policy related ○ Policy formulation ○ Policy contents

	○ Government involvement • Implementation related ○ Investors related ○ Financing ○ Tariffs ○ Revenue generation ○ Specialized arbitration ○ Arbitration time ○ Labour issues ○ Pool and demand related ○ Demand (if prices elasticity of the demand is non zero) ○ Market shares ○ Amount of electricity supplied by each company ○ Supply-demand balance (electricity reserve margin in the market) ○ Pool/wholesale price ○ Expected supply-demand gap and expected pool price, which is used in the investment decision of the investors ○ Loss of Load Probability (LOLP) ○ Annual and monthly peak demand ○ Annual demand growth rate ○ Load duration curves ○ Price elasticity of electricity demand ○ Presence of long term contracts • Regulatory related ○ Competence ○ Interest ○ Licensing rate ○ Enforcement ○ Mechanism
iii.	• Cost of service provision • Affordability • Accessibility • Quality • Ability to attract capital for infrastructure development • Enable greater consumer choice • Greater economic efficiency • Level the competitive playing field
iv.	○ Projection using Vensim tool

Source: NERC, ECN, PHCN, CBN, NBS, NERC, Internet

Tasks in the study objective

Having established the conceptual framework upon which the study is predicated, an explanation of tasks to be accomplished in each of the specific objective of the study is given in this section.

The sole objective of this study is the evaluation of future performance of NEPS through improved supply-demand scenarios by developing a model based on its baseline information. The first step to this evaluation is to generate a feedback from the results obtained in baseline information of the system. This result serves as the input factors into developing the model for evaluation of the performance of the NEPS using feedback compatible data in Vensim environment. Thus the task of in the study objective would first be the incorporation of the relevant inputs to the systems equation, and then followed by iteration process using Vensim software that is developed based on System Dynamics principles. The essence of this task, which is sensitivity analysis, is to ascertain variables/factors that would need to be changed to improve decision making in NEPS that would in turn affect its technical and economic performance in the coming years. The end result is to develop different supply – demand scenarios in the NEPS for the future. The timeframe for the analysis is 30 years starting from 2009. This will also guide the design of different market options for the scenarios.

Study Design and Modelling Overview

Study Design

In the design of the study, the following were taken into consideration. First step was to capture data that are useful for electricity planning and management in Nigeria from secondary sources for the period under review. These sources include the Annual Report of the PHCN, Energy Commission of Nigeria, Nigeria Electricity regulatory Commission, Nigeria National Petroleum Corporation, National Bureau of Statistics (formerly the Federal Office of Statistics (FOS)) annual abstract of statistics, Bureau of Public Enterprises, Central Bank of Nigeria (CBN) statistical bulletin and annual reports, World Bank Reports, and so on. These data were used in the first stage of the NEPS long-term performance evaluation. Where data gaps are identified survey was employed to fill the gap. The second step therefore is the application of partially structured questionnaire (Johnson and Wichern, 1997) to capture these identified data gaps in the NEPS for its long-term performance evaluation. Information was elicited from the various categories of stakeholders in the NEPS. They are: the policy makers (FMP and ECN), players in the electricity sector (PHCN – generation, transmission, distribution and IPP operators), the NEPS regulator (NERC) and all categories of customers in the NEPS, namely residential, commercial, industrial and special purpose customers respectively. Based on the appropriate variable types identified, four sets of questionnaires were designed. These variables were translated into a set of rough questions. From these rough questions, a data set was developed for the questionnaire; these were subsequently subjected to iterations by undergoing critical checks such as: relevance and wording of the questions; appropriateness of the question sequencing; layout and appearance of questionnaire to allow for easy data collection to ascertain its reliability. The sets of questionnaire were subjected to further testing for clarity and understanding through pre-test amongst some selected respondents to ascertain their validity, before being finally administered. The results from the pre-test also formed the basis to test run the models in Vensim software for validity. Data analysis was carried out using descriptive and inferential statistics. A combination of the outcome of these exercises form key inputs to forecast the long-term performance of the NEPS using the Vensim software (a simulation package) developed based on System Dynamics principles. The timeframe for forecasting the long-term performance of the NEPS is 50 years starting from 2009.

Modelling Overview

Over 50% of future investments in electricity sector would be accounted for by the generation sector over the next 25 to 30 years. Modelling of the sector must therefore capture important variables relevant to describing the dynamics in the electric power system. These could be conveniently grouped under generation, transmission and distribution, systems operations and retail trading. This is essentially the **G(s)** of the entire system being studied.

Based on the EPSR Act 2005, the NEPS is being projected be operate as a merchant power market when enabling environments for this kind of operations is achieved through the current on-going reform process (FGN, 2005). **G(s)** component in the system can be represented in two ways to explain the dynamics of the electric power markets and had well been described in Olsina (2005). These two representations are its causal-loop, and the stock-and-flow diagramming. These two representations thus take the present operational conditions of the NEPS into consideration to develop the model for simulating internal behaviour dynamics. This dynamics is described by a set of non-linear differential equations that account for existing system feedbacks, delays, stock-and-flow structures and nonlinearities.

Basic feedback structure depicting a simplified causal-loop for electric power system as adopted from Olsina (2005) is presented in Figures 4 and 5, respectively, to provide an overview of the system's dynamical structure and to guide further discussions when modelling the different system components. The diagram shows the basic balancing feedback that governs the long-term development of any power market. Market participants form expectation on the future electricity prices is formed on the basis of current market conditions and expected fuel prices. These expected prices play crucial role in determining the profitability of possible investment projects. This implies that construction of new power plants is predicated on the assurance that there is enough certainty of investment cost recovery. Therefore, the first delay in the feedback loop is in regard of irreversibility of investment, that is, the investment decision delay, denoted with T_1. In addition to this delay, new power plants are required to get permissions and they need a certain time to be constructed and to be brought on-line. This forms the second delay on the feedback loop and is denoted in Figure 5 as T_2. The existing capacity plus the additions of new capacity, the scrapping/decommissioning of old power plants and the current system demand will determine the new reserve margin and the new prevailing price level. With this therefore, the market becomes self-balancing and resembles the negative feedback loops commonly encountered in control systems. This balancing mechanism is responsible for maintaining an adequate reserve margin to ensure a reliable electricity supply.

However, this causal-loop-diagram (CLD) is useful to represent the causal relationships and the market balancing feedbacks responsible for adjusting the production capacity, it is not capable to show explicitly stock-and-flow structures embedded in the system. In Figure 5, the stock structure underlying delay T_2 is revealed. This stocks-and-flow-diagram (SFD) shows important variables controlling rates of flow into stocks, making the issue of capacity adjustment mechanisms clearer.

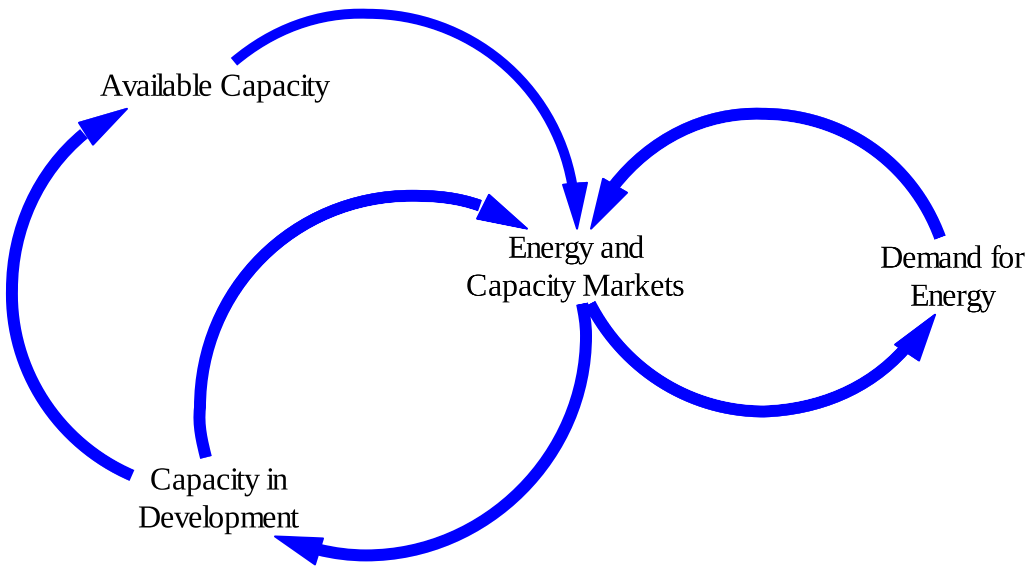

Figure 4 Basic Feedback Structure of Electricity Markets

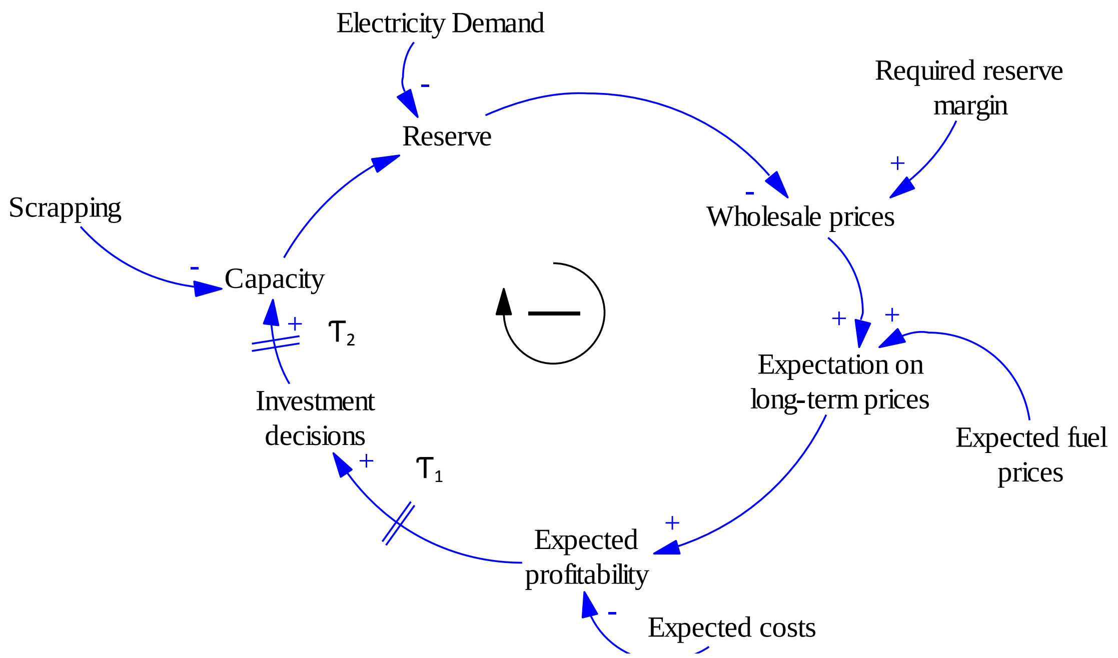

Figure 5 Causal-Loop Diagram of a Typical Electric Power System (adapted from Olsina, 2005)

Model Development

Regulatory authority, NERC, is responsible for reviewing proposals submitted for building of new power plants. Applications to construct new power plants by would-be investors accumulate to NERC for approval or rejection. The time needed to process proposals depends on both capacity of examining multiple projects and project complexities, such as proposed technologies (e.g. nuclear, hydro, CCGT) and the specific siting of the new power station. This process could take some time depending on the technology type and it usually ranges from six months for Gas Turbines (GTs) to five years for nuclear and hydropower facilities. The normal assumption is that when the permits are granted, would-be investor could hold to it in order to monitor market conditions and projected profitability. If market conditions remain attractive after the time elapsed in reviewing of proposals or within the license period, plant construction will be commenced. If it does not, permits will be allowed to lapse.

Addition to this step, investors are permanently checking the stream of plants under construction, since expected reserve margin and expected long-term prices are affected when new plants come into operation. When expected long-term prices are lower, this will impact on expected profitability, which in turn will lead to reduced rate of commencement and thus allowing more permits to be discarded.

In order to achieve balancing feedback, time delay could be reduced to provide a higher stability margin to the system. Nevertheless, when new efficient plants in pipeline are completed and start to generate, electricity prices will be reduced, and likely leading to generators owning old inefficient plants exiting business. The effect of this is increase in the rate of retirements, assuming perfect competition exists.

Another factor that affects reserve margin aside from capacity scrapping/decommissioning rate is the period electricity demand is expected to grow. When the growth leads to tight reserve margin, it can cause a new wave of constructions due to both accumulated permits and a stream of new proposals. For accumulated permits, commencements are immediate; stream of new proposals would have to face delay in the time needed to obtain permits. This implies that even though decision of investing in new plants may be simultaneous, it will however have a different time-period for the market place.

The stock-and-flow structure must be further expanded in parallel stock chains in order to take into account the different characteristics of the several available technologies. Since the stocks represent different stages of the power plant operations such as the installed capacity, the capacity under construction, etc., this has to be disaggregated to account for different lifetimes, construction lead-times, permitting delays, amongst others. In addition to this disaggregation, for the same generating technology, installed capacity has to be distinguished by age to keep track of thermal efficiencies, and therefore, the spread in marginal cost of production.

With the foregoing, the first step to developing the SD model was to assemble and analyze an array of data pertaining to the electric power sector in Nigeria (Oyebisi and Momodu, 2012). This step helped to understand the interconnections in the system that affects its performance. From these interconnections, was developed the causal-loop diagram presented in Figure 6. This simplifies the development of stock and flow diagram that make up the model. With the stock and flow diagram, the set of equations driven the model to run were derived.

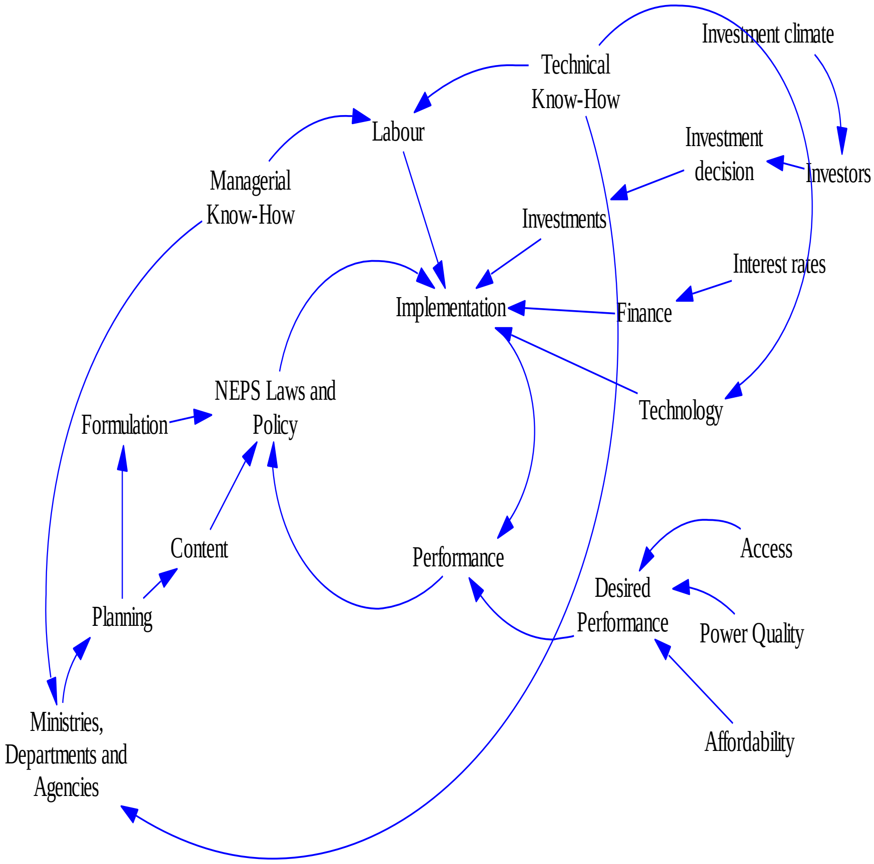

Figure 6 Causal-Loop Diagram of the NEPS

Models developed in Vensim are capable of using time frame of seconds to represent many years, depending on the kind of system being evaluated in the model. The time frame used for developing this model to evaluate the long-term performance of the Nigeria electric power system is 50 years, 2005 to 2055. This can be changed within the model setting.

Evaluating the long-term performance of Nigeria electric power system requires developing a model that takes the dynamics of the structure and behaviour of the system into consideration. Having realized this need from the onset, SD technique was chosen using Vensim software platform, which is one of the recognized software platforms with capability for developing such model (http://www.vensim.com/sdmail/sdsoft.html; Wikipedia website). To develop this model, the main ideas made use of Ford study (1999, 2001) as well that in Oyebisi and Momodu (2012). The model assumes that the NEPS will act as one market, where price of electricity would be driven by demand and supply, that is, levelised cost of energy as well as future retail tariff. Demand of electricity is based on government forecasting data. However, due to suppressed energy demand currently been witnessed within the system, which is targeted for elimination in the forecast, the model also viewed demand from the perspective of the economy through the impact of electricity on gross domestic product (GDP) and vice-versa.

Figure 6 shows the causal loop diagram showing the interconnections in the electric power system in Nigeria. Following from knowing this structure and behaviour characteristics, the first step to developing the model was to make use of historical data available for performance of the system from 2005 to 2009. These include its installed capacity (taking different technologies in the generation park into consideration), availability factor, capacity factor, peak load, energy generated, transmission capacity, losses (transmission, distribution, non-technical and non billed energy sent out), and energy sold. These formed the baseline data to develop the model. Other parameters that were used for the baseline data include gross domestic product and population of the country. From the baseline information other variables which contribute to the structure and behaviour of the system were added. These include capacity addition, future capacity needed, and regulated tariff. Having developed the model based on the baseline information, parameters such as energy intensity (kWh/$) were calculated. This ensures both validation and robustness of the model to explain the behaviour of the NEPS. In order to proceed into examining the model for future performance, policy thrusts of the government concerning the electric power system were included in the model. From this, such factors as performance (measured using reliability (outages), access and price in the system) were calculated.

The four segments of the NEPS namely, generation, transmission, distribution and retail trading were taken into consideration in developing this model. Therefore, the model is split into four sectors to capture the dynamics of these sectors. So the model consists of generation capacity sector, transmission and distribution sector, financial sector as well as the electricity demand sector. A brief description of each of the sector is discussed next.

Generation Sector

In Vensim, state level variables simulate the systems dynamic behaviour using integration technique that is capable of depicting continuous changes taking place within the system (Ventana System, 2010). Figure 7 shows the Generation Sector of the model. The generation sector in the model is made up of four state variables representing stock points, that is, point of accumulations in the system. The first three variables are to depict changes that take place from initiating licensing to build generation capacity up to the point of adding the completed project to installed capacity. Each of the variables has flows into and out of it. Each of the flows has parameters controlling their flow rates. It is this parameters or constants in the model that allows for sensitivity testing of the model to changes in policy concerning the entire system.

The rates as regulated by the constants also depict leverage points through which system adjustment can be made. For example, in the generation sector, CAGR (compounded annual growth rate) represents the accumulated annual rate of capacity addition. This was estimated for the NEPS from available data from 1965 to 2009. To change capacity addition in this sector, the CAGR could just be changed. This change will have chain effects on the entire system, thus serving as a leveraging point.

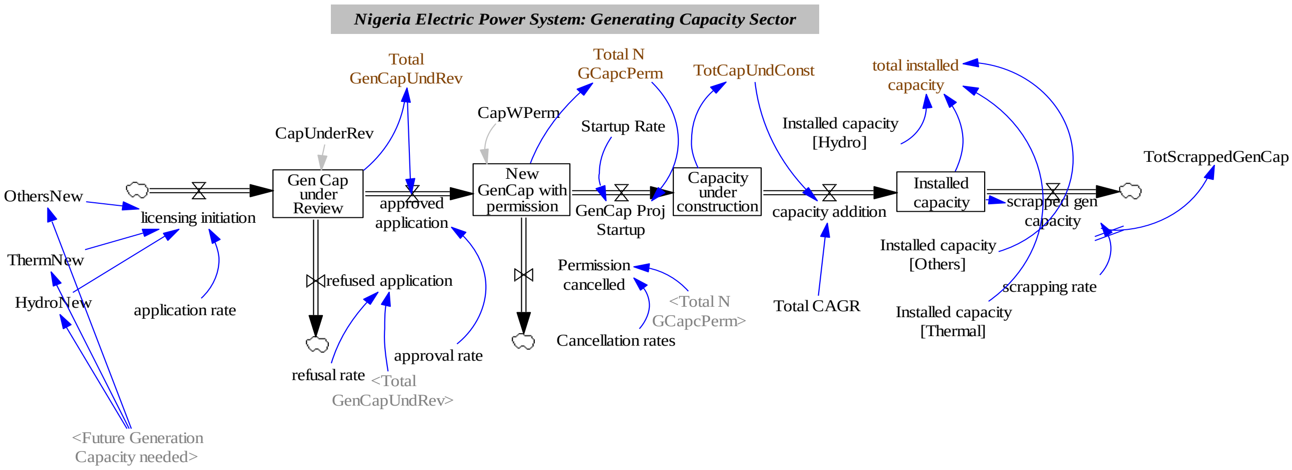

Figure 7 Nigeria Electric Power System Model: Generation Sector

Transmission and Distribution Sector

Transmission and Distribution Sector of the model is shown in Figure 8. Unlike the Generator Sector of the model, the Transmission and Distribution Sector has only one state variable, depicting stock. This stock point could be seen easily as the system operation point (in NEPS the National Control Centre) where electricity generated is sent for distribution to the 8 transmission stations in the country. This sector in the model captured a lot of parameters that affect the operations in transmission and distribution of the NEPS, as it relates to system performance in terms of quality and the Financial Sector in terms of revenue generation and profit/losses. As in the Generation Sector, a number of leverage points are identified in through many constants in the Sector.

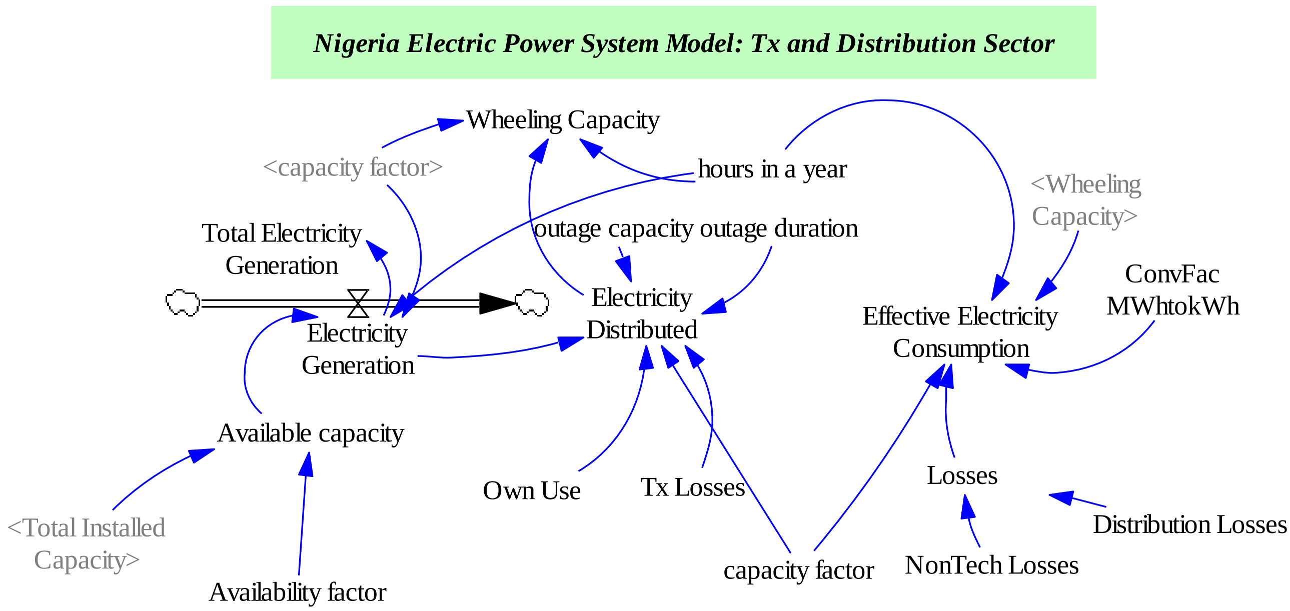

Figure 8 Nigeria Electric Power System Model: Tx and Distribution Sector

Financial Sector

The financial sector of the model shown in Figure 9 depicts the system's retail trading. This sector shows the meeting point between total cost stream and total revenue stream in the system. Like the transmission and distribution sector, the financial sector only has one state level variable which shows its stock point, profit in the system. So with the model it becomes easy to see the profitability or otherwise in the system. As with other sector, the leverage points are the constants such as the transmission cost, distribution cost, electricity tariff amongst others.

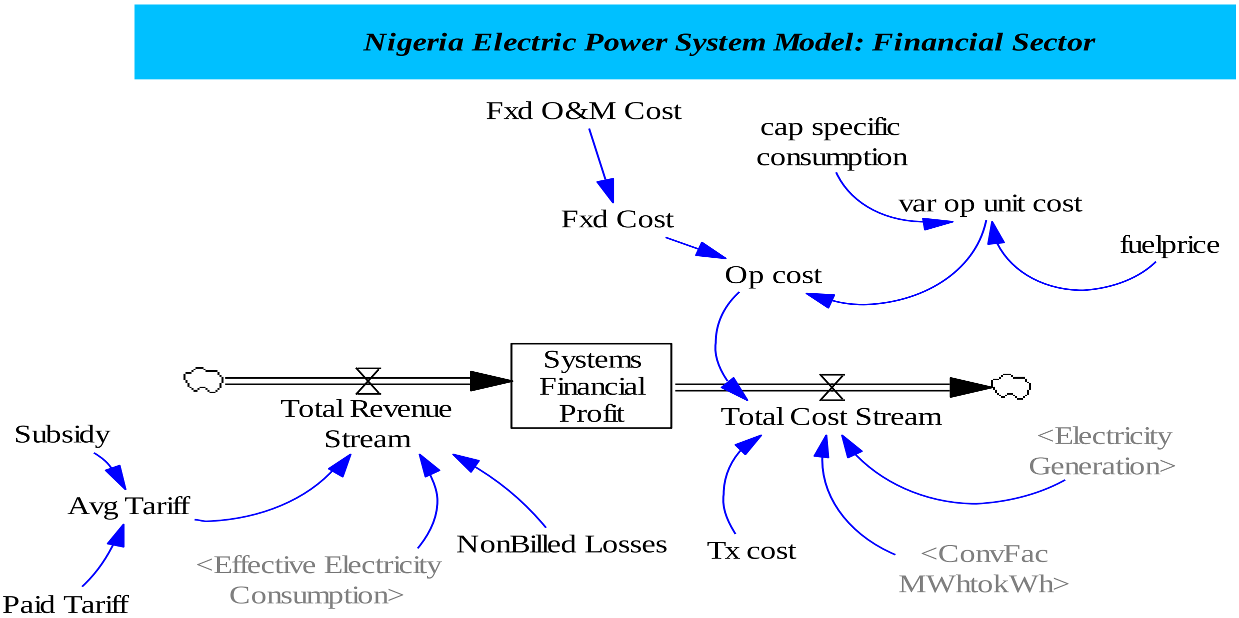

Figure 9 Nigeria Electric Power System: Financial Sector

Electricity Demand Sector

The critical sector for long-term evaluation of the NEPS is the electricity demand sector. This is because whether or not future demand is met will be determined the performance of supply end of the system, namely the generation sector. Two important variables in the economy driving electricity demand are population and gross domestic production (Inglesi, 2010). The sector is therefore made up of population module, economic module depicted by gross domestic production and electricity demand. As can be seen in the sector (Figure 10), there is only one state level variable, namely, population, representing stock in the system. Others are flows, auxiliaries and constants. Description of estimation of each of this module is given next. Also included in this sub model is the module to estimate access level in the system.

a. Estimating future population growth

There are quite a number of variables for estimating future population depending on the level of details needed. However, the most striking variables are those of fertility and mortality rates (Wikipedia, 2011). In this study, a simple approach of birth and death was used to develop a future population trend for Nigeria. Future birth per year of the existing population is a factor driven by birth rate, while death is regulated by average life expectancy. Mathematically, this is represented in the model as:

$$Population = \int_{t=1}^{t=51} (birth - death)$$

where

$$birth_{t+1} = birthrate_{t+1} \times Population_t \text{, and}$$

$$death = averagelife\exp ec\tan cy_{t+1} \times Population$$

(It is important to note that t=1 in the equation is equivalent to year 2006 and t=51 is equivalent to year 2056.)

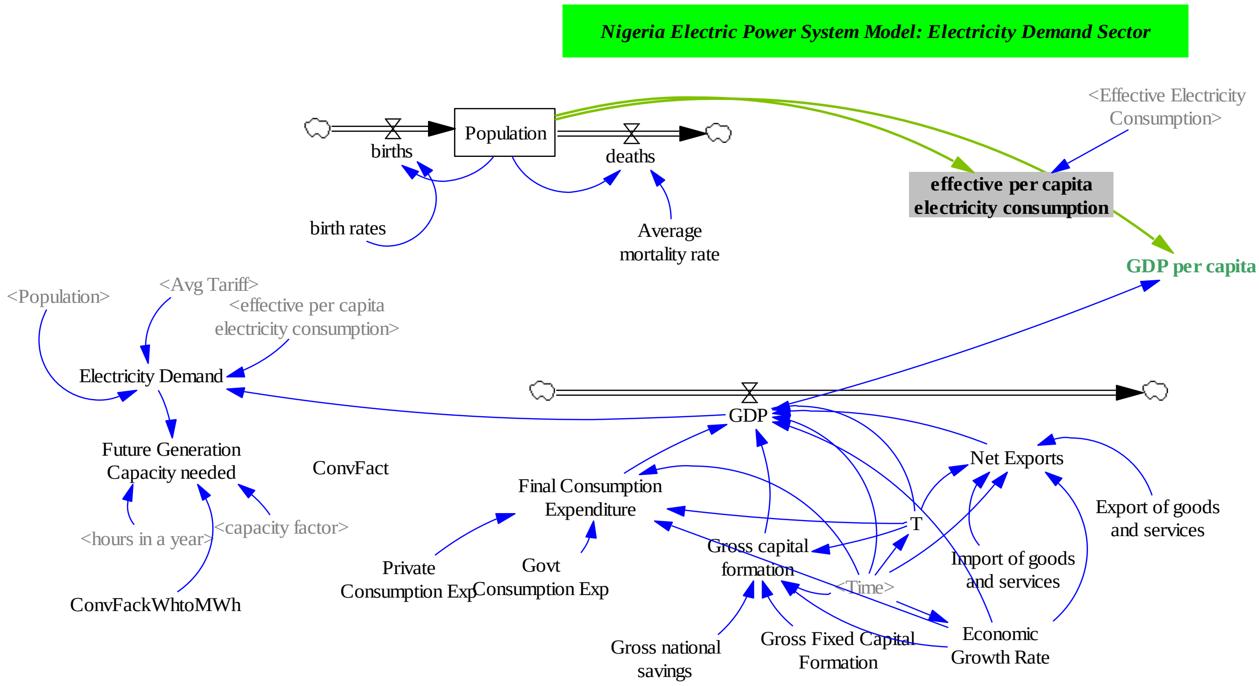

Figure 10 Nigeria Electric Power System: Electricity Demand Sector

b. Estimating Gross Domestic Product and Per Capita Income

According to Xianchun (2002), there are three approaches to estimating GDP. They are production approach, income approach, and expenditure approach. The specific formula of each approach is shown as follows:

GDP by production approach = Σ value-added by production approach
= Σ (output – intermediate input)

GDP by income approach = Σ value-added by income approach
= Σ (compensation of employees + net production taxes + depreciation + operating surplus)

GDP by expenditure approach
= Final consumption expenditure + Gross capital formation + Net export of goods and services
= (Household consumption expenditure + Government consumption expenditure) + (Gross fixed capital formation + Changes in Inventories) + (Export of goods and services – Import of goods and services)

This study estimated the future gross domestic product for Nigeria using by the expenditure approach due to data availability. Calculation of per capita income in the model was done based on connecting the gross domestic product module to that of the population module.

c. Estimating long-term electricity demand and future capacity addition in Nigeria

Various theoretical studies have been documented on the approaches for the estimation of electricity demand (Babatunde and Shuaibu, 2009; Lin, 2003). Dating back to mid-20th century, electricity demand forecasting got matured in the 1980s (Lin, 2003). For econometric approaches, detail work using different combination of variables had been documented in Zhang (1987), Narayan et al. (2007), Lin (2003), Holtedahl and Joutz (2005), Bose and Shukla (1999), Dincer and Dost (1997), Al-Zayerand and Al-Ibrahim (1996), Houthakker, et al. (1974), Zachariadis and Pashourtidou (2006), Ziramba (2008), and Chang and Martinez-Combo, (1997). These set of studies examined the residential demand for electricity in the context of household production theory. If unconstrained by data limitations, studies of the empirical model of the residential demand for electricity are based on household production theory which can be expressed as a function of own price, price of a substitute source of energy, real income, price of household appliances and other factors that may influence household preferences, such as temperature (Babatunde and Shuaibu, 2008).

For this study, the basic model for estimating future electricity demand was adopted from Babatunde and Shuaibu (2008). The study made use of GDP, price of electricity, population (specifically, the urbanization rate) and electricity intensity (as a proxy for industrialization rate) as driving variables for determining demand for electricity in Nigeria. In an economy that is not distorted (as in Nigeria), its GDP is affected by per capita income which in turn is affected by its economic growth rate and its impact on living standards. It is the combination of these variables that represent the main driving force of electricity consumption growth (see Lin, 2003). Therefore, higher real per capita income will increase purchases of electrically powered equipment and hence increase electricity demand. Nevertheless, an increase in the price of residential electricity will cause the residential electricity demand to decrease. Population is another important factor to determine electricity demand higher population level is expected to increase electricity consumption. A positive correlation between population growth and electricity demand is therefore expected. However, more significant is that urban household energy use accounts for a large proportion of commercial fuel consumption in Nigeria. As population and principally urbanization increase, consumption is expected to rise rapidly in the future (Adegbulugbe and Akinbami, 1995). This study therefore sees the need to have information on the utilization pattern and factors driving consumption of urban household energy. Such information is useful within the national energy planning framework for deriving strategies for a more rational energy utilization and increased reliability of energy supply to the urban household.

According to the definition of a demand function, electricity demand, in general, is determined by some main factors including gross domestic product (GDP), prices, and population. To forecast future electricity demand, because of data paucity in country like Nigeria, the approaches mentioned above would be difficult in practice. So this paper adopted a simplistic approach. It first examined the historic effective electricity consumption in the country from 1990 – 2009 from which it derives the per capita electricity consumption and also the GDP for the corresponding period. Next it used the combination of these values to forecast the future electricity demand using the average electricity price (EP), per capita electricity consumption (PCE), population (Y) and Gross Domestic Product (GDP. This is represented mathematically as:

$$ED = \frac{EP \times PCE \times Y}{GDP} \qquad \text{Eqn 3.2}$$

Where:

- ED is Electricity demand (kWh)
- EP is Average Electricity Tariff (US$/kWh)
- PCE is per capita electricity consumption (kWh/Person)
- Y is population (Persons)
- GDP is the Gross Domestic Product (US$)

Once the electricity demand is determined it becomes easy to estimate future capacity addition needed within the system. This is done simply by converting the energy to power using the conversion factors of capacity factor and number of hours in a year. The capacity addition needed is given in MW/Year.

Forecast of long-term performance of the NEPS: Some Results and Analysis

This section presents results and analysis of baseline information and other two different scenarios (namely, capacity addition scenario and that of industrialization process through increased electricity consumption) runs.

The long-term evaluation of the NEPS based on the outcome of performance analysis of this study is summarized in Figure 6, depicting cause and effect in the system. The model developed for the evaluation was validated using NEPS operations data from 2005 to 2009. Being 'management models' (Garcia, 2006), the developed model simply present options to be chosen from for managing the future of the electric power system in a more sustainable way. To forecast long-term performance of the NEPS, the basic socio-economic assumptions and other baseline information for 2009 are presented in Tables 2 and 3 respectively.

Table 2 Basic Socio-Economic Assumptions to Evaluate the Long-Term Performance of NEPS

	2009	2010-2016	2017-2022	2023-2028	2029-2034	2035-2040
GDP (USD Billion)	168.99					
GDP Growth Rate (%)	6.9	13.4	13.8	10.0	9	7
Electricity Demand (GWh)	20,838					
Electricity Demand Growth Rate (%)	5.8	9.5	12.5	10.5	10.0	10.0
Population (Millions)	149.3					
Population Growth Rate (%)	2.2	2.2	2.15	2.05	2.00	1.85
Electricity Demand Per Capita (kWh/Cap)	140	500	1000	1500	2000	2500
Average Levelised Tariff ($/kWh)	0.070933	0.0667	0.0667	0.0667	0.0667	0.0667
Subsidy ($/kWh)	0.024	0.00	0.00	0.00	0.00	0.00
Determined tariff ($kWh) (Res + Comm + Industrial)	0.0466	0.00	0.00	0.00	0.00	0.00
Wholesale generation prices						
Energy ($/MWh)	7.705	7.705	na	na	na	na
Capacity ($/MW/month)	9533.77	10014.00	na	na	na	na
Transmission losses (GWh)	1654.7818					
Transmission losses (%)	8	5	na	na	na	na
Transmission Charges ($/kWh)	0.008	0.008	na	na	na	na
Distribution losses (GWh)	2049.05					

Distribution losses (%)	11	10	9	8	7	5
Non-Technical Losses (GWh)	3352.99					
Non-Technical losses (%)	18	15	12	8	5	4

Source: NERC, (2008); Vision 2020 (2009b, 2010); The Presidency (2010);

Table 3 2009 Baseline Data for Model Runs

Description	Values	Change rates
Population	149.3 million	2.2%
Per Capita Income (US$/person)	2300	
Persons per household	7	-0.5%
Total number of households	21.328 million households	0.5%
Customer population in NEPS	10.5 million households	2.2%
Connectivity rate (%)		
Access rate (%)	46, 60, 80, 96	
Installed Capacity (MW)	8,764.4	2.34%
Available Capacity (MW)	4825.17	
Peak Demand (MW)	3710.1	
New Capacity under Construction (MW)	5000	
Approved Licenses for New Power Plants by NERC	10	0
System Wheeling Capacity (MW)	3875.25	
Actual Capacity Required in Distribution (MW)	9057	
Energy Delivered for Distribution (GWh)	18627.73	
Transmission Losses (MWh)	1654.78	
Distribution Losses (technical + non-technical) (MWh)	5402.04	
Capacity decommissioned (MW)	0	
Wholesale Price US$/kWh	0.02071	
Capacity charge – US$/kWh	0.013	
Energy Charge – US$/kWh	0.00771	
Average levelised Tariff – US$/kWh	0.07093	
NERC adopted tariff – US$/kWh	0.0466	
Subsidy on tariff – US$/kWh	0.024	

Source: NERC, (2008); The Presidency (2010); PHCN Annual Report 2005 – 2009

Following from knowing the system structure and behaviour characteristics, the first step after the NEPS model was developed was to make use of historical data available for performance of the system from 2005 to 2009 to ensure both its validation and robustness to explain the behaviour of the NEPS. Data inputted include its installed capacity (taking different technology in the generation park into consideration), availability factor, capacity factor, peak load, energy generated, transmission capacity, losses (transmission, distribution, non-technical and non billed energy sent out), and energy sold. Other parameters include gross domestic product, economic growth rate, electricity demand and growth rate, future population projection, reserve margin and decommissioning rate of generators within the NEPS. From the baseline information other variables which contribute to the performance of the system were added. These include capacity addition, future capacity needed, and regulated tariff.

Having developed the model based on the baseline information, parameters such as energy intensity (kWh/$) were calculated. In order to proceed in examining the model for future performance, policy thrusts of the government concerning the electric power system were included to the model. From this, such factors as performance (measured using reliability (outages), access and price in the system) were calculated. Significantly the model developed was also able to show how electricity consumption is strongly connected to the economy in a non-linear relationship.

As mentioned earlier, the period of forecast was 30 years starting from 2010 and terminating in 2039. Since the bulk of financial investment required in the electricity sector usually goes to the generation subsector, Table 4a present the generating plants model parameters and Table 4b shows the medium- and long-term generation addition plans in the NEPS.

Baseline Information Runs

Results of the Base Run (NEPS without intervention) from each of the sectors (generation capacity, transmission and distribution, financial and electricity demand) of the model are presented in this section. From the generation capacity sector, Figure 11 shows generation capacity addition trend from project licensing initiation, with feed-in from future generation capacity needed. Figure 12, the installed capacity split into thermal, hydro and other (renewable) capacity respectively. The dynamics of installed capacity long-term evolution from 2005 to 2040 is easily displayed in the figure, recollecting that the variable is affected by capacity addition, CAGR and scrapping rate in the model. Licensing initiation, approved application, generation capacity startup project, and capacity addition amongst others form the rates in the sector. Electricity derived from available capacity, reflecting electricity generated and electricity distributed in the system as shown in Figure 13. The gap between electricity generation and electricity distributed in the figure depicts losses experienced between these two ends of the supply continuum.

Table 4a Generating Plants Model Parameters

Parameter	**Generation Technology**				
	Hard Coal	CCGT	OCGT	ST/GT	Hydro
Installed Capacity for t_0 (GW)	0	1.10	5.186	1.020	2.351
Proportion (%)	0	11.39	53.70	10.56	24.35
Lifetime (years)	40	30	25	25	40
Average unit size (MW)	120	150	30	200	100
Forced outage rate	0.05	0.05	0.05	.05	0.05
Average Construction time (Months)	40	24	12	9	
Fuel costs ($/MWh)	5.20	35.00	35.00	35.00	0
Investment Costs ($/kW)	4855.00	1218.00	1195.00	1186.00	
Discount rate (%/year)	22	22	22	22	22
Amortization period (Years)	25	20	20	20	25

Sources: PHCN Annual Report (Several); Kaplan, S. (2008) Power Plants: Characteristics and Costs – Prepared for Members and Committees of Congress, Congressional Research Services Order Code RL34746 accessed from *www.nei.org/.../The_**Cost**_of_New_Generating_Capacity_in_Perspective.pdf on April 22 2011*
White Paper (2008) The Cost of New Generating Capacity in Perspective - accessed from *www.nei.org/.../The_**Cost**_of_New_Generating_Capacity_in_Perspective.pdf* on April 22 2011

Table 4b Generation Addition Plans in the NEPS

Capacity and Technology Classification	Medium Term – 2010-2014	Long Term – 2015-2040	Estimated Overnight Costs ($/kW)
Thermal (MW) – CCGT	**4879**	**10066**	
Nuclear (MW)		1000	1200.00
Gas (MW)		7066	1218.00
Coal-fired (MW)		2000	4855.00
Renewable Energy (MW)	**198**	**4900**	
Hydro (MW)	187	3400	
Wind and Solar Power (MW)	11	1500	
Total	**5077**	**14966**	

Source: FMP, 2010

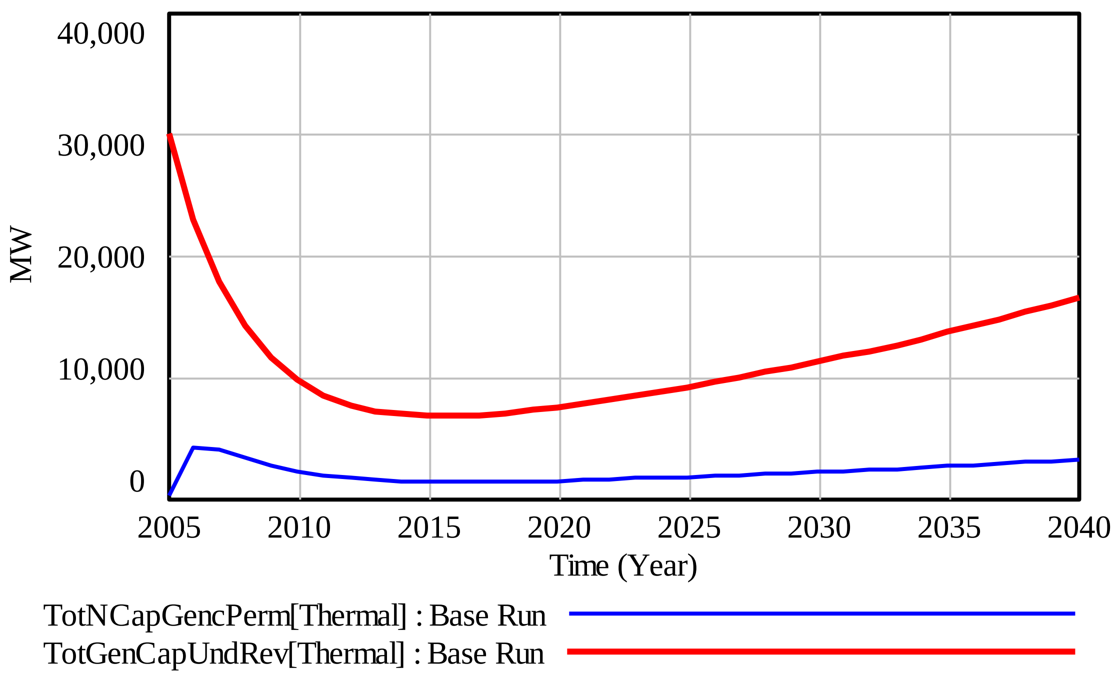

Figure 11 Capacity Addition Trend

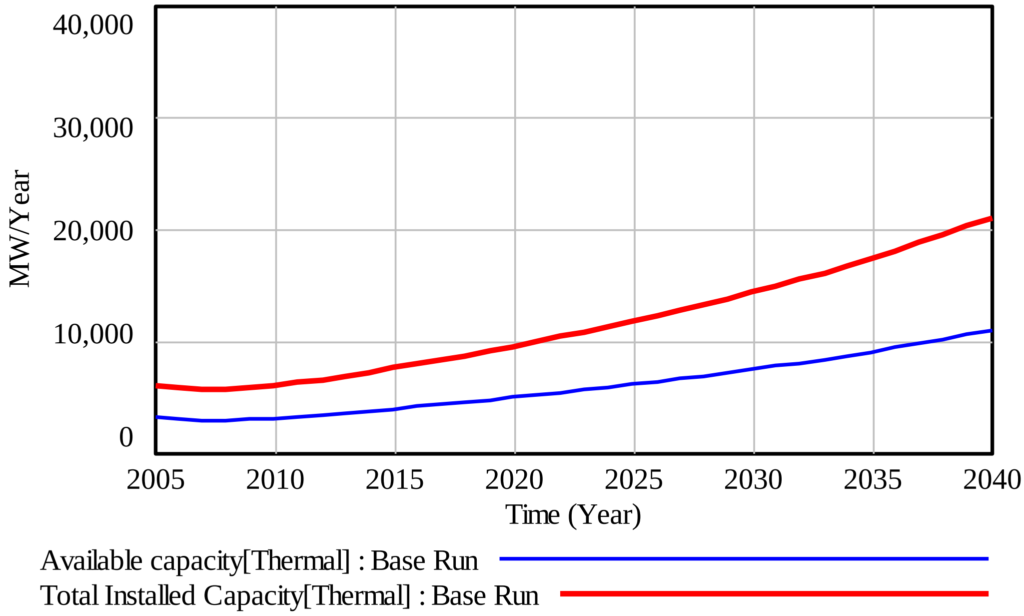

Figure 12 Installed and Available Capacity Trend

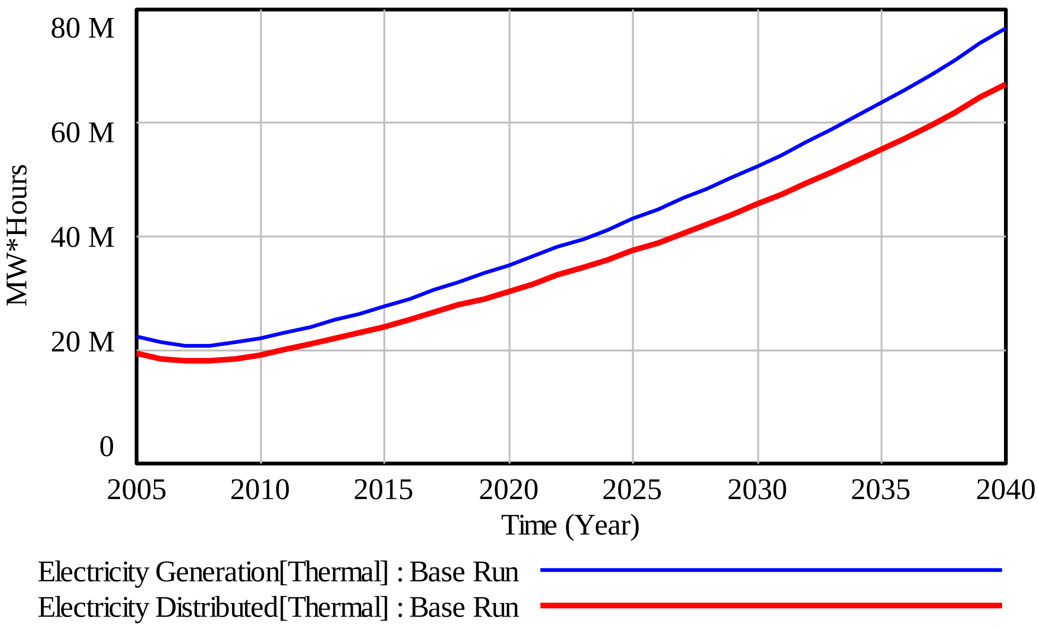

Figure 13 Electricity Generated and Distributed from Installed Capacity

The transmission and distribution sector includes wheeling capacity, electricity generation, electricity distribution and effective electricity consumption aside from the parameters (constants). Figure 14 depicts effective electricity consumption trend in the system. Leaving the trend at the present situation, even though this value seems to increase over the years, it must be stated that it is a far cry from what is desired when compared to electricity demand as shown in Figure 15. The gap between the two curves represents what could be seen as suppressed demand, with a gaping difference between the beginning and the end of the timeframe.

The financial sector includes total revenue and total cost streams to produce the system profit margin aside from the parameters (constants). Figure 16 shows the combination of the results of total cost stream, total revenue stream and systems financial profitability. It must quickly be added that values derived from the model are just approximate as actual tariff and number of customers within the system are disaggregated in the model. The tariff used to calculate revenue stream is based on average tariff in the system. To get a better estimate, there is the need to break the tariff into various categories of customers in the system.

The last sector in the model is the electricity demand sector which comprises the population, the economy represented by GDP and the electricity demand module. Between these variables, estimates of future capacity addition, per capita electricity consumption, per capita income were calculated. The sector also is linked from the financial sector effective electricity consumption and electricity generation while the generation capacity sector is linked to the electricity demand sector with future capacity addition needed. Shown in Figure 17 is the effective per capita electricity consumption, and shown in Figure 18 is the future capacity addition needed. This capacity needed to meet system electricity demand could be taken as the amount of self-generation within the country in this time period. The figure rose from just below 5500 MW in 2008 to over 27000 MW in 2040.

Figure 19 shows gross domestic product (GDP), electricity demand and population trend from the model base run. The figure shows increasing trend of both population and GDP with declining trend for electricity demand. Clearly, the result from this figure supports the assertion that electricity is not contributing meaningfully to GDP growth as well as not meeting the yearnings and aspiration of the people. To buttress this further, Figure 20 shows per capita income (PCI in $/person*year), per capita electricity consumption (PCE in kWh/person*year) and the electricity intensity (in kWh/$). The PCI and PCE both exhibit s-shaped growth tendency with sharp points of inflexion, depicting exponential growth pattern. The electricity intensity on the other hand exhibits goal seeking behaviour.

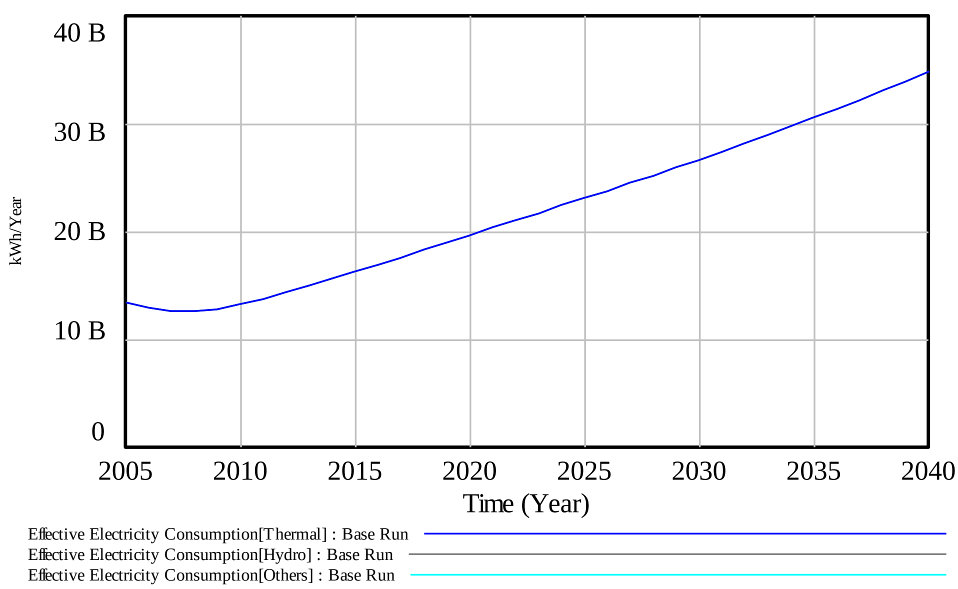

Figure 14 Effective Electricity Consumption Trend

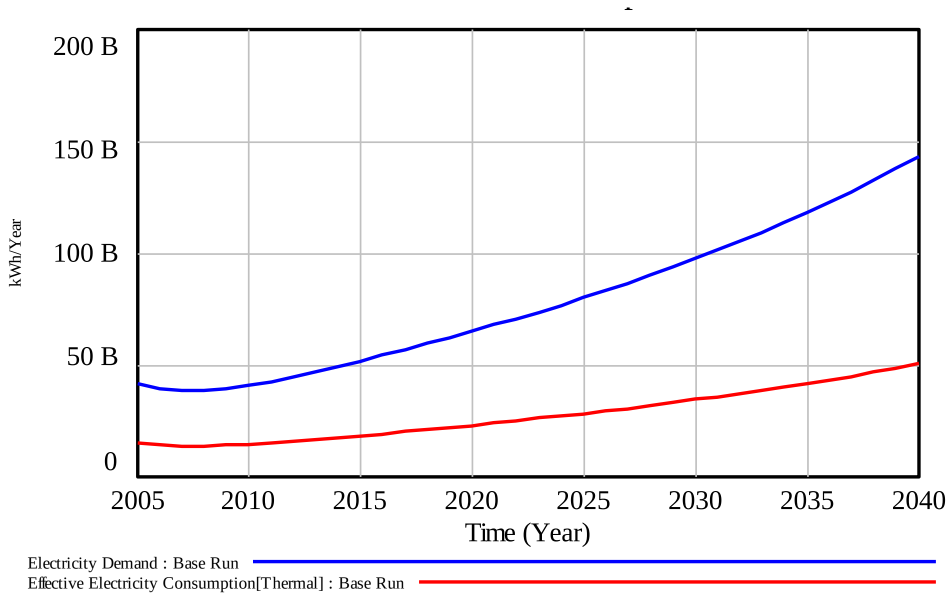

Figure 15 Electricity Demand versus Effective Electricity Consumption

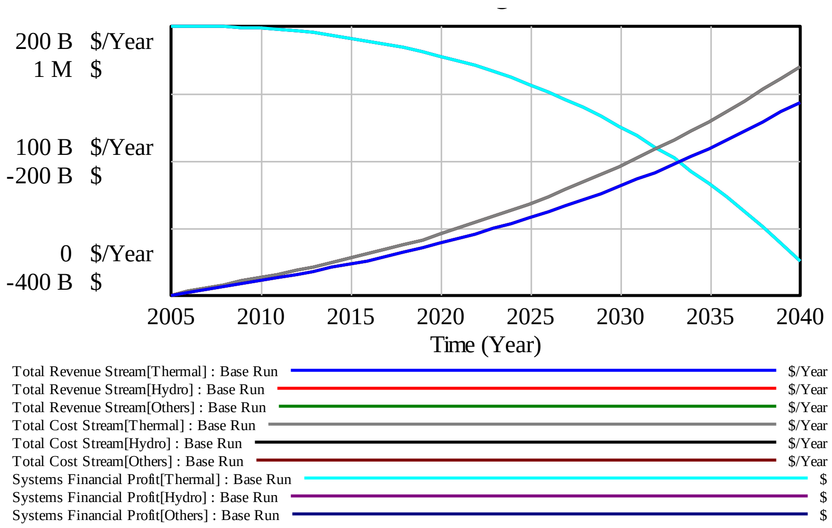

Figure 16 Retail Trading Trend in the System

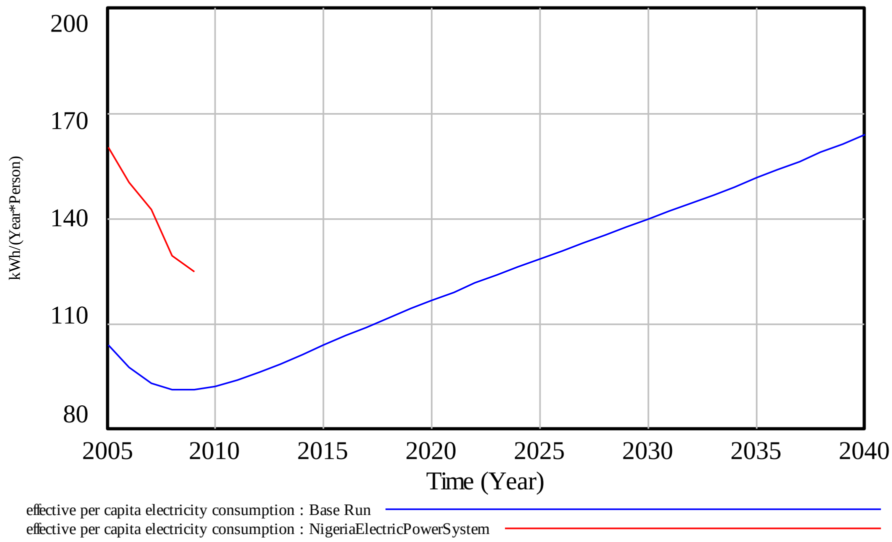

Figure 17 Effective Per Capita Electricity Consumption

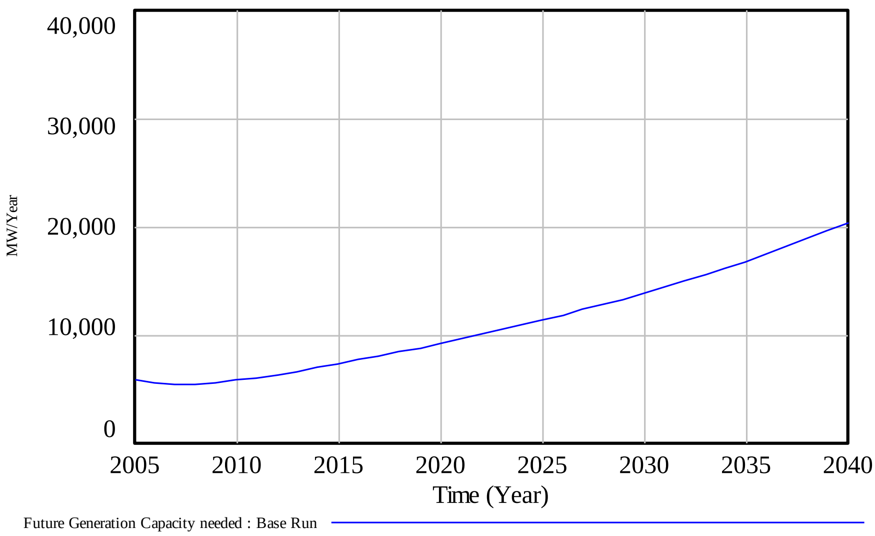

Figure 18 Future Capacity Needed to Meet Future Electricity Demand

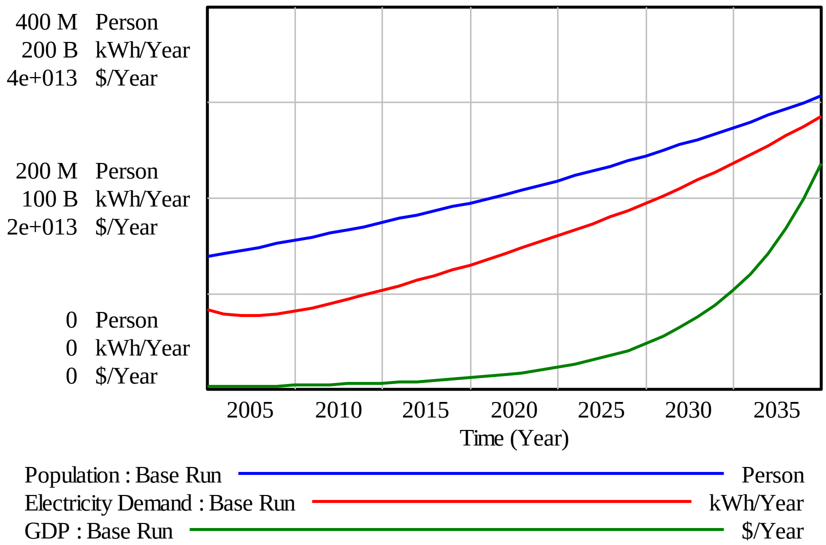

Figure 19 GDP, Electricity Demand and Population Trend

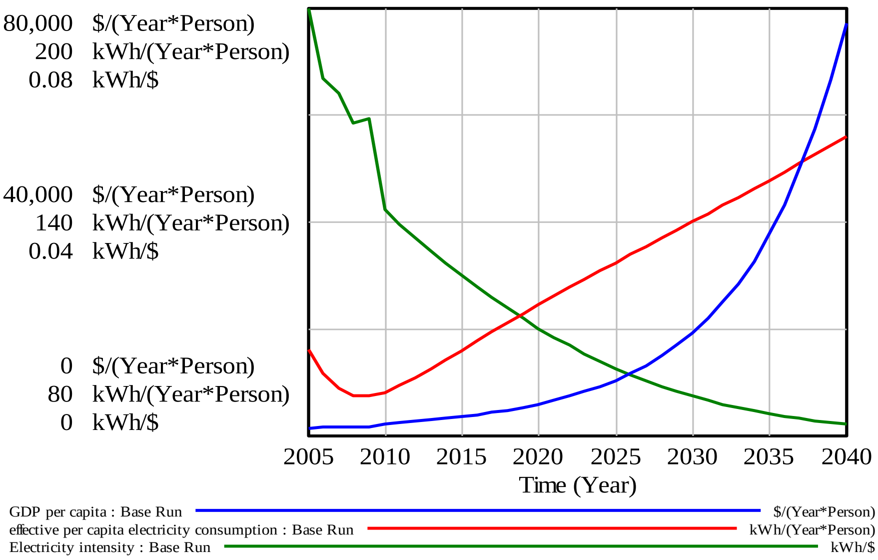

Figure 20 Per capita income, Per capita electricity consumption and Electricity Intensity

Leverage Point Identification

A fundamental principle of system dynamics states that the structure of the system gives rise to its behaviour (Sterman, 2000). So that situational factors, that is, the character of the system determines its behaviour or performance. The implication of this statement is that, in complex systems, different people placed in the same structure tend to behave in similar ways (Sterman, 2000). Redesigning the system or governing policy is then dependent on identifying high leverage points in it, where significant, sustained, beneficial effects on performance can be achieved (Forrester, 1969; Meadows, 1982). In order to conduct scenario runs, leverage points need to be identified in the model using sensitivity analysis. Knowing that the high leverage points in the system are mostly parameters with the model (Meadows, 1990), the sensitivity analysis was limited to these constants in each of the sector as listed in Table 4.24. For scenario runs, the leverage points were varied at a certain percentage from that of the value used in the base run of the model. The values for the leverage points in base run represent the figures for system as it currently is. Multivariate leverage point intervention was pursued in the scenarios to evaluate the system behaviour principally to achieve the intended performance turn around in the system. Of particular interest is to achieve sustained increased capacity addition, loss reductions and profitability. It is also imperative that the goals of increasing PCI and PCE are also achieved to drive industrialization and economic growth.

Table 5 Identified Leverage Points in NEPS

Parameters	Base Run	Scenario 1	Scenario 2
CAGR	0.0234	+100%	+200%
Availability Factor	0.52	+20%	+20%
Tx Loss	0.12	-50%	-50%
Distribution Losses	0.1	-50%	-50%
Non Technical Losses	0.2	-50%	-50%
Non billed losses	0.23	-50%	-50%
Average electricity price	0.0706	+50%	+50%
Price of electricity substitute	0.0702	±50%	±50%
Economic growth rate	0.053	±50%	±120%
Access level	0.46	+50%	+80%

The Scenarios

Two scenario runs based on government aspiration were examined to evaluate NEPS long term performance. The first run, **Scenario 1**, reflects government policy of increasing capacity from 10,000 MW in 2010 to 35,000 MW by 2030 (Vision 2020, 2009b and 2010). In this however, it is observed that total planned capacity addition for the future is less than the expected 35000 MW generation capacity by 2030. According to FMP (2010), total capacity addition in the pipeline is 20043 MW including that of private sector plans. Added to the existing capacity of 9762 MW as at 2010, this will leave a balance of 5195 MW to be mopped up by private sector investment to bridge the gap as anticipated by government. This will be influenced significantly by the prevailing investment climate in the country as from 2020 after government and other planned additions are completed.

The second run, **Scenario 2**, looks also at government desire to increase per capita income from its present level of US$ 1310 in 2010 to US$4000 by 2020 and higher in subsequent years and also to increase electricity consumption from the current level of 124 kWh/cap to 500 kWh/Cap in 2015 and over 1000 kWh/cap by 2020 (Vision 2020, 2009b and 2010). This is anticipated will lead to desired industrialization for the country to bring it amongst the first 20 economies in the world.

For Scenario 1, the impact of adjusting the identified leverage points with the exception of economic growth rate in the model is reflected in installed capacity, electricity demand, future capacity addition and effective per capita electricity consumption as shown in Figures 21a, b, c and d respectively. At 50% CAGR increment at the same time improving all other identified parameters, the system is able to achieve 35000 MW mark by 2038, whereas at 100% CAGR increment while keeping other parameters as that of 50% CAGR increment increase, the system is able to achieve its 35000 MW mark by 2033.

The target in Scenario 2 is to achieve increased per capita electricity consumption (PCE) as well improved per capita income (PCI). So the adjustment was done by 200% increment to the CAGR compared to its Base Run value while also adjusting the economic growth. Impact of these adjustments is reflected in installed capacity, electricity demand, future capacity addition, effective per capita electricity consumption, GDP and the per capita GDP amongst variables in the model. At 200% CAGR increment (i.e. 0.0936), keeping all other identified parameters as in Scenario 1, the system is able to achieve 35000 MW installed capacity mark by 2024, 9 years earlier than Scenario 1 at CAGR of 0.0468. This is keeping in mind that all other parameters that could be adjusted in the model were kept as those of Scenario 1. Other important land marks in the model runs as shown in Table 4.25 are that the system could achieve over 500 kWh/Cap consumption for improved living by 2018 and over 1000 kWh/Cap target for beginning of industrialization by 2029 in Scenario 2. It could also achieve over 500 kWh/Cap target in Scenario 1 by 2037 but not achieving the over 1000 kWh/Cap target in the timeframe of analysis. These targets were never achieved in the Base Run. For per capita income, the government target of US$4000 was met in the three scenarios, but at different timeframe respectively. In Scenario 2, this was met by 2016, Scenario 1 by 2018 and in Base Run by 2017. Interestingly, the system shows marked improvement particularly in installed and available capacity in the years that per capita income grew above the target value of US$4000, even though the system in Base Run remains an extractive industry dependent economy.

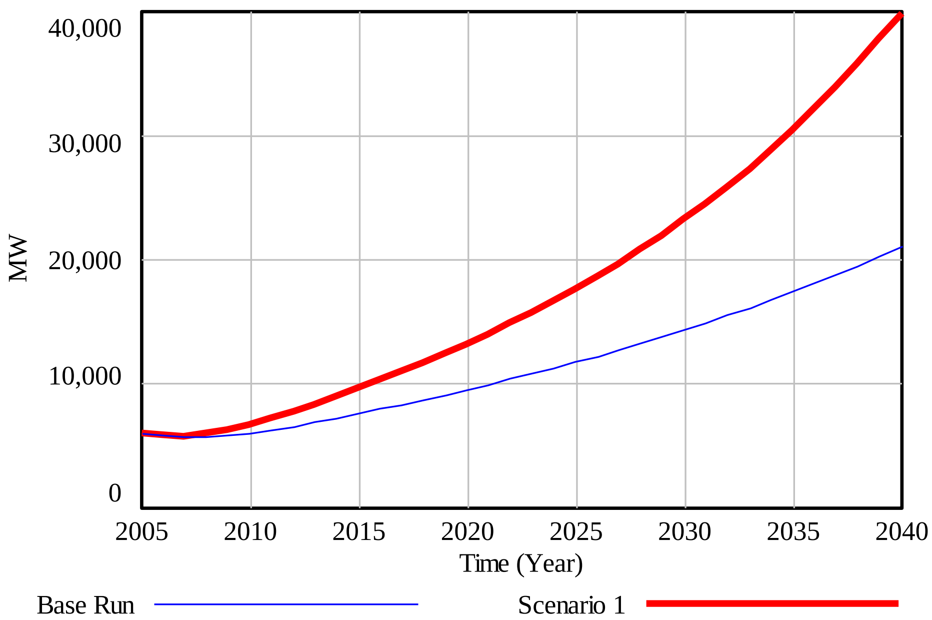

Figure 21a Total Installed Capacity – Base Run versus Scenario 1

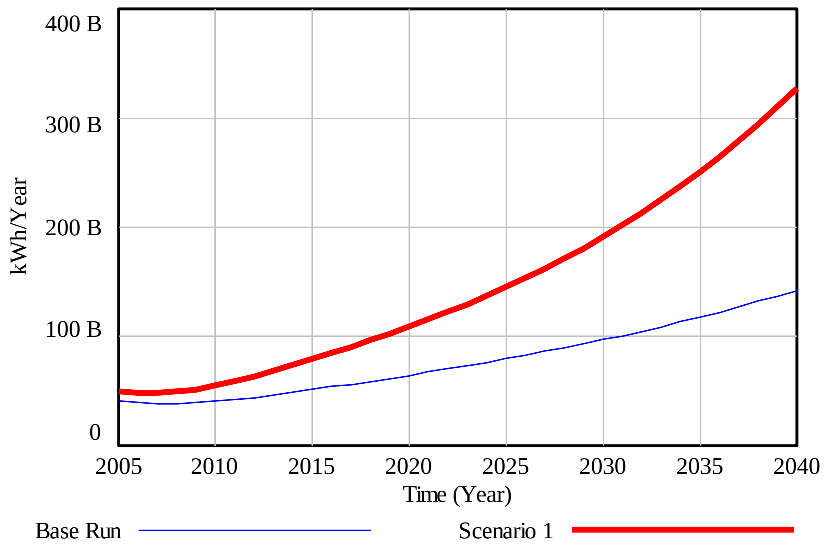

Figure 21b Electricity Demand – Base Run versus Scenario 1

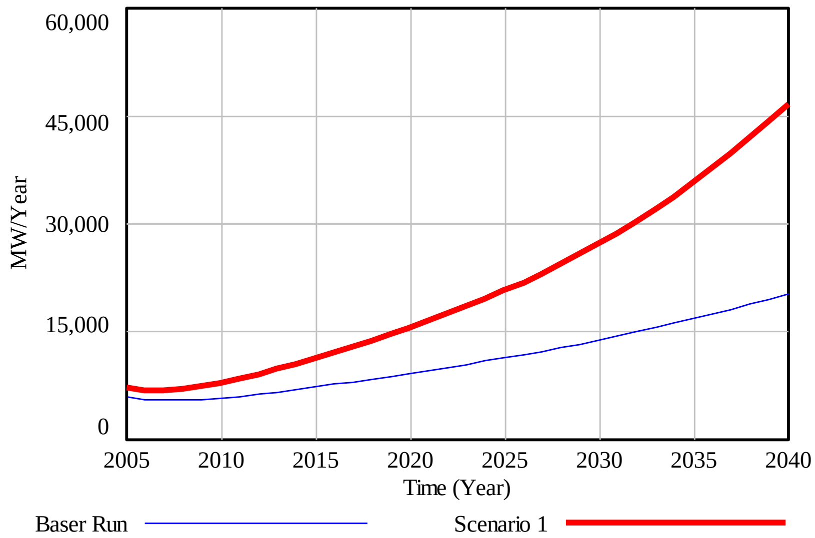

Figure 21c Future Capacity Addition Needed – Base Run versus Scenario 1

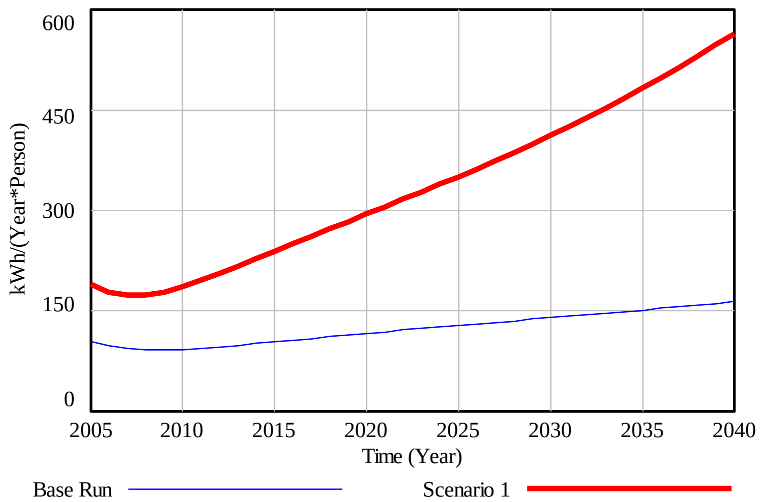

Figure 21d Effective Per Capita Electricity Consumption – Base Run versus Scenario 1

Table 6 Comparing Some Scenario Results of the Model Run

Year	Installed Capacity (MW)			Effective Per Capita Electricity Consumption (kWh/Cap)			Per Capita Income ($/Person)		
	Scenario 2 @ CAGR 0.0936	Scenario 1 @ CAGR 0.0468	Base Run @ CAGR 0.0234	Scenario 2	Scenario 1	Base Run	Scenario 2 @ EGR 0795	Scenario 1 @ EGR 0.053	Base Run @ EGR 0.053
2005	6,060.00	6,060.00	6,060.00	189.11	189.11	104.06	1,303.27	1,303.27	1,303.27
2006	5,895.92	5,830.68	5,797.44	179.87	177.38	97.33	1,456.00	1,456.00	1,456.00
2007	6,226.59	5,863.85	5,674.39	185.71	172.10	93.13	1,454.33	1,454.33	1,454.33
2008	7,019.12	6,153.17	5,688.74	204.66	172.78	91.28	1,560.68	1,560.68	1,560.68
2009	8,133.04	6,634.71	5,809.10	231.83	177.68	91.12	1,541.20	1,541.20	1,541.20
2010	9,450.85	7,251.33	6,006.75	263.37	185.35	92.11	2,184.02	2,162.85	2,176.41
2015	17,281.84	11,304.16	7,576.52	430.06	238.22	103.75	3,602.37	3,237.14	3,467.13
2016	19,017.21	12,222.79	7,948.44	462.66	249.34	106.41	4,020.24	3,509.05	3,829.28
2017	20,830.43	13,172.46	8,331.28	495.43	260.39	109.04	4,501.04	3,803.78	4,238.01
2018	22,739.21	14,156.22	8,723.98	528.72	271.37	111.62	5,055.53	4,123.28	4,700.08
2019	24,762.52	15,178.32	9,126.19	562.88	282.31	114.16	5,696.56	4,469.61	5,223.31
2020	26,919.87	16,243.74	9,537.97	598.23	293.23	116.64	6,439.45	4,845.03	5,816.78
2024	37,288.63	21,052.08	11,291.64	756.92	337.65	126.13	10,855.91	6,689.67	9,132.33
2029	55,759.85	28,754.22	13,786.82	1,010.76	397.67	137.52	22,401.30	10,012.42	16,809.06
2030	60,429.61	30,585.90	14,335.87	1,070.89	410.59	139.80	26,141.04	10,853.40	19,107.66
2033	76,923.83	36,794.79	16,101.00	1,273.70	451.60	146.71	42,334.89	13,824.42	28,413.85
2034	83,369.26	39,129.51	16,732.10	1,349.53	466.10	149.04	50,029.62	14,985.58	32,564.58
2037	106,134.31	47,055.53	18,768.21	1,605.25	512.30	156.21	84,139.75	19,087.74	49,625.67
2040	135,119.20	56,583.01	21,041.47	1,909.48	562.96	163.63	145,553.63	24,312.81	77,023.73

Source: This study

Conclusion

There are currently three major trends regarding electric power system modelling based on Analytical Thinking. These are namely, optimization models, econometric models and simulation models. In order to gain significant insight into structure and long-term performance of Nigeria electric power system, a simulation model based on Systems Thinking, making use of ***System Dynamics*** principles was employed for this study. This was used to evaluate the entire system from policy making to service delivery. This is because, unlike equilibrium market models, this approach focuses on replicating the system structure of NEPS and the logic of relationships among system components in order to derive its long-term performance. The approach included dynamic framework to enhance its usefulness for decision makers.

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