The Transition to an Energy Sufficient Economy

Timothy S. Mbasuen[1] and Richard C. Darton[2]

1 **Department of Engineering Science, University of Oxford**
OX1 3PJ, Oxford, United Kingdom
timothy.mbasuen@eng.ox.ac.uk

2 **Department of Engineering Science, University of Oxford**
OX1 3PJ, Oxford, United Kingdom
richard.darton@eng.ox.ac.uk

Abstract

Nigeria is an energy-rich nation with a huge energy resource base. The country is the largest reserves holder and largest producer of oil and gas in the African continent. Despite this, only about 40% of its 158 million people have access to modern energy services. Around 80% of its rural population depend on traditional biomass. This paper presents an overview of ongoing research to examine energy policies in Nigeria. The aims are: 1) to identify and quantify the barriers to sustainable energy development and 2) to provide an integrated tool to aid energy policy evaluation and planning. System dynamics modelling is shown to be a useful tool to map the interrelations between critical energy variables with other key sectors of the economy, and for understanding the energy use dynamics (impact on society and the environment). It is found that the critical factors are burgeoning population, lack of capacity utilisation, and inadequate energy investments. Others are lack of suitably trained manpower, weak institutional frameworks, and inconsistencies in energy policies. These remain the key barriers hampering Nigeria's smooth transition from energy poverty to an energy sufficient economy.

1998 ACM Subject Classification I.6 Simulation and Modelling

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1 Introduction

Nigeria, though an 'energy-rich' country falls within the category of countries suffering from 'energy poverty' as defined by the UN [1]. The country is the largest reserves holder and largest producer of oil and gas in Africa; yet, only about 40% of its total population have access to modern energy services [2]. Around 80% of its rural population depend almost wholly on traditional biomass for their energy needs [2]. The country's energy industry remains inefficient in meeting the energy needs and aspirations of its customers. This is evident in the dismal performance of the industry in terms of service delivery and per capita output.

For instance, in spite of its enormous oil and gas activities, the petroleum industry currently provides less than 15% of the country's GDP [3, 4]. Similarly, its GDP per capita and electricity consumption per capita remains among the lowest even in Sub-Saharan Africa-behind Angola and Ghana [5]. Persistent energy crisis has significantly weakened the industrialisation of the country, and grossly undermines the sustainable development agenda of the government.

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A review of technical and policy documents [5, 6, 7, 8, 9], and discussions with key policymakers in the energy industry reveal that the most serious challenges hindering the country from meeting its energy aspirations include: burgeoning population, lack of capacity utilisation (at all levels), and inadequate energy investments. Others are corruption, lack of suitably trained manpower, weak institutional frameworks, and inconsistencies in energy policies [6]. These remain the key barriers hampering Nigeria's smooth transition from energy poverty to an energy sufficient economy.

Despite these enormous challenges, there is still the lack of appropriate policy evaluation and planning tools to aid informed decision making process. The only recognised structured tools that have so far been attempted in planning and examining energy policies in the country are the IAEA's[1] MAED[2] and WASP[3][10]. While these models are capable of giving valuable insights into analysis of energy demand and supply in an economy, they are not able to account for other dynamics relating to society and the environment, since they are largely based on a static economic modelling approach.

Elsewhere in the world, particularly in the transition and other developing economies, system dynamics models have been used to support energy policy evaluation and economic planning. Notable among recent examples is the successful application of the T21 model framework of the Millennium Institute (MI) in China, Denmark, the Balkans, and Guyana [11]. In the African continent and the Caribbean, specific examples include Ghana, Mali, Malawi, Mozambique, and Jamaica [11]. The success stories for these countries also serve as a motivation for developing a similar model for Nigeria.

In recognition of the overall long-term energy security and sustainability implications of the current energy/economic crises, the government has embarked on a policy of vigorous reforms to improve the situation. This paper presents an overview of ongoing research being undertaken to examine energy policies in Nigeria using system dynamics modelling and multi-criteria analysis. The aims are: 1) to identify and quantify the barriers to sustainable energy development and 2) to provide an integrated and holistic tool to aid energy policy evaluation and economic planning for the country.

2 The Barriers to Sustainable Energy Development in Nigeria

As an emerging economy, Nigeria has faced a number of development challenges. In its energy industry for example, there is currently a massive gap between energy demand and supply. The inability of the nation to effectively develop its vast energy resources, to improve the economic and the social wellbeing of its people is attributed to a range of barriers. The most fundamental of these factors are considered in this discussion.

2.1 Burgeoning Population

Nigeria's population has continued to grow over the last five decades; the total population was last reported at 158.32 million people in 2010, up from 110.00 million in 1995 [12]. In spite of birth control mechanisms currently available in the country-leading to a steady decline in birth rates, it is still expected that the country's overall population will continue to grow into the future. The implication however, is that a continuous rise in population

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[1] International Atomic Energy Agency.
[2] Model for Analysis of Energy Demand: (for evaluation of future energy demand).
[3] Wien Automatic System Planning: (for finding optimal expansion plans for power generating systems).

means energy demand is likely to increase, even faster. Such a rise in population will not only constitute a serious barrier to energy poverty reduction strategy of the government, but will equally impede the overall human development process of the nation.

2.2 Lack of Capacity Utilisation

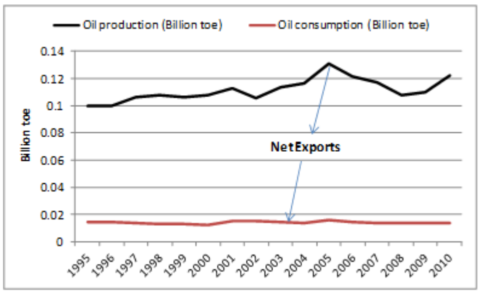
Despite its diverse energy resource base as illustrated in Table 1, the overall capacity utilisation of energy resources (defined in Btoe[4]) in the country remains very dismal. The key challenges include: lack of awareness, lack of skilled manpower, inadequate funding, and technological barriers [2, 13]. Lack of awareness in this context is taken to denote a low perception of the benefits of renewable and decentralised energy options. Furthermore, the inability of government to adopt state-of-the art energy efficient technologies such as CHCP[5] in its energy development strategies remains a serious impediment to sustainable energy development.

Table 1 Nigeria's Proved Conventional Energy Reserves at 2011 [7, 14].

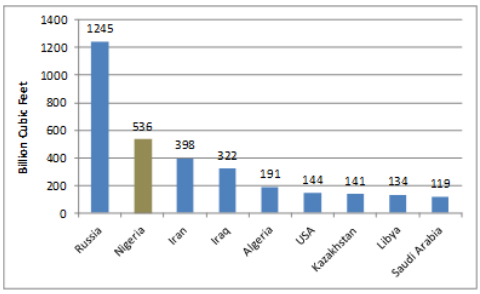
SNo	Resource type	Reserve	Energy value (Btoe)	Lifespan (Years)
1	Crude oil	37.2 billion barrel	5.431	43.1
2	Natural gas	187 trillion scf	4.485	114
3	Coal and lignite	2.175 billion tonnes	1.512	79
4	Tar sands	40.6 billion barrel equiv.	5.928	50
5	Uranium	Not yet quantified	-	-

2.3 Inefficient Energy Supply Infrastructure

In spite of a relatively low energy consumption profile overall (Figure 1a), the in-country energy supply capability is still very depressing. For instance, the country maintains four refineries with a combined crude processing capacity of 450 000 barrels/day; yet, none of the refineries has ever operated to optimal capacity [14]. Over the last 15 years, some of the refineries operated at 0 and 30% capacity, leaving a shortfall of about 85% to be met by imports [14]. In the upstream sub sector, the country is known to substantially flare



(a) Oil Production and Consumption



(b) Gas Flaring (2010)

Figure 1 Nigeria Oil Production & Consumption and Gas Flaring.

4 Billion tonnes of oil equivalent (authors' computations).
5 Combined Heat-Cooling and Power.

its natural gas for lack of infrastructure to market it. According to NOAA[6] [15], about 536 billion scf of natural gas was flared in the country in year 2010 (shown in Figure 1b). In monetary terms, the NNPC[7] estimates that gas flaring[8] costs the nation in average 2.5 billion US dollars per year in lost revenue [7]. While this is largely attributed to technological challenges, the problem is reinforced by inadequate funding, poor maintenance culture, and inconsistent energy policies.

2.4 Inadequate Energy Investments

Another barrier to effective development and utilisation of energy resources in Nigeria is inadequate funding. In the power sector for instance, government proposed to invest a total of 5.8 billion US dollars (for the period 2005 - 2013) [6]. This amount obviously, is inadequate, in view of the deplorable state of the electricity sub sector, and the high take-off investment funds required for developing renewable technologies.

The proposed public sector investment in the oil and gas upstream and downstream is approximately 3.8 billion US dollars [6]. In realistic terms, this amount is only sufficient to build one modern refinery. It implies therefore, that such meagre investment proposals can hardly make any noticeable difference, except more robust funding schemes are adopted.

2.5 Lack of Suitably Trained Manpower

The population structure of Nigeria provides a solid base for assessing availability and the quality of human capital and labour force necessary to transform the energy industry and the entire economy of the country. Review of energy industry and government reports [5, 6, 7], as well as historical data [14, 16] reveal that majority of the country's labour force are either unskilled or semiskilled. These categories of workforce apparently, are unlikely to change the economic fortunes of the country. Further discussions on this barrier are considered in the model representation section of this report.

2.6 Weak Institutional Frameworks

Many established energy institutions are unable to demonstrate focused regulatory and management capability required to improve energy development activities in the country. For example, the NNPC and DPR[9] have been proposing an end to gas flaring in the country for several years, but the deadlines to implement the policies has been repeatedly postponed [14]. Similarly, the loss of about 35 - 48% of electricity generated in the country to transmission and distribution losses is largely blamed on inability of the PHCN[10], to perform maintenance and upgrade of electricity supply infrastructure [2, 6]. These and many similar institutional challenges remain the barriers to smooth transformation of the nation's energy industry.

According to Transparency International's 2011 Corruption Perception Index (CPI), Nigeria is ranked 143 out of 182 countries for corruption-behind other African countries such as Botswana, Rwanda, and Namibia [17]. The evidence and impact of corruption can be seen in different sectors of the Nigerian economy. For example, 'Trading Economics' noted

[6] National Oceanic Atmospheric Administration.
[7] Nigerian National Petroleum Corporation.
[8] Gas Flaring in the context of oil production simply refers to the burning off (into the atmosphere) of natural gas associated with crude oil.
[9] Department of Petroleum Resources.
[10] Power Holding Company of Nigeria.

that Nigeria is one of the most advanced economies in Africa with average GDP growth of about 7.7% (as of last quarter of 2011), and about 95% foreign exchange earnings from oil and gas exports [18]. Yet, agriculture remains the main source of revenue to 2/3 of its population; while more than 50% of Nigerians still live in extreme poverty [12, 18]. Such dismal performance among other crucial issues is largely ascribed to corruption in both public and private sectors, and the lack of proper institutional frameworks for dealing with it [6, 14, 18].

However, the Economic and Financial Crimes Commission (EFCC) and other similar bodies in the country are working to address these issues [8, 9]. More detailed 'quantitative' discussions on corruption in the country is captured elsewhere in the model under 'Government Revenue and Expenditure'.

3 Energy Policy Reforms

As revealed in the foregoing, the current picture of energy development in Nigeria is marred by a number of challenges. It is against this backdrop that government has embarked on ambitious policy plans to improve the nation's energy and economic situation. One of the desired outcomes is to provide secure and sustainable energy access to its teeming population-particularly the rural population. To achieve this, the policy thrust indicates enhanced development of both conventional and renewable energy resources.

4 Current Study Objective and Methodology

4.1 Objective

The focus of this study is to develop a system dynamics (SD) model that maps the interrelations between critical energy variables (in Nigeria) and its impact on the three sustainability domains: the society, the economy, and the environment. The aims are: 1) to combine the SD model with a multi-criteria analysis (MCA) technique to examine energy policies, with the overall intent of identifying and quantifying the barriers to sustainable energy development. 2) To provide an integrated and holistic policy evaluation and economic planning tool to aid informed decision making in the country.

4.2 Methodology

This study consists of four major phases as follows:

Phase I: the first phase of the study (October 2010 – June 2011) involved critical review of literature on sustainability concepts; assessment tools and methodologies; current approaches to policy development and policy evaluation; and critique of the Nigerian energy system. The system dynamics methodology was found to be a useful approach for building an economy-wide dynamic model, which when combined with a simple, stakeholder-focused MCA method such as SMART[11], would provide a robust framework for analysing both the technical and social dynamics of the energy system.

Phase II: the second phase of the research (July 2011 – December 2011) developed a theoretical framework that enables integration of the proposed SD model with the chosen MCA technique. The idea was that combining an SD simulation model with a 'social-oriented'

[11] Simple Multi-Attribute Ranking Technique.

MCA model would result into a more rigorous and inclusive approach to exploring energy policies. The role of the MCA method is to account for stakeholder perspectives and to deal with issues of trade-offs. More importantly, it will aid us in making choices between competing policy alternatives.

Phase III: the third phase of the study (January 2012 – September 2012) is focused on data gathering, and building the proposed SD simulation model. The overall model conceptualisation and formulation process had commenced during the second phase of the research, with a few targeted Nigerian stakeholder contacts/discussions.

Phase IV: the fourth and last phase of the research (October 2012 – September 2013), will focus on full model verification, and a demonstration of how the SD simulation model and SMART value model can work together, for effective policy valuation. The process will initially involve systematic model calibration with historical data. In addition, the integrated model will be reviewed with experts in the ministries of energy and national planning (the potential users of the model), who earlier provided inputs in developing the model.

The verification process is also expected to be iterative, as it will largely involve presenting the model output to stakeholders, getting feedback, updating and representing it for additional comments. The idea is to ensure the most comprehensive input possible from experts and policymakers.

5 The Energy Dynamics Model

5.1 Model Purpose

In broad terms, the purpose of the proposed 'Energy Dynamics Model' is to map the interrelations that characterise the overall energy situation of Nigeria, and to serve as a 'baseline' from where alternative policies aimed at improving the social, the economic, and the environmental conditions of the country can be tested. In a specific sense, the model seeks to answer the overarching research question: *how and over what timescale can Nigeria make a smooth transition from 'energy poverty' to an 'energy sufficient' economy?*

5.2 Dynamical Hypothesis: a High Level Map

A high level map-HLM (Figure 2), was configured to encapsulate the overall model structure considered for the study. The HLM also serves as a dynamical hypothesis, which governs the development of the final model (using vensim™). In the HLM, there are four critical foci: energy resource (availability), energy demand (management), energy production/supply (efficiency), and energy financing (investment). The HLM hypothesises that these critical energy variables need to be broadly in balance, if Nigeria's transition to an energy sufficient economy is to be achieved smoothly. The elements are in a dynamic equilibrium, such that any distortion in their balance is likely to create ripple effects on the entire economy.

As illustrated in the map, availability (centre upper left corner) of viable primary energy resources (top left corner) is the first step towards ensuring energy security for the nation. The supply (centre lower right corner) of these resources is triggered by the demand (centre upper right corner) for energy to power and sustain the economy (top right corner). However, a sustainable production[12] (centre lower left corner) of the energy resources is only feasible

[12] Energy 'production' in this sense is distinguished from 'supply' in that by production, we refer to actual process of extracting/converting primary energy resources; while supply refers to the process of making energy products available (including domestic/exports).

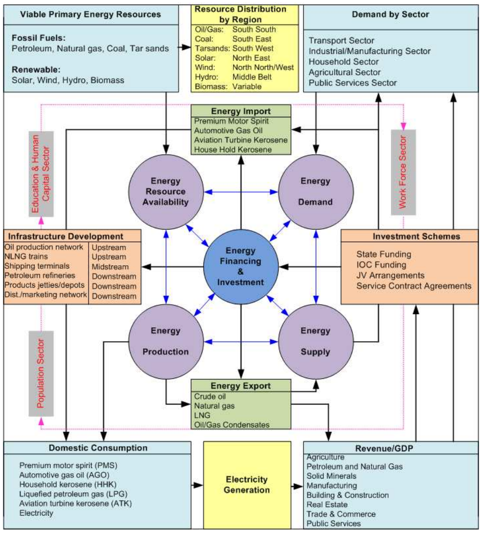


Figure 2 High Level Map: a dynamical hypothesis.

when enabled by continuous investments in energy development (captured in the nucleus). Other auxiliary sectors such as population, education, and workforce are also integrated to serve as drivers to the process.

The approach is not intended to be a definitive energy policy model, but the key significance remains that for Nigeria to break the bounds of energy poverty and put its energy industry on the path to sustainability[13], it is essential for the country to desire for such a balance.

5.3 Model Boundaries/Current Status

The model boundaries reflect energy impact on the three sustainability domains; it so far consists of six views. The first three views depict the core *social* sector variables, while the other views portray the three key *economic* sector variables interacting with the energy sector. The three views focusing on *environmental* impacts are currently being configured.

The model sectors as currently completed are: 1) population sector, 2) education and human capital sector, and 3) labour force sector. Others are 4) revenue/GDP sector, 5) government expenditure sector, and 6) technology sector. In this paper however, we present preliminary analysis on only two of the model views: education and human capital and the labour force sectors.

6 Model Representation

The overall model characterising the energy dynamics is developed for a 30 year timescale (1995–2025). Two simplified views of the model as mentioned above are presented below. The data that provides input parameters for the model are collected in EXCEL spreadsheets. They are however, inputted into the model as lookups, or as imported datasets.

[13] Energy/Economic sustainability in this context refers to dependable energy supply through efficient production and consumption in a thriving economy, with minimum environmental impact.

6.1 Education and Human Capital Sector

This model view focuses on the need for adequate supply of suitably qualified people through education and training.

As shown in the stock and flow diagram (Figure 3), the education sub-model starts with inflow of people (from the corresponding population cohorts) into primary education. A portion of the people who successfully complete primary school (after 6 years), progress to secondary education, while the remaining fraction (of primary school leavers) become available as *pool of labour force with primary education.* This trend continues until a fraction of graduates attain professional qualifications either in arts/commercial or scientific disciplines.

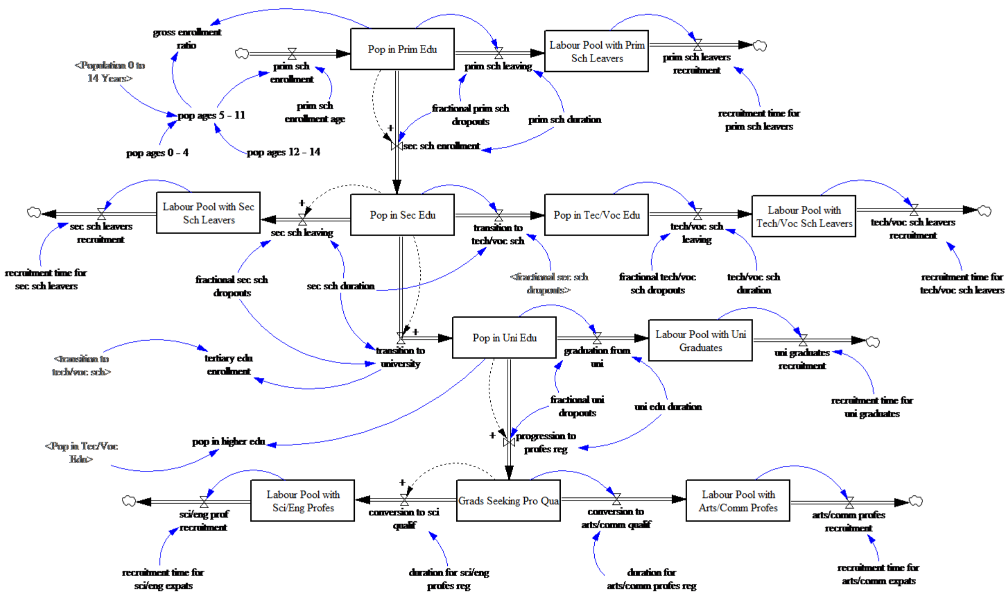


Figure 3 Education and Human Capital Sub-model.

6.2 Workforce Sector

The model view (Figure 4) describes the quality of workforce available in Nigeria. It defines four categories of labour force according to their highest level of education/skills. These include: 1) unskilled workforce (primary/secondary level); 2) semiskilled workforce (technical/vocational level); 3) skilled workforce (university level); and 4) highly skilled workforce (professional level).

7 Model Verification

A specific time is allotted in the research plan for full verification of the model structure and simulated behaviour through experts feedback in Nigeria, which in the context of this study is the most important 'validation'. However, for the purposes of preliminary analysis and in verifying the model's dimensional consistency, initial calibration of completed model views with historical time series data was undertaken. Fifteen years (1995 - 2010) data were inputted into the model as datasets, to systematically verify the model behaviour with what is known. The calibrations are however, not presented here for reason of space, but they generally show a high degree of congruency.

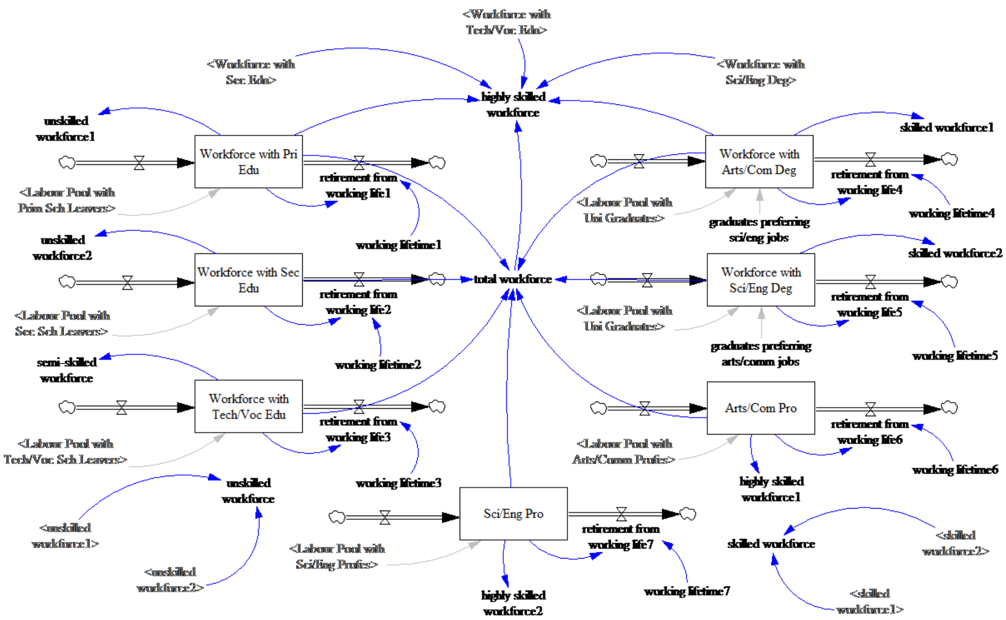


Figure 4 The Workforce Sub-model.

8 Preliminary Analysis

The outputs for model views considered in this report (in base runs) are discussed below.

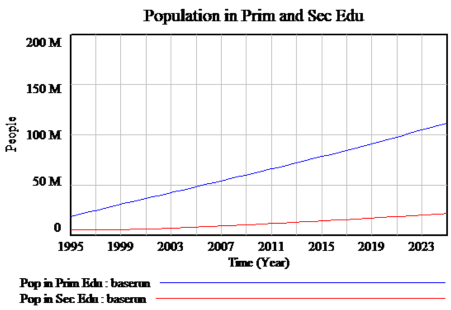
8.1 Simulation Run-1: Education and Human Capital

This model run features the supply of human capital based on educational attainment. The population of people in primary and secondary education for example, changed from 18.58 million and 5.121 million people in 1995 to 62.92 million and 10.90 million in 2010 respectively. As shown in Figure 5a, there is a wide gap between the population in primary education and those in secondary education. This implies that a significant number of people leaving primary education fail to progress to secondary school, perhaps, due to lack of awareness, motivation, or economic hardship. Also in Figure 5b, the population of people preferring to attend university education after secondary as opposed to technical/vocational studies is growing.

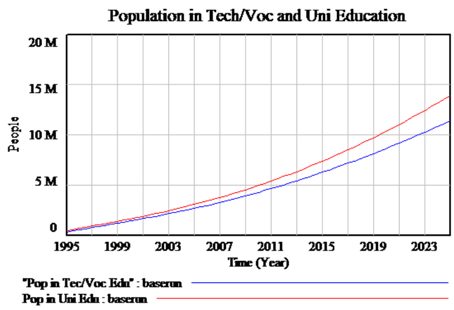
This trend became pronounced in the post 2000 scenarios because of recent 'discriminatory attitudes' of employers (particularly the private sector), in showing preference to university graduates. To that effect, the number of graduates seeking further professional qualifications is also rising (Figure 5c). However, a combination of overall educational attainments (Figure 5d), reveal that majority of the population terminate education after primary school. In view of Nigeria's population size, the trend is becoming worrisome as it is giving rise to unprecedented numbers of unskilled labour force in the country.

8.2 Simulation Run-2: Labour Force

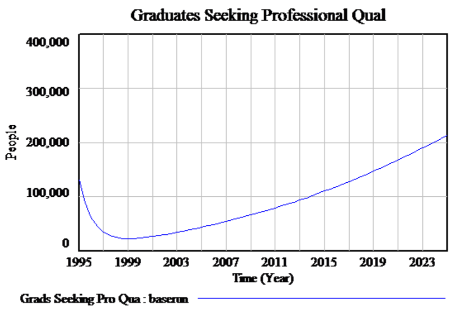
Despite a huge gap between the population progressing to further education and those terminating after primary school, it is glaring in Figure 6a, that the people qualifying to secondary education constitute the largest share of total workforce. Also, university graduates



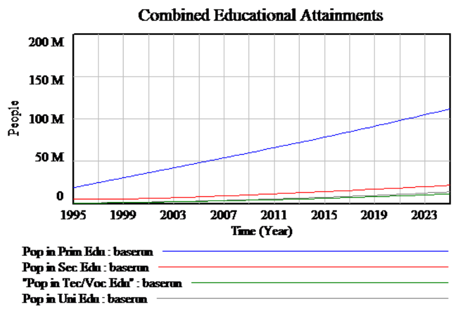
(a) Population in Prim & Sec Edu



(b) Population in Tech/Voc & Uni Edu

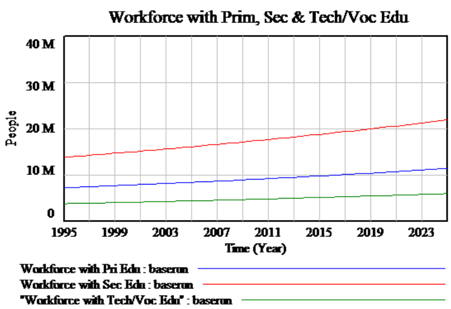


(c) Graduates Seeking Profsnl Qual

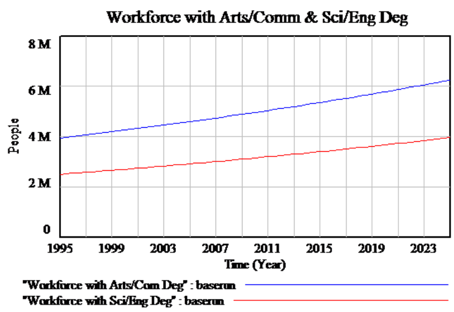


(d) Combined Edu Attainments

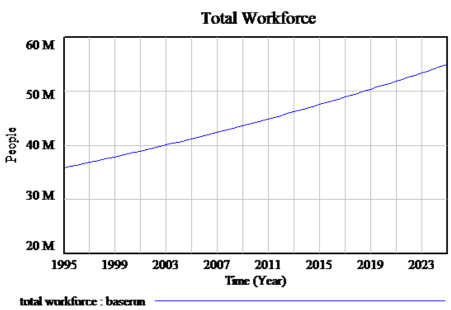
Figure 5 Model Output for Education and Human Capital.



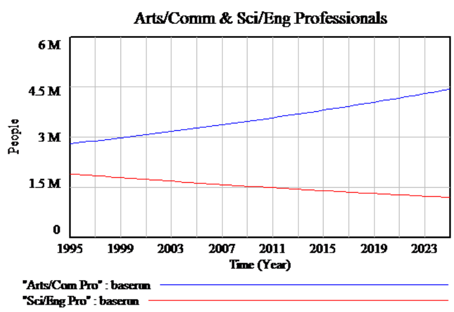
(a) Workforce with Prim/Sec/Tech/Voc



(b) Workforce with Arts/Comm & Sci/Eng



(c) Total Labour Force



(d) Skilled Arts/Comm & Sci/Eng Profsnls

Figure 6 Model Output for Workforce.

with arts/commercial degrees are more than those with science and engineering degrees (Figure 6b). In spite of an overall growth in its workforce (Figure 6c), it is still evident (Figure 6d), that the population of highly skilled professionals in arts/commercial disciplines is growing much faster, while that of scientific disciplines is somewhat on the decline.

In reality, the population with primary, secondary and technical/vocational educational qualifications currently dominate the Nigerian energy sector. They constitute more than 60% of the total labour force, as opposed to skilled and highly skilled labour force. The overall implication is that these semi- and un-skilled categories of workforce are not well trained, and this leads to the general lack of people with advanced technical and leadership skills who can drive development of the energy economy.

9 Summary Findings

Our model, though a work in progress, has provided insights to the barriers to sustainable energy and economic development of Nigeria. It raises concerns about the quality of human capital and workforce available to influence economic revolution in the country. The model emphasises the potential for human capital development, but underscores weak educational system and lack of suitable technical skills as ongoing concerns. Although, no policy scenarios have been generated at this stage, the model foresees the needs for enhanced education and capacity development at all levels.

10 Conclusions and Future Work

Engagements with system dynamics (as a policy evaluation and planning tool) are rare in Nigeria, as there is currently no account of its application anywhere in the country. For that reason, this study becomes novel for its introduction of an integrated approach to examining policy issues, and for providing a tool that will aid informed decision making process in the country. Our approach seeks to combine the quantitative rigour of system dynamics modelling and the social focus of the chosen MCA technique in planning and evaluation of energy/economic policies. To help in charting a new path to a sustainable future for a developing nation like Nigeria; it is essential that such a holistic and integrated tool be provided.

The study focus over the final phase of the research is to complete development of the model sectors, and have it run as an integrated unit. In its full running mode, the model will be used to generate and test different policy intervention scenarios based on selected Nigerian government targets. The emerging policy options (from the model) will further be evaluated (with MCA) against some criteria to determine their robustness.

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