The Sustainability Assessment of Energy Policy in Nigeria:

Scenario Planning and Integrated Modelling

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A thesis submitted for the degree of *Doctor of Philosophy*

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Abstract

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This thesis presents a novel policy assessment tool that serves as a decision support framework for analysis of energy policy problems involving multilevel, multidimensional and multi-stakeholder complexity. This new approach, The Energy Policy Assessment Technique (E-PAT), integrates System Dynamics Simulation and Multi-Criteria Evaluation models into a unified assessment framework. The E-PAT doubles as a systems-thinking model and a multi-criteria evaluation archetype. The E-PAT is designed for assessing policy issues, particularly those relating to energy planning in a national context. It is a suitable tool for evaluation and selection of optimal policies from competing and conflicting alternatives. To test its robustness and practical application, a case study on energy policy evaluation in Nigeria is carried out with this tool. A model of the Nigerian energy economy was constructed, and three proposed government policies for Sustainable Energy Development were evaluated relative to a Business-As-Usual case. The evaluation process identified 'best' policy options according to stakeholder viewpoints. The original contribution of this research is the creation of an integrated, transparent and comprehensive assessment tool, and the development of measurable Energy Sustainability Indicators (ESI), to aid policymakers in diverse policy analysis. The new tool is intended to support assessment of energy policies in relation to impacts on the economy, society and environment.

To my wife Caroline,

for her untiring love and support.

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Table of Contents

Chapter 1

General Introduction

1.1 Research Background

The sustainability assessment of policies—particularly, those relating to national planning revolve around multilevel, multi-domain and multi-stakeholder complexity. Hence, assessing a policy initiative to quantify its sustainability gains or otherwise, requires a range of rigorous assessment tools and procedures from which we can select a methodology suitable for a particular case. We also need to be confident that the selected methodology will yield the required assessment.

For these and similar other reasons, a variety of structured tools focusing on policy assessments are in current use. However, many of such tools are said to be either too linear [1, 2] and simplistic [3, 4] or are unable to represent within a single framework the dynamics of the policy case under consideration and the sustainability domains: society, economy and environment [5]. Feedback from these sustainability domains for example, is particularly difficult to identify, quantify and manage [6] using a normative approach, hence, the need for a robust and integrated assessment approach.

This study introduces a new approach to policy assessment. Its main contribution is the development of an Energy Policy Assessment Technique (E-PAT), which integrates System Dynamics Modelling [7] and Multi-Criteria Evaluation [8] methodologies into a unified assessment framework. The E-PAT doubles as a systems-thinking model and a multi-criteria evaluation archetype. It is a practical tool for use in analysis of diverse policy initiatives including issues of planning, evaluation and selection of optimal policies from competing and conflicting alternatives.

1.2 Study Objective

The overall objective of this study was to develop an integrated technique for assessing policy initiatives, especially those relating to energy planning in a national context. The aim is to provide energy policymakers with a planning and evaluation tool to support informed decision making process. The main argument defended in this study is that combining a structured computer simulation model with a social-oriented evaluation model provides a practical approach to effectively explore the policy environment.

Therefore, it is the hypothesis of this research that a novel framework that combines System Dynamics Simulation Model (SDSM) and Multi-Criteria Evaluation Model (MCEM) will result in a more powerful assessment technique; a robust technique that has the capability for exploring diverse policies. In addition to assessing policies from a nonlinear approach, the new technique is practical for evaluating and selecting an ‘optimal’ or ‘best’ policy case from multiple alternatives. It is also an appropriate integrated tool for use in preliminary policy assessment before adoption and implementation and in the full evaluation of policies after implementation.

This study establishes that SDSMs have the capability of exposing ‘cause and effect’ relationship among system variables [7]. They also help in our understanding of behaviour patterns and potential consequences [9]; they however, are not able to explicitly deal with evaluation of these consequences [10]. To ensure a transparent evaluation of policy impacts and trade-offs based on stakeholder perspectives, the choice of an appropriate MCEM to combine with SDSM becomes necessary [10]. For this study, the Simple Multi-Attribute Rating Technique (SMART) [8]—which is flexible in incorporating stakeholder viewpoints is combined with SDSM.

1.3 Case Study Application

Nigeria, though an 'energy-rich' country, falls within the category of countries experiencing *"energy-poverty"* as defined by the UN [11]. A study of government documents [12-14] reveals that one of the key challenges facing the country is ineffective energy policy formulation and implementation, and the lack of structured tools to aid in the planning and evaluation of effective policies; tools that will support informed decision making process in the country.

For instance, the only recognised tools that have so far been applied to energy planning in Nigeria are the IAEA's models: 1) Model for Analysis of Energy Demand (MAED) and 2) Wien Automatic System Planning (WASP) [15]. 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 the dynamics relating to 'society' and 'environment', since they are based on a *"static economic modelling"* [16]. It is essential therefore, that a robust integrated tool be developed for Nigeria, to aid planning and evaluation of energy policies. This is in recognition of the complexity inherent in the Nigerian energy economy system.

In view of the foregoing, this study has developed the E-PAT and demonstrated its practical application on Nigeria, as a case study example. We have tested the robustness and real world usage of the tool with proposed government policies for Sustainable Energy Development (SED). Three alternative policies were modelled and evaluated using the framework. The evaluation procedure combines simulation output from our model and fieldwork data from Nigeria, to serve as *"front end"* [10]. The process results in the selection of an 'optimal' or 'most preferred' alternative policy based on stakeholder preferences.

1.4 Research Contribution

This is the first time a SD simulation model and a Multi-Attribute Utility Model are integrated for evaluation of real world national energy policies. It is also the first time such an approach has been used for analysis of energy policies in Nigeria. As an important economy in the African continent, Nigeria has huge diversity in energy and other natural resources, and a high potential for future economic growth. The country is consistently ranked among the *"Next 11"* emerging economies of the world [18]. It is essential therefore, that a robust assessment framework such as the one proposed in this study be made available to policymakers for planning and evaluation of energy policies.

An important contribution by the merger of two methodologies into a single assessment framework in this study is that the System Dynamics (SD) approach brings the capability needed in effectively representing the dynamic interactions between system variables [7]. SMART on the other hand, provides the flexibility required in handling stakeholder inputs, and the transparency needed in dealing with issues of trade-offs [10]. A combination of these powerful attributes aims to help decision makers to better their understanding of the dynamics of a policy case under analysis.

Thus, the overall contribution to knowledge by this research is a novel policy assessment tool, developed and made available to aid policymakers in planning and evaluation of energy policies in different settings. The new tool is 'progressive', and it draws its strength from 'dynamism' and 'holism'. This means that the tool supports policy assessments in a *"transparent and comprehensive"* manner [16]. Policy initiatives intended for assessment with the proposed approach are those relating to Sustainable Energy Development, where stakeholder engagements are required.

1.5 Thesis Structure

Chapter 2 and Chapter 3 deal with background issues about this research. Chapter 2 critically reviews the essential elements of sustainability from the standpoint of Sustainable Energy Development. It explores the definition of sustainability and its contrasting paradigms. This helps us in identifying the preferred sustainability approach for this study. Chapter 3 presents an analysis of sector-specific issues about Nigeria. It discusses the core issues of interest to this research, which Nigeria currently faces with its energy economy. The discussion focuses mainly on understanding the 'dynamic interplay' between the energy sector and the economy, society and environment.

Chapter 4, Chapter 5 and Chapter 6 deal with the first part of the thesis argument: developing an integrated policy assessment tool. Chapter 4 presents the model development process and the key model features. Chapter 5 presents an analysis of the model 'Reference Behaviour' also known as 'Baseline Scenario' or 'Business-As-Usual' (BAU) case. It discusses the model outputs that characterise the dynamic interactions between the energy sector and the three sustainability domains in their 'base runs' over a 50 year timescale. Chapter 6 presents 'plausible' scenarios against government's targets and criteria for achieving Sustainable Energy Development (SED) in Nigeria. It analyses the impact of different government initiatives within the energy sector and their economic, social and environmental implications.

Chapter 7 deals with the second part of the thesis argument, which focuses on multi-criteria, multidimensional and multi-stakeholder evaluation of alternative government policies, and the selection of an 'optimal policy' based on stakeholder perspectives. Chapter 8 discusses study findings; it presents the key thesis conclusions and insights into the future work needed to expand the E-PAT framework.

Chapter 2

Sustainability Assessment and Assessment Approaches

2.1 Introduction

This chapter of the thesis critically reviews the essential elements of sustainability from the standpoint of Sustainable Energy Development (SED). It explores the definition of sustainability and its contrasting paradigms. This helps us in identifying the preferred sustainability approach for this study.

The chapter further examines the diverse tools and methodologies for assessing sustainability, the role of stakeholders in Sustainability Assessment and the current approaches to policy development and assessment. The aim is to define the basic concepts and approaches necessary to advance the course of this research, and to provide the overall structure for exploring energy security and sustainability challenges in Nigeria. It also demonstrates how our proposed assessment technique, which combines System Dynamics Simulation and Multi-Criteria Evaluation models into a single assessment framework, fits in the 'family' of integrated assessment tools.

Section 2.2 considers sustainability concepts: the definition, contrasting paradigms and assessment approaches. Section 2.3 surveys existing assessment tools and methodologies, while section 2.4 reviews the current approaches to policy development and assessment. Section 2.5 introduces a new policy assessment approach and the rationale for its development—including application and benefits. Section 2.6 provides the key conclusions for this chapter.

2.2 Definition of Sustainability and Contrasting Paradigms

Sustainability or Sustainable Development is undoubtedly a difficult subject to explore. This is in consideration of the fact, that there is currently no single universal definition or meaning to the concept, neither is there a single modus operandi for assessing its intra- and inter-generational gains. Despite these, sustainability has become a very popular subject in contemporary society and is being diversely explored. Our Common Future [19] which defines Sustainability or Sustainable Development as: *"…development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs"* remains the underpinning definition around which other perspectives of the concept evolve.

By this definition, the World Commission on Environment and Development (WCED) conceptually, explored sustainability in three dimensions—also referred to as the Triple Bottom Line [20]. This reflects on the environmental consequences of the economic and social development activities of the present generation, and the potential impacts on the needs and ability of the future generations. To summarise this approach, a basic conceptual framework for the Triple Bottom Line paradigm, including the policy environment is illustrated in Figure 2.1.

Before the 1987 report of the WCED—popularly known as the Brundtland Report [19], *"many people were not aware of what sustainability is, and its implications to human existence. Even as its awareness is increasing, the inherent ambiguity of the subject remains an issue of global debate"* [20]. Despite the somewhat nebulous nature of the subject however, our *"limits to growth"* and development due to constraints predicted by past scholarships [21-23], underpin the focal issues on sustainability today.

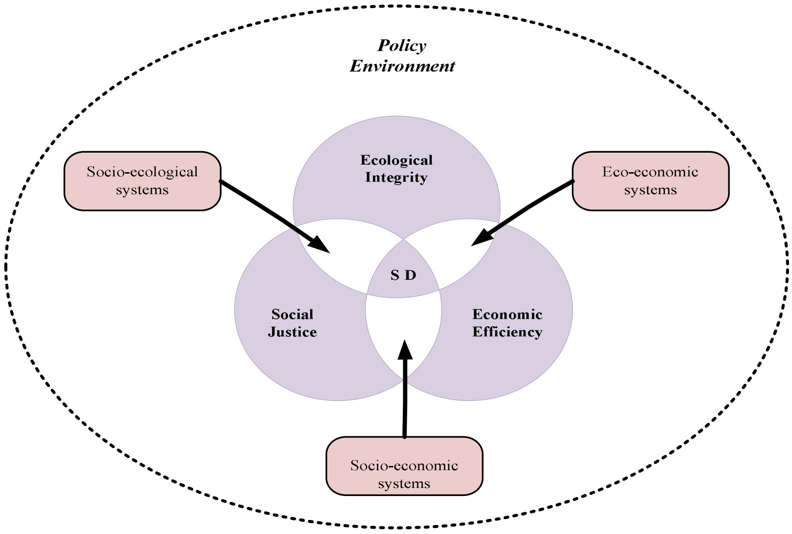

Figure 2.1: Conceptual Framework for the Triple Bottom Line.

2.2.1 Sustainability Concepts

Despite a carefully worded definition of Sustainable Development as presented by the Brundtland Commission, different interpretations of the concept have emerged as ideas continue to evolve. Mainstream thinkers of the notion for instance, believe the definition is too broad, as it did not underpin any specifics within the myriad of issues concerned with *"Our Common Future"* which we are aiming at [24]. In some particular cases, the analysis of sustainability dimensions is found to require attention to specific facts such as institutional, technological and even political sustainability [25, 26]. Other schools of thought [27-30] focus their argument on the timescales of Sustainability Assessment, and whether it is *"Reductionism"* or *"Holism"*. Another segment [31-33] chooses to focus on the opposing views of *"Weak"* versus *"Strong"* sustainability.

2.2.2 Understanding Contrasting Paradigms

The assessment of sustainability is dependent on different interpretations. These include: 1) the definition (whether it is Weak or Strong Sustainability), 2) the timescales (over which sustainability is actually assessed) and its relevance to intergenerational impacts and 3) the extent to which the assessment process is carried (whether it is

Reductionist or Holistic). These opposing paradigms are briefly considered in the following paragraphs, for better understanding of the concept.

i. Weak versus Strong Sustainability

The on-going debate between environmentalists and resource economists on the Weak versus strong aspect of sustainability revolves around the idea of *"natural capital"* and *"manufactured capital"* [32].

Thus, Weak Sustainability or Shallow Environmentalism advocates [30, 32-35] regard the environment as a pool of resources that can be exploited for maximum economic and social prosperity. This aspect of sustainability assumes a human-centered approach to the relationship between man and nature [35]. In this case, human development is expected to be non-diminishing from generation to generation [32].

Neoclassical economists employ the Cobb – Douglas production function to define a straightforward relationship between non-declining utility and resource use [33]. This is defined by:

$$\mathbf{Q} = \mathbf{A}(\boldsymbol{t})\ \mathbf{L}^{\boldsymbol{\alpha}}\ \mathbf{K}^{\boldsymbol{\beta}}\ \mathbf{R}^{\mathbf{1}-\boldsymbol{\alpha}-\boldsymbol{\beta}} \tag{1}$$

Where, **Q** is the output, **A** is factor neutral technological progress as a function of time (t), **L** is labour, **K** is financial capital and **R** is natural resource input. The exponents sum to unity so that there will be constant returns to scale. This formulation remains the guiding principle for the supporters of Weak Sustainability today.

In Strong Sustainability or Deep Ecology, the natural environment is considered to have value in its own right, but is threatened by overexploitation of its resources by human development [34]. This side of the sustainability spectrum focuses on demand-side management, as opposed to the resource-side management approach found in Weak Sustainability. It advocates changing patterns in human dependence and demands on the natural environment. In this perspective, human societies are expected to adapt towards the finitude of nature, rather than adapt nature to meet human needs. Thus, Strong Sustainability does not permit any decrease in the stock of natural capital. Weak versus Strong Sustainability perspectives are summarised in Table 2.1.

Table 2.1: Weak versus Strong Sustainability Perspectives.

	Weak Sustainability (WS)	**Strong Sustainability (SS)**
1	Natural and man-made capital is substitutable.	Natural and man-made capital is complementary.
2	Total capital stock (natural plus man-made) should be kept intact.	All natural and other forms of capital should be independently kept intact over time.
3	Environmental problems as economic problems.	SS is not only an economic problem, but also a problem of conserving environmental resources.
4	WS accepts monetary valuation and cost–benefit approach.	SS favours precautionary principle, and safe minimum standard.

Adapted from [33].

ii. Intra-generational versus Intergenerational Equity

Intra-generational equity can be described as a campaign for equal opportunity, fair sharing and rational behaviour of the present generation over nature's *"bounty"*, which if sustained will momentarily transform into intergenerational equity. This implies that the present generation should be rational in thinking and approach, to accord equal sustainability importance to spatial, social, as well as time dimensions.

Intergenerational equity on the other hand focuses on two philosophical principles—justice and fairness [34]. According to Pearce and Warford [31], it means development that secures increases in the welfare of the present generation, providing that the welfare of future generation does not decrease. Howarth [36] also propose the 'fair sharing principle' where members of present and future societies are entitled to fairly share in the benefits derived from nature.

Despite contrasting views over the actual timescales of intra-generational equity assessment, and its potential impacts on intergenerational equity, human needs and limits [37] remain the fulcrum for both perspectives.

iii. Reductionism versus Holism

The Reductionist process is defined by Bond and Morrison-Saunders [29] as *"the breaking down of complex processes to simple terms or component parts"*. This approach, Bond and Morrison-Saunders [38] and Costanza [39] note is simple and easy to understand. They separately argue that it has the ability to reduce the complexity of environmental impacts to a limited set of numbers, which paves the way for integration of social, economic and environmental considerations in decision making.

On the other hand, there are still ensuing arguments that the Sustainability Assessment process needs to consider 'wholes' rather than 'parts' or individual components, hence the concept of *"Holism"*. According to [29, 40-42], the environment and human societies are complex systems which are dynamic and nonlinear in nature. They are also involved in complex interactions; hence, understanding such a complex system requires a holistic approach.

Despite strong arguments from both camps, most literature [41] reveals that *"Reductionism"* is currently the dominant sustainability approach, with varying degrees of application. For this study, 'holism' based on a 'weak sustainability' approach is adopted, with equal importance attached to intra- and intergenerational equity concerns.

2.2.3 Sustainability Assessment

According to [43], Sustainability Assessment (SA) can be defined as a *"formal process of identifying, predicting and evaluating potential impacts of an initiative (such as a project, legislation, regulation or a policy plan) and its alternatives on the*

Sustainable Development of society". In some literature [44-46] SA is generally viewed as Environmental Impact Assessment (EIA) approach. For this research, our focus is on integrated assessment of policies.

SA is seen by many as a common decision making process, which is designed to direct planners and decision makers towards Sustainable Development [29, 43, 44]. It involves the integration of the environmental, economic and social pillars of sustainability into decision making in a way that acknowledges interconnections [43].

In an ideal situation, policy decisions and the results of scientific Sustainability Assessment should coincide; but for conflicting interest, it is usually not the case [34]. In most cases, the scientific analyses from SA are being leveraged as precursor to decision making. This implies that the SA and decision-making process are two separate procedures, but mutually influencing activities, as one is done in return to the other [47].

A structure that demonstrates SA with decision making process is shown in Figure 2.2. In this case, a typical SA incorporates decision making with analytical tools and methodologies relevant to the sustainability dimension(s) under considerations.

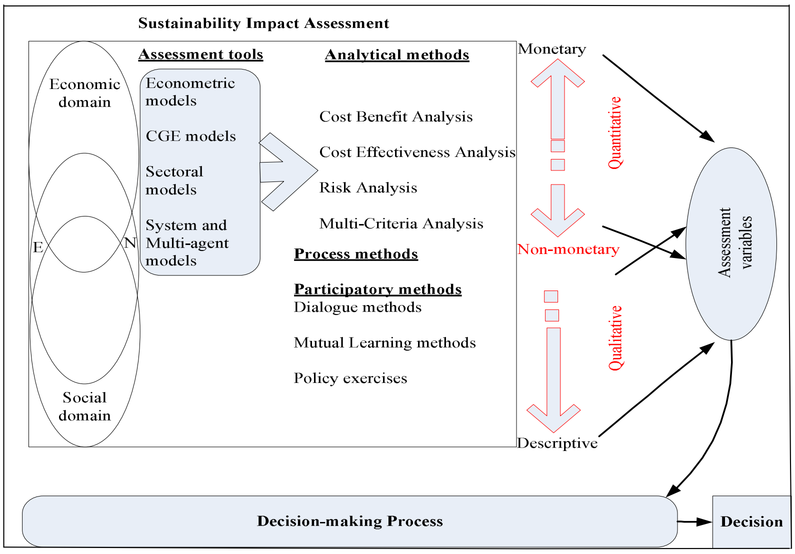

Figure 2.2: Sustainability Assessment Process with Decision. Adapted from [47].

2.3 Assessment Tools and Methodologies

This section presents a critical appreciation of the wide-ranging Sustainability Assessment tools and methodologies in current use, based on established categorising approaches. The discussion includes: time factors, assessment focus, sustainability dimensions and system boundary. It further explores the possibilities of developing a new category of assessment tools based on identified gaps.

2.3.1 A Framework for Assessment Tools

Sustainability Assessment tools found in current literature are broadly categorised into four groups. These are 1) Indicators and indices; 2) Product assessment tools; 3) Process assessment tools and 4) Integrated assessment tools. Following these categorising approaches based on [45], we define a simple framework for Sustainability Assessment tools as shown in Figure 2.3. The approach follows a continuous seamless series, to denote whether the tools are 'forecasting' (prospective) or 'backcasting' (retrospective) tools.

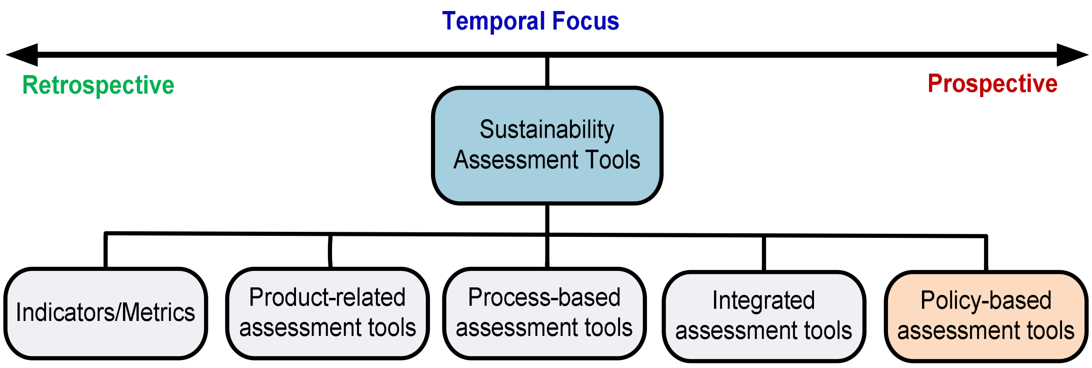

Figure 2.3: Framework for Sustainability Assessment Tools.

For this study, an inventory of the tools focuses on the key features discussed below. Our main reason for focusing the inventory of assessment tools on these features is to adopt an inclusive approach that attempts to capture both the 'depth' and 'breadth' of Sustainability Assessment.

a) Time factors: - a temporal characteristic that determines whether the assessment tool evaluates an 'ex-post' or 'ex-ante' sustainability activity. Ex-post (descriptive) SA refers to evaluation of a past activity, while ex-ante (change-oriented) SA implies evaluation of proposed future initiative, such as a policy change or a new policy plan.
b) Assessment focus: - refers to the coverage area; it determines whether the tool concentrates on product, process or a policy assessment.
c) Sustainability dimensions: - determines the extent to which the tool integrates economic, social and environmental issues in the assessment.
d) System boundary: - refers to that margin which defines the limits of what is included and what is excluded in the system being assessed.

2.3.2 Indicators and Metrics

Indicators can be defined as variables that compress information concerning a relatively complex process, trend or state of a system into a more readily understandable format [34]. In most literature on SA, indicators and metrics are used interchangeably. But for clarity, it is worth noting that indicators as sustainability tools are used to describe trend or the state of a system against a given baseline, while a metric quantifies the degree to which the system possessed quality of the property being measured. The main objective of assessing a sustainability initiative using tools such as indicators and metrics is to measure progress or assess success towards sustainability. For this study, the intended use of indicators is to develop the metrics needed for quantifying progress against government targets for SED in Nigeria.

Indicators are broadly categorised into 'non-integrated' and 'integrated' [34]. Ness et al., [45], who were considering the case of a very large-scale complex system, proposed a third strand referred to as 'regional flow indicators'. This suggestion allows an overview of the structure of resource flows and identification of inefficiencies within a large system. A frame representing these assessment tools is shown in Figure 2.4.

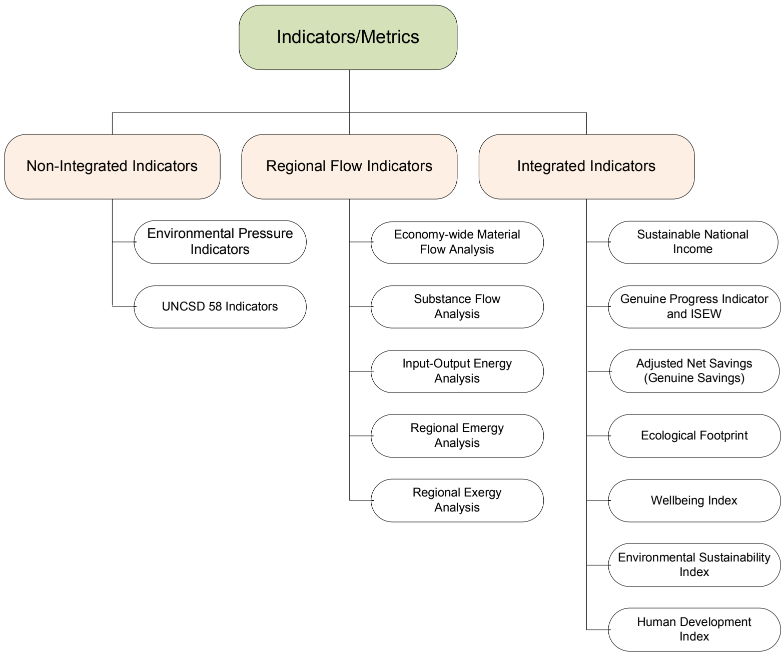

Figure 2.4: Frame for Indicators and Metrics for Sustainability.

Despite being seemingly simplistic and transparent, the selection of appropriate indicators is dependent on several factors. These include: 1) the type of assessment required, 2) the purpose for which the assessment is carried out, 3) the sustainability dimension under consideration and 4) whether the indicator aims to measure the state of a system or explore trends into the future.

Hence, different criteria are adopted for indicator selection and evaluation in particular cases. In spite of these peculiarities, common selection criteria still exist. These include: availability, reliability and measurability of data for the desired indicator [46]. In addition to these commonalities, other context and perspective dependent criteria are available for use in indicator selection. These include: completeness of indicator set, coverage and non-duplication.

2.3.3 Product Assessment Tools

Product-related Sustainability Assessment tools belong to the category of tools that focus on flows in connection with production and consumption of goods and services. They are tools concerned mainly with defining and evaluating different material, energy and waste flows for a product or service. In many current practices, these tools are expanded to include corporate environmental accounting [45].

Tools identified under this category include Life Cycle Costing, which encompasses: Life Cycle Cost Assessment, Full Life Cycle Accounting, Full Cost Accounting, Full Cost Environmental Accounting, Total Cost Assessment, Total Cost Accounting and Full Cost Pricing [48]. Others are Life Cycle Assessment and Product Material Flow Analysis (which includes: Material Intensity Analysis and Substance Flow Analysis) [45]. A structure representing these tools is shown in Figure 2.5.

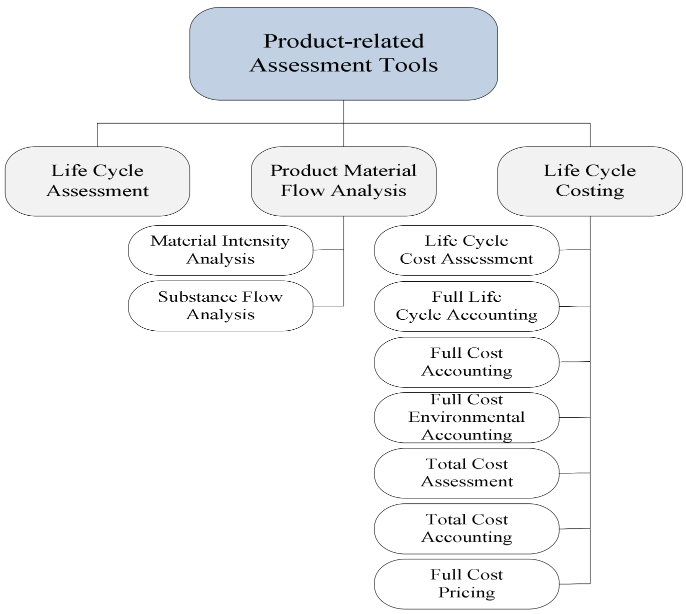

Figure 2.5: A Structure for Product Assessment Tools.

Amongst these product-related assessment tools, Life Cycle Assessment, also known as Life Cycle Analysis (LCA) remains the most developed and well established technique. It is used here as a 'proxy' to discuss tools in this category. The LCA methodology normally follows the *"cradle-to grave"* approach. This implies that the full Life-Cycle Assessment of a product from raw material (*"cradle"*) through manufacturing, distribution and consumption to disposal (*"grave"*) are considered [49].

In practice, the various uses of LCA include: strategic decision, policy assessment and management of environmental risks—including supply chain, material selection and end of life options [49]. Others are product design, process optimisation, resource evaluation and marketing [50]. Also, the LCA has been applied to materials manufacture, fabrication of a building as well as specific-built asset or service requirements such as: waste management, transport services and energy provision [50].

Despite these powerful attributes, and the wide encompassing applications of the LCA methodology, many experts argue that there still exists the need to expand its scope. According to Hertwich [51] and Jeswani et al., [52], the application of LCA and its integration with decision-making process has never been as extensive as anticipated. They observe that the LCA principally report consumer and policy decisions on environmental concerns, but often fail to include vital information on other sustainability dimensions (social and economic).

2.3.4 Process Assessment Tools

Sustainability Assessment tools that focus exclusively or largely on analysis of processes that result in the manufacture of a product, or on measuring the total flow of energy required in a system to produce goods and services, are defined in this study as 'process assessment tools'. Other tools in this category may include those that focus on the selection of indicator sets for analysis of a business operation. Specific examples of tools under this category include the Process Analysis Method (PAM) proposed by Chee Tahir and Darton [53].

Ness et al., [45] also compiled energy analyses procedures including: Process Energy Analysis, Emergy Analysis and Exergy Analysis, based on the work of Odum [54] and Rant [55]. They categorised these methodologies under 'product assessment', but the analytical procedures fit much better in process assessment, hence, their adoption to process assessment tools by this study as shown in Figure 2.6.

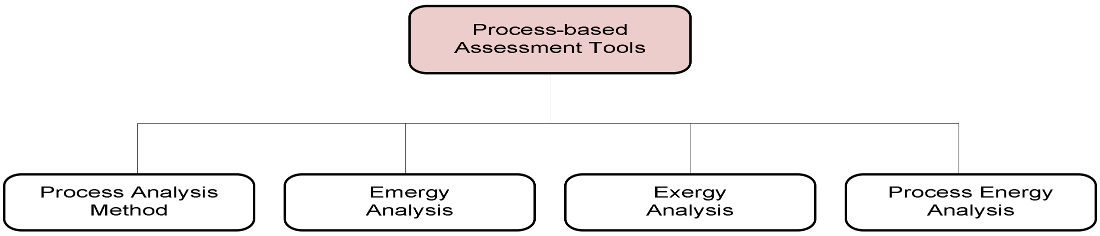

Figure 2.6: A Framework for Process Assessment Tools.

The most practical approaches under this category of tools appear to be Emergy Analysis (EA) and Process Analysis Method (PAM). EA for example, forms part of a larger Emergy theory documented by Odum [56], about the functioning of ecological systems. The methodology has been used in different fields including evaluation of systems in areas such as ecosystems, agriculture and energy resources [56, 57]. The key strength of the EA methodology is its capability to recognise and account for quality differences between forms of energy.

Despite its strengths, EA methodology and its supporting theoretical framework have been criticised as being simplistic, contradictory, misleading and inaccurate [32, 58]. This is particularly, with regard to difficulty in obtaining details about the underlying calculations, and a lack of cross-links with other related concepts [58].

Since indicator selection and evaluation remains a major step towards a successful assessment of a process, the PAM methodology seems particularly suited for these kinds of assessments. The approach does not only focus on *"selection of indicators to quantify the sustainability performance of a business operation"*, it also exposes the *"cause and effect"* relationships within a business process in a manner that is helpful when action targeted for improvement is planned [53]. One of the key strengths of the method is that it allows a particular indicator to be traced back through the analysis which is also found helpful in making remedial action [53].

2.3.5 Integrated Assessment Tools

Integrated assessment tools are construct that combines different tools and procedures in a single assessment. They are used for supporting decision making relating to policy initiative or a project. Project-based tools focus on Sustainability Assessments at local scale, while policy-based assessment tools cover both local and global scale assessments [45]. Integrated assessment tools generally have 'ex-ante' focus, and are mostly carried out using scenarios [45], since they are prospective in nature. Many tools under this category are rooted in a systems analysis approach with particular emphasis on multidimensional, multilevel and multi-stakeholder complexity.

Popular examples of methodologies currently being utilised in this category are Conceptual Modelling (CM), System Dynamics (SD), Multi-Criteria Analysis (MCA) and Risk Analysis (RA). Others are Uncertainty Analysis (UA), Vulnerability Analysis (VA) and Cost Benefit Analysis (CBA) [45]. A framework for integrated assessment tools is summarised in Figure 2.7.

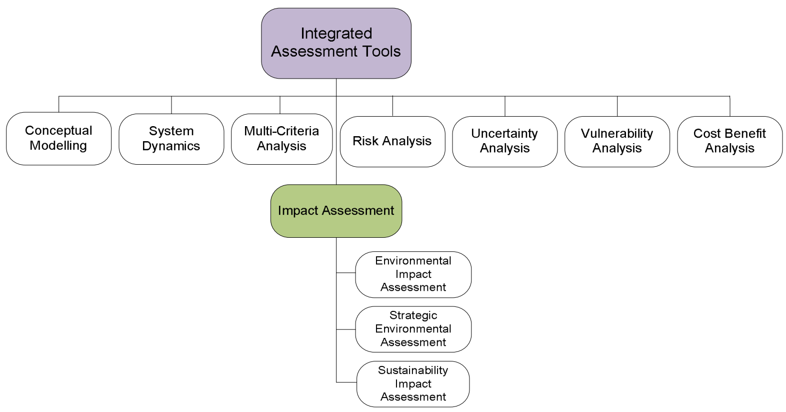

Figure 2.7: Framework for Integrated Assessment Tools.

The most popular and most widely used approach in this group is the Multi-Criteria Analysis (MCA) also known as Multi-Criteria Decision Making (MCDM). The MCDM methodologies have the capability of integrating qualitative information and quantitative data into a single assessment process [59], thereby allowing comparison and ranking of different assessment outcomes from a variety of inputs (indicators).

The MCDM methodologies also accommodate stakeholder inputs, particularly in areas involving multidimensional criteria where single-criterion approaches fail [60]. Despite this robustness, MCDM methods are still widely criticised for being too heavily dependent on experts judgements, which arguably are often subjective [10]. Since the MCDM methodology is of interest in this study, an extended discussion on the approach—including 'Pros' and 'Cons' are considered in a later section in this chapter.

System Dynamics on the other hand, is a thinking model and simulation methodology specifically developed to support the study of dynamic behaviour of complex systems [7]. It combines the theory, methods and philosophy needed to analyse the behaviour of a system in a holistic manner [61]. Since SD is also of interest in this research, a detailed consideration of the approach is presented in a later section.

2.3.6 The Role of Stakeholders in Sustainability Assessment

The level of stakeholder involvement in Sustainability Assessment (SA) and the quality of public-based decisions for sustainability is increasingly becoming an issue of discourse amongst experts in various fields. Some experts claim that stakeholders are not adequately informed to make scientific analyses, and as a consequence are *"too ready to sacrifice technical quality for political expediency"* [62].

Other professionals rely on the fundamental objective of sustainability: social justice (i.e. intra-generational and intergenerational equity), economic efficiency and ecological integrity, to argue their point. They believe that public participation in Sustainability Assessment and the use of stakeholder processes in decision making remain an integral part of sustainability [53, 63, 64]. Some note that most stakeholders do not only have adequate access to technical and scientific resources, but they also add new and useful information, ideas and analysis to sustainability decision making process [62]. Others point out that it is indeed more intensive stakeholder engagements in SA that is more likely to yield higher-quality decision for sustainability [62]. Pinfield [65] however, argued for the case of a classic 'top-down' approach where experts are of the opinion that SA needs to feed through to policymakers for use in decision making process rather than engage policymakers directly in the design and development.

Diverse opinions about the role of stakeholders in Sustainability Assessment are also seen in the development and application of specific SA methodologies. In terms of indicator development and selection for example, Bell and Morse [66] note that because indicator frameworks could be developed to focus on regional, national, local, sector, company or even house-hold activities, they could be set in *"top-down mode"* (expert-driven), *"bottom-up mode"* (public-driven) or *"a combination of both"*. Others such as [67, 68] argue that indicators facilitate community learning about Sustainable Development and should not be seen as information feed into policy-making. Rotmans [63] observes that there is so much to learn from deliberative institutions such as focus group, citizen juries, study circles, planning groups and consensus conferences.

In terms of product-related SA procedures such Life Cycle Aassessment (LCA) and Life Cycle Costing (LCC), Rebitzer et al., [64] note that a wide range of stakeholders such as government organisations, nongovernmental organisations and a variety of industry actors associated with them can readily make inputs at any stage of the process, and equally apply its results in their operations. But Balkema et al., [69] observe that *"LCA limits itself to a restricted set of technical and environmental aspects"* and as a consequence, relies rather too heavily on expert opinions for interpretation of its results. Vander Voet et al., [70] state that LCA supports stakeholder information provision for management strategy at both national and regional level. Gluch and Baumann [48] on the other hand, highlight the usefulness of LCC in environmental decision-making to include learning by stakeholder participation.

For process assessments, procedures such as the Process Analysis Method [53], which *"starts with an in-depth review of a business operation"* recognises stakeholder inputs at the earliest stage in the process. Others such as Suh [71] note that Material Flow Analysis remains an ideal platform to directly involve stakeholders in process assessment at different levels in participatory planning and decision making. Similarly, Emergy and Exergy analyses [54, 55] are thought, even within the league of professionals to be highly expert-driven and contestable concepts [32, 58].

According to Wrisberg et al., [59] and Forrester [7] integrated assessment methodologies such as MCA and SD have the capability of integrating qualitative and quantitative information into a single process, thereby allowing outcomes from a variety of inputs (including stakeholder inputs). Conversely, others tools in this category such as Cost Benefit Analysis (CBA) are seen as expert-driven procedures that are largely 'inaccessible' to non-specialist audience [72]. Sinden et al., [73] argue that CBA plays down *"most profound emotions, beliefs and values of the people by placing them to Dollars and Cents equivalent; which produce hopelessly indeterminate results, clouds transparency and undermine public participation"*.

It is evident from the foregoing, that there is currently no consensus over whether the development, selection and use of assessment tools should or should not involve stakeholders. Despite varying perspectives, we note from the discussions that there are many benefits of stakeholder consultations to the SA decision-making process. Such benefits include: 1) stakeholders provide useful information; they add new ideas and insights to the SA decision-making process; 2) stakeholder engagements yield higher-quality decision for sustainability and 3) stakeholder engagements remain the only way to build confidence that stakeholder priorities are understood and represented.

In view of the highlighted benefits, this study suggests that in assessing sustainability aspects of an initiative, the development or selection of an appropriate tool for any particular case should be based on a harmonised approach, including adequate communication with stakeholders. It should also be based on information rooted in the relevant conceptual framework. Figure 2.8 summarises our approach to SA with stakeholder participation.

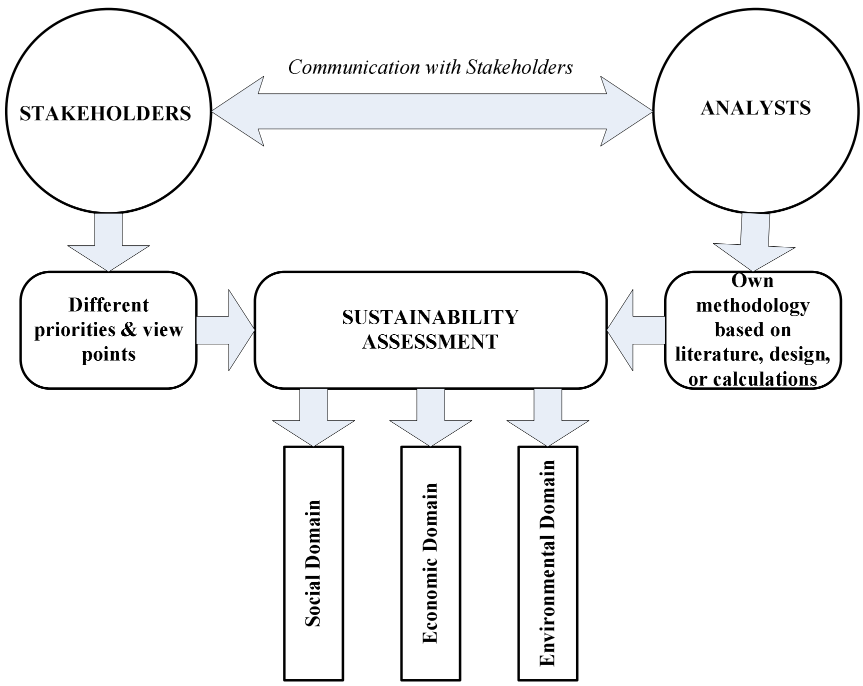

Figure 2.8: Framework for Sustainability Assessment with Stakeholder Participation.

This study also suggests that the question of whether stakeholders can partake in SA process or not, should depend on two important factors: 1) the assessment focus and 2) the complexity of the case under consideration. To maximise stakeholder inputs, it is essential that such tools be unambiguous in assortments, interpretation and evaluation. Moreover, the tools ought to be flexible (at all levels of analysis), consistent and more importantly, responsive to stakeholder concerns—else, their use may not be valid.

2.4 Approaches to Policy Development and Assessment

This section looks at current approaches to policy design and evaluation. It aims to identify the major flaws associated with existing policy development and assessment processes, and equally provides the basis for developing a new policy assessment technique. The discussion also seeks to classify the diverse policy planning and evaluation models in current use. This is to ensure comparisons with the new approach and to identify critical areas for improvement.

2.4.1 Policy Development

Policy according to Pohl [74] *"is a principle or guideline for an action in a specific everyday-world context"*. Its development is conventionally based on normative process—the so called policy cycle (shown in Figure 2.9). The policy environment remains a highly dynamic and complex 'landscape', hence, decision outcomes from policy programmes are largely unpredictable. For these reasons, formulating and evaluating appropriate policies that will not cause unintended and undesirable consequences remain a huge challenge to policymakers and experts.

Thus, the current approach to policy development Taeihagh et al., [75] note *"is a manual, labour-intensive task involving many types of objectives and criteria for* *success"*. In addition, the inconsistency in fixing system boundaries and the differences in policy focus remain another part of the challenge.

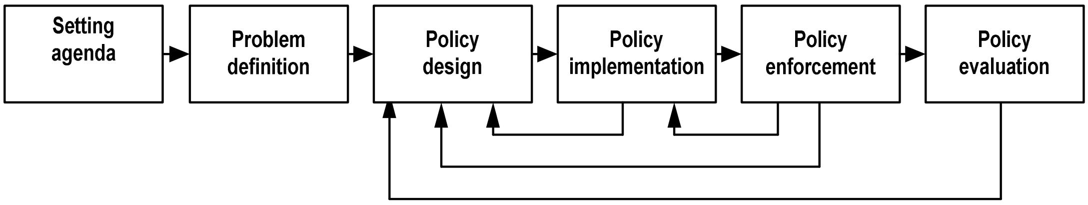

Figure 2.9: A Model for Policy Process. Adapted from [75].

Despite these concerns, opportunities to advance the cause of policy development and policy assessment still exist. It is essential therefore, that research continues in this direction. To this end, experts, particularly engineers are gradually becoming involved with policy development and assessment. Their contributions focus mainly on developing tools and procedures to support policy formulation, implementation and enforcement—the specific policy cycle stages [76].

2.4.2 Policy Analyses

Policy analysis according to Nagel [1] is the process of *"determining which of the various alternative policies will most achieve a given set of goals…"* Different approaches for analysing policies exist. These include the 'analycentric', the 'policy process' and the 'meta-policy' approaches [2]. The type of problem addressed by the analycentric approach is usually of a micro-scale and technical nature [2]. The policy process on the other hand focuses on political processes with a meso-scale [2]. The meta-policy approach is systems and context dependent, with a macro-scale and structural problem interpretation appropriate for large and complex problems [2].

A wide range of policy analysis models in current use fall within the above three general categorising approaches. Despite a sufficient availability of such models, many of them have been criticised for being too linear [1, 2] and simplistic [3, 4]. Such linear, causal thinking paradigm, Sterman [9] notes leads to *"event-oriented view of the world, where decisions are based on perceived gap between goals and the actual situation of the system"* [9]. See Figure 2.10 for an illustration of *"event-oriented view of the world"*.

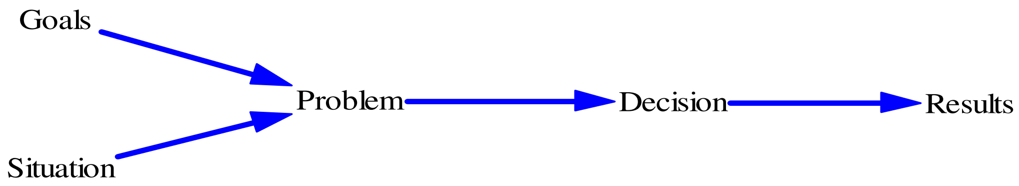

Figure 2.10: Event-oriented View of the World. Re-sketched from [9].

Policies largely include multilevel, multi-dimensional and multi-stakeholder complexity involving feedback, time delays and non-linearity. As a consequence, any analysis approach based on mechanistic structuring does not meet with great success. A number of such approaches are being used to attempt policy planning and evaluations, but they often fail to produce the desired results. This possibly, is due to their inability to capture the interconnectedness and interactions between the system variables.

In view of these complexities, the development and implementation of robust and holistic policy assessment tools and procedures becomes necessary. Yet, this remains one of the major challenges confronting policymakers and experts in this field. In spite of the recognition of the needs for improvement, it is still well known that there are currently few unified approaches for attempting holistic policy assessments [9, 16].

Therefore, to effectively deal with this complexity, a systems approach to policy planning and evaluation becomes essential. The appropriateness of such an approach however, depends on many factors. These may include: 1) the policy objective; 2) stakeholder interests or concerns; 3) the sustainability dimension in question and 4) the timescale over which the policy objective is realisable.

2.4.3 Energy Policy Planning and Evaluation Models

A number of 'dynamic' and 'static' models focusing on energy and national policy planning and evaluation are in current use. However, many of such models are either too simplistic [3, 4], or are unable to represent within a single framework the interplay between energy and the three sustainability domains: society, economy and environment [6]. Feedback from society, economy and environment involving energy is particularly difficult to identify, quantify and manage [6]. For this reason, most existing models fail to capture the interesting dynamics of the energy economy [6].

According to [16], two categories of such formal models exist: 1) energy and national planning models and 2) dynamic and static models. The US EIA, IEA, IAEA and other similar institutions make energy planning models that produce very detailed energy projections [16]. However, they lack the feedback structure that describes energy dynamics within all the three sustainability domains [16]. In addition, these models do not focus on policy planning but on energy projections [16]. The models are based on an econometric or linear regression approach; and for this reason, they do not capture the medium and long term dynamic trends [77]. Policymakers are presented with a number of future world views, based on the assumptions explicit in the different projections. National planning models include models such as Revised Minimum Standard Model Extended (RMSM-X), Computational General Equilibrium (CGE) and other Econometric models [16]. These are both comprehensive and complex; however, they lack the interactions necessary to describe the dynamics between energy sector and the sustainability dimensions [16].

A few System Dynamics-based models focusing on analysis of energy issues in a comprehensive way have also been built. These include: FOSSIL (1977), IDEAS (1979), Energy Transition Model (1981) and Feedback-Rich Energy Economy Model

(1997) [6]. However, these models do not include energy interactions with the Triple Bottom Line. The T21 model of the Millenium Institute (MI) remains a versatile and comprehensive tool that is based on the System Dynamics methodology [7]. *"It is a leading country-level example of a new type of model that emerged over the past few decades"* [6]. The major challenge with the T21 model however, is that it does not deal explicitly with evaluation and selection of optimal policies arising from the numerous alternative policy scenarios. Policymakers are usually left at their discretion to decide *"which policy run is best"* [10]. This arguably leaves more room for uncertainties in the midst of conflicting alternatives, and the likelihood of wrong choices.

2.5 New Assessment Approach and the Rationale

The need for a holistic approach to assessing sustainability revolves around multi-domains, multi-level and multi-stakeholder complexity. Hence, quantifying sustainability gains requires a range of rigorous assessment tools and procedures from which we can select a methodology suitable for a particular case. We also need to be confident that the selected methodology will yield the required assessment.

2.5.1 Theoretical Concepts

Of the established integrated policy assessment tools previously discussed, our approach known as the 'Energy Policy Assessment Technique' (E-PAT) is similar to the T21 framework; both models are conceptually similar but structurally different. The conceptual similarities between them are that 1) both focus on policy planning in a national context and 2) their theoretical framework is based on SD modelling methodology. However, the E-PAT accomplishes more because 1) the E-PAT incorporates Multi-Criteria Evaluation (MCE) model in explicit evaluation and selection of policies and 2) the E-PAT integrates energy policy planning and evaluation with specifically defined sectors in a Triple Bottom Line analysis.

This study develops a technique for analysing and selecting 'optimal' policies. The E-PAT is a nonlinear, systems-thinking model and a multi-criteria evaluation archetype. Policy analyses with the E-PAT lead to systemic view of the world. In this case, decisions are based on feedback loops, time delays and nonlinearity of the policy case being considered [7, 9]. The SD modelling approach is illustrated in a 'stock' and 'flow' diagram in Figure 2.11. Here, r1, r2 and r3 represent 'flow into Stock X', 'flow out of Stock X and into Stock Y' and 'flow out of Stock Y' respectively. The diagram incorporates a feedback system where, D represents feedback time delay from Stock Y.

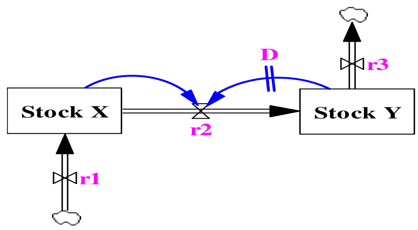

Figure 2.11: A Systems View of the World. Based on [7].

In addition to approaching policy assessment from a nonlinear perspective, the E-PAT is practical for evaluating and selecting optimal policies using the MCE method, known as SMART—Simple Multi-Attribute Rating Technique. It is appropriate for use in preliminary policy assessment before adoption and implementation and in the full evaluation of policies after implementation (illustrated in Figure 2.12). The new concept differs from conventional policy approach in that it provides for interim assessment in the planning phases and full evaluation after implementation.

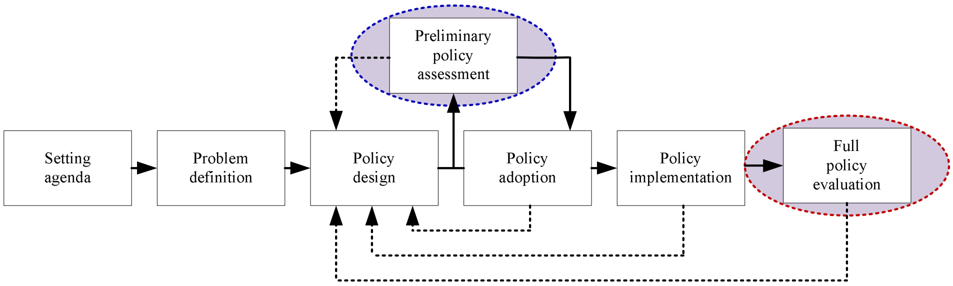

Figure 2.12: Policy Cycle with Enhanced Assessment Process.

In a conventional policy cycle (Figure 2.9), policy evaluation is usually left at the last stage in the overall policy cycle. This arguably points to the reason why many policies fail after implementation. In most cases, decision makers are unable to test the robustness of the policies, or understand the implications of such policy interventions before execution. However, in view of the dynamic and systemic nature of the policy environment, this study also suggests some form of preliminary policy assessments before implementation. This implies that a preliminary assessment should fall between policy design and adoption. This will not only help reduce the risk of policy failures after implementation, but it will equally save financial, labour and time costs.

2.5.2 Integrating SD Simulation and MCE Models

Integration in the context of this study refers to the combination of the powerful attributes of the selected methodologies into a single procedure, to form a robust assessment technique. The integration of simulation models with multi-criteria evaluation models is in itself not a new idea; a few attempts have been made in the past, to use simulation models (including SD models) and some MCE methods in an integrated manner [10, 78-83]. Other attempts can also be found in [60, 84-86]. Apart from earlier attempts as cited above, not many discussions on such combinations are found in recent literature. Our knowledge of current literature suggests that it is the first time a SD simulation model and a Multi-Attribute Utility model are combined for evaluation of real life policies in a national context. It is also the first time such an approach has been used for analysis of energy policies in Nigeria.

The main argument presented in this study is that combining SD and MCE models provides a practical approach in which the policy environment can effectively be explored. In previous attempts to combine simulation models with MCE methods—in what is referred to as *"hybrid modelling"* [87], two approaches have been considered.

The 'type one case' involves actual embedding of the chosen MCE method into the SD model, where both interact dynamically. This study names it the 'Inclusion Approach'. In this case, decision rules are implicit in the SD model [87]. In the 'type two case', the emerging policy runs from the simulation model are explicitly evaluated with MCE method, and optimal policy or policies are selected. We denote this case the 'Exclusion Approach', which is adopted in this research. The reason for this choice is to ensure transparency in the evaluation and selection of competing and conflicting alternative policies. The approach also exposes issues of trade-offs, which are largely concealed in the 'Inclusion Approach'. From a more general perspective, the strengths and weaknesses of the SD and MCE methodologies can be summarised as in Table 2.2.

Table 2.2: Strengths and Weaknesses of SD and MCE Methodologies.

Strength and Weakness of SD	
Strength	**Weakness**
1: Supports understanding the behaviour of nonlinear, complex systems. 2: Gives internal feedback and time delays that influence the behaviour of a system. 3: Employs differential equations for modelling which are rigorously quantitative. 4: SD models enhance policymakers' understanding of system behaviour over time.	1: Feedback structures can be subject of controversy due to different problem perspectives. 2: Relies heavily on expert consensus to ensure credibility of models. 3: SD models do not in themselves deal explicitly with evaluation of the system. 4: Deals mainly with confirmatory analyses.
Strength and Weakness of MCE	
Strength	**Weakness**
1: Supports decision making in conflicting situations. 2: Highlights trade-offs during decision making process. 3: Capable of integrating qualitative/quantitative data into a single assessment process. 4: Supports ranking of alternatives to expose best and worst decision alternatives.	1: Evaluation process is inherently subjective. 2: Different techniques often produce dissimilar results for the same problem. 3: Choice of the right method to apply is in itself a multi-criteria problem. 4: Nonlinear relationships of variables go unnoticed.

2.5.3 SD Modelling and Simulation Approach

The SD methodology employs calculus as its underlying mathematics. The SD models are based on nonlinear differential equations [7, 9]. The models use the concept of 'stock' and 'flow', where integration of one or more 'flows' accumulate 'stock' (Figure 2.11). The SD modelling language employed in this study is Vensim® [88]. It employs the Euler or Runge-Kutta methods for numerical integration of differential equations. In accumulation, the general form of these equations can be given as:

$$\mathbf{Y} = \int_{t_o}^{t} (\mathbf{X})\, \mathbf{d}x + \mathbf{Y}_{t_o};\ \frac{\partial Y}{\partial X} > \mathbf{0} \tag{2}$$

$$\mathbf{Y} = \int_{t_o}^{t} (-\mathbf{X})\, \mathbf{d}x + \mathbf{Y}_{t_o};\ \frac{\partial Y}{\partial X} < \mathbf{0} \tag{3}$$

Where, $\mathbf{X}$ and $\mathbf{Y}$ are system variables; $\mathbf{t}$ and $\mathbf{t_o}$ are final and initial simulation time respectively, $\mathbf{d}x$ is the change in $\mathbf{X}$ at time interval $\mathbf{t_o}$ and $\mathbf{t}$, $\mathbf{Y}_{t_o}$ is the value of $\mathbf{Y}$ at initial simulation time $\mathbf{t_o}$ and $\frac{\partial Y}{\partial X} > \mathbf{0}$; $\frac{\partial Y}{\partial X} < \mathbf{0}$ is when the partial differential of $\mathbf{Y}$ with respect to $\mathbf{X}$ is greater than zero and vice versa.

The SD modelling approach was chosen in this study because; it provides the quantitative basis for rigorous policy analysis, which helps us to better predict the consequences and effectiveness of policies [7, 9]. Our motivation for its choice was based on the consideration that SD models have shown a better capability of exposing the 'cause' and 'effect' relationships among system variables, when compared to similar alternatives such as Agent-Based Modelling (ABM). Our review of the ABM approach for example, reveals that ABM is a robust, non-linear modelling technique that is capable of representing and investigating real world problems involving the interactions and actions of autonomous agents (i.e. individual or collective entities) [89, 90]. The main reason ABM was not adopted for this study is because of its 'narrow focus' of examining the dynamic behaviour of individual agents, as opposed to entire system behaviour—which is the 'thrust' of this research. The SD approach on the other hand, was found to be effective in representing and interpreting the dynamic behaviour of a 'whole' system. This helps our understanding of entire system behaviour and potential consequences. Overall, the SD approach was found to be better for our project because it can help us to recognise a particular pattern of system behaviour, understand causes and effectively predict future consequences. The SD modelling architecture proposed for this study can be summarised as shown in Figure 2.13.

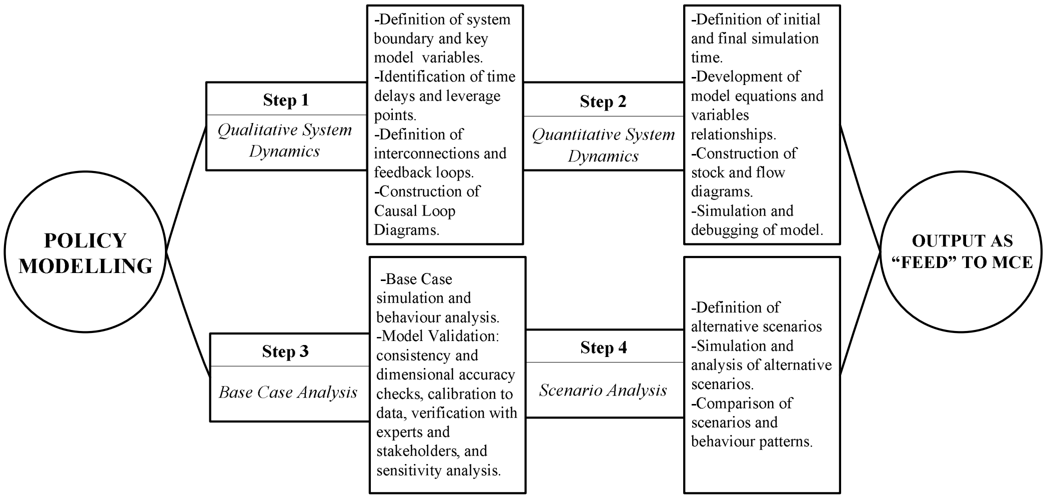

Figure 2.13: The SD Modelling Architecture.

Despite providing the advantages highlighted above, considerable criticism has been directed at SD methodology. Most of these criticisms focus on the final step of the modelling process, which calls for *"experimentation by means of further simulations with possible alternative policies"* [91]. For example, despite the use of policy optimisation tools, SD modellers are usually criticised for failing to adequately justify, why one simulation result is often announced as preferable to another [10]. Similarly, critics have said that SD does not explicitly deal with issues of trade-offs between stakeholder views and conflicting alternative policies [10]. Yet, in spite of what might be termed an *"incomplete process"* [10], policy decisions are often made and implemented on the basis of such results. One of the main problems is that trade-offs are not fully evaluated within the SD model. As a consequence, policy recommendations based on such an approach often fail to capture stakeholder interests or concerns, as model interpretations and recommendations are usually left to the intuition of the modeller or analyst. A better approach is described in subsection 2.5.4.

2.5.4 Multi-Criteria Evaluation Approach

To ensure a transparent evaluation of stakeholder inputs and trade-offs, and in judging the effectiveness of alternative policies, the choice of an appropriate MCE model to combine with SD models becomes useful. The MCE models, just like SD models, help decision makers to better understand the policy challenge under consideration. They however, differ from SD models in that they aid understanding that leads to appropriate and justifiable choices in the face of competing options. They aid in the overt evaluation of alternatives and the effects of actions generated.

In this research, we combine SD and MCE models, which provide better insights into policy assessments and informed decision making process. A collection of wide-ranging MCE methods (shown in Figure 2.14) were reviewed, including the one adopted for this study. The suitability of these MCE methods was tested, in terms of 'transparency' and 'ease' in handling stakeholder inputs and issues of trade-offs in conflicting situations. It was found in our analyses, that the Outranking Methods are the most sophisticated—with the theoretical elegance to match, particularly in the area of detail computations and iterations. They were however, not selected for integration with SD model due to their lack of flexibility in handling stakeholder inputs and trade-offs.

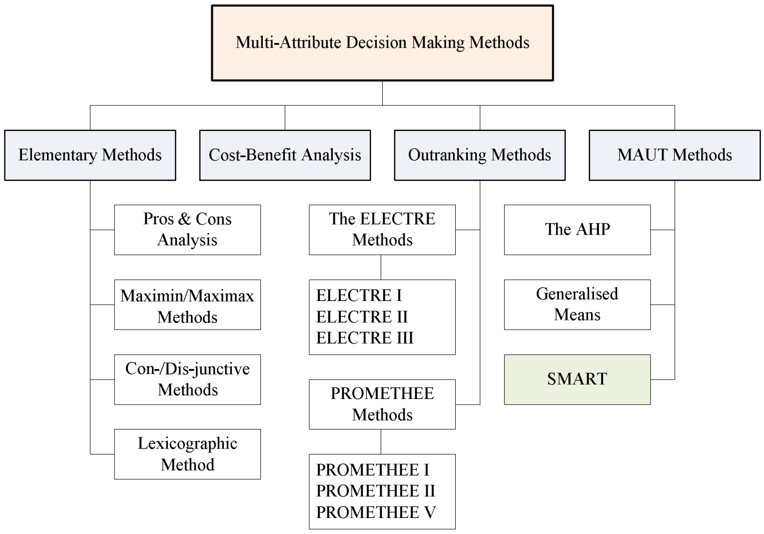

Figure 2.14: A Collection of MCE Methodologies.

We used in this study, a MCE method from within the family of Multi-Attribute Utility Theory known as SMART—Simple Multi-Attribute Rating Technique [17]. SMART has evaluation rules for 'weighting' and 'aggregation', which can be used to identify the different impact dimensions and their relative importance [10]. It is chosen for use in this study, for its transparency and ease in handling stakeholder inputs. Since our evaluation approach focuses largely on wider stakeholder participation, with a high degree of transparency, the SMART approach becomes a useful choice in this study. The SMART evaluation is based on the following 'weighted linear average' equation:

$$\mathbf{U}_{ij} = \sum_{k=1}^{K} \mathbf{w}_{ijk}\ \mathbf{v}_{ijk}, \boldsymbol{i = 1, 2, \dots, I;\ j = 1, 2, \dots, J;\ k = 1, 2, \dots, K} \qquad \textbf{(4)}$$

Where, $\mathbf{U}_{ij}$ is aggregate utility for the $\mathbf{i}^{th}$ entity according to $\mathbf{j}^{th}$ viewpoint, $\mathbf{w}_{ijk}$ is normalised importance weight given to the $\mathbf{i}^{th}$ entity by $\mathbf{j}^{th}$ viewpoint along $\mathbf{k}^{th}$ impact dimension and $\mathbf{v}_{ijk}$ is the location of the $\mathbf{i}^{th}$ entity by $\mathbf{j}^{th}$ viewpoint on the $\mathbf{k}^{th}$ dimension. In this context, 'entity' refers to the item whose value is being evaluated; 'viewpoint' represents stakeholders' opinion over the entity being assessed; dimension refers to identifiable area of impact according to stakeholder viewpoint while entity location is a measure of entity position on each dimension according to stakeholder viewpoint.

2.6 Conclusion

This chapter has described the relevant concepts and techniques that can be leveraged to advance the work of subsequent chapters. From a critical review of sustainability and our understanding of its concepts, we have identified the choice of 'Weak Sustainability' and 'Holism' as the preferred approaches for this research, with equal importance given to intra- and inter-generational equity concerns.

This chapter has also presented an analysis of Sustainability Assessment (SA) tools and methodologies currently in use. This helped us to demonstrate how our new SD-MCE approach fits in the 'family' of integrated assessment tools. Also, our review of the role of stakeholders in SA has shown that despite on-going debates over stakeholders' level of involvements in SA, there are many benefits of stakeholder participation in the SA decision-making process. For instance, we established that stakeholder engagements remain the only way to build confidence that their priorities are understood and adequately represented in the process.

It is also shown in this chapter, that existing approaches to policy development and assessment are based largely on normative ideas, and that these linear causal thinking paradigms are not robust enough for assessment of complex dynamic systems. In addition, they do not support preliminary assessment and early mitigation measures.

Finally, this chapter presented an overview of a new approach—the E-PAT. It highlighted the 'strengths' and 'weaknesses' of current assessment tools, and demonstrated the needs for an enhanced assessment approach. The new approach is based on integration of SD and MCE models into a unified framework, where feedback loops, time delays and nonlinearity govern the system behaviour. Overall, this chapter has laid the foundation for developing and testing the E-PAT.

Chapter 3

Analysis of the Case Study Area: Nigeria

3.1 Introduction

This chapter presents an analysis of sector-specific issues about Nigeria. It discusses the core issues of interest to this research, which Nigeria currently faces with its energy industry. The chapter provides the link between the previous and subsequent chapters, in that it employs the knowledge of sustainability concepts explored in Chapter 2 to examine the 'dynamic interplay' between the energy sector and the economy, society and environment. This helps us to highlight the impacts of energy usage in Nigeria on the three sustainability domains over the period (2000 – 2010), and enables us to explore future outlook, as described in subsequent chapters.

The chapter further considers the current policy responses and reform agenda of the government. These help us in identifying the needs for this study, and in forming an understanding of a plausible solution approach to the identified issues. The information presented here is based on analyses of fieldwork data from Nigeria. A summary of the current state of affairs in the areas under scrutiny is presented, together with stakeholders' perspectives on how things are likely to change in these areas over time.

Section 3.2 presents the methodological approach adopted in data collection. Section 3.3 gives an overview of Nigeria from the standpoint of its geography. Sections 3.4 – 3.6 deal with analyses of the current social, economic and environmental issues facing the country. Section 3.7 discusses the nation's present energy situation. Section 3.8 examines current government policy responses and reforms. Section 3.9 presents the main conclusions for this chapter.

3.2 Approach for Data Collection

This section discusses the methods used in obtaining information presented in this chapter and other parts of the thesis. Two main approaches were adopted: 1) survey of relevant literature from authoritative sources and 2) a field trip to Nigeria.

3.2.1 Literature Survey

Analyses of energy usage in Nigeria and its impacts on the economy, society, and environment started with literature search. This involved survey of authoritative national and international data sources on Nigeria. In addition to review of published journal articles, reliable national sources of information were consulted for data collection. These include official government sources listed in Appendix A.1. Credible international data sources were also accessed for the purposes of data collection and analyses. A comprehensive list of these sources is shown in Appendix A.2.

Information uncovered through literature search helped us in early identification of the major issues affecting Nigeria in the area of energy-economy interrelations. Critical among the issues identified are energy policy challenges. These are fully discussed in later sections. Data collected over this phase of the research were also used in designing a new solution approach, aiding the development and preliminary analysis of an Energy Policy Assessment Model, also known in this study as E-PAM.

3.2.2 Fieldwork

Information obtained from literature search was substantiated through stakeholder consultations during fieldwork in Nigeria. Five federal ministries: 1) Nigerian National Petroleum Corporation (NNPC); 2) Ministry of Petroleum Resources (MPR); 3) Energy Commission of Nigeria (ECN); 4) National Planning Commission (NPC) and 5) Federal Ministry of Environment (FME) were visited during a three-week field trip. These five government agencies were chosen because of their direct relevance to this study, and their potential use of the output of this research. A population sample of fifty policymakers at 'top management' and 'middle management' levels was consulted during the visit—with a representation of ten individuals per ministry. The idea was to capture a variety of opinions from both 'top-level' and 'operational-level' decision makers in the selected ministries. The approach also aimed to eliminate respondents' biases in answering the research questions [92].

Of the four common data collection methods: interviews, surveys, observation and experimental cases [93] used in quantitative research, the survey approach based on the use of questionnaire is most relevant, and was adopted for data collection in this study. In terms of the design, the survey questionnaire was constructed with twenty five mixed *"'closed' and 'open-ended' questions"* [94]. The questions were conceived with the objective of obtaining quantitative data based on the perspectives of energy policymakers in Nigeria. The aim was to test the *"dynamic hypothesis"* of our model with quantitative data [95].

In terms of procedure, a mixed 'one-on-one' and 'group' presentation approaches were adopted in conveying research information to stakeholders. In addition, the research questionnaire (shown in Appendix B) was used as Data Collection Instrument (DCI) [94], to gather research data and feedback. Five broad research themes focusing on the energy sector and the economic, social and environmental domains were formulated. Each of these was further translated into five precise individual research questions. The questions were relevant to the overall study objective, with a high probability of yielding the desired quantitative data [96]. The research questions were *"non-compound questions"* [97], and were directed to the right respondents in the relevant ministries.

In terms of quality, the questionnaire was validated through series of quality control measures [96] before the final copy used for fieldwork was produced. The research questions were at the development stage of the questionnaire, iteratively reviewed with peers at Oxford, to ascertain relevance of the questions as well as the difficulty level [98, 99]. A draft questionnaire was produced, and copies were made and shared amongst fifteen other researchers for a test run. General comments and specific feedback on the quality of the questionnaire, and the difficulty level of the research questions were collated and used to update the questionnaire before final copies were produced and taken to Nigeria for fieldwork.

3.3 Country Overview: Geography

Nigeria, officially known as Federal Republic of Nigeria is a sovereign state in the West African Sub-region. Nigeria is located between latitudes 4 and 14^{o}N and longitude 3 and 14^{o}E, along the Gulf of Guinea [100]. Its neighbours are the Republics of Cameroon (1,690 km) and Benin (773 km), to the east and west respectively and it is bordered in the north and north-east by the Republics of Niger (1,497 km) and Chad (87 km). The southern part of the country is bordered by the Atlantic Ocean—with total coastline of about 853 km. Nigeria occupies a total area of about 923,768 km^2—comprising 910,768 km^2 of land (98.6%) and 13, 000 km^2 of water (1.4%) [100]. A map of Nigeria showing its key geopolitical indicators is shown in Figure 3.1.

Figure 3.1: Map of Nigeria Showing Key Geopolitical Features [100].

3.4 Analysis of the Social Domain

Specific social issues of interest to this study are: 1) population dynamics, 2) labour demand and supply—including sector employment and unemployment issues and 3) education and human capital development. Information from literature search relating to progress made in these areas over the period (2000 – 2010), together with stakeholder opinions on future potential are presented in the following subsections.

3.4.1 Population Structure

Nigeria is the most populous country in the African continent and the 8th most populous in the world [101]. The UNDP Human Development report [102] puts the total population of Nigeria in 2010 at 158.4 million—representing 49.8% rural and 50.2% urban, with a population density of approximately 174 people per square kilometre. According to the Central Bank of Nigeria (CBN) [12], the Nigerian population is currently growing at the rate of 2.7% per year. At this growth rate, and at a Constant Fertility Variant (CFV), the UN Population Division [103] projects the population of Nigeria to reach 275 million by year 2030—indicating a burgeoning population over the coming years. A map of Nigeria showing the country's population density in its 36 states and the Federal Capital Territory (FCT) is shown in Figure 3.2.

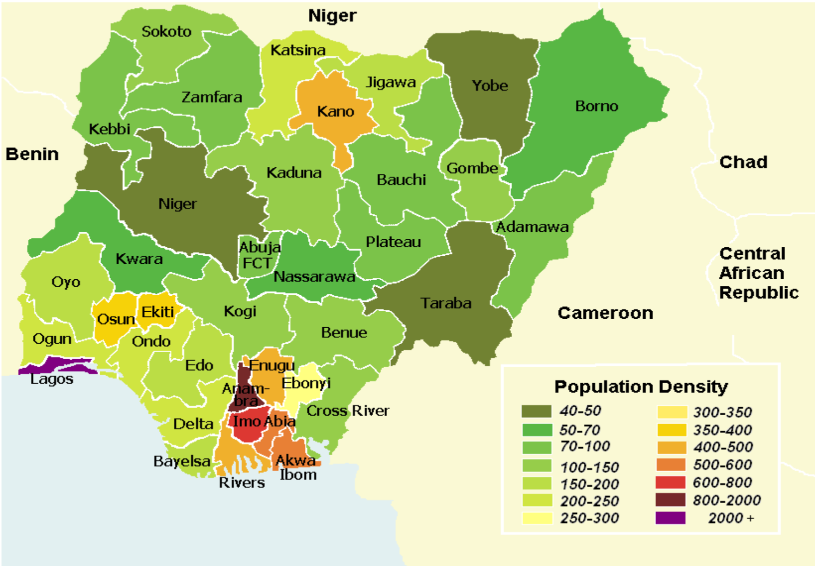

Figure 3.2: Population Density Map of Nigerian States [104].

When asked during the fieldwork (Question C1 Appendix B), to comment on how they 'foresee the population structure of Nigeria changing over the stated timescales', policymakers responded as shown in Table 3.1. The question received 100% response rate from fifty participants in five ministries. As shown in the table, 96%, 62% and 50% of policymakers foresee a *"rising population"* over years 2025, 2040 and beyond 2040 respectively. 38% of respondents predicted a *"steady population"* by year 2040, while 34% reasoned that a *"steady population"* may be possible only beyond year 2040. Overall, only 16% of the people think that the population of Nigeria will likely be on the path of decline in the post 2040 scenario.

Table 3.1: Stakeholders Responses to Question C1.

	Year 2025						**Year 2040**					
	NNPC	MPR	ECN	NPC	FME	**Total**	NNPC	MPR	ECN	NPC	FME	**Total**
Rising Population	10	10	9	9	10	**48**	7	5	6	5	8	**31**
Steady Population	0	0	1	1	0	**2**	3	5	4	5	2	**19**

Declining Population	0	0	0	0	0	**0**	0	0	0	0	0	**0**
Total	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**	**50**
	Beyond 2040											
	NNPC	MPR	ECN	NPC	FME	**Total**						
Rising Population	7	3	5	5	5	**25**						
Steady Population	2	4	4	3	4	**17**						
Declining Population	1	3	1	2	1	**8**						
Total	**10**	**10**	**10**	**10**	**10**	**50**						

3.4.2 Labour Demand and Supply

As at end of 2010, about 21 – 24% of the country's population remains unemployed [105]. Youth unemployment is particularly high, with figures put at >35% [106]. Agric. sector remains the largest employer of labour in the country—employing between 60 – 70% of total labour supply over the period (2000 – 2010) [107].

In view of discrepancies in youth unemployment figures as reported by different official sources [106, 107], policymakers were asked during the fieldwork (Question C2), to 'give an indication of what they think youth unemployment is at present'. Stakeholders' positions on this are shown in Table 3.2. 60% of policymakers—representing 30 out of 50 participants responded that youth unemployment rate in Nigeria is >35%. 13 people (representing 26% of respondents) reported figures to be in the range of 25 – 35%, while 14% of respondents put it at 15 – 25%. The position of the majority on this question corroborates the >35% reported by CBN in year 2010.

Table 3.2: Stakeholders Responses to Question C2.

	NNPC	MPR	ECN	NPC	FME	**Total**
15 – 25%	0	1	3	3	0	**7**
25 – 35%	3	3	1	2	4	**13**
>35%	7	6	6	5	6	**30**
Total	**10**	**10**	**10**	**10**	**10**	**50**

Question C3 of the fieldwork questionnaire further queried 'the timescale over which stakeholders anticipate single digit unemployment in the country'. To this, 32 out of 50 respondents (64%) expect single digit unemployment in Nigeria beyond year 2030. This is in consideration of what they described as *"unrealistic economic growth"*—where the country's GDP growth figures are not reflected in the actual wellbeing of the people. 28% of respondents were optimistic this is possible by year 2025, while the most optimistic group—representing 8% foresee this happening by year 2020, as shown in Table 3.3.

Table 3.3: Stakeholders Responses to Question C3.

	NNPC	MPR	ECN	NPC	FME	**Total**
Year 2020	1	0	1	2	0	**4**
Year 2025	5	6	2	0	1	**14**
Beyond 2030	4	4	7	8	9	**32**
Total	**10**	**10**	**10**	**10**	**10**	**50**

3.4.3 Education and Human Capital

The education sector in Nigeria has witnessed a significant decline in quality over the years—particularly in the last decade (2000 – 2010) [108]. This phenomenon, the World Bank [109] observe has led to a systematic rise in school dropout rates. The effect of this trend is also obvious in the quality of labour force available in Nigeria.

When asked in (Question C4) to state 'what they think are the major causes to school dropouts in the country', policymakers indicated that: i) lack of motivation and interest, ii) high costs of education and iii) economic hardship (poverty) are the three major causes of rising school dropout rates in the country. An elicitation of these causes by individual participants from the five ministries resulted in a total of 25 social, economic, and political factors. The research question however, asks for the three major factors. These major factors were obtained by 'grouping' and 'ranking' of individual responses according to relevance and frequency of mention as shown in Table 3.4.

Table 3.4: Ranked List of Stakeholders Responses to Question C4.

1. Lack of Motivation/Interest (10)	**2. High Cost of Education (08)**
- Lack of employment opportunities after school (02) - Poor social orientation (02) - Religious/cultural values (01) - Lack of awareness (01) - Loss of value for education (01) - Negative perceptions/lack of patriotism (01) - Parental failure (01) - Lack of educational sensitisation programmes (01)	- Lack of educational incentives(02) - Lack of supportive learning environment (01) - Inadequate teaching/training facilities (01) - Lack of skilled teaching personnel (01) - Inadequate teaching/training facilities (01) - Unsustainable educational policies (01) - Inadequate educational infrastructure (01)
3. Economic Hardship (Poverty) (07)	
- High cost of living (02) - Early family responsibilities (01) - Peer pressure/misplacement of priority (01) - Weak/poor educational regulatory framework (01) - Early/high desire for affluence (01) - Political instability/insecurity (01)	

In answering the question 'why the country currently produces higher numbers of graduates in arts and commercial subjects than science and engineering subjects' (Question C5), respondents suggested: i) poor comprehension of science and engineering, ii) lack of science and engineering teaching facilities and iii) cost of science and engineering education in the country are the main reasons. The question received 100% responses with 18 individual elicitations. A condensed and ranked list of the three major factors (indicating equal weights in importance) is shown in Table 3.5.

Table 3.5: Ranked List of Stakeholders Responses to Question C5.

1. Poor Science/Engineering Comprehension (06)	**2. Lack of Science/Engineering Teaching Facilities (06)**
- Lack of motivation/general apathy for sciences (02) - Lack of basic training in science/engineering (01) - Lack of awareness (01) - Lack of early career guidance in sciences (01) - Poor scholarly attitude to science subjects (01)	- Inadequate teaching/research facilities (02) - Lack of trained/qualified personnel (01) - Poor standard of science/engineering infrastructure (01) - Lack of technical expertise in the use of equipment (01) - Lack of industries for employment after school (01)
3. Cost of Science/Engineering Study (06)	
- Higher tuition for scientific courses (01) - Longer study duration for science/engineering (01) - Lack of public incentives for science education (01) - Lack of institutional collaborations (01) - Poor government policies on science education (01) - High cost of science/engineering practical tools (01)	

In line with the themes explored in this section, selected relevant social indicators for Nigeria for the period (2000 – 2010) are presented as shown in Table 3.6.

Table 3.6: Selected Nigeria Social Indicators (2000 – 2010).

	Indicator	**Year**		
		2000	**2005**	**2010**
1	Total population (million)	123.7	139.8	158.4
2	Population growth rate (%)	2.9	2.8	2.7
3	Employment to population ratio (%)	52.4	52.5	52.8
4	Total labour supply (%)	56	56	56.2
5	School enrolment (%)	97.9	95.8	83.3
6	Adult literacy rate (%)	54.8	60.8	68.2

UNDP HDI [102]; Central Bank of Nigeria [106]; World Bank [110].

3.5 Analysis of the Economic Domain

This analysis of the Nigerian economic domain focuses on three key areas: 1) production and GDP growth, 2) economic capital and investment and 3) government revenue and expenditure. These are further considered in the following subsections.

3.5.1 Production and GDP Growth

According to the IMF [111], Nigeria's petroleum production sector accounts for over 95% of its export earnings and about 65% of government revenues. In addition to petroleum, agricultural production—including cocoa, cotton, groundnuts and rubber remain its other major export commodities [106]. In spite of enormous oil and gas production, the petroleum industry still contributes less than 20% of GDP, behind agriculture, which contributes more than 40% [111, 112].

Considering the prevailing economic situation in the country, policymakers were asked in (Question B1 Appendix B) to comment on their 'expected annual GDP growth to year 2025 under *"optimistic"* and *"pessimistic"* growth scenarios'. Their comments are presented in Table 3.7. 62% of respondents stated that Nigeria's GDP under *"optimistic"* growth scenario is likely to grow at 7 – 12% (average 9.5%) per annum to year 2025. 56% of respondents foresee annual growth rate of between 2.5 – 5% (average 3.75%) under a *"pessimistic"* growth scenario. The 12% expected growth is closer to government's Vision 20: 2020, which aims at GDP growth of 13.8% to year 2020 for the country to become one of the top 20 world largest economies [113].

Table 3.7: Stakeholders Responses to Question B1.

	Optimistic Growth					**Total**	**Pessimistic Growth**					**Total**
	NNPC	MPR	ECN	NPC	FME		NNPC	MPR	ECN	NPC	FME	
2.5% to 5%							4	5	4	9	6	**28**
5% to 7%	2	2	0	1	2	**7**	5	4	4	1	3	**17**
7% to 12%	7	6	6	6	6	**31**	1	1	2	0	1	**5**
>12%	1	2	4	3	2	**12**						
Total	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**	**50**

Despite an impressive expected growth, the majority of policymakers foresee *"agriculture"* remaining the mainstay of the economy to year 2025 and even beyond. This implies that the oil sector is still unlikely to contribute much to the country's domestic growth as captured in stakeholders' responses to (Question B2) in Table 3.8.

Table 3.8: Stakeholders Responses to Question B2.

	Contribution to Real GDP					**Total**
	NNPC	MPR	ECN	NPC	FME	
Agriculture	4	7	6	3	7	**27**
Oil & Gas	4	3	2	1	2	**12**
Other Industries	2	0	1	6	0	**9**
Services	0	0	1	0	1	**2**
Total	**10**	**10**	**10**	**10**	**10**	**50**

3.5.2 Economic Capital and Investment

At the end of year 2010, Nigeria exports in financial terms were estimated at about US $76.33 billion, with a current account surplus of US $27.77 billion [106]. The country's reserves of foreign exchange and gold according to year 2010 estimates were

US $43.36 billion [100]. Also, the nation's total import, based on 2010 estimates stood at US $34.18 billion [100]. At the end of that year, its stocks of direct foreign investments at home and abroad were respectively, US $67.23 and US $6.071 billion [100]. Stakeholders believe that the country's financial management is not satisfactory in a number of respects, including planning and direction of the large oil and gas sector.

When asked in (Question B3), to 'state the two major barriers, in their opinion, constrict GDP contribution from the oil sector', stakeholders responded as shown in the ranked Table 3.9. 30 out of 59 view financial and investment-related barriers to be the major issues affecting the oil sector, followed by politics.

Table 3.9: Condensed List of Elicited Barriers to GDP Growth (QB3).

1. Financial-Related Barriers (30)	2. Political-Related Barriers (29)
- High-level corruption in the oil sector (06) -Weak oil and gas regulatory structure (05) -Capital flight from the oil industry (04) -Theft and Unaccounted oil proceeds (04) -Overdependence of petroleum products import (04) -Lack of local employment in the oil & gas sector (03) -Lack of transparency/accountability (02) -Lack of technology development capacity (02)	-Lack of planning/mismanagement of the oil sector (06) -Inadequate investment in the oil sector (04) -Political instability/insecurity in the country (04) -Limited in-country capacity utilisation (03) -Lack of in-country manufacturing/refining capacity (03) -Lack of domestic utilisation of oil & gas (03) -Lack of local content development capacity (03) -Underdevelopment of domestic oil & gas market (02) -Non-implementation of oil and gas master plan (01)

3.5.3 Government Revenue and Expenditure

Nigeria is the world's 7th largest exporter of oil; its oil revenue contributes over 95% of foreign exchange earnings, and over 60% of government revenue [111]. Yet, the nation's economy remains inefficient in meeting the development needs and aspirations of its people. For instance, the country imports more than 50% of its daily fuel consumption to meet domestic needs [106]. This has been shown to be due largely, to lack of investment and misplacement of government priorities in expenditure [106, 110, 111]. Thus, (Question B4) sought to know from policymakers the 'chief economic factors responsible for this anomaly'. They responded as shown in Table 3.10. A majority (36.2%) of policymakers saw lack of domestic investment as the major issue.

Table 3.10: Combined List of Economic Factors (QB4).

1. Lack of investment in the downstream sector (17)	**2. Poor energy pricing and reform (16)**
-Embezzlement/diversion of public funds (04) -Lack of maintenance of energy infrastructure (04) -Lack of training/human capital development (03) -Lack of transparency/accountability (02) -Inadequate budgetary allocation to downstream (02) -Lack of technology development/transfer (01) -High import duty on machinery/equipment (01)	-Weak energy legislation/regulatory structure (04) -Inappropriate disbursement/use of energy subsidies (04) -Monopoly/corruption by oil cartel (03) -Overdependence on joint venture arrangements (02) -Incessant government bureaucracy (02) -Lack of visionary leadership/inconsistent energy policies (01)
3. Underdeveloped domestic oil & gas market (14)	
-Lack of appropriate energy policy formulation (03) -Inadequate supply of energy infrastructure (03) -Government insensitivity/lack of political will (02) -Poor management style and lack of patriotism (02) -Theft and vandalism (02) -Insecurity/instability in the country (02)	

In view of these concerns, (Question B5) further explored with policymakers the 'timescale over which they foresee a definite turnaround in the economy of the nation', such that at least 85% of the country's energy requirements, as well as manufactured goods are met in-country. To this, stakeholders responded as shown in Table 3.11. 48% of policymakers—representing 24 out of 50 affirmed that with the current policy structure, and at the current rate of economic growth, Nigeria is likely to see a definite turnaround in its current economic situation in *"20 years' time"*. 40% thought this is feasible in *"10 years' time"*. Only 12% of participants stated it might take *"over 30 years"* for Nigeria to attain this degree of change.

Table 3.11: Stakeholders Responses to QB5.

	NNPC	MPR	ECN	NPC	FME	**Total**
10 Years' Time	5	6	2	4	3	**20**
20 Years' Time	5	4	7	3	5	**24**
Beyond 30 Years' Time	0	0	1	3	2	**6**
Total	**10**	**10**	**10**	**10**	**10**	**50**

Based on the analysis presented in this section, some relevant, key economic indicators for Nigeria over a 10 year period (2000 – 2010) are shown in Table 3.12.

Table 3.12: Selected Nigeria Economic Indicators.

	Indicator	Year		
		2000	2005	2010
1	Total production (billion Current US$)	46.0	112	229
2	Real GDP growth (%)	2.8	6.5	7.5
3	Total reserve (billion Current US$)	10.1	28.6	35.9
4	Foreign Direct Investment (billion Current US$)	1.14	4.98	6.05
5	Government revenue—excluding grant (% of GDP)	6.3	9.7	10.2
6	Government total expenditure (% of GDP)	4.7	7.2	8.5

Central Bank of Nigeria [106]; World Bank [110].

3.6 Analysis of the Nigeria Environment

Major environmental problems relating to Climate Change concerns in Nigeria include: loss of forest and agricultural land; air, water and land quality degradation; as well as loss of natural habitat for ecosystem [114]. Others are pollution and carbon emissions from oil and gas activities and water security-related issues [114]. In this study, Climate Change and Water Security concerns due to pollution and emissions from oil and gas activities, desertification and erosion are the key issues of interest.

3.6.1 Pollution and Carbon Emissions

Carbon emissions from oil and gas activities are known to be among the major drivers of climate change around the world [115, 116]. For Nigeria, data from the EIA [117] show that energy-related CO_2 emissions is about 101 million metric tons, while CO_2 emissions per capita and CO_2 intensity are 0.8 metric tons and 0.86 metric tons per thousand $2005 – PPP respectively. The UNDP HD report [102] also states that 12% of Nigeria's population presently live on degraded land—representing a population of approximately 19 million people.

In view of significant incidences of 'oil spills' and 'gas flares' in the country and the attendant threats, policymakers were asked (Question D3 Appendix B) to 'propose environmental improvement measures' in these contexts. A ranked list of responses is shown in Table 3.13. A majority of respondents emphasised two measures as possible solution approach: 1) development of domestic market for gas commercialisation and utilisation and 2) prompt environmental remediation to oil spill incidences.

Table 3.13: Ranked Listing of Stakeholders Responses to Question D3.

Proposed Solutions to Gas Flaring (71)	**Proposed Solutions to Oil Spills (71)**
- Development of domestic market for gas commercialisation and utilisation (21) - Improvements in gas capture and re-injection in production wells (15) - Enactment/enforcement of gas flare-out policy (13) -Stringent penalty/enforcement against gas flaring (09) - Increase in funding for gas gathering and gas flare-out projects (04) - Introduction of gas monetisation policy (03) - Improvement in environmental awareness campaigns (02) - Increase in environmental remediation measures (02) - Proper monitoring of gas development and gas flare-out programmes (01) - Introduction of carbon trading (01)	- Prompt environmental remediation (17) - Stringent penalty/enforcement against oil spills (09) - Regular security surveillance along oil pipelines (08) - Preventive/proactive maintenance strategies for oil pipeline integrity (06) - Improvement in HSE awareness campaigns (05) - Imposition of severe punishment on oil thieves and pipeline destroyers (05) - Timely containment of oil spills (04) - Efficient and adequate monitoring and evaluation of oil production activities (04) - Improvement in oil production technologies (04) - Early detection and replacement of weak oil pipelines/infrastructure (03) - Provision of adequate incentives and compensation to host communities (03) - Enactment/enforcement of strong legislation against oil spills (02) - Land filling and re-habitation (01)

3.6.2 Desertification

Environmental statistics from National Bureau of Statistics [118] has shown that the Sahara desert is rapidly encroaching on Nigeria—advancing at the rate of 6 km^2 per year. This translates to a loss of about 600 hectares of arable land a year. Considering the climate impact of desertification, policymakers were asked in (Question D1a), to 'indicate if Climate Change indeed, is a *"threat"* to Nigeria'. The results of stakeholder positions are shown in Table 3.14 (a).

A total of 48 out of 50 policymakers (96%) *"Agreed"* that Climate Change is a threat to Nigeria; 4% of respondents were *"not sure"* it is a threat to the country. On their 'level of satisfaction to government's current responses to climate change issues in the country and globally' (Question D1b), 34 out of 50 participants (representing 68% of respondents) reported they were *"not satisfied"*. 30% of the respondents were *"slightly satisfied"*, while only one person indicated being *"quite satisfied"* with government's current responses as in Table 3.14 (b).

A further questioning on 'national strategies to combat climate change' (Question D2), reveals that 78% of stakeholders would like government to focus on *"both mitigation and adaptation"* strategies. Only 12% and 10% suggested *"mitigation"* only or *"adaptation"* only strategies respectively; see Table 3.14 (c)-D2.

Table 3.14: Stakeholders Responses to Question D1a, D1b and D2.

	(a)					**Total**
	NNPC	MPR	ECN	NPC	FME	
Yes	9	10	10	10	9	**48**
No	0	0	0	0	0	**0**
Not Sure	1	0	0	0	1	**2**
Total	**10**	**10**	**10**	**10**	**10**	**50**

	(b)					**Total**
	NNPC	MPR	ECN	NPC	FME	
Quite Satisfied	1	0	0	0	0	**1**
Slightly Satisfied	2	3	5	1	4	**15**
Not Satisfied	7	7	5	9	6	**34**
Total	**10**	**10**	**10**	**10**	**10**	**50**

	(c)-D2					**Total**
	NNPC	MPR	ECN	NPC	FME	
Mitigation Strategies	2	1	1	0	2	**6**
Adaptation Strategies	1	0	1	1	2	**5**
Both	7	9	8	9	6	**39**
Total	**10**	**10**	**10**	**10**	**10**	**50**

To propose a solution to desert encroachment issues in the country, stakeholders were specifically asked in (Question D4), to 'suggest action that could be taken', to: 1) combat desertification and 2) restore soil fertility. It is glaring in Table 3.15, that majority placed emphasis on two measures: 1) afforestation practice to combat desertification and 2) the use of farm land manure to improve soil fertility.

Table 3.15: Ranked List of Stakeholders Responses to Question D4.

Proposed Actions to Combat Desertification (80)	**Proposed Actions to Restore Soil Fertility (74)**
- Introduction of afforestation practice (43) - Enactment of legislation and strategic policy against	- Use of farm land manure (15) - Enactment and enforcement of legislation against bush

deforestation (13) - Development of irrigation projects (12) - Introduction of desert-based agricultural techniques (03) - Provision/promotion of alternatives for fuel wood (03) - Construction of water canals (03) - Awareness and sensitisation campaign against bush burning and deforestation (02) - Provision of funding and incentives for afforestation practice (01)	burning and uncontrolled animal grazing (14) - Shifting cultivation practice (13) - Cultivation of nitrogen fixing plants (11) - Irrigation farm practice (07) - Application of chemical fertilizer (06) - Introduction of agroforestry practice (03) - Introduction of desert-adaptive agricultural crops (02) - Reduction in greenhouse gas emissions (02) - Rain harvesting and erosion control (01)

3.6.3 Water and Land Erosion

According to Ajaero and Mozie [119], the most devastating form of gully erosion is found in the South Eastern part of the country. In their submission, the gully, which was estimated to have advanced at the rate of 20 – 50 m per year, had destroyed about 1100 km^2 of land in four eastern states over a 10 year period. It was thought in 2010, that the gully has a mean advance rate of 150 m in every 3 – 5 years [119]. Erosion problems are already causing serious water security concerns in Nigeria [120].

When asked (Question D5a), ‘whether shortage of clean water supply is being anticipated in the country in the near future’, 24 out of 50 policymakers (48%) say the water supply situation in the country will remain normal in the foreseeable future. 28% of respondents believed the country is likely to face severe water supply challenges by around year 2030, while 24% thought it might take up to year 2050 and beyond for any large-scale water supply problems to occur (Table 3.16).

Table 3.16: Stakeholders Responses to Question D5a.

	NNPC	MPR	ECN	NPC	FME	**Total**
Yes, by 2030	3	1	0	5	5	**14**
Yes, by 2050	2	2	1	4	3	**12**
No, things will normalise	5	7	9	1	2	**24**
Total	**10**	**10**	**10**	**10**	**10**	**50**

The consulted policymakers were further probed (Question D5b), to ‘state the factors they believe are likely to trigger water security challenges in the country within the chosen timescale’. As shown in Table 3.17, most respondents felt increase in future population might put pressure on water demand in the country; this possibly, will cause water security concerns, particularly, in view of a rapidly changing climate. A sizable number also thought a dramatic change in economic fortunes of the country—leading to some sort of *"industrial revolution"* might drive up water demand, and that could also create a concern over water supply security.

Table 3.17: Causes of Potential Water Security Challenges in Nigeria (QD5b).

1. **Population Growth (16)**	2. **Climate change (16)**
-Absence of policy plan on water security (05) -Poor/lack of water conservation/management strategies (04) -Poor irrigation/agricultural practices (04) -Inadequate water supply infrastructure (01) -Underground water pollution (01) -Corruption/government insincerity (01)	-Desertification (06) -Unusual drought (05) -Global warming (03) -Flood/erosion (01) -Natural disaster (01)
3. **Industrialisation (9)**	
-External factors (04) -Lack of investment in portable water supply (02) -Lack of rain water harvesting/storage (01) -Lack of scientific research in water security (01) -Poor maintenance of water infrastructure (01)	

In accordance with analysis presented here, some key environmental indicators for Nigeria over a 10 year period (2000 – 2010) are summarised in Table 3.18.

Table 3.18: Selected Environmental Indicators for Nigeria.

	Indicator	**Year**		
		2000	**2005**	**2010**
1	Total CO_2 emissions (kilo tons)	99183	104044	70000
2	CO_2 emissions per capita (metric tonnes)	0.75	0.69	0.59
3	Arable land (% of land area)	32.9	38.4	39.5
4	Total forest area (square kilometre)	131370	110890	90410
5	Water supply (% of rural population with access)	36	40	43
6	Total water demand (billion cubic meters)	9.891	10.79	12.63

World Bank [110]; World Resource Institute [116]; FAO [121].

3.7 Current Energy Situation

This section of the report is concerned with analyses of Nigeria's energy situation from three perspectives: 1) energy resource base, 2) primary energy demand and supply and 3) electricity supply mix. Each of these is further considered.

3.7.1 Energy Resource Base

Nigeria is an 'energy-rich' country, hugely endowed with diverse energy resources. Its proved energy resources include: fossil fuels (petroleum, natural gas and coal and lignite), renewable resources (hydro, solar, wind and biomass) and uranium resources [117, 122, 123]. These energy resources are naturally distributed in such a pattern that no part of the country's six geopolitical regions remains without one form of energy source or the other. Proved viable energy resources of the country, for both conventional and renewable sources are shown in Table 3.19 (a) and (b). Detailed calculations for energy resource potential are shown in Appendix C.

Table 3.19 (a): Proved Nigeria Fossil Energy Resources (2010).

	Resource Type	**Reserve**	**Energy Value (Btoe)**	**Lifespan (Years)**
1	Crude oil	37.2 billion barrel	5.431	49.1
2	Natural gas	187 trillion scf	4.485	107
3	Coal and lignite	2.175 billion tonnes	1.512	∞*
4	Tar sands	40.6 billion barrel equiv.	5.928	∞*
5	Uranium	Not yet quantified	-	∞*

EIA [117]; Energy Commission of Nigeria [123]; Author's Computations.

*There is currently no production of these resources, and the lifespan goes to infinity.

Table 3.19 (b): Estimated Potential for Nigeria Renewable Energy Resources.

	Resource Type		**Capacity (Estimated Annual Potential)**		**Energy Value per Year (Btoe)**	
1	Hydro	Large	11, 250 MW (at 95% electric efficiency)		0.008	0.010
		Small	3, 500 MW (at 90% electric efficiency)		0.002	
2	Solar		3.5 – 7.0 kWh/m^2/day (using 1% of Nigeria's land area; 10% device efficiency)		0.241	0.241
3	Wind		(2 – 4) m/s (at 10 m height main land; 0.1% land as total swept area; 1.1 kg/m^3 air density; 60% of Betz limit for turbine efficiency).		0.001	0.001
4	Biomass	Fuel wood	11 million hectares of forest area	2.97 Mt (at 20% MC; 15 GJ/t NCV)	0.021	0.026
		Animal waste	211 million assorted animals	50 Mt (at 15% av. MC; 13.5 GJ/t NCV)	0.004	
		Agric. residue	28.2 million hectares of arable land (30% of total land area)	65 Mt (at 45 m^3/tonne; 35% electric efficiency)	0.0005	

Energy Commission of Nigeria [123]; Author's Computations.

3.7.2 Primary Energy Demand and Supply

Despite possessing enormous energy resources, different reports [12, 109, 124] have shown that only about 40% of Nigeria's total population have access to electricity. About 80% of its rural population rely mainly on traditional biomass for their energy needs [125]. Policymakers were asked during fieldwork (Question A1 Appendix B), to 'indicate their level of satisfaction with current energy development in the country'. As shown in Table 3.20, 57% of stakeholders indicated *"not at all satisfied"* with current performance of the oil and gas and the power sectors. 35% indicated *"somewhat satisfied"*, while only 8% indicated they were *"very satisfied"* with the current progress in both sectors. Of these respondents, stakeholders from the National Planning Commission (NPC) appear particularly unhappy with the current trends as 90% and 60% of its policymakers were *"not at all satisfied"* and *"somewhat satisfied"* with development of the power sector and the oil and gas industry respectively.

Table 3.20: Stakeholders Responses to Question A1.

	Oil and Gas Sector					**Power Sector**					**Total**
	NNPC	MPR	ECN	NPC	FME	NNPC	MPR	ECN	NPC	FME	
Very Satisfied	2	0	0	0	1	1	1	1	0	2	**8**
Somewhat Satisfied	5	5	6	4	5	2	3	2	1	2	**35**
Not at all Satisfied	3	5	4	6	4	7	6	7	9	6	**57**
Total	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**100**

Participants were further asked in (Question A2) to 'identify what the major barriers to Sustainable Energy Development are'. 124 sets of barriers were enumerated; they could be grouped into a ranked list of ten as shown in Table 3.21. The candidate items were identified based on the highest frequency of mention by policymakers.

Table 3.21: Summary of Major Barriers to SED in Nigeria (QA2).

1. Poor Energy Policy (18) - Poor policy formulation/implementation strategies (06) - Lack of privatisation/liberalisation of energy sector (04) - Inconsistencies in government policies (04) - Slow drive for renewable energy development (03) - Lack of visionary leadership and strategic planning (02) ***2. Inadequate Energy Financing/Investment (15)*** - Inadequate energy financing (08) - Lack of investment in renewable energy (03) - Insufficient budgetary allocation to energy sector (02) - Lack of government subsidies/incentives (01) - High upfront cost for energy investments (01) ***3. Corruption in Public/Private Sectors (14)*** - Corruption in government/energy industry (05) - Lack of transparency/accountability (04) - Tribalism and nepotism (02) - Poor governance/mismanagement of resources (02) - Misappropriation/diversion of public funds (01) ***4. Lack of Expertise/Technical Knowhow (13)*** - Lack of skilled manpower (05) - Poor quality of education and training (03) - Low capacity in R&D activities (02) - Poor maintenance culture (02) - Lack of industry best practice knowledge (01) ***5. Lack of Capacity Availability (12)*** - Inadequate/poor energy infrastructure (05) - Inadequate capacity building (04) - Lack of employment in the energy sector (02) - Misplacement of priorities (01)	***6. Political Barriers (12)*** - Theft and vandalism of infrastructure (05) - Political instability/insecurity (04) - Lack of patriotism and sabotage (01) - Bogus government programmes/bureaucracy (01) - Weak policy responses to climate change (01) ***7. Weak Institutional Framework (11)*** - Government insensitivity/lack of political will (05) - Skewed joint venture arrangements (03) - Weak legal/judicial system (02) - Poor energy pricing/regulatory regime (01) ***8. Lack of Diversification of Energy Sourcing (11)*** - Lack of awareness/public resistance (05) - Excessive government control and meddling (03) - Lack of private sector participation (02) - Overdependence on oil and gas (01) ***9. Technological Barriers (10)*** - Lack of investment in technology development (02) - Inadequate technology transfer capacity (02) - Lacks of interest/motivation for technology develop. (01) - Inappropriate taxation/regulatory policies (01) ***10. Burgeoning Population (08)*** - Cross border immigration (01) - Increase in birth rate (early/multiple marriages) (01) - Poor capacity for birth control (illiteracy and lack of awareness) (01) - Cultural values/tradition and poverty (01)

While broad issues of strategic importance to the country were captured in the list of barriers, stakeholders appear mostly concerned about the level of corruption in the country. All the fifty policymakers who responded to the question reported that *"corruption in the public and private sectors"* remains a major factor militating against Sustainable Development of the energy sector.

Another question (Question A5) on 'the role of coal and tar sands in the total energy supply mix by year 2025' reveals the results shown in Table 3.22. A total of 29 (58% of respondents) foresee coal contributing between 5-10% of total primary energy supply in the country by 2025. 42% of policymakers did not expect the use of tar sands for energy supply over this timescale. In contrast, 6% of respondents thought that coal would contribute nothing to the nation's total energy supply by 2025.

Table 3.22: Stakeholders Responses to Question A5.

	Coal					Total	Tar sands					Total
	NNPC	MPR	ECN	NPC	FME		NNPC	MPR	ECN	NPC	FME	
None	0	1	1	1	0	**3**	5	4	3	6	3	**21**
5% to 10%	7	4	6	6	6	**29**	4	2	5	3	6	**20**
10% to 30%	3	4	1	2	4	**14**	1	2	1	0	1	**5**
>30%	0	1	2	1	0	**4**	0	2	1	1	0	**4**
Total	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**	**50**

3.7.3 Electricity Supply Mix

Despite abundance of energy resources in Nigeria, the country still grapples with issues of steady electricity supply. It is estimated that only about 40% of Nigeria's 158 million people have access to the current grid electricity supply [124, 126]. The current electricity supply structure, which is based on a centralised grid system distributes power generated from two sources: large hydro (31.3%) and gas thermal (68.30%) [126].

When asked in (Question A3a), if there are 'any government policy targets to develop renewable energy sources in the country', 39 out of 50 respondents (representing 78%) confirmed government plans to develop renewable energy sources by year 2025. 11 of the 50 respondents (representing 22%) thought the government was not ready for renewable energy development. In all, the FME was most optimistic about government's plans to deploy renewable energy technologies within the timescale, with 9 out of 10 reporting in affirmative. The NNPC appeared most sceptical about such plans, with 60% *"Yes"* and 40% *"No"* as shown in Table 3.23 (a).

Table 3.23: Stakeholders Responses to QA3a and QA3b.

(a)	NNPC	MPR	ECN	NPC	FME	**Total**
Yes	6	8	8	8	9	**39**
No	4	2	2	2	1	**11**
Total	**10**	**10**	**10**	**10**	**10**	**50**

(b)	NNPC	MPR	ECN	NPC	FME	**Total**
Grid Supply	2	2	3	3	5	**15**
Decentralised Use	0	4	3	1	2	**10**
Other Objectives	0	1	1	2	2	**6**
Grid & Other Objectives	4	1	1	2	0	**8**
Total	**6/10**	**8/10**	**8/10**	**8/10**	**9/10**	**39/50**

In terms of 'government's objective in promoting the use of renewable energy resources in the country' (Question A3b), responses to the question remain a *"mixed bag"*. There was no distinct response to apparently highlight the strategic objective of government on renewable energy development in the country as captured in Table 3.23 (b). 38.5% of policymakers stated, *"increasing power available from the grid"* was government's objective in promoting renewables. 25.6% reported it is meant for *"decentralised rural electrification"*, 15.4% said its pursuit is to achieve *"other objectives"*, while 20.5% thought the purpose is rather diverse, including *"grid electricity supply and other objectives"*. Some of the other objectives participants highlighted include: 1) green transport use, 2) global drive towards green economy, 3) desire for clean energy supply and 4) diversification for energy security.

If pursued, (Question A4) sought to know from policymakers 'the most realistic target for renewable capacity growth to year 2025'. 19 people (i.e. 38% of respondents) believed that at the current level of preparedness shown by government, solar energy capacity is likely to grow at a maximum of 4% per annum. The same rate of growth was predicted for wind and biomass by majority of the respondents—representing 56% and 50% respectively. Most optimism was shown about hydroelectricity, as a total of 21 people (42% of respondents) thought, that hydro was likely to grow at more than 9% to year 2025 (Table 3.24).

Table 3.24: Stakeholders Responses to Question A4.

	Solar					**Total**	**Wind**					**Total**
	NNPC	MPR	ECN	NPC	FME		NNPC	MPR	ECN	NPC	FME	
0-4%	2	3	1	6	7	**19**	5	3	8	5	7	**28**
5-9%	1	4	4	1	2	**12**	1	5	0	2	2	**10**
>9%	3	1	3	2	0	**9**	0	0	0	2	0	**2**
Total	**6/10**	**8/10**	**8/10**	**9/10**	**9/10**	**40/50**	**6/10**	**8/10**	**8/10**	**9/10**	**9/10**	**40/50**
	Hydro					**Total**	**Biomass**					**Total**
	NNPC	MPR	ECN	NPC	FME		NNPC	MPR	ECN	NPC	FME	
0-4%	0	0	1	0	4	**5**	3	4	5	6	7	**25**
5-9%	2	3	1	6	2	**14**	2	3	3	1	2	**11**
>9%	4	5	6	3	3	**21**	1	1	0	2	0	**4**
Total	**6/10**	**8/10**	**8/10**	**9/10**	**9/10**	**40/50**	**6/10**	**8/10**	**8/10**	**9/10**	**9/10**	**40/50**

3.8 Policy Responses and Reform Agenda

Our analyses have shown that despite possessing considerable energy resources, Nigeria still faces huge energy challenges. It is evident from the foregoing, that energy supply in the country is currently characterised by inefficient and unreliable energy systems. Some of the key issues uncovered include issues of weak governance and poor energy policy, infrastructural and technical problems, poor management of finance, and the challenges of a growing population and the supply of skilled manpower.

In view of these challenges, the Nigerian government has embarked on vigorous reforms to improve the situation. One of the desired outcomes is to provide Sustainable Energy access to the people through development of renewable energy resources. This section looks at the current reform agenda of the government from three perspectives: 1) oil and gas sector reforms, 2) power sector reforms and 3) development of the national energy policy. We focus our discussion on energy sector reform because it is the only sector amongst other economic sectors currently undergoing robust transformations.

3.8.1 Oil and Gas Sector Reform

Though, Nigerian oil and gas legislation has existed since 1897 when the first Petroleum Ordinance was enacted, the current major laws are the Petroleum Act which came into force in 1969 [127]. This has been the legal framework guiding oil and gas activities in Nigeria. In 1977, Nigeria created the Nigerian National Petroleum Corporation (NNPC), charged with the responsibility to oversee the regulation of the oil industry, and development of the upstream and downstream sectors [127].

To better manage the country's oil industry activities, which are mainly Joint Venture Projects, the government in 1988 divided NNPC into 12 subsidiary companies [127]. Despite this split and diversification, not much progress has been made in putting the nation's oil industry to a world-class standard. Therefore, with the hope of creating a more effective sector, the government has embarked on a new transformation agenda, which seeks to unbundle the NNPC, commercialise and privatise its subsidiaries, and equally deregulate the downstream sector [117].

In 2000, the government set up a National Privatisation Council (NPC) committee, with the mandate to unbundle the NNPC into 5 functional companies [127]. While these discussions have been underway for many years, a new Petroleum Industry Bill (PIB) is currently being debated on the floor of the Nigerian parliament. The new Bill mainly seeks to: 1) increase government's share of the oil revenue, 2) increase natural gas production, 3) unbundle the NNPC and 4) promote local content development [13]. The Bill also seeks to increase revenue allocation to the oil producing communities, and equally increase domestic consumption of gas for electricity generation [13].

In addition to the PIB, the Nigerian president in 2010 signed into law the Nigerian Content Development Bill (NCDB) [13], which aims at increasing the role of

Nigerian companies in all aspects of oil and gas development in Nigeria. The new law requires that the indigenous companies obtain contracts and win bids, so long as they are capable and the Nigerian content is higher [13].

Despite many concerns about the PIB, there is evidence of some improvement. The gas sector for example, has seen a significant boost in recent years. Gas flaring from oil production for instance, has dropped from 70% in 2000 to about 35% in 2010 [128]. In financial terms, this implies that Nigeria will be saving more than a third of its previous revenue losses accruing from gas flaring.

Also, the start-up of Nigeria LNG project in Bonny Island has increased the capacity for gas development. The NLNG facility (a Joint Venture (JV) between NNPC, Shell, Total and Agip) currently (2010) has 6 trains, with annual capacity of 22 million metric tons [117]. A 7th train is underway with the hope of taking off in 5 years' time. Three additional LNG plants (in three other locations), with a total of 7 trains were expected to come on stream, but start-up has been postponed to a future date [117].

Nigeria through the NNPC is also in a JV with Chevron and South African Sasol, to build a new Gas-to-Liquid (GTL) plant at Escravos. The GTL plant is expected to convert 325 million cf of natural gas per day into 33,000 barrels of liquids (mainly synthetic diesel) [122]. When completed, the plant is expected to supply diesel fuel in Europe and elsewhere [122].

Similarly, Nigeria and Algeria are currently discussing the possibility of a Trans-Saharan Gas Pipeline (TSGP) project [117]. The 2,500 mile pipeline would carry natural gas from Nigerian oil fields to Algeria's export terminal on the Mediterranean [117, 129]. In 2009, NNPC signed Memorandum of Understanding (MoU) with Sonatrach—the Algeria's national company for the project. While other companies such as Total and Gazprom also continue to generate interest in this project, security concerns along the entire pipeline route, increasing costs as well as on-going political uncertainties in Nigeria continue to delay this project [117].

3.8.2 Power Sector Reform

The Nigerian power sector, which is currently characterised by excess energy demand and supply shortages, needs urgent attention in order to revamp it. Historically, electricity in Nigeria dates back to 1896 when it was first produced in Lagos, fifteen years after its introduction in England [130], but its subsequent development has been at a very slow pace.

In 1950, the Nigerian government established a central body known as Electricity Corporation of Nigeria which had the responsibility of buying electricity produced by another government agency—the Niger Dams Authority (NDA), for distribution and sales at utility voltages [131]. In 1972, the activities of the electricity Corporation and the NDA were merged to create the National Electric Power Authority (NEPA) [131]. The new power authority was given 'monopolistic' power to generate, transmit, distribute and sell electricity in Nigeria [131].

For over 25 years of its existence prior to 1999, NEPA grossly underperformed, as the power sector did not witness any substantial investment in infrastructural development. For example, between 1972 and 1999, no new power plants were constructed, and the existing ones were poorly maintained—bringing the power sector to a deplorable condition [125]. In 2001, electricity generation went down from installed capacity of 5,600 MW to about 1,700 MW, as compared to the load demand of 6,000 MW [124]. At that time, only 19 out of 79 installed generating units countrywide were in operation [124].

In addition to generation; transmission and distribution problems, inefficiency in electricity tariffs collection remained another huge challenge for NEPA. Some reports [12, 125, 130] maintain that the rate of recovery of revenue derivation from electricity consumption in Nigeria hardly reaches 75 – 80%, as opposed to 100% in the developed world. These problems put serious constraint on power sector development.

It is against this backdrop that the Nigerian government has embarked on current power sector reform programmes. In 1999, the privatisation drive of the government led to the restructuring of NEPA. The power company was unbundled into 7 generation companies, 1 transmission company and 11 distribution companies [132]. The idea was to encourage private sector investment in the sector. The power sector reform Bill already approved by government came into effect in 2004, with the new structure known as Power Holding Company of Nigeria (PHCN). In 2005, the Nigerian Electricity Regulatory Commission (NERC) was inaugurated and charged with the responsibility of tariffs regulation and monitoring of the quality and service provided by PHCN [130]. Despite this drive to make energy available and affordable to the people, there are still elements of economic, technical, political and environmental challenges that are hampering substantial progress in this direction.

3.8.3 Development of the National Energy Policy

In 1979, the Nigerian government established the Energy Commission of Nigeria (ECN), which was given the statutory responsibility for strategic planning and coordination of all national energy policies in the country [123, 133]. The ECN produced its first draft National Energy Policy (NEP) for Nigeria in 1993 [123, 133]. The draft document was reviewed in 1996 at the instance of the government [133]. The policy document was again reviewed in 2002 in response to the privatisation, commercialisation, and deregulation Act that seeks to restructure the entire economy towards greater private sector participation. The policy document was approved by the government in 2003 and launched in 2005 [123, 133]. The NEP articulates the need for sustainable exploration and utilisation of all viable energy resources in the country.

In order to have a planned and coordinated implementation of the NEP, the government inaugurated a committee in 2006, to draw up a comprehensive road map [133]. As a result, a National Energy Master Plan (NEMP) was approved by government in 2007 [123, 133]. The NEMP focus mainly on development of conventional energy resources. Also in 2005, the ECN in collaboration with the UNDP drafted the Renewable Energy Master Plan (REMP) [123, 133]. The REMP is a roadmap for planned implementation of renewable energy component of the NEP. It is the combination of NEMP and REMP with timelines and targets that make up the current NEP document of Nigeria.

3.9 Conclusion

This chapter has introduced the case study area—Nigeria from three standpoints: 1) its geography, 2) its energy economy challenges and 3) its current policy responses and reform agenda. The analyses altogether conveyed a detailed description of the current situation in the energy sector and the three sustainability domains: society, economy and environment. The analyses have helped us to identify the most problematic areas and the key issues needing further investigation in this study.

Analyses of the social domain have shown that burgeoning population, raising unemployment and lack of skilled labour supply resulting from poor quality of education and training, are the major issues affecting this area. Under the economic domain, it was discovered that the lack of domestic investment, *"unrealistic GDP growth"* and misplacement of government priorities in expenditure are the key issues needing further study. The environmental impacts of oil and gas pollution, desertification and raising GHG emissions from energy use were identified as major environmental concerns needing further investigations in this research.

It can be inferred from the fieldwork data based on stakeholder opinions, that despite possessing huge energy potential, Nigeria is still likely to face significant energy crisis in the near future. This, stakeholders thought is particularly possible, if there are no substantial changes in existing energy policies. In view of these concerns, a thorough review of the current policy responses in the aforementioned areas and the on-going challenges with the reform agenda of the government have also been undertaken in this chapter. An understanding of the main issues helped us in identifying the needs for developing an integrated policy assessment tool—the E-PAM. The development process for the E-PAM is described in the next chapter.

Chapter 4

Development of an Energy Policy Assessment Model

4.1 Introduction

This study presents two main perspectives on policy assessment for Sustainable Energy Development (SED). As illustrated in Figure 4.1, the first approach focuses on the development of an integrated policy assessment model. This is based on System Dynamics (SD) modelling simulation and analyses of a Business-As-Usual (BAU) case and alternative policy scenarios, with a case study application on Nigeria.

The second approach involves evaluation of the alternative policies, and the selection of an optimal policy. This is based on multi-criteria evaluation using SMART—Simple Multi-Attribute Rating Technique [8]. In this case, the output from the SD model serves as *"feed"* or *"front end"* to the SMART evaluation [10]. The outcome of the two procedures aims to provide combined information necessary to propose effective policy options to deal with the barriers to SED uncovered during fieldwork.

This chapter deals with the first question: development of an Energy Policy Assessment Model (E-PAM). It presents the model development process and the key model features. Section 4.2 describes the problem area and background. Section 4.3 deals with model conceptualisation—including the definition of its purpose, dynamic hypothesis and boundaries. Section 4.4 describes the model development procedure—including the methodological approach, the formulation steps and a representation of its sub views. Section 4.5 demonstrates the model validation steps using a composite approach. Section 4.6 presents the key chapter conclusions.

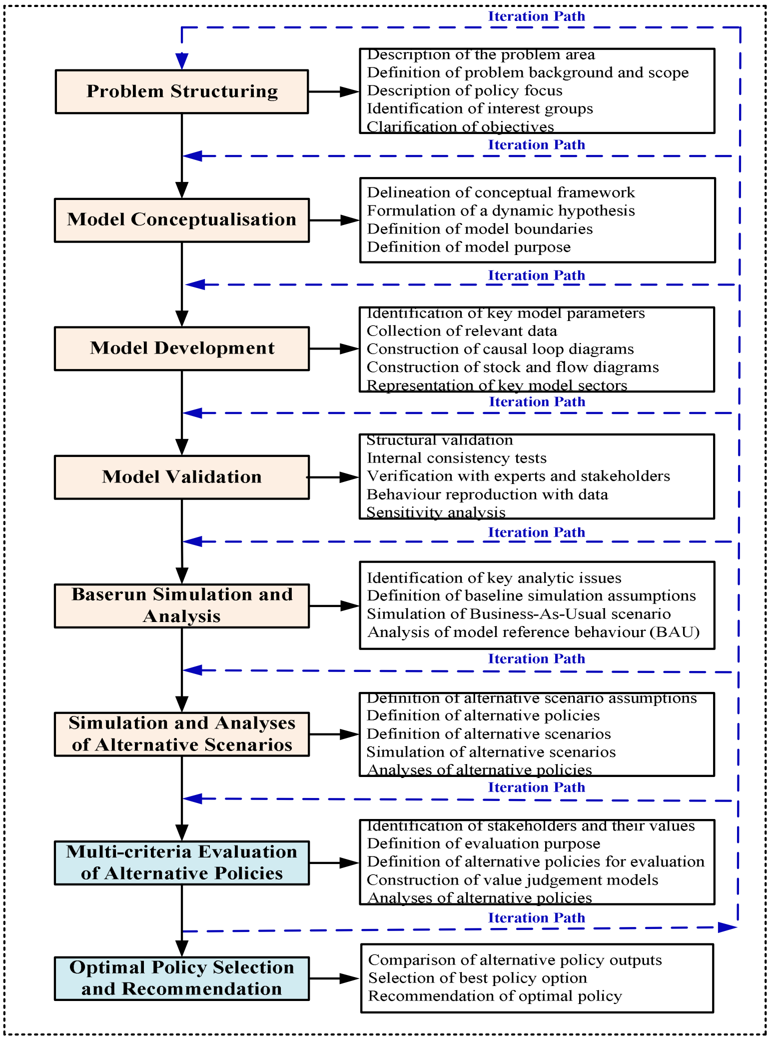

Figure 4.1: Framework for Development and Evaluation of the E-PAM.

4.2 Problem Definition

In this era of economic growth and technological advancement in many parts of the world, a dependable supply of energy services remains crucial to shaping the future course of events [134]. Such energy supply, the UNDP et al., [135] note is an essential element of Sustainable Development. For the emerging regions, adequate and affordable energy services are crucial to their 'social' and 'economic' development. For the industrialised nations, reliable energy supply is essential to maintaining a healthy economy and living standards.

However, the UN [11] observe that the current patterns of energy development around the world are unsustainable. The 'environmental' and climate impacts of energy usage in some parts of the world are such as to threaten economic growth. Energy poverty arising from lack of access and affordability remain a hindrance to Sustainable Development in other regions.

In view of the interconnected nature of the above mentioned issues and the wide-encompassing implications for Energy Security and Sustainability, it has become necessary to find sustainable ways of dealing with these global issues. For these reasons, policymakers around the world are faced with a huge challenge of developing, analysing and implementing effective policies that could deal with these concerns. One of the challenges faced by policymakers is having an informed understanding of the broader future implications of their policy interventions. Other challenges include finding ways of mitigating any negative consequences that could arise from the implementation of such policies.

Therefore, it is essential to develop structured tools, which can provide insights into the current issues, and equally form the basis for exploring alternative futures. Two questions become important to consider: 1) "*how should the energy economy be developed to maximise sustainability?*" and 2) "*what sort of roles should engineers play to help policymakers in the development, analysis and implementation of effective policies?*" The conceptual ideas that can be employed in structuring such policy problems are summarised as shown in Figure 4.2.

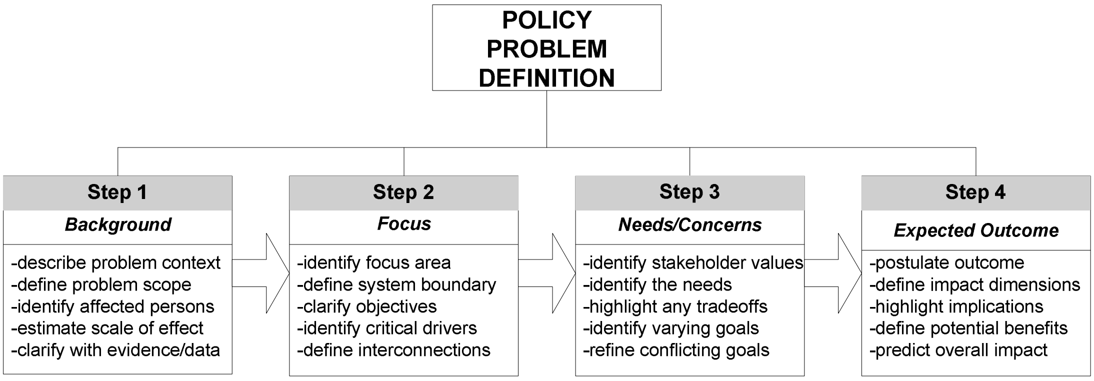

Figure 4.2: A Framework for Structuring a Policy Problem.

4.3 Model Conceptualisation

Nigeria, though an 'energy-rich' country, falls within the category of countries experiencing 'energy-poverty' as defined by the UN [11]. The country is currently the largest reserves holder and producer of oil and gas in the African continent—with proved 37.2 billion barrels and 187 trillion cubic feet of crude oil and natural gas reserves respectively [123, 136, 137]. Nigeria is also known to retain about 2.175 billion tonnes of proved and inferred coal and lignite resources, and tar sands of around 41 billion barrels of oil equivalent [123]. In addition to possessing a high potential for renewable energy resources, in 2005, commercially exploitable deposits of uranium were discovered in six of Nigerian states by the British Geological Survey[1]. Despite this huge energy potential, only about 40% of the country's 160 million people are estimated to have access to modern energy, with about 80% of the rural population depending almost wholly on traditional biomass for their energy needs [12, 123, 125].

In Mbasuen and Darton [138], it is noted that the Nigerian energy industry has not been very efficient in meeting the energy needs and aspirations of its customers. This is

[1] New Uranium Mining Projects-Africa; available at: http://www.wise-uranium.org/upafr.html

evident in the dismal performance of the industry in terms of service delivery and per capita output [138]. For instance, in spite of the enormous oil and gas activities in the country, the petroleum industry provides less than 20% to GDP [111, 112]. Similarly, the income per capita and electricity consumption per capita of Nigeria remain among the lowest, even in Sub-Saharan Africa—behind Angola and Ghana [12, 139]. Persistent energy crisis has significantly weakened the industrialisation of the country, and grossly undermines the Sustainable Development agenda of the government [138].

A study of government documents [12-14] reveals that one of the key challenges facing the country is ineffective energy policy formulation and implementation, and the lack of structured tools to aid planning and evaluation of effective policies; tools that will bring about informed decision making process in the country. It is also evident in these reports that energy policymakers in Nigeria usually rely largely on their 'intuition' in designing policy programs and in shaping the policy direction, without rigorously evaluating the robustness of such policy initiatives. Such efforts, as already discussed in Chapter 2, are based on 'linear' and 'mechanistic' approaches, such that they usually do not account for other complexity associated with the policy system [61].

The only recognised tools that have so far been applied to energy planning in Nigeria are the IAEA's models MAED[2] and WASP[3] [15]. 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 the dynamics relating to 'society' and 'environment', since they are based on a 'static economic' modelling [16].

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[2] Model for Analysis of Energy Demand

[3] Wien Automatic System Planning

4.3.1 The Conceptual Framework

In this study, we propose a dynamic modelling approach that employs System Dynamics [7] as its main methodology. As illustrated in Figure 4.3, we introduce the concept of *"energy dynamics"*, an approach which describes the interconnectedness between the energy sector and the three Sustainability domains: society, economy and environment. This framework provides an overall structure for exploring the dynamic interplay between these key model sectors. The hypothesis behind the *"energy dynamics"* concept is that the underlying forces of energy demand and supply generate varying degrees of impact on the economy, society and environment, and that these impacts are received in different sectors within the sustainability domains. The impacts are analysed within the ten most relevant sub-domains (level IV in Figure 4.3) with most relevance to the energy sector.

Under the **social domain**, three key sub-domains are considered. These are: 1) population, 2) education and human capital and 3) labour force. Under the **economic domain**, the four critical subdomains are: 1) GDP and investment, 2) employment and productivity, 3) government revenue and expenditure and 4) R&D and technology. For the **environment domain**, the subdomains considered are: 1) resource availability, 2) resource use and 3) carbon footprint of energy use. To ensure a measurable assessment of the impacts created by energy demand and supply in each of the aforementioned sub-domains, specific 'indicators' are further defined. These are located in the fifth level of the hierarchy in Figure 4.3. These indicators are not only useful in quantification of the impacts, but are also a helpful means of identifying the key model variables at an early stage of the model development process.

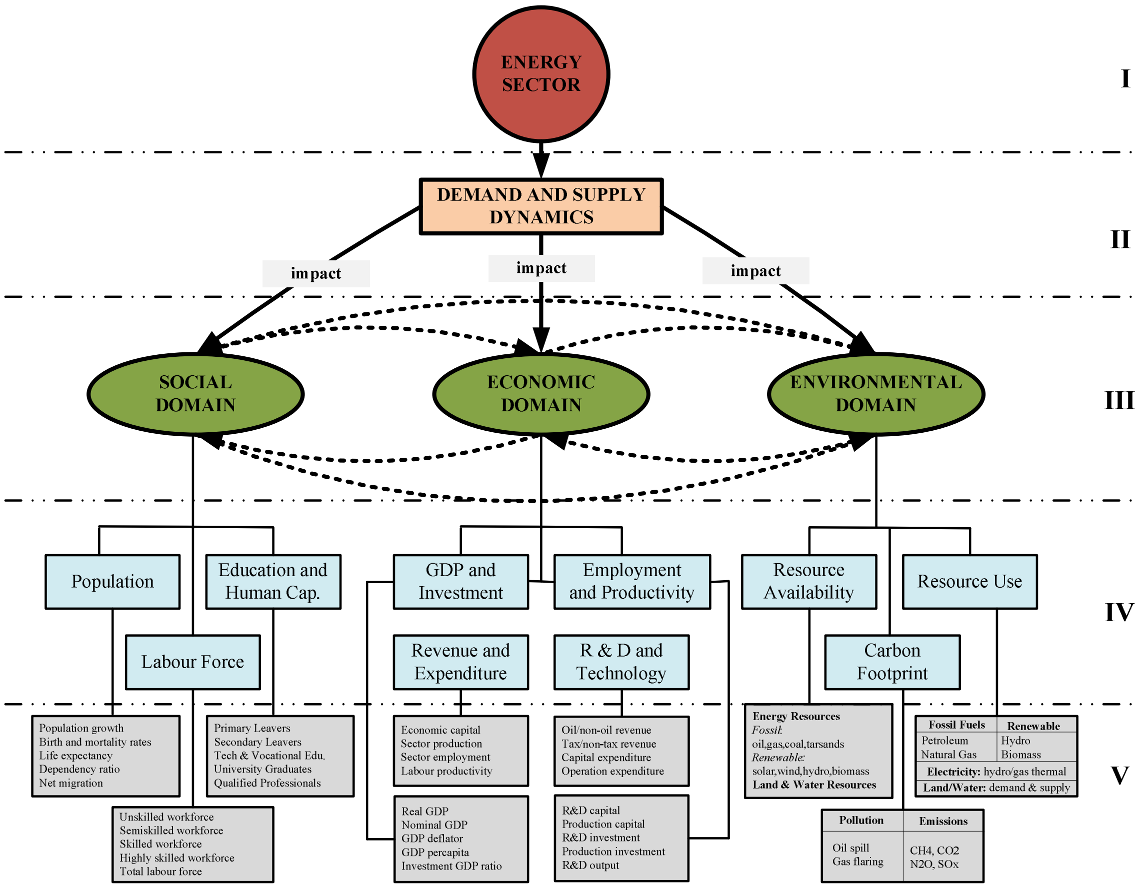


Figure 4.3: Conceptual Framework for the E-PAM. After [5].

Our focus on the ten sub-domains under consideration is as a result of stakeholder input during the first phase of stakeholder consultations in Nigeria, to determine what is relevant to the model, and to define the system boundary. The suitability of the choice of these sub-domains will be assessed at a later stage when the results are reviewed.

4.3.2 Dynamic Hypothesis: A High Level Map

Dynamic Hypothesis (DH) in SD modelling is taken to mean an intuitive representation of the causal relationships amongst system variables that cause observed system behaviour [140]. DH is seen by many as a precondition for developing a SD model [141], although, there are no strict rules specifying this. It is however, good practice to propose a DH before constructing a SD model, as it serves as a useful guide to model development, *"particularly in complex model building"* [9]. In this study, a

DH is configured in the form of a High Level Map (HLM), illustrated in Figure 4.4. The HLM represents the overall structure for the key model variables; it also serves as a dynamic hypothesis, which governs development of the E-PAM (using vensim™) [88].

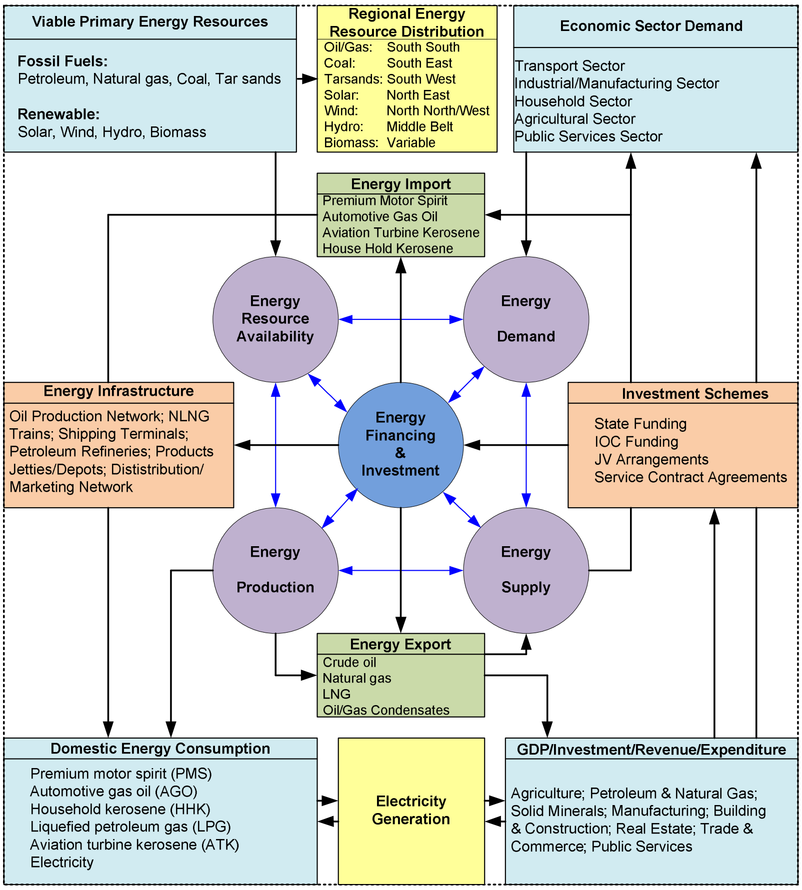


Figure 4.4: Dynamic Hypothesis: a High Level Map.

In the HLM, there are four critical foci: energy resource (availability), energy demand (management), energy extraction and conversion (efficiency) and energy financing (investment). The DH postulates 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 placed in a dynamic equilibrium, such that any distortion in their balance is likely to create significant ripple effects on the three sustainability domains.

As illustrated in the map, the Energy Resource Availability (centre upper left corner) of Viable Primary Energy Resources (top left corner) is the first step towards ensuring Energy Security. The Energy Supply (centre lower right corner) of these resources is triggered by the Energy Demand (centre upper right corner) to power and sustain the Economic Sector Demand (top right corner). However, a sustainable Energy Production (centre lower left corner) is only feasible when enabled by continuous Energy Financing and Investment (captured in the nucleus).

4.3.3 Definition of Model Boundaries

In the context of a SD modelling, a system boundary as discussed in Chapter 2 is a margin that separates internal elements of the system from its external components. For our model, the internal elements of the system are defined either as *"exogenous"* or *"endogenous"* variables [9, 142, 143]. Exogenous variables are those parameters brought in to drive the model from other external sources, while endogenous variables are those generated from within the model [88]. The major difference between the two is that unlike exogenous variables that can influence the behaviour of the model from a standalone source, endogenous variables influence each other in their interactions [144]. Furthermore, those driving forces that can potentially influence the behaviour of the model, but are not included within the model boundary are termed *"excepted"* variables in this study.

As demonstrated in Figure 4.5, the model boundary is defined to reflect the key model sectors and their *"dynamic interplay"* [9, 145, 146]. The model boundary encompasses the dynamics of the energy sector and the three sustainability domains. The exogenous (input) variables from the energy sector and the three domains are located on the left; the endogenous (output) variables from the same domains are located on the right, while the excepted variables to the model are located below the model boundary. In terms of scope, this implies that the E-PAM focuses on analysis of energy sector interplay with the economy, society and the environment in Nigerian context. Variables such as political and religious crises, natural disaster, terrorism, war, and corruption [6] are acknowledged as influential *"external actors"*, but are treated as *"excepted variables"* in our model—meaning that they are not included in the model, and do not directly influence its behaviour.

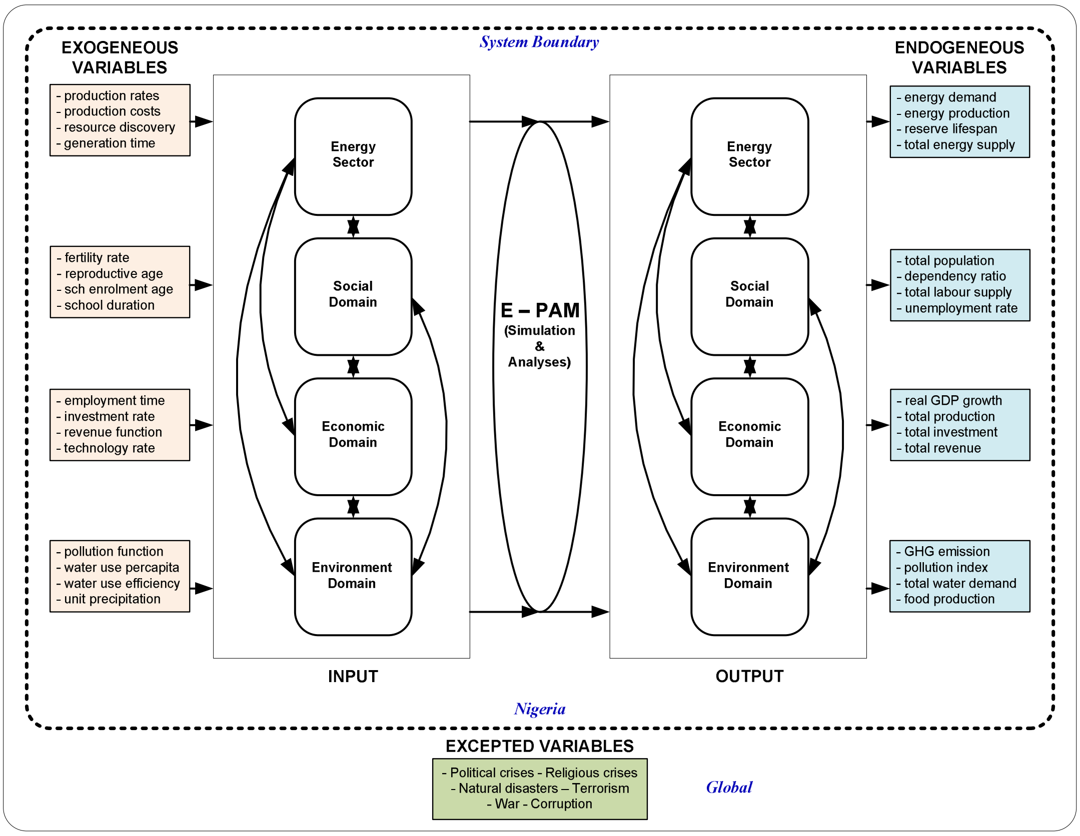


Figure 4.5: An Integrated System Boundary for the E-PAM.

4.3.4 Model Purpose

In broad terms, the purpose of the E-PAM is to characterise the dynamic interplay between the critical energy variables and the three sustainability domains. The model aims to serve as a 'baseline' from where alternative energy policies aimed at improving the status quo 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?"* This also means that the model aims to deal with the question *"how should the Nigerian energy sector be developed to maximise sustainability?"*

Thus, the need for an integrated and holistic tool to aid policymakers in effectively handling the current reform efforts of the Nigerian government cannot be overemphasised. It is expected that the E-PAM will aid policymakers in Nigeria in the assessment of energy policies in relation to impacts on the economy, society and environment. The model will be useful in the formulation and analysis of alternative policy strategies involving *"multilevel, multidimensional and multi-stakeholder complexity"* [138]. The key advantages of the E-PAM are 'dynamism' and 'holism' [147, 148]. This means that the tool aims to support policy planning in an integrated and comprehensive manner [16]. It also aims to be a flexible and customisable tool that provides a solid base for examining policy issues in their reference cases and for testing alternative scenarios [16].

Elsewhere in the world, particularly in transitional economies, System Dynamics-based models have been used to support energy policy and economic planning. Among such examples is the application of the T21 model framework of the Millennium Institute (MI) in China, Denmark, the Balkans and Guyana [5]. In the African continent and the Caribbean, specific examples of such use include Ghana, Mali, Malawi, Mozambique and Jamaica [5]. However, no such tool has been developed and used for the purposes of planning and evaluation of national policies in Nigeria, hence, the motivation for developing a similar tool in this research.

4.4 Model Development Process

This section discusses the overall model development process. As shown in Figure 4.6, the development process for the E-PAM consists of seven main phases (I – VII). Each of these development phases is considered in details in the following subsections.

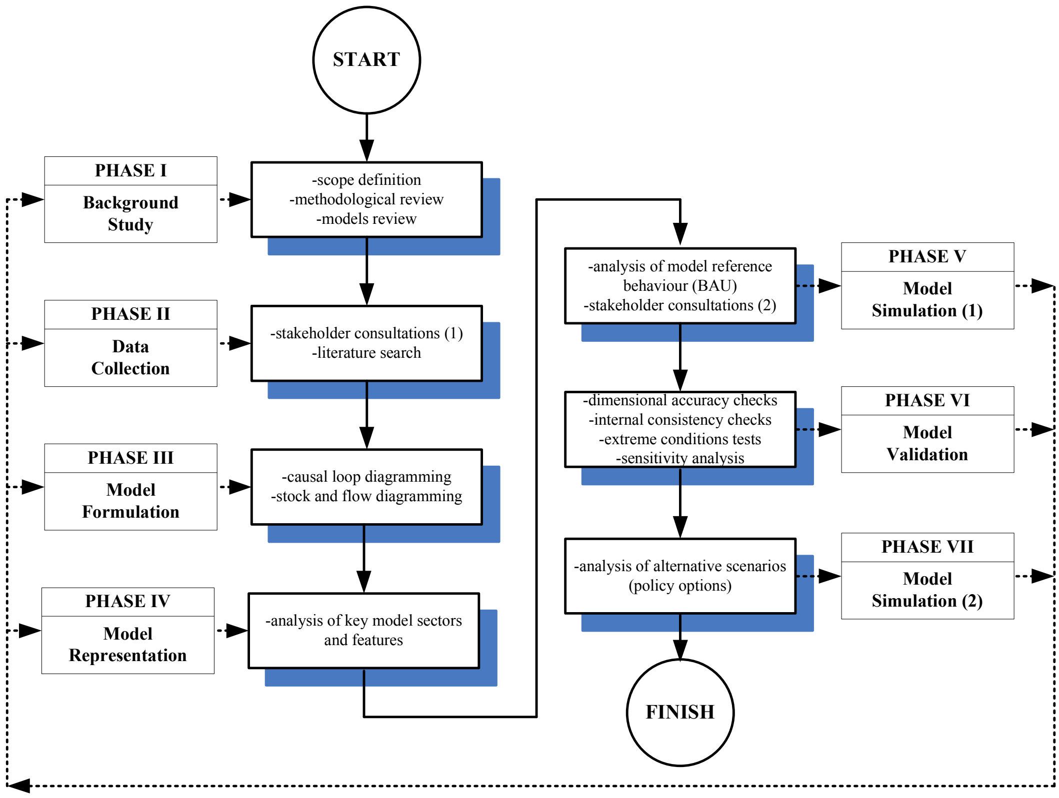


Figure 4.6: Development Process for the E-PAM.

4.4.1 Phase I: Background Study

The first phase of the model development process began with a critique of the Nigerian energy situation. During this phase, publicly available technical and strategic policy documents [13, 14, 106, 123] for the Nigerian energy economy sector were reviewed. The object was to become familiar with the latest thinking of government and its level of preparedness in dealing with the defining challenges to Sustainable Energy Development in that country. These background studies enabled an understanding of the main issues, which also helped us in defining the model scope.

Furthermore, a critical review of existing assessment tools and methodologies, and analysis of national energy planning and evaluation models in current use was undertaken. The System Dynamics methodology was found to be a useful approach for building an integrated dynamic model, which when combined with a simple, stakeholder-focused MCE[4] method such as SMART[5], would provide a robust framework for analysing the energy economy situation of Nigeria. This helps in making choices between competing alternative policies targeted at improving the status quo.

The choice of a dynamic model for this study was in consideration that the static modelling approaches are unable to represent within a single framework, the dynamic interactions between the interconnected system variables [6]. Dynamic models on the other hand, present a holistic way of dealing with integrated complex problem, as they capture interesting dynamics of the system variables [16].

Based on the understanding formed on the basis of these background analyses, the model scope was designed, with the aim of representing a holistic problem solving approach. The scope of the E-PAM was defined to focus on analyses of energy sector impacts and interactions with the economy, society and environment in Nigeria.

4.4.2 Phase II: Data Collection

The second phase of the model development process focused on collecting relevant data from diverse sources. This includes sourcing of information through stakeholder consultations as well as literature and database searches. It can be recalled that the original idea of combining a SD simulation model with a 'social-oriented' MCE model in this study was to provide a rigorous and inclusive platform for exploring

[4] Multi-Criteria Evaluation

[5] Simple Multi Attribute Rating Technique

energy policies in a national context. The SD model aimed to provide the quantitative basis for policy analysis [149], while the MCE method accounts for stakeholder perspectives—including issues of *"values"* and *"trade-offs"* [8, 17]. More importantly, the MCE aids in choice selection between competing alternative policies [17, 150-152].

To achieve this purpose, targeted contacts were made (see Section 3.2 of Chapter 3) with energy experts and members of the government economic team—the potential users of the model. Some policymakers from five government ministries: MPR, NNPC, ECN, NPC and FME were at this stage contacted by telephone and email communication, to provide preliminary inputs. The work enabled gathering of country-specific energy, social, economic and environmental data, and in defining appropriate model boundaries.

Since the energy industry is generally well developed, with many international stakeholders and interest groups, valuable energy sector data on Nigeria were also obtained from international energy corporations, foreign government departments, and multilateral organisations. These include: BP, Shell, Chevron, ExxonMobil and Total. Others are US EIA, IEA, IAEA as well as the CIA, UNDP and the World Bank Group.

Major national sources consulted to obtain social, economic and environmental data include: the Central Bank of Nigeria (CBN), National Bureau of Statistics (NBS), Energy Commission of Nigeria (ECN) and Nigerian National Petroleum Corporation (NNPC). The model sectors were configured with data collected from these sources, to reflect the dynamic interaction between the energy sector and the three sustainability domains; see (Appendix A for a full list of research data sources).

4.4.3 Phase III: Model Formulation

The actual configuration of the E-PAM is made up of two segments: 1) illustration of causal loop diagrams [7, 9, 149, 153] and 2) building of stock and flow diagrams [7, 9, 149, 153]. These are further elaborated in the following discussion.

a. Causal Loop Diagrams

In SD modelling, positive (+ve) and negative (-ve) feedback are represented by a system of reasoning known as Causal Loop Diagram (CLD) [153], also referred to as Influence Diagram (ID) [153]. These are visual representation of 'cause' and 'effect' relationship amongst system variables, which when linked together form closed loops [9]. The CLD procedure helps us in understanding how interrelated variables affect one another dynamically [149]. For the E-PAM, four sets of influence diagrams were defined, one for the energy sector, and one for each of the three sustainability domains.

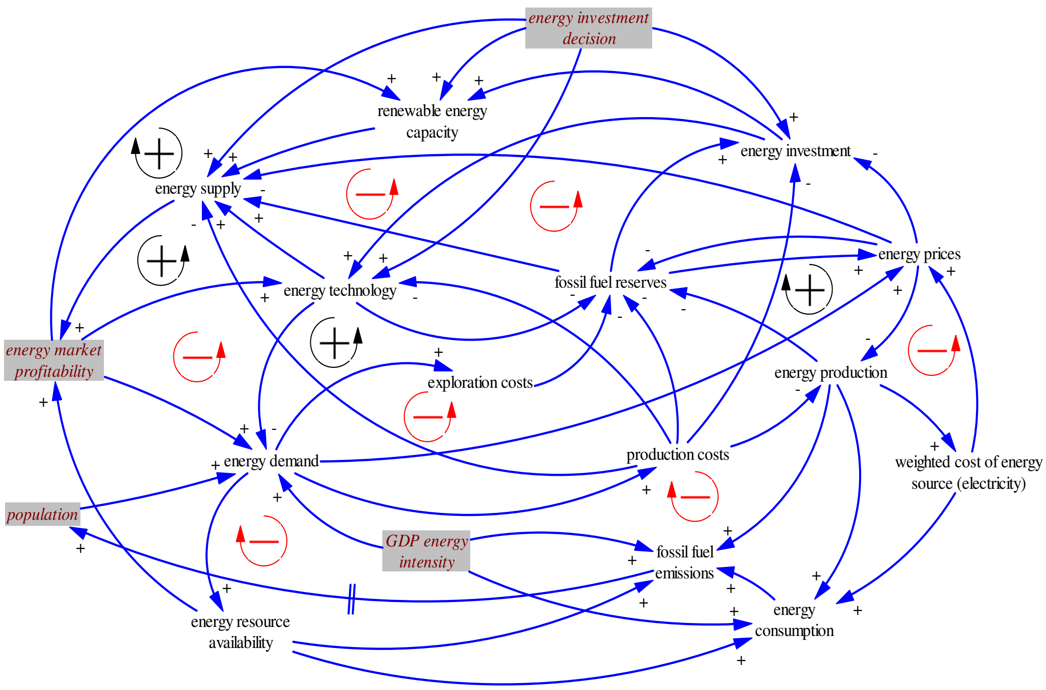


Figure 4.7: Influence Diagram for the Energy Sector.

As represented in Figure 4.7, the energy sector is made up of variables such as energy resource availability, energy production, energy consumption, energy demand, energy supply and energy prices and costs, among others variables. The highlighted variables (in grey boxes) such as energy investment decision, energy market profitability, population and GDP energy intensity are termed *"exogenous variables"* because they influence the energy sector, but are themselves externally determined—meaning they are constituent members of the larger model, but do not belong to the sector they are influencing. For example, population and GDP (highlighted in Figure 4.7) are variables within the social and economic domains, which have direct links to the energy sector as major drivers of 'energy demand'. The 'cause' and 'effect' relationship amongst these variables produces a particular pattern of behaviour.

Conventionally, CLD can have 'positive' (reinforcing) or 'negative' (balancing) feedback structure [153]. Negative or balancing loop means that the variables closing a loop carry 'uneven' number of negative links [153], while the variables with positive or reinforcing loops maintain 'even' number of negative links [153]. For example, the black circular shapes (with "+") in Figure 4.8 and other similar diagrams represent closed feedback loop, with the sign convention indicating the direction of the loop. Similar interpretations can be made for the red circular shape (with "-"). These system feedback loops help us in understanding what is causing a particular behaviour pattern in a system [7]. This behaviour can be observed through simulation, after the 'system boundary' and 'time conditions' have been defined [9].

The sub-domains that constitute the social domain in the E-PAM are: population, education, human capital and labour supply, among others. Different variables within these subdomains influence each other in a dynamic interaction as shown in Figure 4.8. Their 'cause' and 'effect' relationships and behaviour reproduction follow the same convention as described in the previous paragraphs under the energy sector.

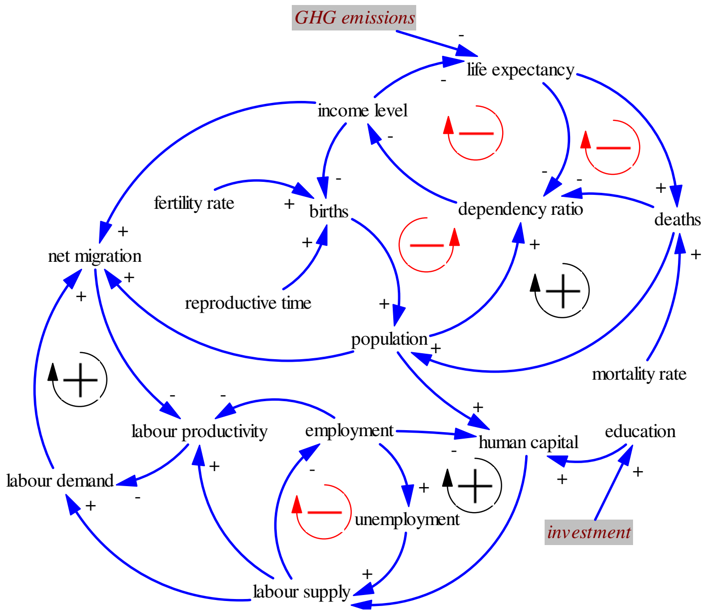


Figure 4.8: Influence Diagram for the Social Domain.

For the economic domain (Figure 4.9), the variables that define the causal relationships are: economic production, GDP, investment, labour productivity and income level. Others are production capital, government revenue, expenditure and debt servicing. Here, economic investment decisions, taxation policy, GDP deflator and market profitability are considered *"exogenous"* to this domain, as they influence the system but are by themselves not influenced by any variable within the domain.

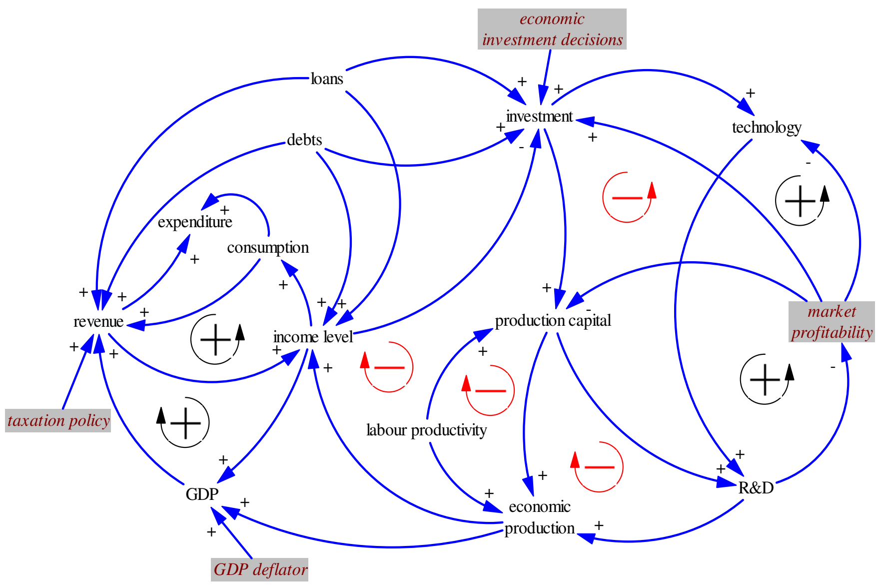


Figure 4.9: Influence Diagram for the Economic Domain.

Model variables for the environment domain were defined to include carbon emissions, water and land demand, water and land availability and agriculture intensity, among others. In this case, the time delay (indicated with a delay mark //) in Figure 4.10 is used to represent the delay experienced between an 'action' and a 'response' [9]. In reality, this represents the time delay that could be experienced, before effect of technology on land availability for example, could be noticed. The same principle of delay is applicable to other sectors with a delay mark. For this study, the influence diagrams provide the basis for developing the model 'stock' and 'flow' structures.

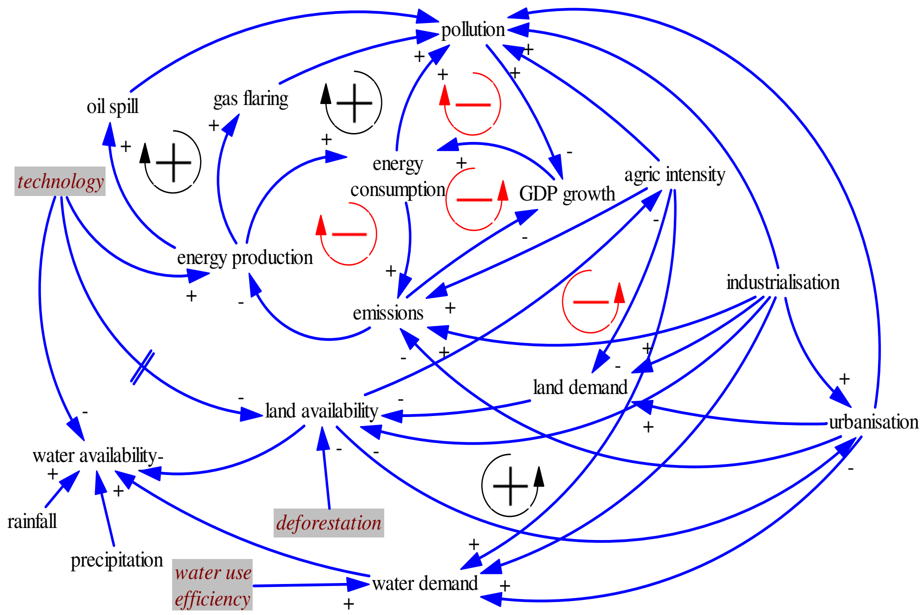


Figure 4.10: Influence Diagram for the Environment Domain.

b. Stock and Flow Structures

The SD methodology employs simulation modelling for experimental analysis, and for solving a variety of complex problems [149]. As mentioned in earlier sections, the approach aids decision making by providing a set of tools for describing, modelling, and analysing the cause-and-effect relationship among system variables [153]. One of such simulation and analyses approaches involves building 'stock and flow' structures, also known here as *"Model Building Blocks"*. These structures cause a characteristic behaviour pattern in a system [9]. A 'stock' (i.e. level variable) is an accumulation over time due to inflows (i.e. addition to the stock) or depletion over time due to outflows (i.e. subtraction from the stock), while a 'flow' (i.e. rate) changes stock over time. In SD modelling, this phenomenon is known as the principle of accumulation [7].

Detailed 'stock and flow' diagrams of the E-PAM developed in this study are located in the attached CD. However, as an illustration of how a stock and flow model works, we present here, one of the model views (population sub model) as shown in Figure 4.11. An example of equations behind the model formulation is also explained.

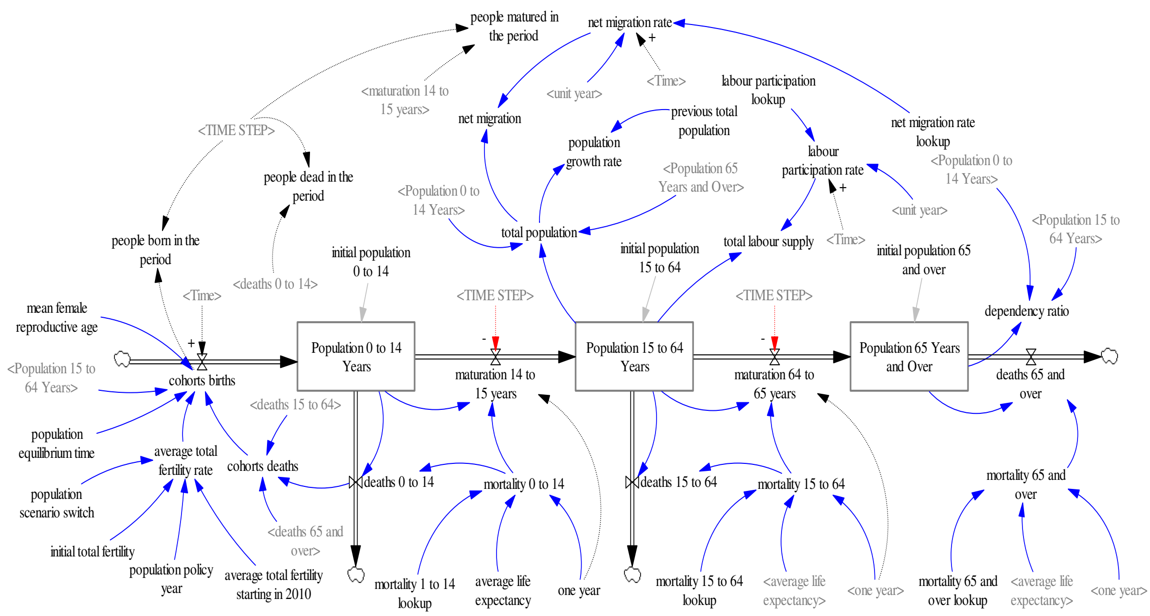


Figure 4.11: Stock and Flow Diagram of the Population Sub-model.

The population sub model is the first model view developed in the E-PAM because of its significance in structuring other model views: 1) It provides the foundation for assessing the availability and quality of human capital needed to transform the energy economy of Nigeria; 2) It directly influences the behaviour of other important model variables such as primary energy demand, energy use per capita, GDP per capita, electricity consumption per capita and several other indicators.

The model view presents an age-based population structure of Nigeria, which is stratified into three broad groups. These are 1) population ages 14 years and under (i.e. under-aged dependent population); 2) population ages 15 to 64 years (i.e. working population) and 3) population ages 65 years and over (i.e. ageing dependent population). In addition, total population growth, dependency ratio and net migration (key demographic indicators) are also endogenously computed in this sub model. This helps us to also highlight the extent of 'pressure' exerted on the working population by the non-active groups, and the impact of human capital losses due to migration.

As shown in Figure 4.11, the indicator 'cohorts births'—which is the total birth rate in Nigeria (measured in Persons/Year) for example, is defined in the E-PAM as a function of six other variables, which is defined by the following equation:

Cohorts Births = IF THEN ELSE (Time >= population equilibrium time, cohorts deaths, (average total fertility rate*Population 15 to 64 Years*0.5/mean female reproductive age)) **(5)**

Where, **Time** is the internally defined simulation time (Year), **population equilibrium time** is the time at which, as a model, the population is forced to remain constant (Year), **cohorts deaths** is the total death rate in Nigeria (Person/Year), **average total fertility rate** is the total number of children a woman produces on average (Dmnl), Population 15 to 64 Years is the working population (People), and **mean female reproductive age** is the number of years women can reproduce (Year). The **IF THEN ELSE** (argument) is a Vensim^{TM} defined internal function. Its purpose is to *"switch between alternative formulations based on some condition"* [88]. For example, the meaning of Equation (5) is: *"d = IF a THEN b ELSE c"*, written as *IF THEN ELSE (a,b,c)*. It is implemented to assign a variable *"IF a THEN b ELSE c"* to the variable *d*.

4.4.4 Phase IV: Model Representation

The overall influence diagram representing the E-PAM is shown in Figure 4.12. It encapsulates all the high level variables for the four model domains under consideration. These are: energy, social, economic and environmental domains. The model is developed for a 50 year timescale from (2000 – 2050).

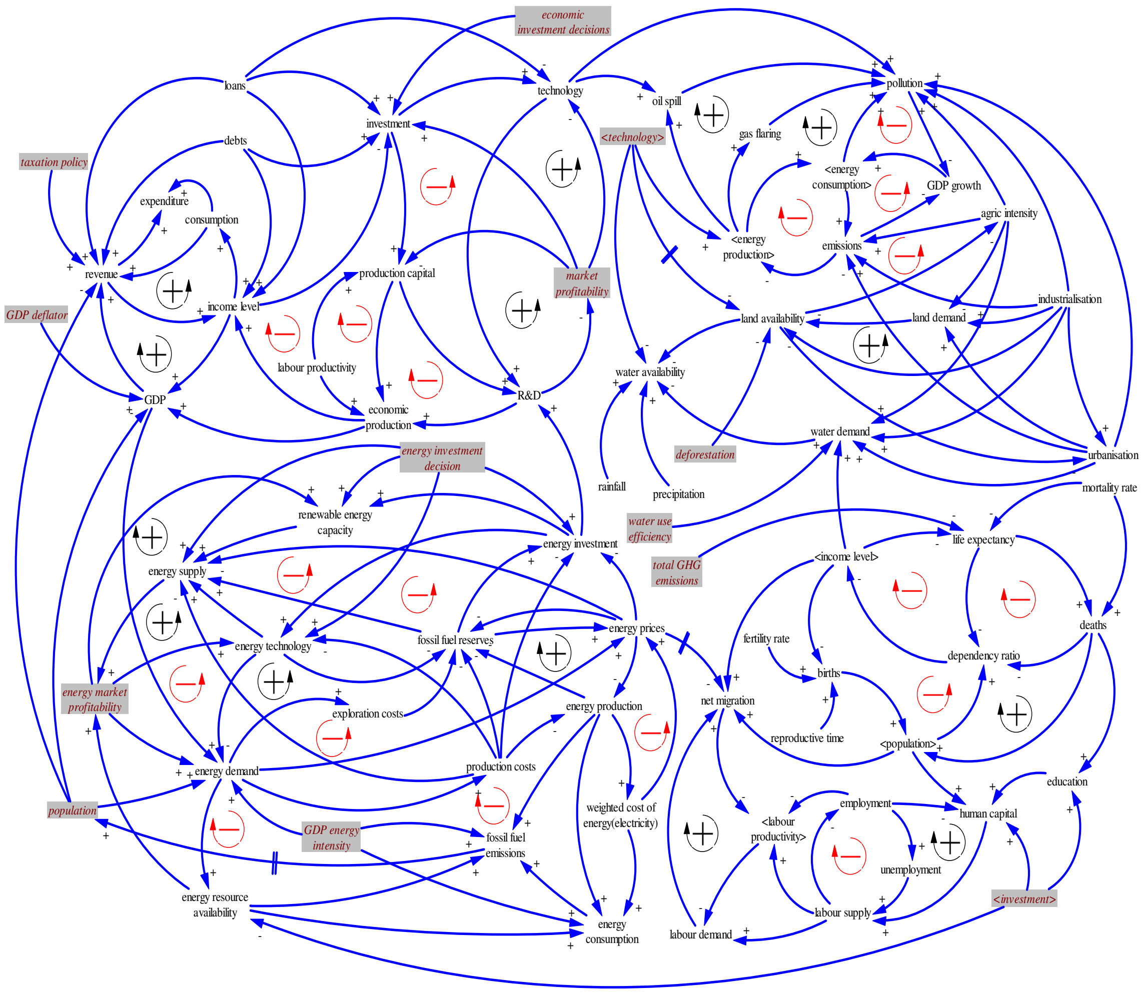


Figure 4.12: Integrated Influence Diagram for the E-PAM.

It consists of a total of 10 subdomains in 18 views, 999 individual relationships and equations and 81 'high level' feedback loops. The model also includes a total of 1132 symbols, 120 Lookups, 224 Level variables, 733 Auxiliaries and 85 Initial + 498 Constants. In view of space limitation for this report, individual views for the remaining 17 sub models are not presented here; they are located in attached CD in this thesis.

However, the 18 model views can be summarised according to domain as shown in Table 4.1.

Table 4.1: Summary of Model Views according to the Four Domains.

ENERGY SECTOR SUB MODELS	**SOCIAL DOMAIN SUB MODELS**	**ECONOMIC DOMAIN SUB MODELS**	**ENVIRONMENTAL DOMAIN SUB MODELS**
-petroleum -natural gas -coal and tar sands -renewable energy -energy demand & supply -electricity generation	-population -education and human capital -workforce availability -employment and productivity	-GDP and investment -government revenue -government expenditure -R&D and technology	-oil and gas pollution -GHG emissions -water use -land use

Data collected from various sources earlier described, provided input parameters for the model. Data were collected in EXCEL spread sheet format; they were however, inputted into the model as 'Constant' or 'Lookups' [88]. This implies that the E-PAM is configured to run endogenously, without data inputs from any other external sources. The purpose of this approach is for the model to remain self-driven, and to avoid data loss and the task of moving large EXCEL data files, which could easily introduce errors to the model. The initial model conditions were setup by specifying key parameters such as the Time Bounds (i.e. Initial Time = 2000 and Final Time = 2050), Units of Time = Year, the Time Step = 0.5 and the Integration Type = Euler.

The model parameters were also *"tuned"* through an optimisation process using Vensim™ automated policy optimisation software. The approach involved first defining the *"payoff"*—a measure of fit to show *"what is good"* and *"what is bad"* [88], as expected in the simulation output. A range of model Constants (in each of the sub models shown in Table 4.1) were then inputted and varied with Optimisation Control to maximise the *"payoff"*. The purpose was to perform multiple simulations with Vensim™ to find optimum Constants to fit the output. An analysis of the key model features is captured in the following subsections.

i. Representation for Energy Domain

As previously highlighted, the energy domain variables considered in the E-PAM framework include: energy resource availability, energy production and consumption, demand and supply, energy prices and energy investments. Others are production costs (for fossil fuels) and installation costs (for renewable).

Total primary energy demand is disaggregated into agriculture, household, industry and manufacturing, transport and power sectors demand. Energy demand as configured in the E-PAM is driven by GDP growth, population growth, energy prices and technology. The demand influences energy investment, production and prices.

From the supply side, total primary energy supply is categorised into fossil fuels (oil, gas, coal and tar sands) and renewable (hydro, solar, wind and biomass). Energy supply is driven in the model by demand, availability of reserves (for fossil fuels), availability of installed capacity (for renewable), investment, technology as well as other exogenous factors such as policy decisions. Energy supply in turn, is considered to influence consumption, prices, pollution and emissions.

The electricity supply sector is modelled from a two source supply structure: hydropower and gas thermal. The key outputs of interest under this sector are total electricity demand; sector electricity demand; electricity demand per capita and total electricity supply. On the one hand, electricity demand is dependent on a number of factors including GDP, technology, oil and gas prices and price elasticity. On the other hand, supply is dependent on demand, fuel source, investment, plant availability and plant efficiency. Overall, energy investments in the context of the E-PAM are dependent largely on market profitability, technology and production costs.

ii. Representation for Social Domain

As already highlighted in the conceptual framework (Figure 4.3), the subdomains defined under the social domain are: population, education and human capital and labour force. The population structure is defined by sex and age of cohorts. Key variables of interest under this sub-domain include: number of births, population growth, life expectancy, cohorts deaths, net migration and dependency ratio. Also, population pyramids are constructed to show changes in population over time to 2050.

The education subdomain represents the influence of human capital development on labour force supply. The education subdomain is segregated into five classes according to level of educational attainment. These are: 1) primary; 2) secondary; 3) technical and vocational; 4) university and 5) professional qualifications. The subdomain aims to provide the basis for assessing the quality of human capital required to catalyse energy development in the country through research and technology.

On the other hand, labour force supply (in terms of both quantity and quality) is affected in the model by population and education and training. In this study, the labour force supply subdomain is categorised into four major groups according to skill level. The skill levels considered are: 1) unskilled (primary and secondary levels); 2) semiskilled (technical and vocational level); 3) skilled (university level—for both arts and commercial and science and engineering) and 4) highly skilled (professional level). The output from this subdomain helps us to determine the amount and quality of workforce necessary to turnaround the energy industry in Nigeria.

Overall, we aim to examine the interplay between the energy sector and the social domain. On the one hand, we seek to assess energy impacts on society, and on the other hand, we aim to quantify the social factors that influence energy usage in the country.

iii. Representation for Economic Domain

The E-PAM's economic domain is concerned with GDP and investment, employment and productivity, government revenue and expenditure, and R&D and technology. The GDP is influenced in the model by activities of the productive subsectors, which for the purpose of this study are grouped into: agriculture, services, oil and gas, and 'other industries'. *"Other industries"* in this context include sectors such as mining and manufacturing.

The production subdomain, which is characterised by the Cobb – Douglas production function (also see Chapter 2, Section 2.2), is affected by resources, labour, capital and technology development. Investment as configured in the model is influenced mainly by GDP, relative prices and consumer spending, while government revenue and expenditure is affected by these and other economic activities. Revenue derivation is shaped by activities such as taxes, exports earnings, royalties, privatisation proceeds as well as custom and excise duties. Government expenditure is influenced mainly by revenue derivation, investments and budget and debt services. The R&D and technology subdomain is driven mainly by production capital and investment.

Under GDP and investment, the indicators defined are: real GDP, GDP growth rate, income per capita as well as domestic and foreign direct investments. In employment and productivity, the variables of interest for further consideration are: economic sector employment, total labour demand, unemployment rate and productive capital. Government revenue is considered mainly as 'oil and non-oil' and 'tax and non-tax' revenue, while government expenditure is categorised into 'operations' and 'capital' expenditure. For R&D and technology, the key variables are productive capital, productive investment and public and private sector R&D investment.

iv. Representation for Environmental Domain

The environmental sub-domains configured in E-PAM are: energy resource availability, energy resource use, and the carbon footprint of energy usage. Energy resource availability is affected by demand, prices and technology. Resource use is influenced by energy demand and resource availability, while the carbon footprint is affected mainly by fossil fuels production and consumption.

Further analysis of energy resource availability and resource use are considered for fossil fuels, renewable energy and electricity use. The fossil fuel resources considered are: crude oil, natural gas, coal and tar sands, while renewable energy resources include: solar, wind, hydro and biomass. GHG emissions defined for further analysis in this study are: CH_4, CO_2, N_2O and SO_x. Also, the oil and gas industry pollution from 'oil spill' and 'gas flare' are specifically modelled in this subdomain to examine their degree of impacts. Other important pollution factors included are 'effect of pollution on productivity' and 'pollution abatement cost'.

4.5 Model Validation: a Composite Approach

Model validation is a difficult process because of our inability to demonstrate what actually constitutes a good model. Several literature sources [7, 9, 154, 155], have noted that the concept of model 'validation' or 'verification' is not only ambiguous, but it is also untenable. In Business Dynamics, Sterman [9] states that model validation is impossible—explaining that *"the impossibility of validation and verification is not limited to computer models, but to any theory that refers to the real world"*.

Despite on-going debates about model validation, there is still the need to define and develop procedures that will ensure 'credibility' and 'acceptability' of structured models. In this study, a composite approach was adopted as a means to check the structural robustness and dimensional consistency of the E-PAM. A composite validation approach in this context refers to the process of combining several techniques to test the model. The approach is illustrated using the algorithm shown in Figure 4.13. Each of these validation steps is further discussed in the following subsections.

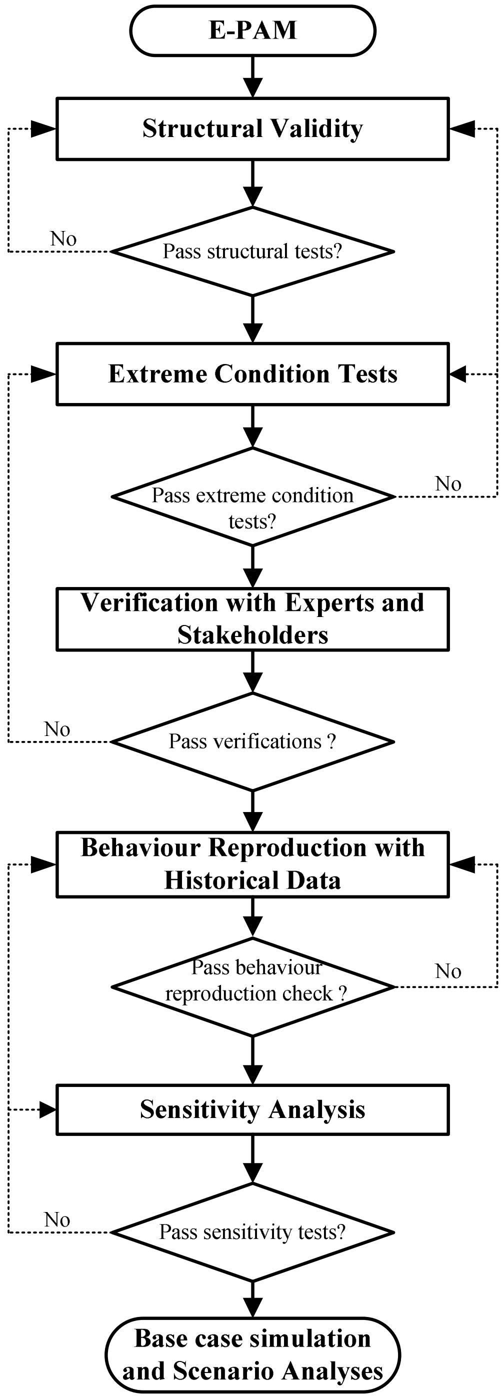


Figure 4.13: E-PAM Validation Algorithm.

4.5.1 Structural Validity

The first step in the E-PAM validation began with thorough consideration of the model structure. The tests carried out here focused primarily on three areas 1) boundary adequacy, 2) dimensional consistency and 3) parameter assessment [9]. The procedures adopted in conducting these tests are further described in the following paragraphs.

a) Boundary Adequacy Check

Boundary adequacy is a structural test that was used to assess the degree of appropriateness of the E-PAM boundaries with respect to the defined model purpose. The test sought to provide answer to the following: 1) whether the concepts employed in addressing the problem statement are 'exogenous' or 'endogenous' to the model and 2) whether the simulated behaviour of the E-PAM changes significantly with changes in boundary assumptions [9].

Three different approaches were used in examining the above questions. The first was review of relevant literature and archival materials [9]. The aim of this procedure was to determine whether our model boundaries are radically different from, or are in line with what has been done elsewhere for similar, integrated national planning models. The second approach followed direct inspection of the model structure. This was done to ensure that the E-PAM structure is correctly formulated—reflecting the defined boundaries. The third assessment method focused on structural modifications [9]. The approach was based largely on making 'exogenous' variables 'endogenous', so that the model can be self-driven, to avoid data loss and the task of carrying large EXCEL files that could easily introduce such errors.

b) Dimensional Consistency Test

Dimensional analysis remains one of the basic and early tests carried out on the E-PAM during its development phase. The approach involved judging the relationship of the model variables and their units. The test sought to know if the equations defined are correct, and whether the model parameters and units have real world meanings [9].

Two main procedures were used to evaluate the model dimensions: 1) direct inspection of equations and 2) use of dimensional analyses software [88]. The relationship amongst model parameters and the assigned units were systematically inspected to ensure consistency. In addition, inbuilt vensim™ automated dimensional analysis software was used to test dimensional errors [88]. The approach helped us to effectively deal with issues of meaningless names and strange combination of units [9].

c) Parameter Assessment

The parameter assessment test ensures that every defined model parameter has clear and real-world meaning [9]. In a specific sense, the approach was deployed by direct inspection to measure: 1) whether the defined parameters were consistent with the described system problem and 2) whether all the parameters used in E-PAM formulation have real world meaning. This helped us in dealing with other model accuracy issues highlighted above.

4.5.2 Extreme Condition Tests

The second stage of the E-PAM validation procedure dealt with issues of model robustness when subjected to extreme conditions. The procedure known as 'Extreme Condition Test' [9] focused on two major issues: 1) whether the equations defining the E-PAM make sense, even when their inputs take on extreme values and 2) whether the model remains responsive as expected when subjected to extreme parameters.

In answering the first question, a set of extremely low and high parameter values were assigned to randomly sampled model equations and simulated. The idea as already explained, was to examine (by direct inspection) whether the relationship between the affected model variables remains valid under such extreme conditions or not. Secondly, the overall behaviour of the E-PAM was examined under the assigned conditions, to determine whether the model produces the desired pattern of behaviour or there were dramatic changes in its *"response to shocks"* [9]. All errors detected at this stage were corrected before further development of the model.

4.5.3 Verification with Experts and Stakeholders

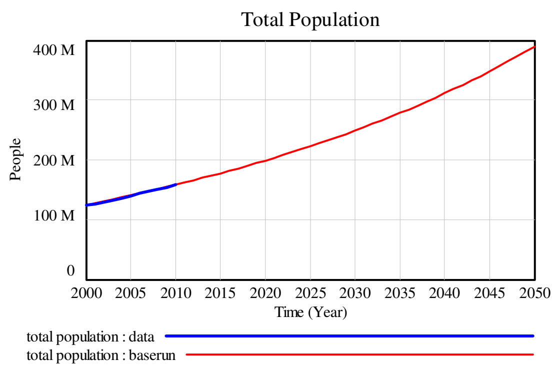
Model verification with experts comprised presenting the E-PAM to experts and peers at different forums during the development process. Different model (views and outputs) were presented at three international conferences in Nottingham, Botswana and Switzerland, to obtain expert opinions and feedback [134, 138, 156]. In two of these conferences, a structured approach to feedback was used. In the Nottingham [138] and Switzerland [134] conferences, 27 and 35 participants who attended the two presentation streams respectively, were all given a form with specific questions to provide their comments. Feedback questionnaires were designed by the conference organisers to cover issues such as presentation style, quality of paper and relevance of material. Individual feedback were collated and returned to the author after paper presentation. In addition, specific feedback was received from conference paper reviewers during the 'blind review' process. The researcher collated this information, which was found useful for updating and improving the model during development.

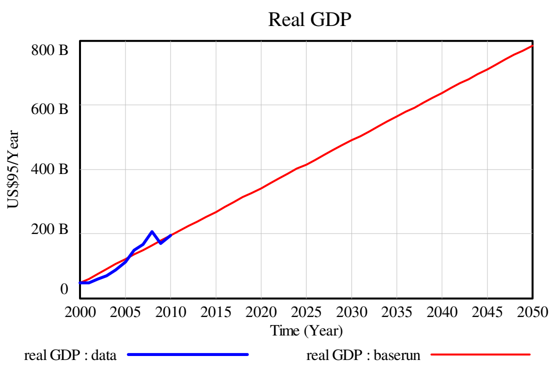
After this phase, the updated model was presented to stakeholders in Nigeria (the potential users of the model) during a short field trip. A group of fifty policymakers from five ministries in Nigeria (fully discussed in Chapter 3) were consulted during the fieldwork. The model structure and the simulated outputs were presented to them for their comments and inputs. A standardised Data Collection Instrument (DCI) (shown in

Appendix B) was used to gather stakeholder opinions about the model. This information was also found useful, and was again used to update the model, and in some cases, modify it to reflect the new inputs. Verifications exercise with stakeholders enhanced our understanding of their level of awareness and preparedness in using structured tools like the E-PAM. As shown in Appendix E, 92% of stakeholders consulted stated the E-PAM is very relevant and useful to their operations, 68% thought they fully understood the model and its mechanisms, and 90% were very willing to use it if made available.

4.5.4 Behaviour Reproduction

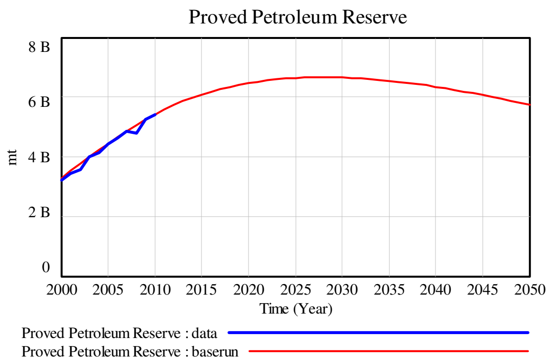
Behaviour reproduction in this context means, fitting the behaviour patterns of the E-PAM to real-world data. Here, the concept was used to ensure that the model replicates the pattern of behaviour of what is known in real life [9]. This implies that the behaviour of the four model domains for the period (2000 – 2010) is fitted to a 10 year historical data; the behaviour patterns for the remaining 40 year timescale (2010 – 2050) are based on model forecast. Historical data were used to verify congruency of the model behaviour with real data. A few examples of the behaviour reproduction results for some of the indicators (one for each domain) are shown in Figure 4.14.



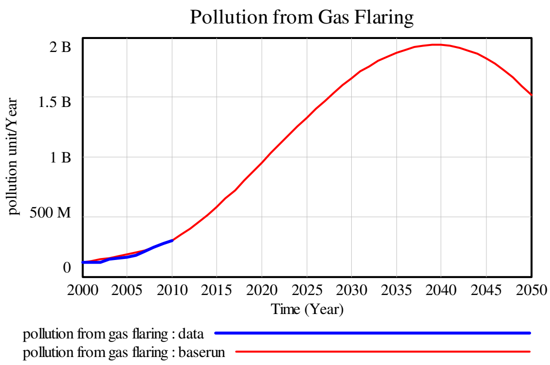


(a) total population

(b) real GDP



(c) proved petroleum reserve



(d) pollution from gas flaring

Figure 4.14: Behaviour Reproduction with Historical Data for Some Indicators.

4.5.5 Sensitivity Analysis

In SD modelling, sensitivity testing involves changing model assumptions about the values of the model constants (also known as parameters), in order to examine the resulting output [88]. This can either be done manually (i.e. changing and simulating model parameters one at a time) or automatically (using a procedure known as Monte Carlo Simulation or Multivariate Sensitivity Simulation—MVSS) [88].

In our case, the MVSS procedure was done by repeated random sampling of the E-PAM parameters over a range of values. The approach helped us to further examine the properties of the model parameters and the behaviour of the model under varying conditions. Here, parameters were selected and assigned 'maximum' and 'minimum' values along with a probability distribution over which to vary them [88]. The probability distribution used for data sampling is the *Random Uniform Distribution*[6]. The results of these tests are discussed in a relevant section in Chapter 6 of this report.

[6] A probability distribution utility where any number between the *min*. and *max*. values is likely to occur.

4.6 Conclusion

This chapter has discussed the development process for the Energy Policy Assessment Model (E-PAM), proposed to serve as a tool to aid policymakers in the planning and analysis of energy policies in a national context. The E-PAM specifically seeks to be an integrated tool for examining the dynamic interplay, and long term impacts of the energy sector on the Nigerian economy, society and the environment, and it can be customised for use elsewhere.

The model development process provided significant insights into the challenges to Sustainable Energy Development (SED) in Nigeria. Some of the key insights drawn from the process include the following: 1) that one of the major challenges Nigeria currently faces is ineffective energy policy formulation and implementation and 2) that there is a general lack of structured tools to aid planning and evaluation of effective policies; tools that will bring about the process of informed decision making. It was also found that stakeholder consultations through fieldwork in Nigeria proved to be an essential part of the process, as this helped us in gaining valuable insights and inputs for the development and modelling of the E-PAM.

This chapter further discussed the key model features, which include 'dynamism' and 'holism'. This means, that the E-PAM supports policy planning and analysis in an integrated and comprehensive manner. The chapter finally, discussed the 'composite validation' procedure used to validate the model. The approach proved to be a useful way of ensuring a holistic representation and verification of the model. It also helps in ensuring the credibility and acceptability of the E-PAM, not only to experts but to target users as well. Analyses of the model's reference behaviour, also known as Business-As-Usual scenario are presented in the next chapter.

Chapter 5

Analysis of Model Behaviour: The Business-As-Usual Case

5.1 Introduction

This chapter presents an analysis of the E-PAM's 'Reference Behaviour', also known here as 'Baseline Scenario' or 'Business-As-Usual' (BAU) case. It discusses the model outputs that characterise the dynamic interactions between the energy sector and the three sustainability domains in their 'base runs', over a 50 year timescale (2000 – 2050). The behaviour of the model variables for the period 2000 – 2010 represents historical patterns. It is based on time series data obtained from data sources previously described in Chapter 4. The outputs for the period 2010 – 2050 are based on model projections under a BAU scenario.

The purpose of the discussion presented in this chapter is to examine behaviour patterns for the period (2000 – 2010) and the future trends of key model variables under BAU assumptions. The BAU case is a path that foresees no changes or any government interventions to the current (2000 – 2010) energy, social, economic and environmental policies. This means that under BAU, existing conditions for the four model domains being examined will continue into the future. In addition to a critical appreciation of the calculated results, the model outputs are presented in a tabular or graphical format. The aim is to increase visual impact of the highlighted variables of interest.

Section 5.2 presents a definition of the analytic issues under scrutiny. Section 5.3 explains the BAU assumptions and Section 5.4 presents analysis of the energy sector. Sections 5.5 – 5.7 discuss model outputs for the social, economic and environmental domains. Section 5.8 presents the chapter conclusions.

5.2 Definition of Analytic Issues

Within the interconnected energy sector and the three sustainability domains, a number of model variables have been identified through sensitivity analysis and stakeholder consensus, as focal issues for further analyses under the BAU case. The selection of these critical variables is also in line with our previous analyses on the dynamic interactions between the energy sector and the three domains in Chapter 3, and they represent the measurable indicators defined in Figure 4.3 in Chapter 4. These critical variables are summarised in a framework shown in Figure 5.1.

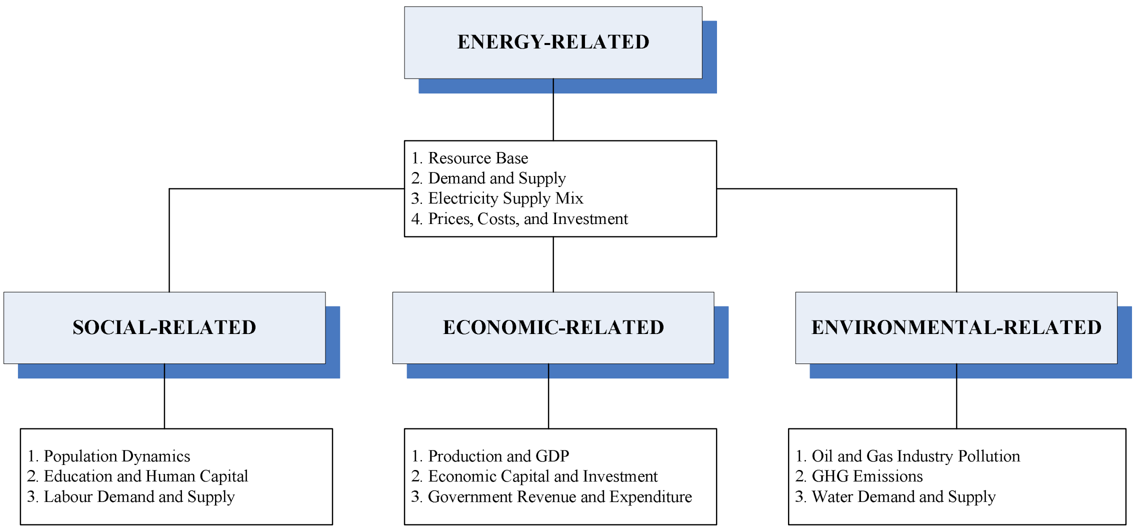


Figure 5.1: Analytic Framework for the E-PAM.

5.3 Key Baseline Scenario Assumptions

Analyses of the E-PAM under BAU are based on two main assumptions:

a) That no government interventions are expected to the current (2000 – 2010) energy, social, economic and environmental policies.

b) That current (2000 – 2010) trends in activities within the energy sector and the three sustainability domains will continue to year 2050.

In addition to these two broad assumptions, sector specific assumptions for the period 2010 – 2050 are considered as follows:

⇒ That no significant improvements in existing energy use conditions are expected in the country within the timescale under consideration. Here, the model assumes that technology progression for fossil fuels discovery (for both oil and gas) will continue at the rate of 0.09% to year 2050. This implies that crude oil and natural gas reserves will maintain annual growth rate of 0.14% and 0.39% respectively [117]. At these reserve growth rates, and at their respective production rates of 1.40% and 7.2% [117], oil and gas will maintain reserve-to-production ratio of 41.36 years and 153.1 years respectively. In terms of renewable, only hydro and biomass, with 0% and 12% capacity growth rates will continue [123]. Total primary energy demand growth will continue to year 2050 at the existing rate of 2.35% per annum [106].

⇒ That rising population, low quality of education, higher labour supply, and a rising unemployment will characterise the social domain. In this case, the country's total population will continue to grow at the rate of 2.37% per year [109]. This is based on a Constant Fertility Variant of 5.5 births per woman [103], and a reproductive age of 30 years [103]. At this population growth rate, it is assumed that dependency ratio for (ages 0 – 14 and 65+ years) to the working population (ages 15 – 64 years) will also continue to grow at the rate of 1.44% to year 2050. In terms of education, annual primary school enrolment is assumed to continue at the rate of 3.47% [12]. Considering the declining quality of education and technical training in the country, the model assumed that unskilled labour force will remain the dominant labour group—growing at an annual growth rate of 1.72% [110] to year 2050.

⇒ That oil revenue, higher operational government expenditure, and low domestic investment will continue to dominate the economic domain. This means, economic performance under BAU will remain dependent on oil revenue, which is assumed to grow at rate >10% per annum [157] to year 2050. In terms of expenditure, government operational costs are expected to maintain dominance over capital expenditure, with both growing at an annual rate of 0.3% and 0.25% respectively [109]. In comparison with growth in operational expenditure, overall economic investment is expected to remain low—growing at an annual rate of 0.19% [12].

⇒ That rising trends in oil and gas pollution, emissions, and water demand, as well as a declining water supply capability will depict the environmental situation. Here, the model assumes that in view of continued oil and gas activities, oil industry pollution from gas flares and oil spills will continue, growing at an annual rate of 10% and 13% respectively [128]. Total GHG emission is assumed to rise into the future; it will grow at the rate of 1.47% per year to 2050. Under the BAU scenario, the model also assumes that water demand in the country based on municipal, agriculture and industry demand will grow at the rate of 6.4% per annum, while water supply capacity will maintain an annual growth rate of 7.62% [106] to year 2050.

5.4 Energy Sector Analyses

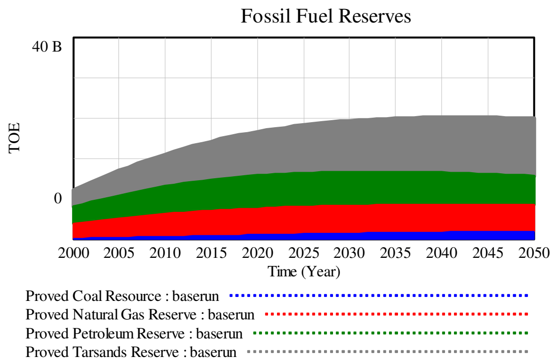
This section presents an analysis of the Nigerian energy sector from four standpoints: energy resource base; energy demand and supply; electricity supply mix; and energy prices, costs and investment. Each of these is considered below.

5.4.1 Energy Resource Base

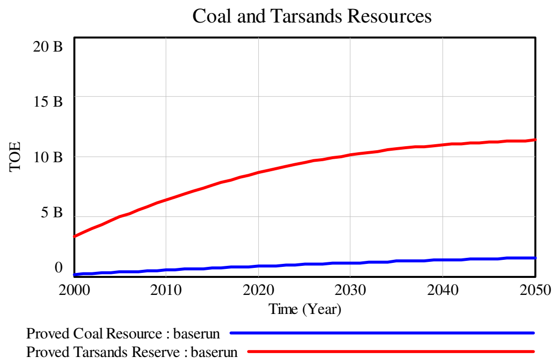
Energy resource base for the purpose of this study is considered for three resource types: 1) fossil fuels, 2) renewable energy and 3) nuclear energy resources.

i) Fossil Fuel Resources

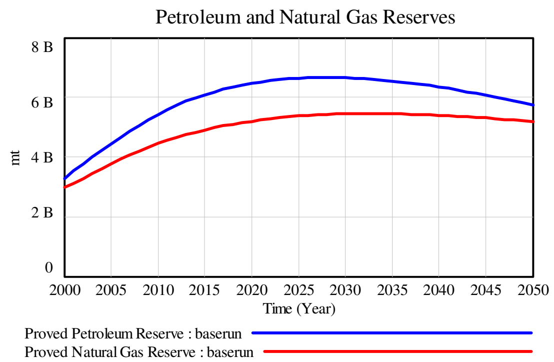
Figure 5.2 (a) provides model output for fossil fuel reserves. As already introduced, reserves growth for the four fossil fuels for the period 2000 – 2010 are based on historical data. Projections to year 2050 are based on the BAU assumption that 2000 – 2010 trends will continue [5]. Under this scenario, the model assumes that existing technologies for fossil fuels reserves discovery, as well as current production rates will prevail. As shown in Figure 5.2 (c), oil and gas reserves for the period 2010 – 2050, are projected to grow by 5.67% and 16.6%, representing effective annual growth rate of 0.14% and 0.39% respectively.



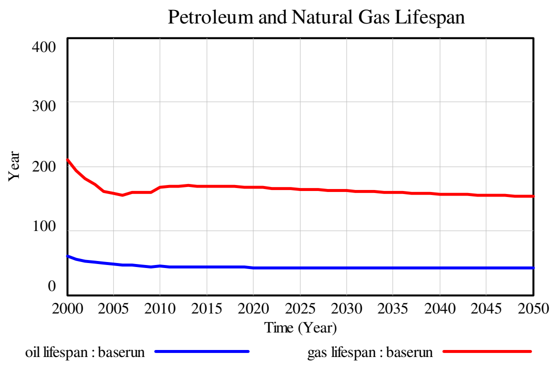
(a): fossil fuels reserves



(b): coal and tar sands reserves



(c): oil and gas reserves



(d): oil and gas lifespan

Figure 5.2: Nigeria Fossil Fuels Resource Potential.

At their current reserves growth and production rates, oil and gas reserves will respectively, deplete from 44.36 years and 167 years in 2010 [158, 159] to 41.36 years and 153.1 years by 2050 as shown in Figure 5.2 (d). These represent annual decline of 0.18% and 0.22% respectively.

In terms of coal and tar sands, Nigeria's coal and tar sands resources are presently at zero production rates. This means, their reserves are annually being added following exploration activities without any production [123, 160]. The stark contrast in their reserves potential as captured in Figure 5.2 (b), is due to the fact that coal reserves were substantially depleted for over 50 years before the discovery of oil and gas, and tar sands resources have never been produced in the country [123, 160].

Table 5.1: Fossil Fuels Resource Potential to Year 2050 under BAU.

Fossil Fuel Reserves and Lifespan								
Run	***Petroleum***		***Natural Gas***		***Coal***		***Tar Sands***	
	Bmt	*YEAR*	*BTOE*	*YEAR*	*BTOE*	*YEAR*	*BTOE*	*YEAR*
2000	3.285	60.33	2.976	210.2	0.132	∞*	3.357	∞*
2010	5.431	44.36	4.447	167.0	0.512	∞*	6.376	∞*
2020	6.467	42.68	5.198	167.0	0.842	∞*	8.661	∞*
2030	6.659	42.21	5.443	161.9	1.120	∞*	10.14	∞*
2040	6.340	41.77	5.391	157.2	1.348	∞*	10.97	∞*
2050	5.739	41.36	5.186	153.1	1.532	∞*	11.38	∞*

* Reserves lifespan goes to infinity because there is currently no production.

ii) Renewable Energy Resources

Four economically viable renewable energy resource types have been identified in Nigeria by this study and similar studies elsewhere. These are: solar, wind, hydro, and biomass resources. See Appendix C, for detail calculations for energy resource potential. Of these four viable renewable energy sources, only 'hydro' and 'biomass' are currently being utilised in the country [131, 161]. Hydropower for example, has an estimated annual total exploitable potential of about 14750 MW [161, 162]. This comprises 11250 MW of large hydro and 3500 MW of small hydro [161, 162].

However, only a combined 15.87% (i.e. about 2341 MW) of this potential is currently being utilised [161]. Historical data from government sources [14, 106] have shown that there has not been any increase in hydroelectric capacity over the period (1972 – 1999). Instead, there has been a drop in hydro capacity. As illustrated in Figure 5.3, the E-PAM also assumes under the BAU scenario, that prevailing conditions will continue, and hydroelectric capacity will remain flat into the foreseeable future.

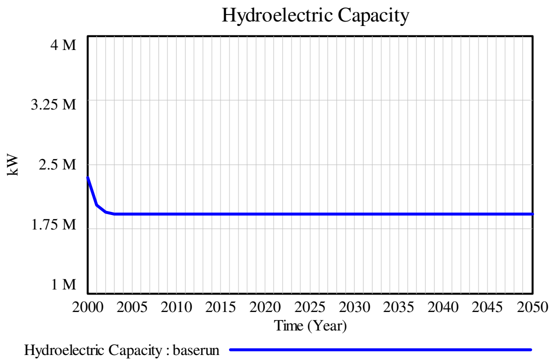


Figure 5.3: Hydroelectric Capacity Growth under BAU.

In terms of Bioenergy, biomass generation in Nigeria is consistent with natural distribution of vegetation and agricultural practice. These include production of crop residue and animal waste—predominantly in the North, and production of fuel wood—predominantly in the Southern part of the country [106]. To model biomass potential for the country, detail computations of the parameters used are presented in Appendix C.

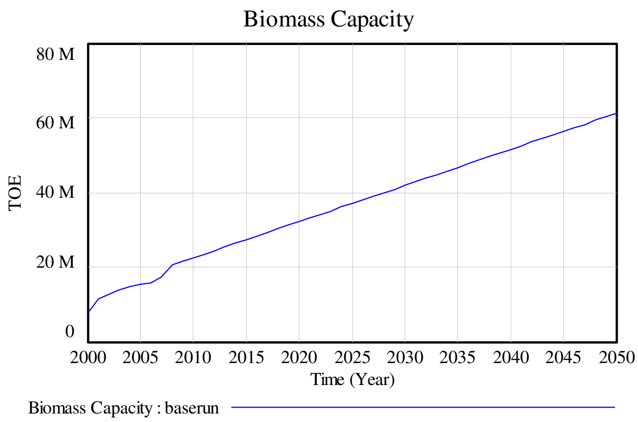


Figure 5.4: Biomass Capacity Growth under BAU.

The model output for renewable energy capacity growth is shown in Table 5.2.

Table 5.2: Renewable Energy Potential to Year 2050 under BAU.

Renewable Energy Capacity								
Run	*Hydro*		*Biomass*		*Solar*		*Wind*	
	MTOE	*GWh*	*MTOE*	*GWh*	*MTOE*	*GWh*	*MTOE*	*GWh*
2000	1.763	20,504	7.800	90,714	0	0	0	0
2010	1.444	16,794	22.47	261,326	0	0	0	0
2020	1.444	16,794	32.16	374,021	0	0	0	0
2030	1.444	16,794	41.83	486,423	0	0	0	0
2040	1.444	16,794	51.51	599,061	0	0	0	0
2050	1.444	16,794	61.19	711,640	0	0	0	0

iii) Nuclear Energy Resources

In 2005, uranium resources of commercial quantity were discovered in six of Nigerian states by the British Geological Survey[7]. However, despite maintaining huge deposit of uranium resources, nuclear energy is currently not being used in the country, as the discovered uranium resources are not yet qualified [160].

5.4.2 Combined Fossil Fuels and Renewable Energy Potential

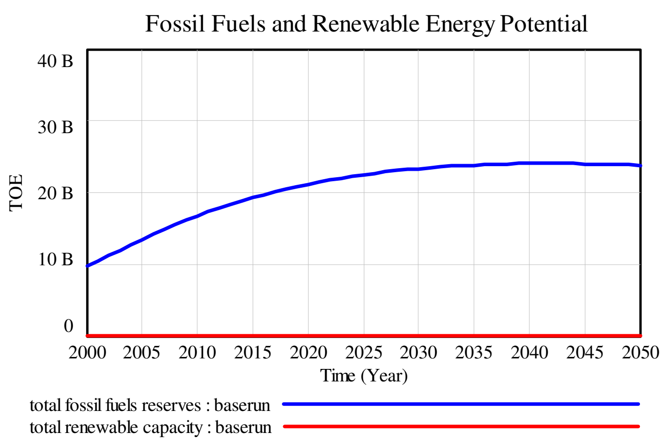


Figure 5.5: Combined Fossil Fuels and Renewable Energy Potential under BAU.

As illustrated in Figure 5.5, it is projected that between 2000 and 2050, total fossil fuels reserve will grow from 9.715 BTOE to 23.84 BTOE—representing 144.5%

[7] New Uranium Mining Projects-Africa; available at: http://www.wise-uranium.org/upafr.html

overall growth or 1.84% effective annual growth. Total renewable capacity over the same period is expected to grow from 0.009563 BTOE to 0.06263 BTOE—representing overall growth of more than 500% or 3.91% annual growth rate. In spite of an impressive growth in renewable capacity, it is evident that in terms of energy value, fossil fuel's contribution by 2050 will be significantly higher than renewable resources.

5.4.3 Comparison with Work of other Energy Institutions

Our model projections on Nigeria's energy resource potential are consistent with energy institutions such as British Petroleum (BP), World Energy Council (WEC) and Energy Commission of Nigeria (ECN). In its Review of World Energy [158], BP projects the lifespan of Nigeria crude oil to be 43.4 year. The World Energy Council [159] predicts crude oil lifespan of 46.8 years. Our model predicts oil lifespan to be 44.3 years (2010), 42.6 years (2020), 42.2 years (2030) and 41.3 years (2050) respectively.

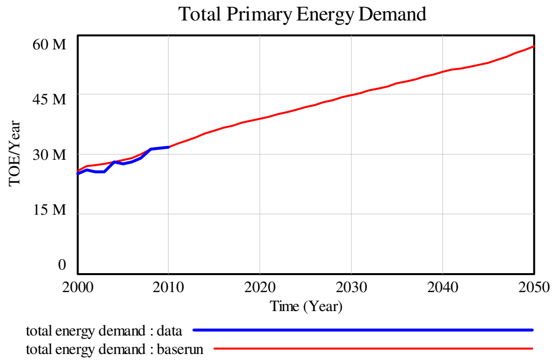
Also, the 2005 projections of the ECN (using IAEA models) show, that at effective growth rate of 2.75% per year, Nigeria's oil reserves are likely to reach 68.7 billion barrels by 2030 [15]. At an effective growth rate of 2.75%, our model predicts oil reserves growth to be around 68.4 billion barrels by 2030. These figures are harmonious with projections of the ECN and other institutions. Similar harmonious results are seen in other resource projections such gas, coal and tar sands reserves.

5.4.4 Primary Energy Demand and Supply

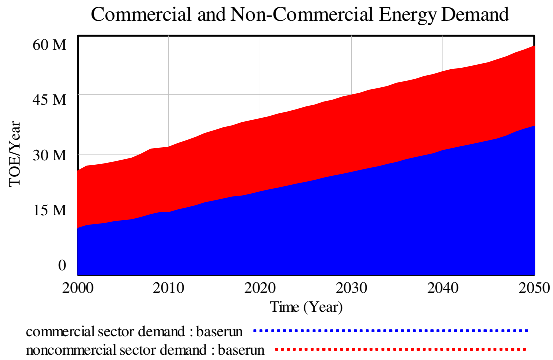
This section presents model results on total energy demand and supply dynamics under the BAU case. Energy demand side is concerned with total primary energy demand, commercial and non-commercial demand, and economic sector demand. The supply side focuses on analyses of energy supply by fuel type and fuel source.

a) Energy Demand

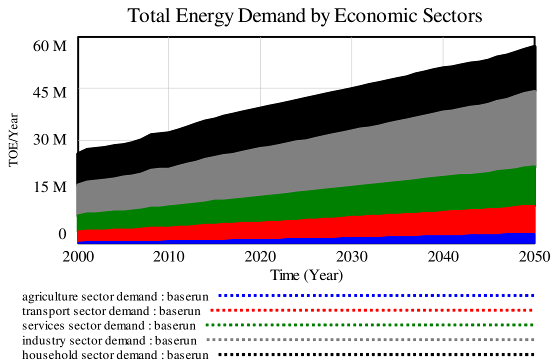
As shown in Figure 5.6 (a), total energy demand grows from 25.74 MTOE in 2000 [117] to 57.06 MTOE by 2050. This demand growth is consistent with our model projections on population and GDP growths—the major drivers of energy demand.



(a) total energy demand



(b) commercial and non-commercial energy demand



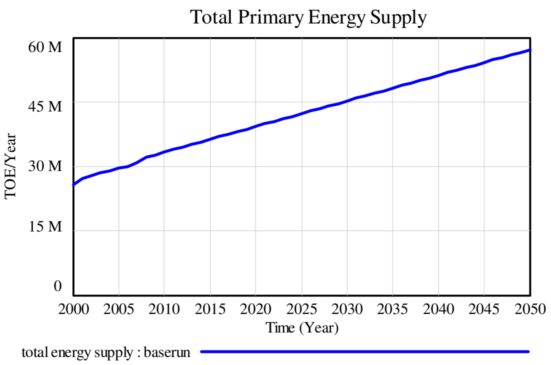
(c) total energy demand by economic sectors

Figure 5.6: Primary Energy Demand under BAU Scenario.

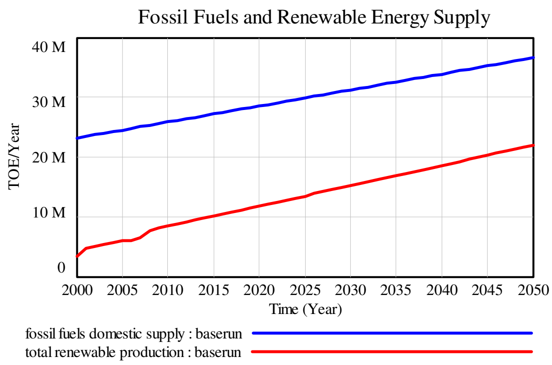
In the base year (2000), non-commercial energy demand (dominated by traditional biomass) constituted 55% of total energy demand [125]. This share is projected to decline to 35% by 2050, leaving commercial forms of energy (fossil fuels and electricity) to grow from 45% [125] to 65% over the same period as shown in Figure 5.6 (b). This change in energy demand patterns is due to expected paradigm shift in the nation's economic activities towards industrialisation. Individual economic sectors are also set to witness a restructuring in energy demand. For instance, in the base year, the residential sector accounted for 35% of total energy demand, followed by industry (34%), service (18%), transport (12%) and agriculture (1%) [163]. It is projected that by 2050, industry energy demand (driven mainly by growth in manufacturing) would constitute 38% of total demand. This is followed by household (23%), service (20%), transport (14%) and agriculture (5%), as shown in Figure 5.6 (c).

b) Primary Energy Supply

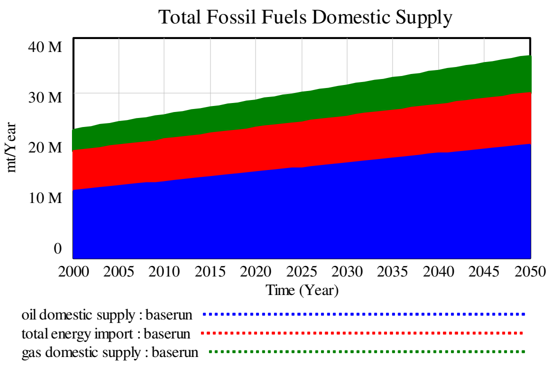
As shown in Figure 5.7 (a), total energy supply in the country under BAU will grow from 25.74 MTOE in 2000 [117] to 57.12 MTOE by 2050. This growth is expected to be driven by energy demand, energy investment, technology growth, market profitability and resource availability; also see CLD in (Section 4.4 Chapter 4).



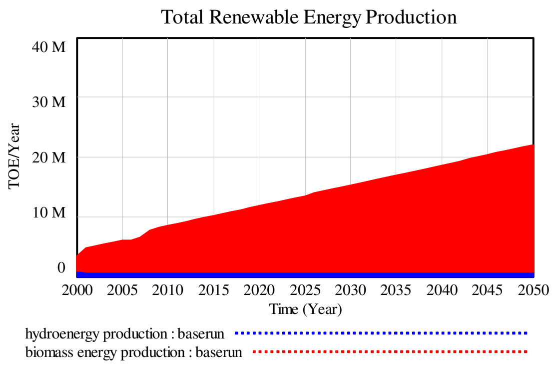
(a) total energy supply



(b) combined fossil fuels and renewable energy supply



(c) total fossil fuels domestic supply



(d) total renewable energy production

Figure 5.7: Primary Energy Supply under BAU Scenario.

Despite an expected growth in biomass use in the country over this period as evidenced in Figure 5.7 (d), it is still obvious that fossil fuels will continue to play a dominant role in the nation's total energy supply mix as shown in Figure 5.7 (c). It is also glaring in Figure 5.7 (b) that under BAU scenario, coal and tar sands will contribute nothing to energy supply in the country to year 2050. The same scenario applies to the use of solar and wind energy resources.

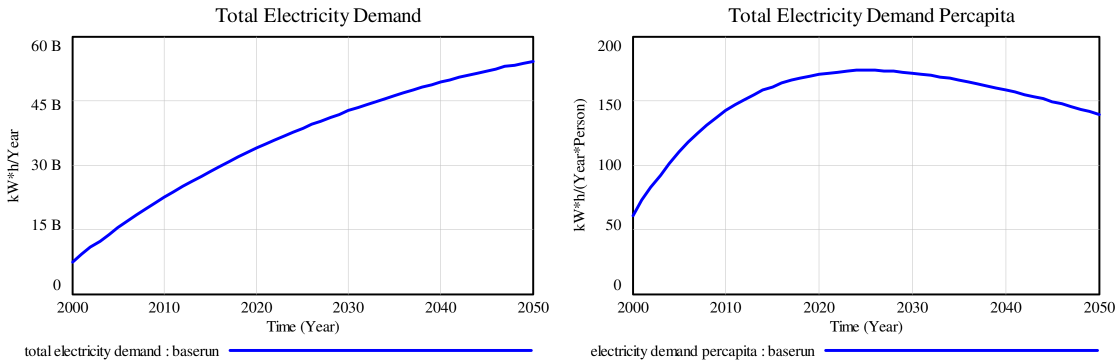
5.4.5 Electricity Demand and Supply

Electricity generation in Nigeria currently comes from only two sources: hydropower and gas thermal [124]. Hydro accounts for about 39%, while gas thermal contributes 61% of total electricity use in the country [124]. In our model, the demand side for electricity is defined as a function of changes in GDP, population, technology and energy prices. The supply side is influenced by demand, fuels type, capacity availability as well as plant efficiency; (see model structure in attached CD).

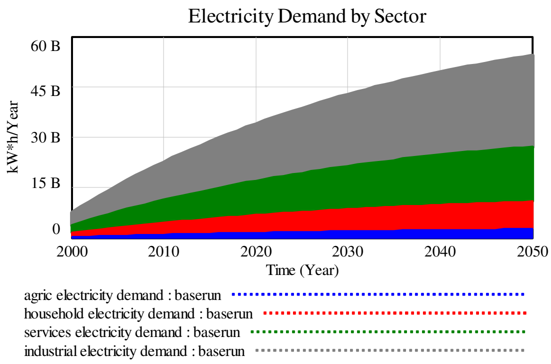
i. Electricity Demand

As shown in Figure 5.8 (a), total electricity demand in the country for the period 2000 and 2050 is projected to grow by more than 600%. This is in anticipation of population growth and increase in economic activities. In view of a significantly higher growth in population over the short to medium term, electricity demand per capita is likely to rise to a peak around 2025 before following a declining path as in Figure 5.8 (b). Unless there is a corresponding increase in electricity supply, which is not expected under BAU, electricity consumption per capita will continue to dip beyond 2050.

A reordering of electricity demand by economic sectors is also not expected over this timescale. Demand by industry, service, household and agriculture sectors will continue in that order of decreasing magnitude to year 2050. In view of a revamp in domestic manufacturing, industry electricity demand is expected to witness the highest growth (accounting for 50% of total electricity demand), followed by service (30%), household (15%) and agriculture sector (5%), as illustrated in Figure 5.8 (c).



(a) total electricity demand (b) electricity demand per capita



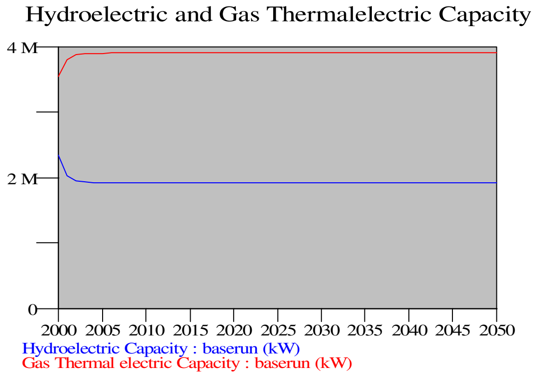
(c) total electricity demand by sector

Figure 5.8: Electricity Demand under BAU Scenario.

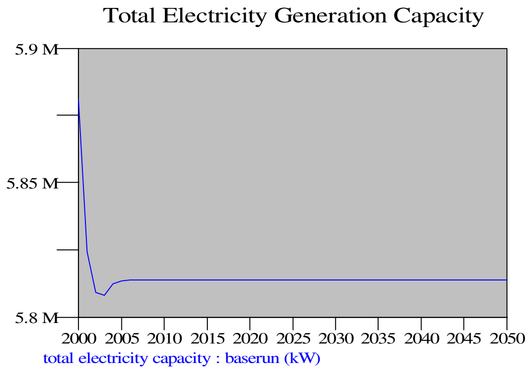
ii. Electricity Supply

As shown in Figure 5.9 (a) and 5.9 (b), the future of electricity supply based on current supply scheme is not very bright—meaning that capacity expansion under the BAU is not expected. In Figure 5.8 (a), hydropower between 2000 and 2003 lost its capacity from 2341MW to 1938 MW and remained in that state [14], while gas thermal capacity over the same period, gained from 3540 MW to 3950 MW and remained in the same condition [14]. In Figure 5.9 (b), their combined capacity, following an overall decline is set to return a flat growth and will remain so under BAU.

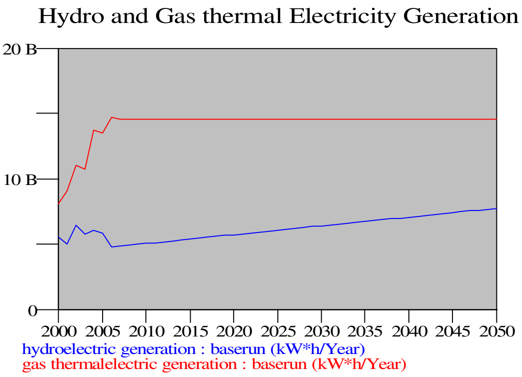
A similar situation is experienced with actual electricity generation as illustrated in Figure 5.9 (c) and 5.9 (d). Total electricity generation grew marginally between 2000 and 2010. By year 2010, total electricity generation in the country stood at 20.13 billion kWh (BkWh), transmission and distribution losses accounted for 9.9% of total generation, leaving around 18.14 BkWh for domestic consumption [124]. For a country with an estimated 160 million people, this is equivalent to consumption per capita of about 113.4 kWh. In comparison, based on our computations, this is less than the UK consumption of 5,733.14 kWh, South Africa 4,802.54 kWh and Ghana 297.80 kWh.



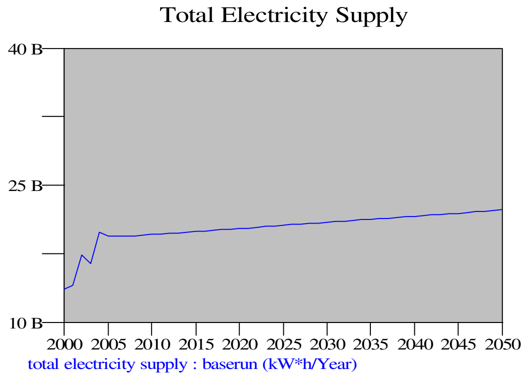
(a) hydroelectric and gas thermal electric capacity



(b) total electricity capacity



(c) hydro and gas thermal electricity generation

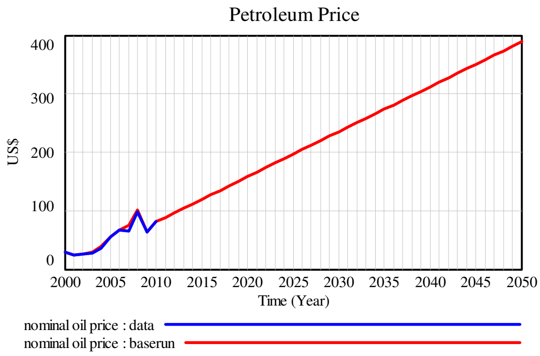


(d) total electricity supply

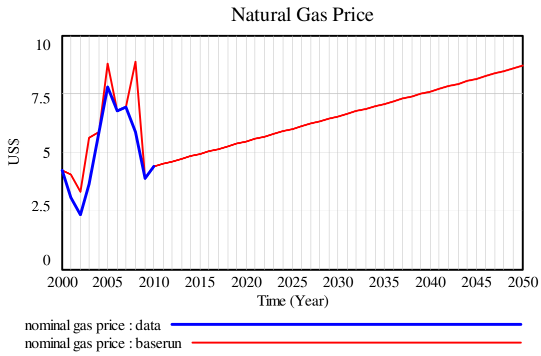
Figure 5.9: Electricity Supply under BAU Scenario.

5.4.6 Energy Prices, Costs and Investment

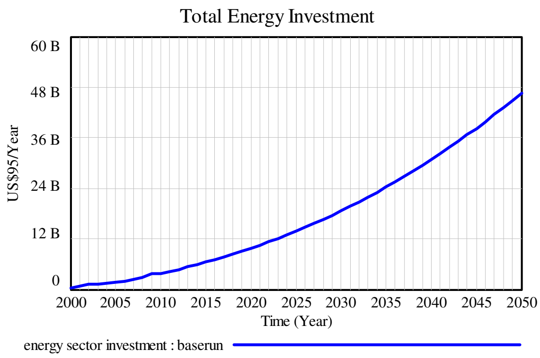
In our model, fossil fuel prices are influenced largely by energy demand and resource availability. Exploration and production costs are driven by technology, investment and reserve potential. Investment in energy is dependent on reserves availability, production costs, and technology. For renewable energy, prices are determined exogenously based on investment decision and market profitability.



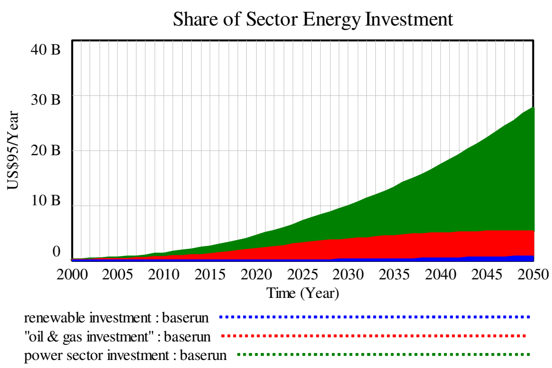
(a) petroleum price



(b) natural gas price



(c) total investment in energy development



(d) energy investment by sector

Figure 5.10: Energy Prices and Investment Costs.

As represented in Figure 5.10 (a) and 5.10 (b), oil and natural gas prices (corrected for inflation), have witnessed different levels of growth over the period (2000 – 2010). Spot crude oil prices of ‘Nigeria’s Forcados Crude Oil’ for example, grew from US \$28.42 per barrel (/bbl) in 2000 to US \$81.05/bbl in 2010 [137]. This represents 185% increase in oil price in 10 years. It is projected that by 2050, at an average exploration and discovery cost rate of US \$3.5/bbl, this finest Nigerian crude oil will reach US \$388.94 on the spot market.

Natural gas prices have also grown from US $4.23 to US $4.39 per million BTU in the US Henry Hub between 2000 and 2010 [164]. As at end of May 2013, natural gas price stood at about US $4.04 per million BTU. At an estimated exploratory cost of US $10 per 1000 cubic feet (cf), our model projects under BAU, that gas prices will reach US $8.683 per million BTU by year 2050. This represents total price increase of 105% over the period. Although, technology is expected to largely drive this change, resource availability remains the most crucial factor.

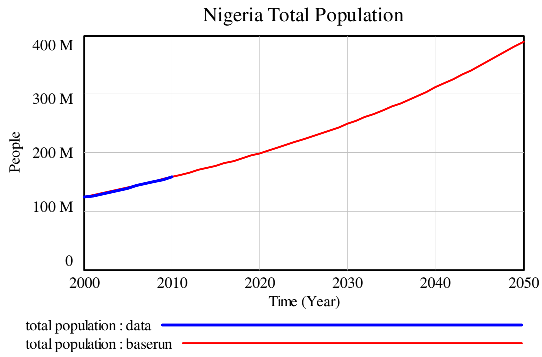
In terms of investment in energy development, public sector investment in oil and gas and power sector (about 12.6% of real GDP) grew by over 400% for the period (2000 – 2010) [106]. At 13% annual increase, total investment in energy development is projected to top US $46.60 billion by 2050 from US $0.455 billion in year 2000. The projected investment shares over the period are: (60%) power sector, (38%) oil and gas and (2%) renewable energy.

5.5 Analyses of the Social Domain

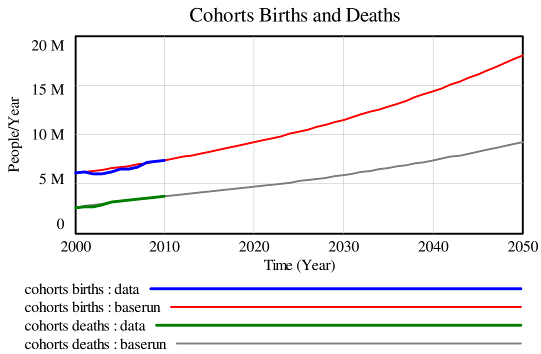
This section presents model outputs for the social domain under the BAU scenario. Here, population dynamics, education and human capital and labour demand and supply are analysed in the following subsections.

5.5.1 Population Dynamics

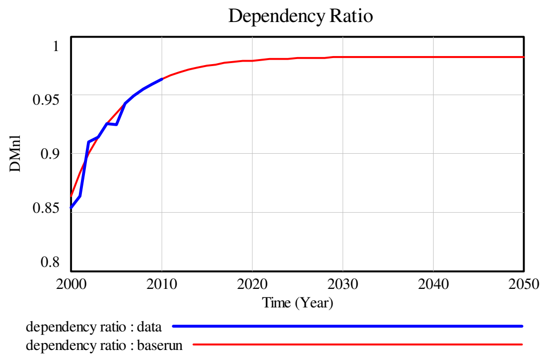
The total population of Nigeria (for both sexes) is defined in the E-PAM as sum of population cohorts ages 0 – 14, 15 – 64 and 65+ years. In Figure 5.11 (a), the total population is projected to grow from 123.68 million in 2000 [110] to 389.23 million by 2050. This represents overall growth of 215% over 50 years or annual growth rate of 2.37%. This projection is based on a Constant Fertility Variant (CFV) of 5.5 births per woman, and female reproductive age of 30 years. Cohorts' births and deaths are also projected to grow in a similar pattern as evidenced in Figure 5.11(b).



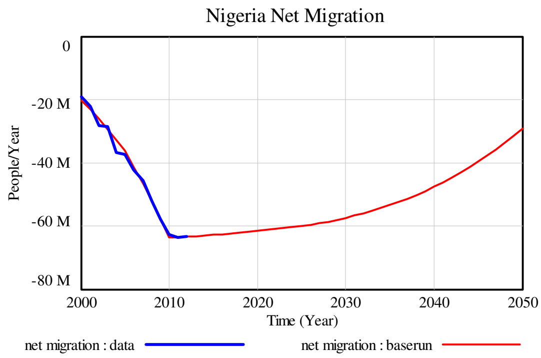
(a) total population



(b) cohorts births and deaths



(c) total dependency ratio



(d) net migration

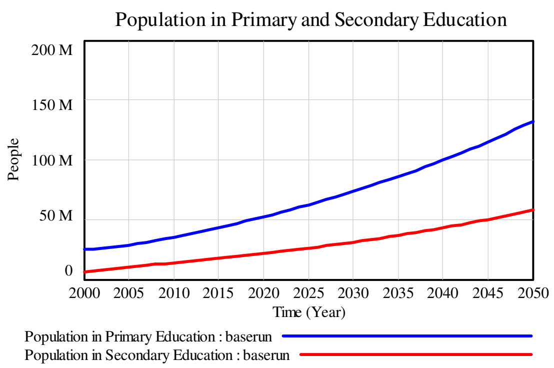
Figure 5.11: Nigeria Population Structure.

In Figure 5.11 (c), the dependency ratio of the 'non-productive' population (i.e. ages 0-14 and 65+ years) to the 'productive' population (i.e. ages 15 – 64 years) is expected to rise from 0.8641 in 2000 [110] to 0.9825 by 2050. Despite a counterbalancing growth from the working population, a steep rise in overall dependency over a 20 year period (2000 – 2020) is expected. The expected accelerated rise in birth numbers over the 20 year timescale will lead to a significant increase in the number of (0 – 14) aged children from 53.35 million to 88.84 million—representing 67% overall growth.

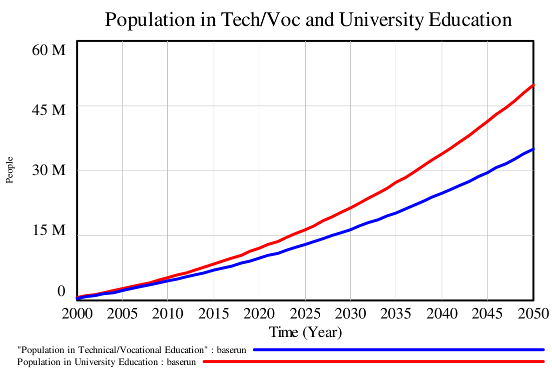
The direct impact of this high dependency ratio is a high rate of emigration[8] over the same period as evidenced in Figure 5.11 (d). The net migration rate for Nigeria is expected to change from -0.185 to -0.270 between 2000 and 2020. These in terms of human population, represent -20.16 million people in year 2000 [110] and -61.41 million by 2020. The change in migration trend from year 2010, as can be seen in the sudden change in gradient of Figure 5.11 (d) is due to the positive changes in Nigeria's economic fortunes which began to attract more immigrants into the country following return to democratic rule in 1999 and the relative stability of its neighbours. It is expected under the BAU scenario that this change in migration trend will continue into the future to year 2050.

5.5.2 Education and Human Capital

The education subdomain of the model focuses on human capital development based on level of training. Model outputs for this subdomain are categorised according to educational qualification as presented in Figure 5.12 (a) – (d). These are primary level; secondary level; technical and vocational level; university graduates and graduates seeking additional professional qualifications.

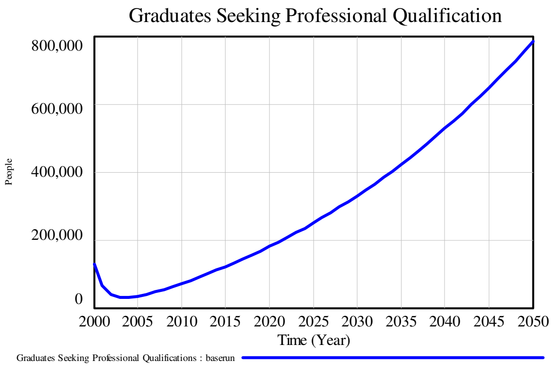


(a) population in prim. and sec. education

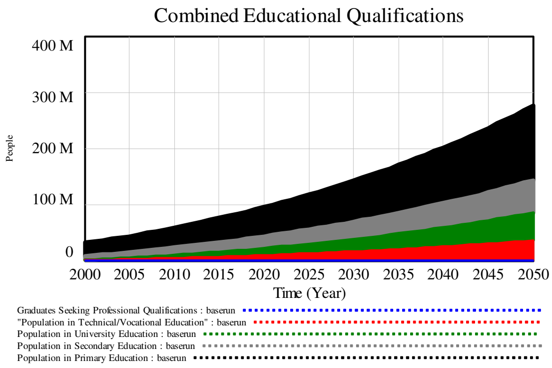


(b) population in tertiary education

[8] Represents the total number of persons (per 1000 population) leaving Nigeria for other countries in search for better conditions of living.



(c) graduates seeking professional qualifications



(d) combined educational qualifications

Figure 5.12: Nigeria Education Structure.

a. Primary and Secondary Education

Primary school in Nigeria, like in many other countries remains the basic level of educational attainment. As of 2010, the gross primary school enrolment ratio[9] was 83.6%, down from 98.6% in 2000 [157]. These reflect total population in primary education of 35.28 million and 24.89 million respectively [106, 110]. It is projected that at an annual growth rate of 3.47%, the population in primary education will reach 132.20 million people by 2050; this represents gross enrolment ratio of 90.4%.

b. Technical and Vocational Education

As of 2000, people attending technical and vocational institutions accounted for about 40% of total population in tertiary education in the country [106]. The number grew to 46% by 2010 [106]. In view of changes in employment preferences in the Nigerian labour market, it is expected that this number will drop to 44% by 2025 and 41% by 2050. It is also evident in Figure 5.12 (b) that the population of people attending technical and vocational and university education is also growing. The gap between them however, is expected to continue to widen in the post-2015 scenario.

[9] According to World Bank, this is a ratio of total primary school enrolment in a country (regardless of age) to total population.

c. University Graduates and Professionals

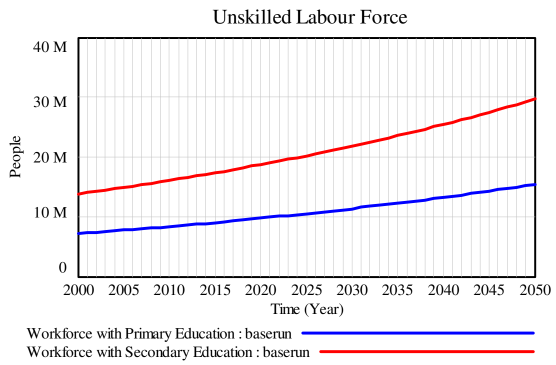
It is apparent in Figure 5.12 (c) that although, the number of university graduates going onto professional qualifications is raising, this number still remains negligible compared to the total number of university graduates in any given year. In year 2010 for example, only about 71, 000 graduates (representing 1.4% of total university graduates) were reported to have sought professional qualifications [165]. The number is predicted in our model to increase to 249, 000 (or 1.5%) by 2025. The implication is that over the next 15 years (2010 – 2015), more than 15 million Nigerian graduates might still not be seeking professional qualifications, which is not in line with the current global trends.

5.5.3 Labour Demand and Supply

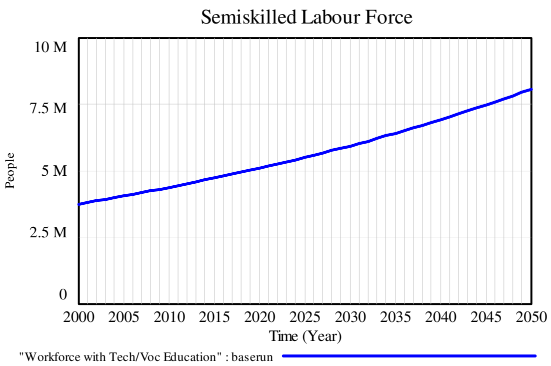
The labour force subdomain of the model deals with issues of labour demand and supply. The supply side is examined by skill level, based on training and educational attainment. The skill categories considered are: unskilled; semiskilled; skilled and highly skilled. The demand side focuses on analysis of labour demand by economic subdomain in terms of sector employment.

i. Labour Supply

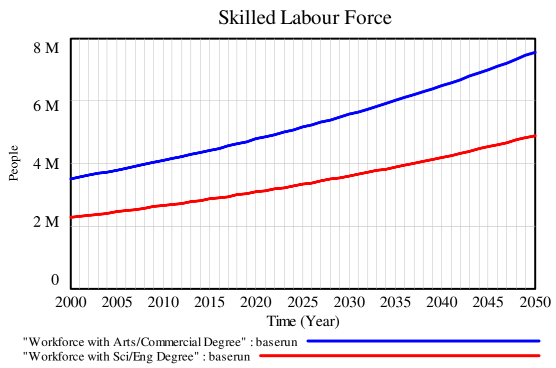
As shown in Figure 5.13 (a), the unskilled labour force constitutes the largest labour group in Nigeria. In the base year, this group represented 20.94 million people or 58.5% of total labour supply in the country [107]. The unskilled workforce is projected to reach 45.07 million people or 60.4% of total labour supply by 2050. The semiskilled category is also expected to increase from 3.74 million in 2000 [107] to 8.047 million people by 2050.



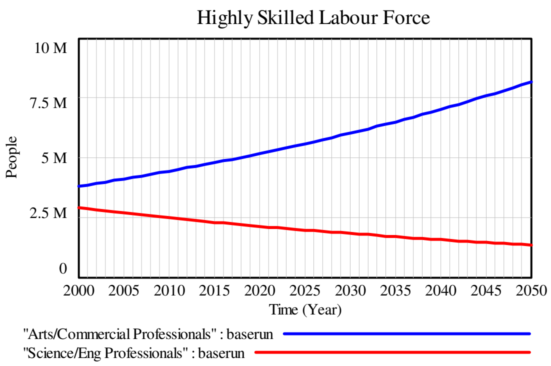
(a) unskilled labour force



(b) semiskilled labour force



(c) skilled labour force



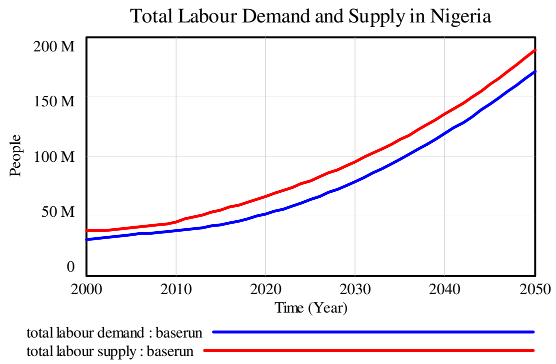
(d) highly skilled labour force

Figure 5.13: Labour Supply by Educational Level under BAU.

At a projected 1.57% annual growth rate, skilled labour force (representing people with arts and commercial and science and engineering degrees), is set to grow from 5.78 million to 12.43 million people between 2000 and 2050, as shown in Figure 5.13 (c). It is expected that the labour pool with arts and commercial degrees will account for more than 60% of total labour supply in this category. While many attribute this trend to lack of employment and career opportunities in sciences in the country, others argue that it is due to total lack of motivation by students to follow scientific route, as many students claim science and engineering courses are rather difficult and time consuming to follow, hence, a drift to arts and commercial subjects. Also see stakeholder responses to research (Question C5 in Appendix B), for similar arguments.

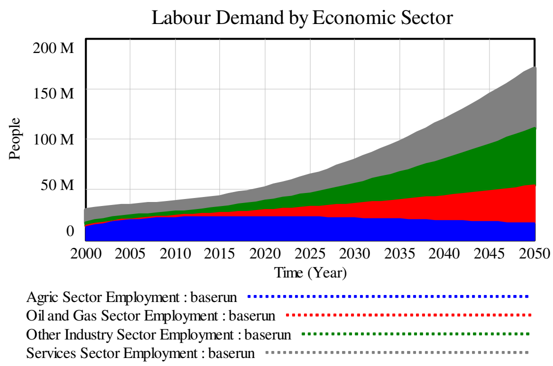
ii. Labour Demand

Labour demand in Nigeria is significantly lower than supply [106]. In 2000 for example, about 19.3% of available labour was not utilised [106]. As shown in Figure 5.14 (a), total labour demand grew from 29.96 million in 2000 to 37.36 million in 2010 [157]. At an average growth rate of 3.61% per annum, labour demand in the country will reach 170.65 million people by 2050. This means that unemployment in the country will also change from 19.34% in 2000 to 9.45% by 2050 as shown in Figure 5.14 (b). Here, the unit (DMnl) is defined in vensim^{TM} to mean a dimensionless quantity.



(a) total labour demand and supply

(b) total unemployment rate



(c) labour demand by economic sectors

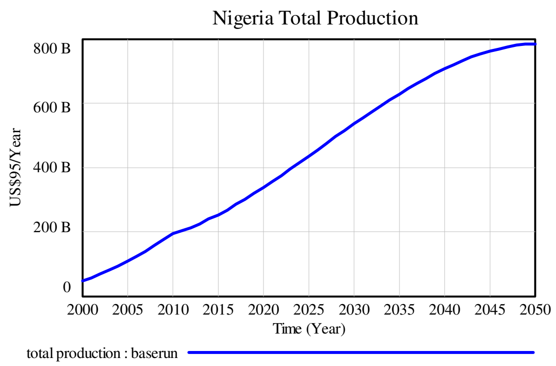
Figure 5.14: Labour Demand under BAU Scenario.

In view of a declining dominance and prospect in agriculture, a reordering of labour demand by economic sectors in the country is expected. Employment in agriculture, which constituted 44.6% of total labour demand in the country in the base year [12], is set to decline to 9.82% by year 2050. Employment in *"Other Industry Sector"* is set to witness the highest growth, changing from 11.5% in 2000 [12] to 33.3% by 2050. This is followed by the oil and gas sector, which also moves from 2.2% in 2000 [12] to 21.7% by year 2050.

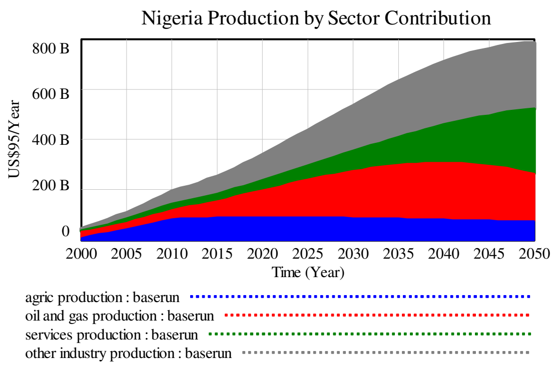
5.6 Analyses of the Economic Domain

This section presents analyses of the economic domain under the following themes: production and GDP, economic capital and investment and government revenue and expenditure.

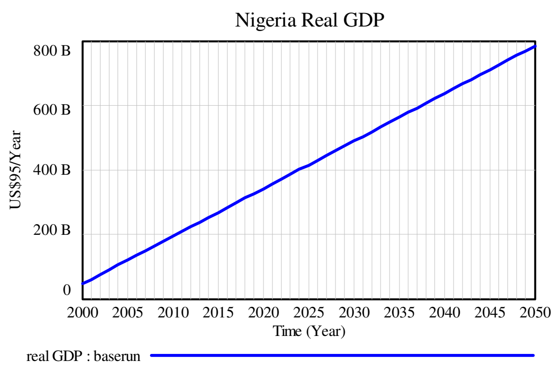
5.6.1 Production and GDP



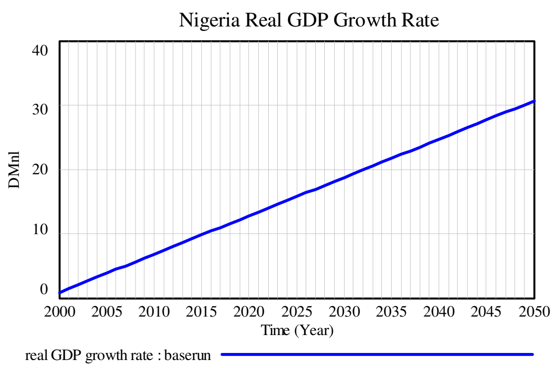
(a) total production



(b) production by economic sector contribution



(c) Nigeria real GDP



(d) real GDP growth

Figure 5.15: Nigeria Economic Production and Real GDP Growth under BAU.

The production subdomain is a major contributor to real GDP growth in our model. It consists of four economic sectors: agriculture, service, oil and gas and other industries. As shown in Figure 5.15 (a), total production is set to grow by more than 1500% over the 50 year timescale, changing from US $45.98 billion in 2000 [110] to US $784.15 billion by 2050. This growth is expected to be driven by rejuvenating economic activities in the aforementioned production sectors. Of these production sectors, *"other industry production"* is expected to contribute the most to GDP growth by year 2050, followed by service, oil and gas and then agriculture as summarised in Table 5.3. Agriculture, which contributes more that 20% of total production in the base year, is likely to contribute less than 10% by year 2050. This is due to expected decline in agricultural activities in the country—paving the way for industrialisation under a service economy.

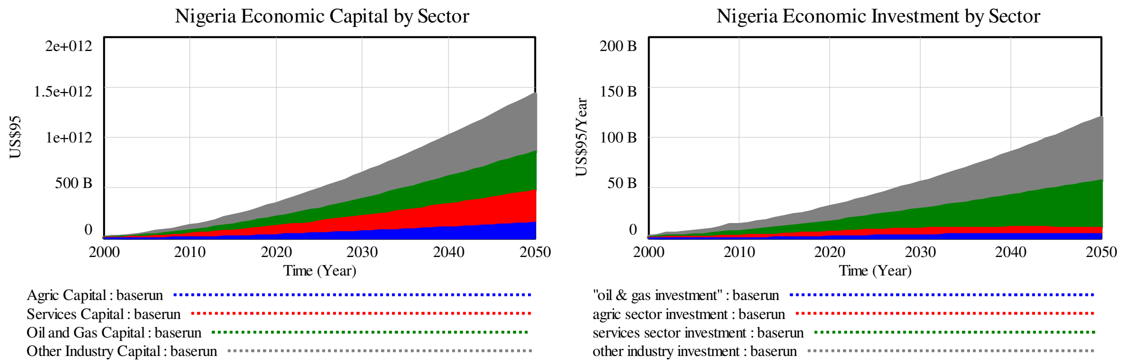
Table 5.3: Nigeria Economic Production to Year 2050 under BAU.

Economic Production (US95 $/Year)					
Run	***Total Production***	***Other Industry Production***	***Service Production***	***Oil & Gas Production***	***Agriculture Production***
2000	45.98	9.071	3.724	21.85	11.33
2010	193.69	50.35	23.37	35.44	84.51
2020	337.37	101.76	38.28	105.20	92.11
2030	534.51	182.35	78.24	184.63	89.27
2040	706.43	249.54	150.01	224.50	82.35
2050	784.15	262.76	258.78	188.18	74.40

In terms of GDP, the real GDP of the country has also witnessed an impressive growth over the last decade. As illustrated in Figure 5.15 (c), between 2000 and 2010, the GDP has grown from US95 $45.98 billion to US95 $193.69 billion [157]. In view of continuous investment in all the productive sectors—particularly the non-oil sectors, it is expected that real GDP will maintain its continued growth to year 2050—reaching about US95 $784.15 billion.

5.6.2 Economic Capital and Investment

The Nigerian economic capital is also divided into four areas: agriculture, service, oil and gas and other industry capital. These are driven in the model by their individual shares of investment as a percentage of real GDP.



(a) economic capital by sector (b) economic investment by sector

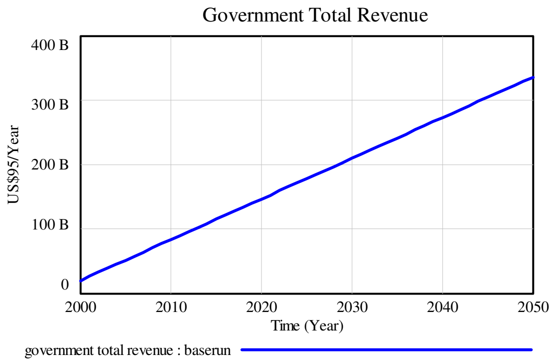
Figure 5.16: Nigeria Economic Capital and Investment by Sector.

The nation's total capital as a function of real GDP has seen a similar pattern of growth over the last 10 years (2000 – 2010) [106], and is projected to continue in a similar manner to year 2050. As revealed in Figure 5.16 (a), 'other industry capital' will again witness the most growth, followed by oil and gas, service and agriculture, in order of decreasing magnitude. A similar growth pattern is expected in the investment subdomain shown in Figure 5.16 (b). The obvious difference is that investment in service is expected to be significantly higher than investment in oil and gas. This is due a paradigm shift to a service-oriented economy, with declining oil and gas production.

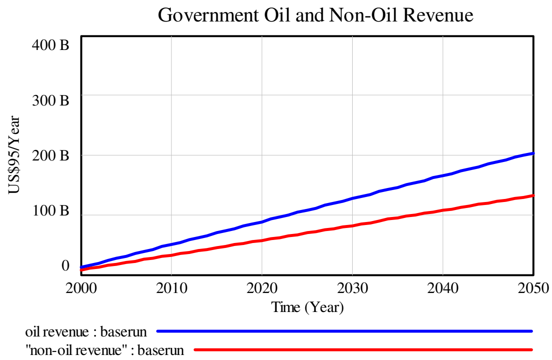
5.6.3 Government Revenue and Expenditure

The government revenue subdomain comprises mainly 'oil revenue' and 'non-oil revenue', while the expenditure subdomain focuses on 'capital expenditure' and 'operational expenditure'. As illustrated in Figure 5.17 (a), government total revenue is set to grow from US95 $19.69 billion in 2000 [12] to US95 $335.79 billion by year

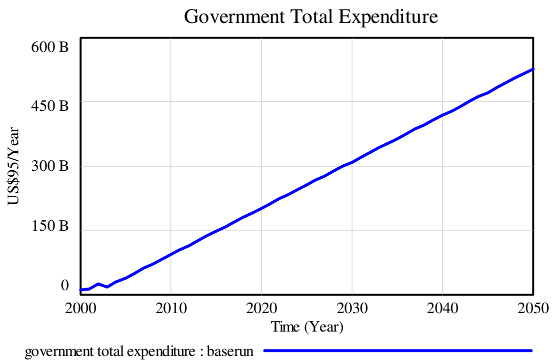
2050. This represents total growth of more than 1600% over a 50 year period or an annual growth rate of 5.96%. Of this growth, oil revenue which comes mainly from oil and gas export, royalties and domestic crude oil sales will contribute more than 60% of total revenue by 2050. Non-oil revenue, which is tax- and non-tax-based is expected to grow from US95 $7.739 billion in the base year to US95 $131.95 billion by 2050—contributing slightly more than 39% of total government revenue.



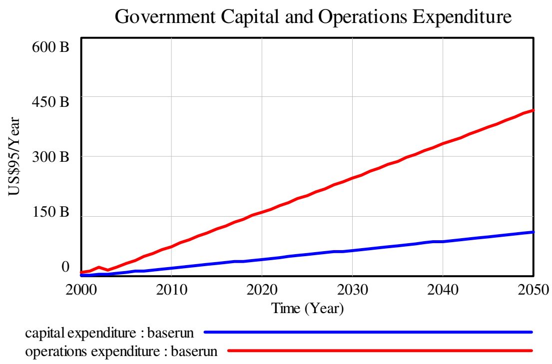
(a) government total revenue



(b) government oil and non-oil revenue



(c) government total expenditure



(d) government capital and operations

Figure 5.17: Nigeria Revenue and Expenditure under BAU.

Despite an impressive growth prospect in both oil and non-oil revenue, it is glaring in Figure 5.17 (c) and (d) that government expenditure is set to grow even higher. As indicated in Figure 5.17 (c), government total expenditure will grow by over 4000% between 2000 and 2050. This represents annual growth rate of more than 8%. Of this growth, operations expenditure will account for about 79% of total expenditure over the period. This expenditure includes administrative costs (21.8%), social and economic services (21.8%) and public debt servicing (31.1%) [106].

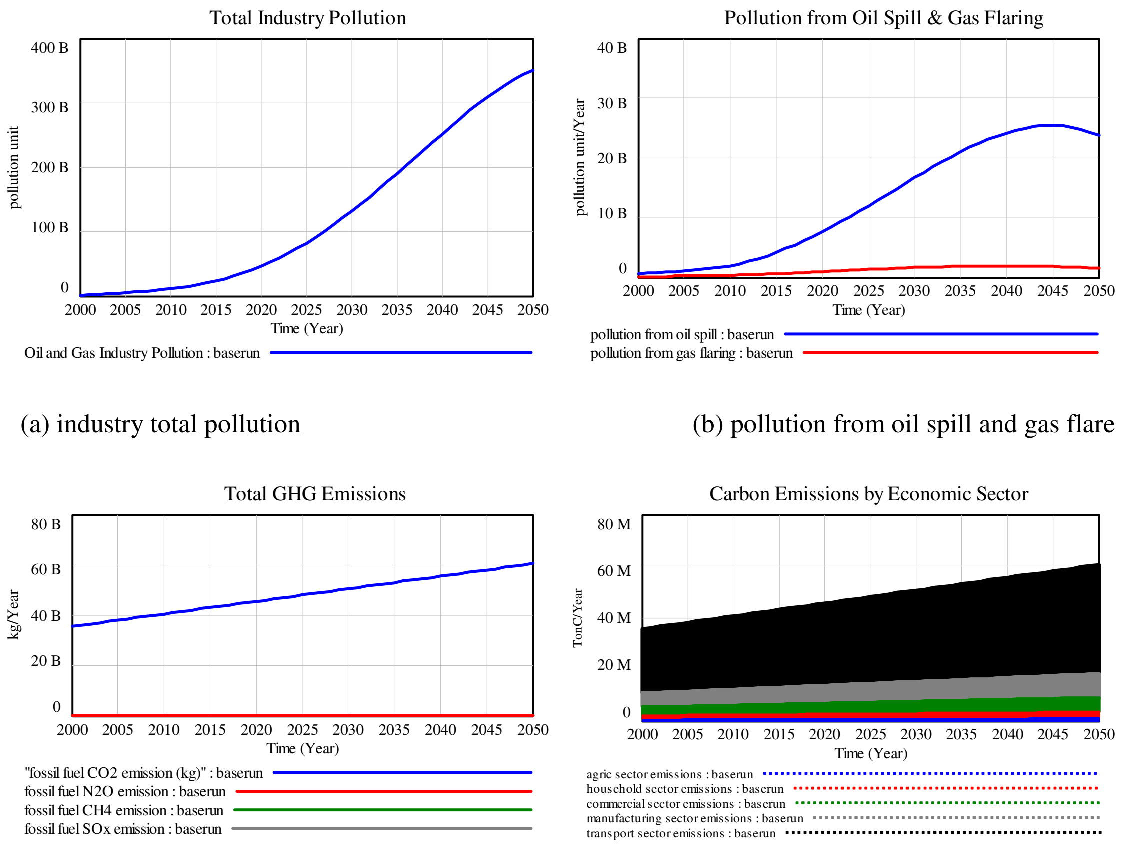
5.7 Analyses of the Environment Domain

This section presents model outputs for the critical environmental issues considered in this study. These are: 1) oil and gas industry pollution, 2) greenhouse gas emissions and 3) water demand and supply. Oil and gas industry pollution in this context, is considered to be a combination of air pollution resulting from gas flaring and water and soil pollution from oil spills. Other forms of pollution considered are smoke from burning debris and even noise from heavy equipment operations. These together provide a composite pollution indicator for the oil and gas industry (measured in total pollution unit per year).

5.7.1 Pollution and Emissions

The pollution subdomain of the model focuses on describing the environmental impact of 'oil spills' and 'gas flares' from oil and gas industry activities in the country. As shown in Figure 5.18 (a), oil and gas industry total pollution grows from 1.5 billion (pollution unit/year) in 2000 [139] to 350 billion (pollution unit/year) by 2050. This rise in pollution is in view of increased oil and gas production activities, with little or no specific action to implement pollution reduction strategies. Incidences of oil spill and its pollution impact are significantly higher than the impact of gas flaring in the country [157]. This is also evident in Figure 5.18 (b), where oil spills account for 83% of total pollution in 2000 and more than 93% expected by 2050 under BAU growth.

In Figure 5.18 (c), fossil fuel CO_2 emission is shown to be the largest contributor to GHG emissions in the country. With a projected growth in oil and gas production and economic activities, fossil fuel CO_2 emissions are expected to witness an upward growth, increasing from 35.57 million (TonC/year) in the base year to 60.49 million (TonC/year) by 2050. This represents an annual growth rate of about 1.09%. In terms of emissions by economic sectors, Figure 5.18 (d) shows that the transport sector accounts for around 70% of total fossil fuel CO_2 emissions. This is followed by manufacturing (15%), commercial (9%), residential (4%) and agriculture (2%) [106]. As shown, CO_2 emissions indicate a rising trend to year 2050.



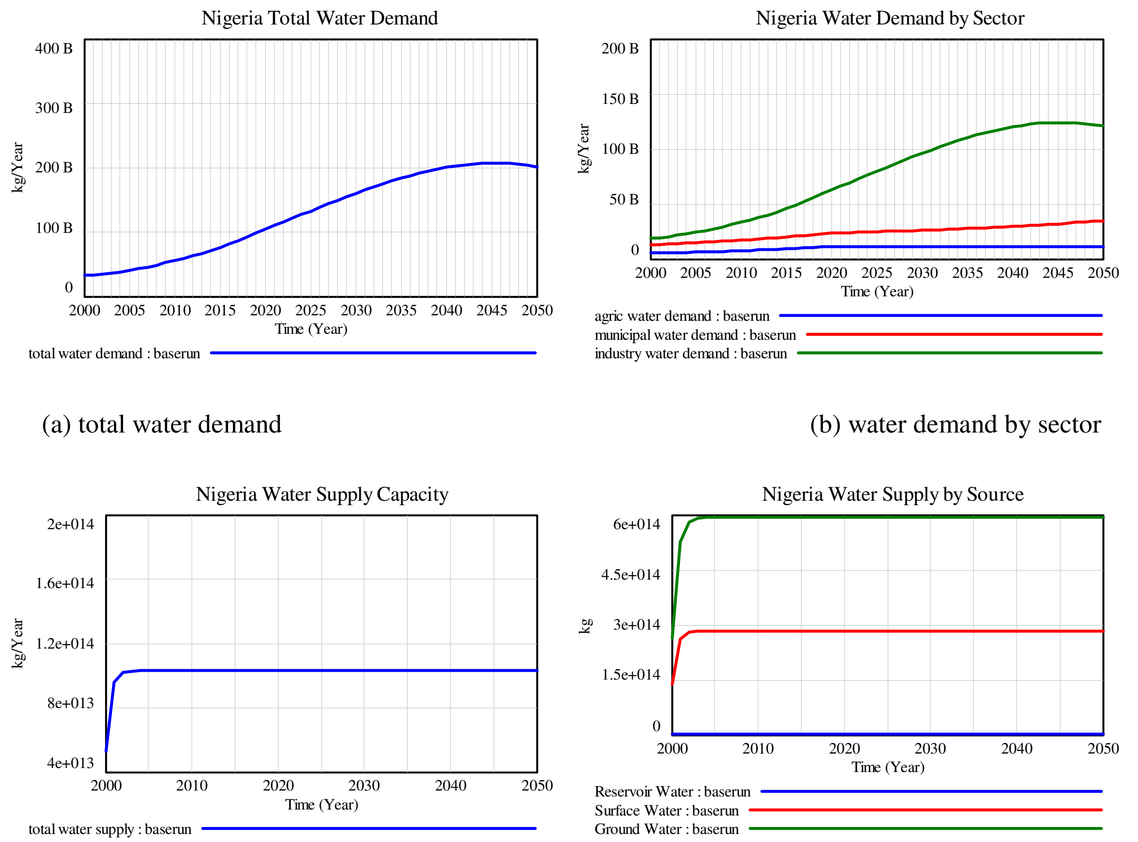
(c) total GHG emissions (d) carbon emissions by economic sector

Figure 5.18: Pollution and Emissions in Nigeria under BAU.

5.7.2 Water Demand and Supply

Water demand in our model is disaggregated into industry water, municipal water, and agriculture water demand. In Figure 5.19 (a), total water demand is projected to grow by >500%, from 32.05 billion kg/year in 2000 [12] to 201.18 kg/year by 2050. This growth will be driven by revamped domestic industrial activities, particularly the manufacturing sector [12], also see stakeholder responses to (Question D5b in Appendix B). It is expected that this will lead to a peak in industry water demand by around year 2044 as evidenced in Figure 5.19 (b).

The water supply side is divided into ground water, surface water, and reservoir water, as shown in Figure 5.19 (d). Considering the impact of climate change on rain fall, which is already affecting water supply in the country [25], this model foresees a flat growth pattern for water supply capacity in the country over the coming years. This means that under the BAU scenario, no appreciable growth in water supply capacity is expected over the coming years to 2050 as illustrated in Figure 5.19 (c).



(a) total water demand (b) water demand by sector

(c) total water supply capacity (d) water supply by source

Figure 5.19: Water Demand and Supply in Nigeria under BAU Scenario.

5.8 Conclusion

This chapter has presented an analysis of the behaviour of the Energy Policy Assessment Model (E-PAM), under a Business-As-Usual (BAU) case. The BAU scenario was based on two main considerations (assumptions): 1) that no new government interventions are expected to the existing energy, social, economic and environmental policies and 2) that current (2000 – 2010) trends in activities within the energy sector and the three sustainability domains will continue to year 2050.

The following key insights were drawn from analysis of this chapter. It was found under BAU, that existing technologies for fossil fuels discovery will prevail at an annual growth rate of 0.09% to 2050. This implies that oil and gas reserves will grow at annual rate of 0.14% and 0.39% respectively. Total primary energy demand will grow at the rate of 2.35% per annum. It was also found that the country's total population will continue to grow at the rate of 2.37% per year to 2050. This is based on a Constant Fertility variant of 5.5 births per woman and a female reproductive age of 30 years.

Our analysis revealed that the Nigerian economy will remain dependent on oil revenue, which is expected to grow at >10% per annum to 2050. The implication is that government operational costs will also remain dominant over capital expenditure, growing at an annual rate of 0.3% and 0.25% respectively. For the environment domain, it was found that oil industry pollution from gas flares and oil spills will continue to rise at annual growth rate of 10% and 13% respectively. Total GHG emission will also rise into the future, growing at the rate of 1.47% per year to 2050.

Overall, this chapter has characterised the key model variables in their reference cases. It provides the basis for testing alternative scenarios against government criteria for achieving SED. These alternative scenarios are considered in the next chapter.

Chapter 6

Analysis of Model Behaviour: Alternative Scenarios

6.1 Introduction

This chapter presents 'plausible' scenarios against the criteria of government to achieve Sustainable Energy Development (SED) in Nigeria. It analyses the impact of different government initiatives within the energy sector and their economic, social and environmental implications. It further examines the long-term perspectives that underpin *"actions"* and *"measures"* aimed at achieving targeted SED results over the timescale under consideration.

The scope of the chapter is to evaluate the effect of three government policies in specific subdomains within the three sustainability domains: society, economy and environment. The assessment includes a measure of fulfilment of the SED agenda of government from four energy objectives: *"availability, accessibility, affordability* and *acceptability"*. The goal is to explore the broader implications of the proposed government policies in the face of future uncertainty. This aims to: 1) appraise the role of policy in achieving targets on Energy Sustainability, 2) enable an understanding of the possible energy futures that might unfold for the country and 3) examine the major barriers to SED and define options for achieving targeted results.

Section 6.2 provides a working definition of Sustainable Energy. Section 6.3 defines alternative scenarios—including key assumptions and policies under consideration. Section 6.4 examines the results of alternative scenarios relative to BAU. Section 6.5 presents the output of Sensitivity Analysis used to assess uncertainty of key model parameters. Section 6.6 provides chapter conclusions.

6.2 Working Definition of Sustainable Energy

In a generic sense, the notion of Sustainable Energy (SE) is readily seen by many to mean renewable energy alternatives to conventional energy sources such as fossil fuels [166]. Others view the concept from the perspective of 'smart' and 'efficient' energy systems that minimise energy waste or losses [167]. Despite diverse perspectives, discussions on energy sustainability are usually not separated from the fundamental principles of Sustainable Development (discussed in Chapter 2), hence, the needs to further examine the concept in this study.

For the purpose of this study, a working definition of SE is provided from four standpoints: 1) energy availability, 2) energy accessibility, 3) energy affordability and 4) energy acceptability. These are considered in this context, to be 'the four grand energy objectives' of SED. This is based on stakeholder perspectives as revealed in policymakers' responses to (Question A2 of Appendix B). These energy objectives form the basis for defining *"impact dimensions"* and *"measurable indicators"* needed to assess targets or progress towards SED. An integrated framework that depicts this concept is shown in Figure 6.1. Indicators defined under each objective according to the sustainability dimension being maximised are extended in Table 6.1. These altogether, provide a working definition of SED in this case. The framework serves as an expanded view of the four domains defined in Figure 4.3 in Chapter 4, as it provides further insights into the energy objectives and the sustainability dimensions being optimised.

An evaluation of energy usage under these four perspectives is in itself not a new idea. Institutions such as the World Energy Council [168], Asia Pacific Energy Research Centre [169] and the IEA [170], as well as authors such as Kruyt et al., [171] have used this idea to discuss energy in different contexts. For this research, we employ the concept to investigate how proposed government policies will meet the emerging social, economic and environmental challenges of achieving energy use that is consistent with the four objectives. Each of these objectives, with a specific question to consider is briefly discussed in the following subsections.

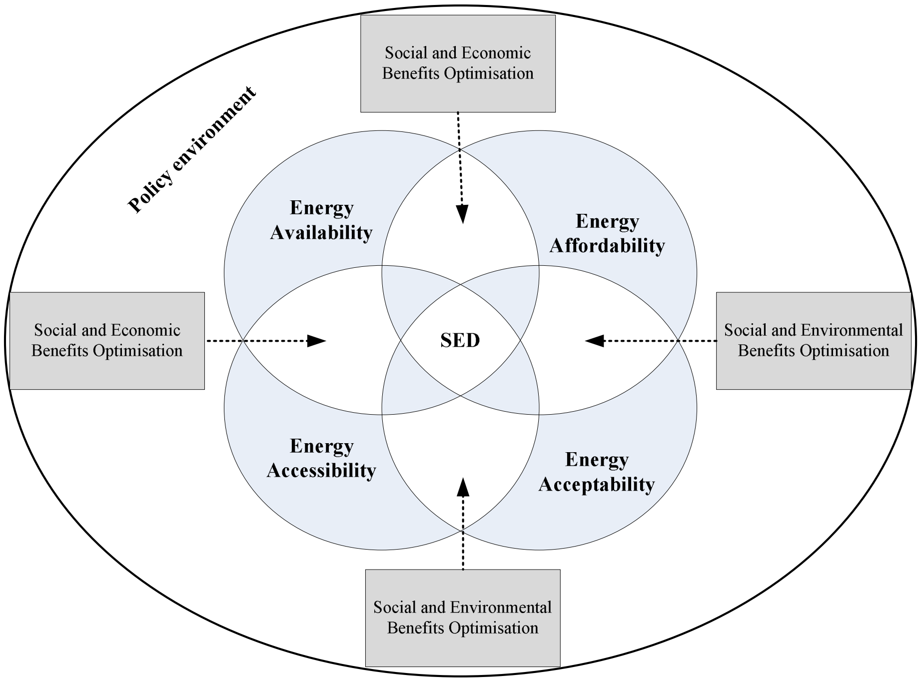


Figure 6.1: Integrated Framework for Sustainable Energy Development.

Table 6.1: Energy Sustainability Indicators (ESI).

	ENERGY OBJECTIVE	SUSTAINABILITY DIMENSION	ASSESSMENT METRIC
1	AVAILABILITY	1. Society 2. Economy	1) petroleum reserve; 2) petroleum production; 3) petroleum reserve-to-production ratio; 4) natural gas reserve; 5) natural gas production; 6) natural gas reserve-to-production ratio; 7) coal reserve; 8) coal production; 9) coal reserve-to-production ratio; 10) tar sands reserve; 11) tar sands production; 12) tar sands reserve-to-production ratio; 13) petroleum products imports; 14) renewable energy total capacity.
2	ACCESSIBILITY	1. Society 2. Economy	1) total primary energy demand; 2) energy demand per capita; 3) electricity total demand; 4) electricity demand per capita; 5) oil domestic consumption; 6) gas domestic consumption; 7) coal domestic consumption; 8) tar sands domestic consumption; 9) decentralised renewable energy production.
3	AFFORDABILITY	1. Society 2. Economy	1) end use gasoline price; 2) income per capita; 3) population dependency ratio; 4) unemployment rate; 5) oil and gas sector investment cost; 6) power sector investment cost; 7) renewable sector investment cost; 8) energy sector total investment cost; 9) total domestic investment cost.
4	ACCEPTABILITY	1. Society 2. Environment	1) CO_2 total emissions; 2) CO_2 emissions per capita; 3) total GHG emissions; 4) GHG emissions intensity; 5) GDP energy intensity; 6) GDP electricity intensity; 7) pollution from oil spills; 8) pollution from gas flares.

6.2.1 Energy Availability

The *“availability”* of energy resources and energy services in the context of this study refers to the short, medium and long term security of primary energy supply in Nigeria. The Nigerian government aims to increase energy use for its 160 million people from the current (2010) 29 GJ/capita to about 400 GJ/capita by year 2020 [14]. This is about the present energy consumption levels of Canada and Iceland [168]. The key question to consider for this kind of target is: *“where will this energy come from?”* In view of such a question, this study has defined indicators that can be used to measure targets or assess progress towards achieving sustainable supply of primary energy in the country. These indicators are shown under energy availability objective in Table 6.1. As previously mentioned, indicator selection here is based on policymakers’ opinions as captured in stakeholder responses to (Question A2 Appendix B).

6.2.2 Energy Accessibility

“Access” to reliable energy services remains an essential ingredient for improving the wellbeing of the people, and the functioning of the economy. Yet, different kinds of threats hinder sustainable access to energy services in Nigeria. As at end of year 2010 for instance, only about 40% of the country’s total population was estimated to have access to modern energy services [114]. About 80% of its rural population depend wholly on traditional biomass for their energy needs [114]. The implication here is that even if government succeeds in securing a well-defined energy supply portfolio for the nation, the question to still consider is: *“how will this energy be used, and who will benefit from it?”* To help deal with the question, this study has defined a set of indicators as a standard of measure. These are shown in Table 6.1. The metrics defined under this category aim to maximise the benefits accrued to the social and economic sustainability dimensions.

6.2.3 Energy Affordability

The imbalance between energy demand and supply in Nigeria is caused by variable consumption due to purchasing power [106]. The huge energy investments and upstream production costs also remain the key factors influencing energy *"affordability"* in the country [13, 14]. According to the World Bank Group report on World Development [157], average life expectancy in Nigeria is less than 52 years, income per capita is below US $2800, and 83.9% of the population live on around US $2 a day. It is evident therefore, that majority of Nigerians who desire access to modern energy services are still not confident of their purchasing power. The question the general public yearning for modern energy services still ask is: *"what will be the cost of using this energy even if made available?"* The metrics defined under this objective also aim to quantify benefits accrued to the social and economic sustainability domains.

6.2.4 Energy Acceptability

Energy-related CO_2 emissions and other forms of energy industry pollution remain critical challenges to SED [172-175]. To this end, environmental and social sustainability concerns are seen as the biggest issues for *"acceptability"* of energy usage, particularly fossil fuels use.

A high level of CO_2 concentration in the atmosphere for example, is arguably, a major driver of global warming today [176-179]. The current CO_2 concentration of 0.04% at 388 parts per million (ppm) by volume and +15^{o}C average earth surface temperature are considered by many [180-186] to be scientifically acceptable. However, research has shown that over the past decades, energy-related carbon emissions have been on the increase in different parts of the world [187-190].

Therefore, to increase modern energy access for over 160 million Nigerians from 40% to 75% by 2020 [14] means that energy production and consumption in the country will almost double the current rate. The key question to consider in this circumstance is: *"what will be the environmental consequences of dramatically increasing this energy use?"* Eight indicators (shown in Table 6.1) have been defined by this study, to provide the metrics for assessing progress in this direction. These aim to measure benefits for the social and environmental sustainability domains.

6.3 Definition of Alternative Scenarios

In order to analyse broader implications of the different policy interventions, generating alternative scenarios to examine the impacts of such policies and assumptions becomes essential [143]. This is particularly so, when the overall objective involves finding ways of *"mitigating negative effects"* of such policies [143]. In this section, the main 'assumptions' and 'policies' that can be adapted to generate alternative energy scenarios and compare results with the BAU case are presented.

6.3.1 Alternative Scenario Assumptions

In an effort to promote SED in a manner that is beneficial to the economy, society and the environment, the Nigerian government has designed a number of policy interventions aimed at achieving this agenda [13, 14, 123, 191]. The three most relevant of these policies are selected for further analyses in this study. The three policies underpin three key assumptions for SED as summarised in Table 6.2.

In this case, the desire to achieve *"energy sufficiency"*, *"energy diversity"* and *"energy efficiency"* are presumed to be the main motivation and the driving forces behind these three policies. The three key assumptions aim to serve in twofold: 1) a starting point for exploring the SED agenda and 2) an expected end to the SED initiatives. Sublevel assumptions are defined under each of the three main assumptions. These represent variables configured in the E-PAM that can be altered to produce the desired change effect for each policy. It is important to note that each of the sublevel assumptions aims to impact more on a particular sustainability dimension.

Table 6.2: Alternative Scenario Assumptions for SED.

Main Assumptions and Sublevel Assumptions	
1. Energy Sufficiency ▪ Effects of GDP on energy demand. ▪ Effects of population on energy demand.	**3. Energy Efficiency** ▪ Effects of technology improvements on: carbon reduction, pollution control, climate change mitigation and energy resource conservation.
2. Energy Diversity ▪ Effects of energy imports on supply. ▪ Effects of increased fossil fuel sources on supply. ▪ Effects of renewable development on supply.	

6.3.2 Government Policy Interventions

As discussed in Chapter 4, the E-PAM is formulated to consist of 10 subdomains in 18 'views' also known as 'sketches'. Individual mappings for its parameters are in excess of 950 relationships and equations, with a total of 81 feedback loops. Innumerable scenarios can be undertaken with the model. However, in keeping with this study objective of SED, only three alternative scenarios relative to the BAU are considered. These are based on three government policy initiatives for achieving SED in Nigeria.

The three government policies are: a) Vision 20: 2020 policy—denoted here with the acronym *"VISION 2020"*; 2) Fuels Subsidy Removal policy—designated here as *"SUBSIDY TRANSFER"* and 3) Nigerian Content Development policy—termed here as *"LOCAL CONTENT"* [13, 14, 191]. These policies in all, aim to advance the SED agenda by tackling the supply pressure, demand pressure, environmental pressure and political pressure relating to energy usage in the country [168]. The three policies are briefly discussed in the following subsections under three headings: i) policy focus, ii) policy description and iii) policy objective.

A. VISION 2020

i) Policy Focus

VISION 2020 is a policy of desire for *"Energy Sufficiency"* in a *"Thriving Economy"*. It is a government initiative that aims to maximise energy use to create economic and social benefits, with minimum environmental impacts [14]. The policy aspires to achieve SED through firm control of critical economic and social parameters like 'GDP growth' and 'population growth'—the major drivers of energy demand. This, the government hopes will lead to internal energy sufficiency and social stability in a thriving economy [14].

ii) Policy Description

In 2009, the Federal Government of Nigeria (FGN) through its National Planning Commission (NPC) announced the first implementation plan for its Vision 20: 2020 agenda. The policy is a government initiative to 'fast track' its economic and social development to become one of the world's 20 largest economies [14]. In pursuit of this vision, the country has recently been experiencing a growth 'turnaround' in all sectors of its economy [106]. This growth is consistent with Nigeria's listing by Goldman Sachs [18] as one of the 'Next 11' transitional economies of the world.

The VISION 2020 articulates amongst other things, the nation's energy, social and economic development strategies for the next decade (2010 – 2020). Under this policy, the country aims to grow its GDP from 7% in 2010 [106] to 13.8% by 2020—reaching real GDP growth of about US $900 billion, and income per capita growth of US $4000 [14]. These growth targets, the government expects will be driven by *"agriculture"* and *"industry"* sector production over the short and medium term, with the aim of becoming a *"service-based economy"* in the long term [14]. To ensure a sufficient availability of energy to drive this growth, the government plans to keep population growth under control, with a projected decline in Total Fertility Rate from 5.5 in 2010 to 4.5 by year 2020 [14].

iii) Policy Objectives

The key objectives of this policy initiative include the following:

- Increase funding for energy sector investment
- Increase total primary energy and electricity use
- Increase total productive capital and domestic investment
- Reduce population growth
- Reduce unemployment
- Enhance income per capita
- Reduce total energy intensity

B. SUBSIDY TRANSFER

i) Policy Focus

SUBSIDY TRANSFER is a policy of desire for *"Energy Diversity"* in a *"Transitional Economy"*. This government initiative also focuses on optimising the social and economic sustainability benefits. It aspires for SED through diversification of energy supply portfolio, with reduced dependence on energy imports [13]. The policy seeks to promote investment in domestic energy supply capability, including development of renewable energy sources. These in all, aim towards achieving an energy self-reliant transitional economy.

ii) Policy Description

In 2012, the Nigerian Government announced the withdrawal of its long-existing fuels subsidy programme [192-194]. The subsidy policy was government's initiative to create 'artificial' low pump price for petroleum products imported into the country [192]. Under this policy, government was buying refined petroleum products at a much higher price on the global market and selling it to 'Service Operators' at about 1/3 of the purchase price [191]. According to the government, *"Operators hijacked the subsidy scheme, as they were selling the subsidised fuels to final consumers at more than double the benchmark price"* [193]. In addition, others diverted the subsidised products to neighbouring countries like Benin, Cameroon, Chad and Niger, to sell for a much higher gain [191].

The implication is that the Nigerian public, the intended beneficiaries never enjoyed the subsidy scheme, hence, government's decision to fully withdraw it [193, 194]. As a result of the policy change, prices of Premium Motor Spirit (PMS)—used here as a proxy to discuss the situation, was to rise from US $0.4/litre to US $0.87/litre [193]. Following mass protests by Organised Labour Unions (OLU) in the country, the pump price was renegotiated to US $0.6/litre [191].

Government stated that the subsidy removal will save about US $8 billion per year, an amount it spent in year 2011 in subsidising fuels imports [193]. It is the intention of government to 'transfer' the proceeds from subsidy removal to increase investment in in-country refining capacity expansion, energy supply infrastructure development and building of efficient regulatory institutions [13]. Development institutions like World Bank [194], IMF [193], and policy institutions such as Brookings Institute [195] have all commented that policy change on fuels subsidy is long overdue. Moyo and Songwe [192] have also commented that "*Nigeria's fuels subsidy continues to crowd out other development spending*".

iii) Policy Objectives

The SUBSIDY TRANSFER policy is designed to achieve a range of objectives; the most relevant to this study include the following:

- Reduce dependence on petroleum products importation
- Increase fossil fuels sources in the nation's total energy supply mix
- Increase share of renewable energy in electricity supply
- Increase total primary energy domestic supply
- Increase investment in oil and gas sector development
- Increase investment in renewable energy development
- Reduce energy intensity

C. LOCAL CONTENT

i) Policy Focus

LOCAL CONTENT is a policy of desire for *"Energy Efficiency"* in a *"Green Economy"*. This policy aims to maximise environmental sustainability objectives from an energy use perspective [13]. On this path, the SED agenda will be pursued through energy technology improvements [13]. The policy seeks to promote indigenous capacity building in all facets of energy technology, including technology development and technology transfer [14]. The overall target is to reduce carbon emissions and energy industry pollution, and ultimately mitigate climate change. This policy also aims to promote a low-carbon economy through reduction in fossil fuel use, conservation of non-renewable energy resources and increase in development and use of renewable energy sources [13].

ii) Policy Description

The Nigerian Government in 2010, signed into law the Nigerian Content Development Bill [13]. The Bill articulates increasing the role of Nigerian companies in all aspects of oil and gas development in the country. By this policy, government through its Nigerian Content Division of the NNPC has defined the categories of work that must be executed in the country [13].

According to government [14], a minimum of 75% local content target must be set and met by all oil and gas 'majors' operating in the country. This, the government hopes will encourage local engineering design and fabrication of equipment and spares in-country through the use of local materials. The drive is to maximise technology through enhanced indigenous capability, and improve efficiency in the management and operation of the energy sector [123].

According to government [123], the policy, if fully implemented will: 1) improve energy technology use in the country and 2) promote a green economy through carbon reduction and pollution control from energy development activities. In view of immense social and environmental benefits the full implementation of this policy possesses, government aims to pay particular attention to implementation of gas capture and gas-reuse technologies, and development of the domestic gas market [123].

iii) Policy Objectives

The key objectives of implementing the LOCAL CONTENT policy include:

- Increase fossil fuels reserves
- Reduce petroleum and natural gas production
- Reduce total primary energy demand.
- Reduce electricity demand

- Increase domestic investment in energy sector development
- Reduce GDP energy intensity
- Reduce CO_2 emissions

The proposed government policies and their key targets, along with alternative energy scenarios defined for further analyses are summarised in Table 6.3.

Table 6.3: Proposed Government Policies and Key Policy Targets.

	POLICY INTERVENTION	POLICY START YEAR	KEY POLICY TARGET	ENERGY SCENARIO
1	VISION 2020	2010	-reduce total fertility rate from 5.5 in 2010 to 4.5 by 2020. -increase GDP growth from 7% in 2010 to 13.8% by year 2020. -enhance income per capita from US $1200 in 2010 to US $ 4000 by 2020. -increase energy sector investment by >100% by 2020.	Energy Sufficiency in a Thriving Economy
2	SUBSIDY TRANSFER	2015	-reduce net energy import of 7.55 MTOE in 2010 by 45% in year 2020. -increase renewable energy capacity of 23.9 MTOE in 2010 by >16% in 2020. -increase total primary energy supply by >25% in 2020. -increase commercial energy use by more than 50% in 2020.	Energy Diversity in a Transitional Economy
3	LOCAL CONTENT	2015	-increase oil reserve of 5.43 Bmt and gas reserve of 4.4 MTOE in 2010 by 20% and 15% in 2020 respectively. -reduce total energy consumption by >2% in 2020. -reduce GDP energy intensity by >20% in 2020. -bring gas flaring to 0%, and reduce oil spill incidences by 50% in 2020.	Energy Efficiency in a Green Economy

6.4 Alternative Energy Scenario Analyses

In Chapter 5, we presented an analysis of the current energy situation in Nigeria, as well as future projections based on a BAU scenario; a path where existing policies are assumed to continue into the future without government interventions. The BAU case depicted a scenario of *"Energy Poverty in a Developing Economy"*. In this chapter, three alternative energy scenarios based on the three proposed government policies described in Section 6.3 are explored. The alternative energy scenarios are termed: 1) Energy Sufficiency in a Thriving Economy; 2) Energy Diversity in a Transitional

Economy and 3) Energy Efficiency in a Green Economy. This section presents an analysis of the three energy scenarios relative to the BAU case. This implies that outputs from the E-PAM for a total of four scenarios will be analysed. The discussion will focus on fulfilment of the 'four grand energy objectives' of SED earlier defined in Section 6.2 of this chapter. A framework that provides a schematic representation of these four energy scenarios is shown in Figure 6.2. This is an excerpt from Figure 6.1 that focuses mainly on describing the four energy scenarios and their relative impacts.

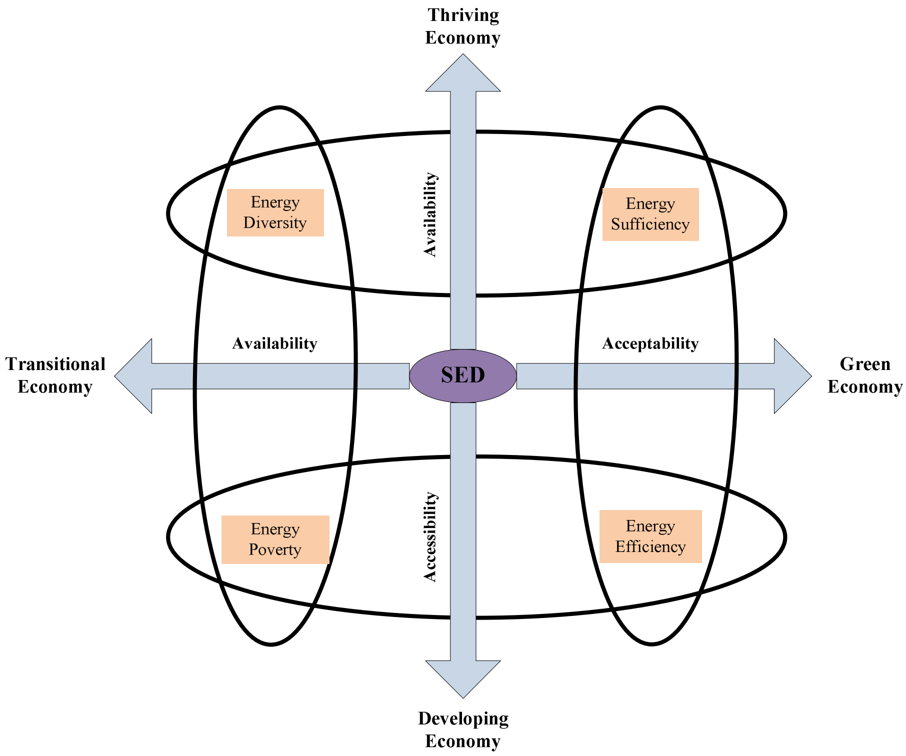
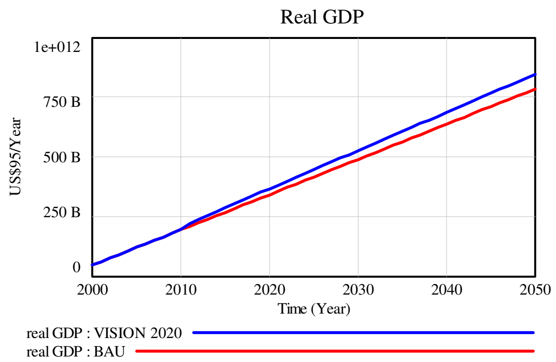


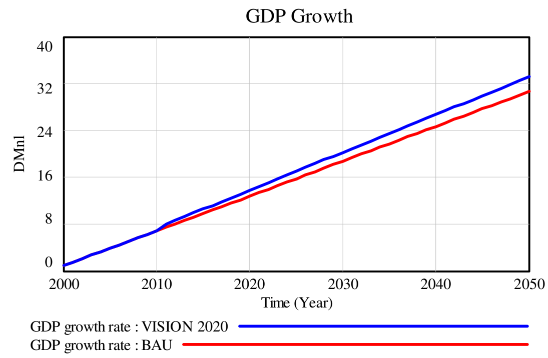
Figure 6.2: Schematic Representation of Energy Scenarios.

6.4.1 Scenario 1: Energy Sufficiency in a Thriving Economy

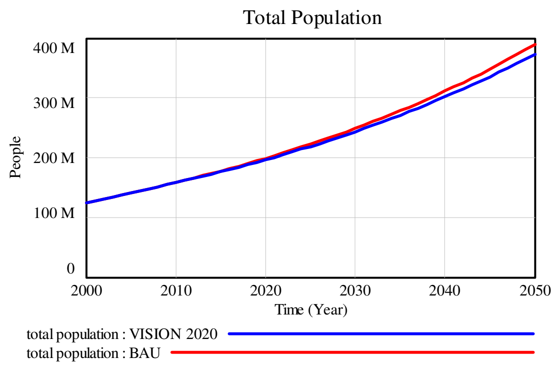
In this scenario, two model parameters: 1) GDP growth rate and 2) Total fertility rate are varied at year 2010, to replicate the desired behaviour for real GDP growth and total population growth by year 2020 as described in the policy statement [14]. The result of these variations in comparison with BAU is shown in Figure 6.3.



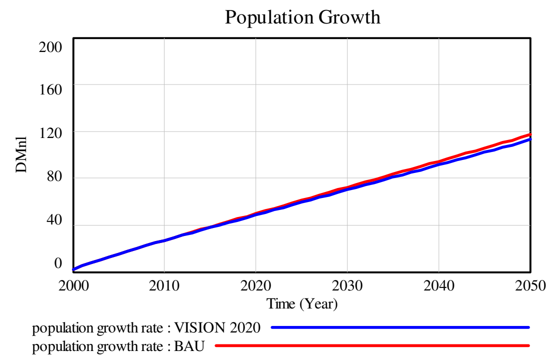
(a) real GDP



(b) real GDP growth



(c) total population



(d) population growth

Figure 6.3: Nigeria GDP and Population Growth.

As proposed by government under VISION 2020, the GDP is expected to grow at the rate of 7% in 2010 to 13.8% by year 2020 [14]. This represents an expected change in real GDP growth from US95 \$193.6 billion to US95 \$900 billion and income per capita from US95 \$1200 to US95 \$4000 over the 10 year period [14]. Calculated model results show that real GDP will reach US95 \$366.02 billion by 2020, with income per capita reaching US95 \$1862 over the same period. By our calculations, this is about 42.2% and 36.4% less than government expectations for real GDP growth and income per capita growth respectively. It is worth noting that the unit *"DMnl"* in Figure 6.3 (b) and (d) and elsewhere in this report represents Vensm™ way of defining a 'dimensionless' property.

It is also evident in our model that by year 2020, real GDP (with 89.1% total growth projection under the new policy), will almost double its 2010 value; this will be about 7% higher than the value of real GDP under BAU scenario. Despite an impressive real GDP growth prospect under this policy, an expected marginal change in total population growth (about 1.1%) in comparison to the BAU means, that income per capita will only change by 8.5% over the 10 year period. This readily points to a fact, that proposed government intervention in population control is still insignificant when compared with economic growth.

However, an expected 89% overall growth in real GDP and 24% overall growth in total population over a 10 year period also means, that significant impact on energy use in the country are expected. The question to now consider is: *"what impact would expected changes in real GDP growth and population growth have on energy use in Nigeria from the standpoint of the four grand energy objectives?"* The behaviour of the E-PAM relating to these four objectives are summarised in Table 6.4. The policy impact measures (metrics) are based on the indicators defined in Table 6.1 of this chapter.

Table 6.4: Impact of Vision 20: 2020 on SED in Nigeria.

	SCENARIO 1: ENERGY SUFFICIENCY IN A THRIVING ECONOMY	
	ENERGY OBJECTIVE	**POLICY IMPACT OVER THE PERIOD (2010 – 2020)**
1	AVAILABILITY	- the policy has no direct influence on energy availability; GDP and population growth are the major drivers of energy demand and not supply. - petroleum products importation will continue in line with BAU conditions. - oil and gas reserves discovery, production rates and reserve-to-production ratio will all continue in line with the BAU assumptions. - renewable energy capacity will also grow in accordance with BAU assumptions. - funding available for energy sector investment is set to grow from US95 $3.806 – 10.44 billion (indicating over 170% growth in energy sector investment).
2	ACCESSIBILITY	- total primary energy consumption grows by 27.8%, indicating an increase of 4.2% over BAU. - energy consumption per capita grows by 3%, about 5.4% higher than the BAU case. - electricity total demand increases from 22.49 – 36.29 BkWh, denoting total growth of 61.4% over a 10 year period. - electricity demand per capita grows by 30.1%, which is 8% higher than BAU. - total productive capital is set to grow from US95 $118.72 – 355.85 billion, representing 199% total growth prospect and access to productive capital.
3	AFFORDABILITY	- income per capita increases by 52.5% (from US95 $1221 – 1862), about 8.5% higher than BAU, which indicates little change in purchasing power.

		- dependency ratio changes from 0.9632 – 0.9669, signifying a weakening purchasing power for the productive population (i.e. ages 15 – 64 years). - unemployment increases from 17.31 – 20.91% over 10 years, indicating a negative impact on overall purchasing power. - oil and gas total investment grows from US $0.616 – 2.094 billion, denoting >300% growth over 10 years, and about 7.3% growth above BAU. - renewable energy investment grows from US $0.1339 – 0.7539 billion over the same period, denoting >400% growth, and 7.3% growth above BAU.
4	ACCEPTABILITY	- GDP energy intensity (i.e. energy/GDP) decreases by 47.9% over the 10 year period, about 1.4% less than BAU. - GDP electricity intensity decreases by 17.3%, about 0.2% less than BAU. - CO_2 emission per capita decreases by 10%, about 1.1% higher than BAU. - GHG emissions intensity decreases by 68.3%; CO_2 intensity decreases by 68.4%. - pollution from oil spills increases by 300%, while pollution from gas flares increases by 200%.

In addition to having direct impact on energy use, especially on energy accessibility, affordability and acceptability, the Vision 20: 2020 policy has significant influence other important areas within the social, economic and environmental domains. Our model configuration has captured these sectors to include variables such as: net migration, labour demand and supply, total production, domestic investment as well as government revenue and expenditure. Others are pollution regulation cost, pollution abatement cost and water demand.

The E-PAM projects the Nigerian economy to grow by more than 80% over the next decade (2010 – 2020), with real GDP increasing from US95 $193.59 in 2010 [157] to US95 $366.02 by year 2020. Despite expected economic growth under the new policy, some existing social challenges are likely to continue. According to model predictions, net migration[10] for example, is set to improve by only 1.1% over the BAU case. This implies that only about 1% of the people leaving Nigeria for other outside opportunities would choose to remain even if this policy is fully implemented. In view of a revamped economy however, total labour demand is likely to grow by 39.6%, increasing from 37.36 million people in 2010 [105, 157] to 52.14 million by 2020. Yet,

[10] According to World Bank is the net total of migrants during a period (i.e. the total number of immigrants less the annual number of emigrants, including citizens and noncitizens.

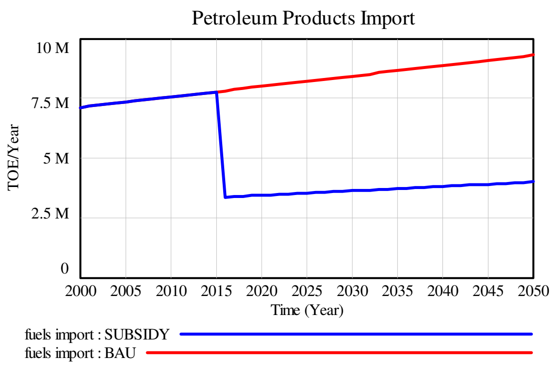
a rising population trend means that unemployment will continue to grow, reaching 20.91% by 2020 *"from 17.31% in 2010"* [106]. This also means that total labour supply will grow from 45.19 million in 2010 [106] to 65.93 million by 2020.

In terms of economic impact, total production under VISION 2020 is set to outgrow the BAU case by more than 7% in year 2020—growing from US95 $341.19 in 2010 [157] to US95 $366.02 by 2020. Domestic investment which comprises of agriculture, commercial, service, transport, energy and other industry sectors is set to grow from US95 $47.74 billion in 2010 [157] to US95 $94.55 billion by 2020—representing 98.1% total growth, about 7.3% higher than investment projections under BAU. The total domestic investment projection corresponds to about 25.8% of real GDP. Over the same period, both government revenue (comprising 'oil' and 'nonoil' revenue) and government expenditure (comprising 'operations' and 'capital' expenditure) are also expected to witness a growth trend that is consistent with real GDP growth. Total government revenue increases by 89.1% while expenditure increases by 45.5%, with both outgrowing the BAU case by 7.3%.

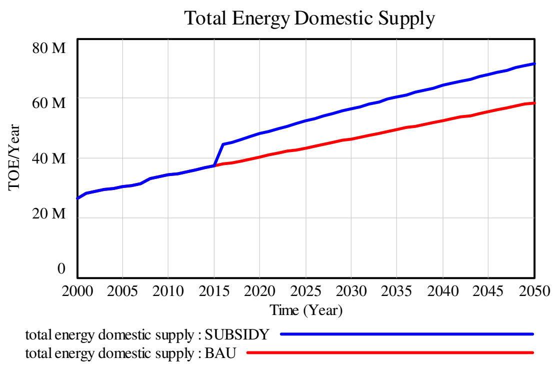
From the environmental perspective, the model forecasts oil and gas total pollution to grow by more than 300% over the 10 year period. In view of this, it is expected that government pollution regulation cost and pollution abatement cost will also increase. Both are estimated to increase by >200% over the period under consideration. Similarly, total water demand in the country, comprising of agric. water demand (17.7%), municipal water demand (19.4%) and industry water demand (62.9%) is set to grow by 88.9% over the 10 year period. This projected growth in total water demand follows from stakeholder responses to (Questions D5 (a) and D5 (b) of Appendix B) about the future of water security in the country.

6.4.2 Scenario 2: Energy Diversity in a Transitional Economy

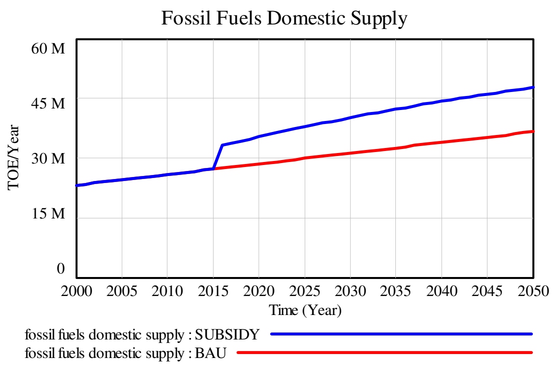
In this scenario, the impacts of the SUBSIDY TRANSFER policy were tested by varying three model parameters: 1) reduction in petroleum products importation, 2) increase in fossil fuel sources and 3) addition of renewable energy sources to total energy supply mix. Here, the above three model parameters were simultaneously varied at year 2015—the base policy year, to examine their effect on the 'four grand energy objectives', and on other essential social, economic and environmental sectors. The model outputs for these parameters are shown in Figure 6.4.



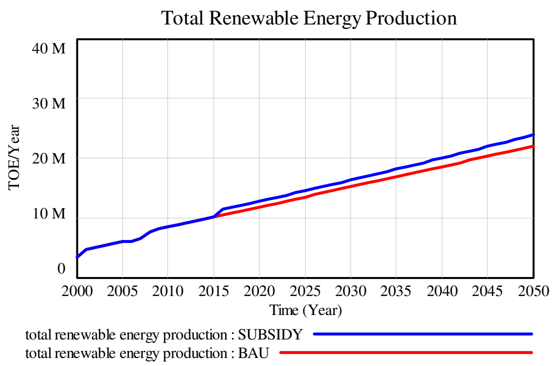
(a) petroleum products import



(b) total energy domestic supply



(c) fossil fuels domestic supply



(d) total renewable energy supply

Figure 6.4: Nigeria Energy Supply by Source.

As mentioned in the policy statement, government under the SUBSIDY TRANSFER targets to annually save approximately US $8 billion through divestment in subsidy for petroleum product imports [191, 193]. By this, the government seeks to reduce dependence on refined fuels importation. This can be achieved by investing the subsidy proceeds in domestic refining capacity expansion, renewable energy development and the use of domestic fossil fuel sources.

In view of this policy change, it is expected as evidenced in Figure 6.4 (a), that by year 2020, petroleum products import into the country will in comparison to the BAU decline by 45.5%. It is also expected that the planned re-introduction of coal use and tar sands production in the country from year 2015 will increase domestic fossil fuels total supply by 20.6%, increasing from 27.46 to 33.12 MTOE. Of this new supply mix, domestic oil supply will contribute the most with (48.6%), followed by gas (15.3%), coal (14.2%), tar sands (11.8%) and petroleum products importation (10.1%).

In terms of renewable energy, the planned addition of ‘solar’ and ‘wind’ energy sources to the existing ‘hydro’ and ‘biomass’ sources, is expected to increase renewable energy production in the country by 8.9%. This means that by 2015, renewable energy will have contributed 25.6% of total energy domestic supply. It is important to note however, that despite a projected decrease of about 5.3% in biomass use in the country over the period; traditional biomass will remain the dominant renewable energy source in use in Nigeria. This being the case, we forecast, that by year 2020, biomass will account for (82.7%) of renewable energy use in the country, followed by hydro (8.5%), solar (5.7%) and wind (3.1%).

The overall impact of the SUBSIDY TRANSFER policy on energy availability, accessibility, affordability and acceptability is summarised in Table 6.5. It is worth noting that this policy has shown no direct impact on domestic oil and gas supply because its aim is not to increase domestic oil and gas, but to diversify total energy supply portfolio, with a focus on developing coal, tar sands and renewable sources.

Table 6.5: Impact of Energy SUBSIDY Policy on SED in Nigeria.

	SCENARIO 2: ENERGY DIVERSITY IN A TRANSITIONAL ECONOMY	
	ENERGY OBJECTIVE	**POLICY IMPACT OVER THE PERIOD (2015 – 2020)**
1	AVAILABILITY	- petroleum products import decreases from 7.991 – 3.436 MTOE, more than 130% decline over BAU. This indicates 7.1% overall potential shortage in petroleum products supply. - the policy has no direct impact on oil and gas discovery, production, and reserves-to-production ratio. These are projected to grow with BAU assumptions. - coal and tar sands will contribute 14.2% and 11.8% respectively, to total fossil fuels use in the country. - renewable energy total capacity will increase by 16.7% (from 33.92 – 39.58 MTOE), with 82.7% biomass; 8.5% hydro; 5.7% solar and 3.1% wind. - total primary energy domestic supply will increase by 28.9%, about 19.2% higher than the BAU case by 2020.
2	ACCESSIBILITY	- this policy impacts more on energy supply than demand, however, total primary energy demand will also grow by 10.9% over the period. - in view of 11.9% growth in total population over the 5 year period, primary energy demand per capita over the same period will decline by about 1%. - of the total energy demand, non-commercial energy will account for 44%, while commercial energy demand will increase by 56% over the 5 year period. - by year 2020, total energy demand by industry sector will be highest with 37.8%, followed by household 25.8%, service 19%, transport 14% and agric. 3.4%. - the policy shows no significant influence on electricity total demand and electricity demand per capita.
3	AFFORDABILITY	- the policy has no significant impact on investment in oil and gas development; it focuses more on increasing the share of coal and tar sands for energy diversity, with overall effect on energy prices. - investment in renewable energy is set to increase by >100% over the period, denoting significant increase in cost of renewable energy development, with overall impact on final end use energy prices. - end use gasoline price increases from US $0.4/litre to US $0.87/litre, representing more than 110% increase in fuel price over 5 years.
4	ACCEPTABILITY	- GDP energy intensity under the SUBSIDY policy will decrease by 15% over the 5 year period. - in view of increased fossil fuel use, including coal and tar sands, total fossil fuel CO_2 emissions are expected to rise by 66.7%, about 55.2% above BAU. - CO_2 emission per capita will increase from 0.2291 – 0.3554 Ton Carbon, indicating total increase of 46.6%, and >55% over the BAU emissions. - total GHG emissions will increase from 43.28 – 71.03 B kg/Year, denoting 64.1% overall increase over 5 years, about 55.1% above the BAU case. - GDP electricity intensity is set to decrease by more than 7% over a 5 year period.

Similarly, in addition to having direct impact on energy use, especially on energy availability, accessibility and acceptability, the SUBSIDY TRANSFER policy has significant influence other important areas within the social, economic and environmental domains. Our model configuration has captured these sectors to include variables such as: cohorts mortality rate, dependency ratio, domestic R&D investment, and income per capita. Others are CO_2 emissions, CO_2 intensity and land use.

It is glaring in our model outputs on renewable energy that government's plan under the SUBSIDY policy, to increase the contribution of 'solar' and 'wind' to renewable energy use to a combined 7% by year 2020 is achievable. Considering our model projection of 5.7% solar and 3.1% wind contribution by 2020, it is evident that this target can even be exceeded by 1.8%. This is however, based on the consideration that government is able to demonstrate continued interest in renewable energy development, by investing at least 1% of the annual fuels subsidy proceeds of US $8 billion into yearly deployment of solar and wind energy technologies. This will translate to a total investment of US $400 million in solar and wind technologies by year 2020.

At an estimated average cost of US $2200 per 1kWp of solar PV system [196], we estimate that half of the expected US $400 million investment in renewable, will by 2020, produce approximately 91 x 10^3 kWp of solar PV system. Considering that a typical 3.5 kWp PV system can generate around 3 x 10^3 kWh of electricity per year [196], we estimate that this is capable of producing about 78 MWh of electricity by 2020. Similarly, assuming an estimated total cost of US $140,000 for a 20 kW wind turbine installation [197], we estimate that the remaining 50% of expected investment in renewable energy would install approximately 29 x 10^3 kW worth of wind turbines by 2020. Assuming a **Betz limit**[11] [198] of only 50% for wind turbine conversion efficiency, we estimate that this is capable of generating 127 MWh of electricity in the country. According to World Bank [139], electricity consumption per capita of Nigeria is 136.5 kWh.

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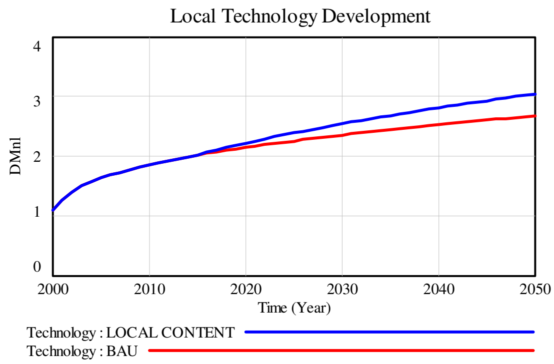
[11] A theoretical limit of the percentage of power which a turbine can extract from the energy of a moving wind given to be 59.6%.

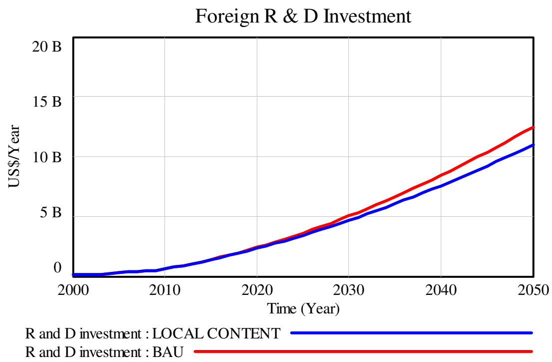
6.4.3 Scenario 3: Energy Efficiency in a Green Economy

In this scenario, the effect of government policy to pursue a low-carbon economy with energy efficient technologies using 75% local materials and know-how is investigated. Here, the variable 'technology progression' driven in our model by 'productive capital' and 'productive investment' is modified to examine any impact on the four energy objectives. Based on government target of 75% *"local content"* by 2020 [13], 'technology progression rate' in the model is varied from 0.09% in 2015 to 0.15% by 2020. The key model variables reflecting this change are shown in Figure 6.5.

Figure 6.5 (a) shows technology progression rate under the 75% 'local content' target. The model output indicates that to achieve this target, indigenous technology development will have to grow at 9.9% over the five year period or 2.41% per annum.



(a) technology progression



(b) foreign R&D investment

Figure 6.5: Nigeria Technology Development and Investment.

It is evident in Figure 6.5 (b), that under the LOCAL CONTENT policy, government expenditure on technology transfers and foreign R&D activities will in year 2020 drop by around 3.3%, as compared to the BAU case. This means, that about US $76.2 million would be savings that can be put into local technology development. It is also expected that under this new scheme, R&D capital for indigenous technology development would grow from US $29.17 million in 2015 to US $34.71 million by

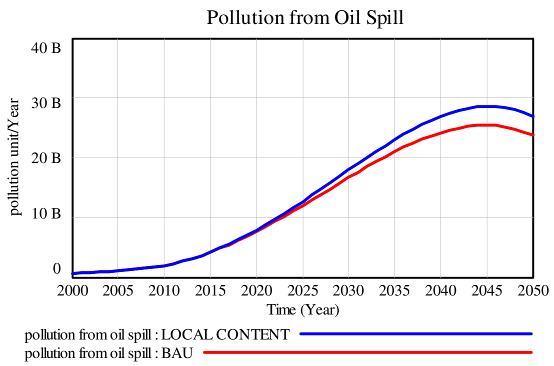
2020—indicating a growth of over 18% in 5 years. The impact of this policy on our four energy objectives are summarised in Table 6.6.

Table 6.6: Impact of LOCAL CONTENT Policy on SED in Nigeria.

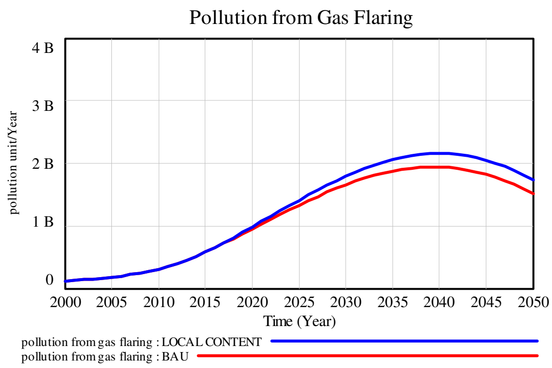
	SCENARIO 3: ENERGY EFFICIENCY IN A GREEN ECONOMY	
	ENERGY OBJECTIVE	**POLICY IMPACT OVER THE PERIOD (2015 – 2020)**
1	AVAILABILITY	- this policy has no direct impact on petroleum products importation; fossil fuels import are expected to continue in similar manner as BAU. - oil discovery fraction will change from 0.0361 to 0.0376, representing 4.2% total growth, while gas discovery fraction changes from 0.0656 to 0.0714, representing 8.8% total growth over a 5 year period. - oil production is set to grow from 141.99 – 151.51 MTOE, about 7.5% total growth over 5 years, and less than 1% over BAU. Total natural gas production over the same period grows by 9.1%, about 1.6% growth over the BAU case. - in view of higher production, oil reserve-to-production ratio will decline from 42.68 – 42.45 years, while gas reserve-to-production ratio declines from 166.46 – 164.48 years, about 1.5% lower than the BAU case. - renewable energy capacity will grow in line with the BAU assumptions.
2	ACCESSIBILITY	- in view of energy efficiency gains through improvements in technology, total primary energy demand is set to decrease from 35.94 – 36.85 MTOE, indicating total decline of 2.5% in five years, and 5.5% improvement over the BAU case. - total primary energy demand per capita over the same period, will decline by 9.2%, about 5.6% less than the BAU demand. - electricity total demand will also decrease by 16% over 5 years, indicating 1.7% improvements over BAU. - by year 2020, industry sector will account for most of electricity demand—taking (50%), followed by service (30%), residential sector (15%) and agric. (5%). - electricity demand per capita over the same period will decline by 4.3%, reflecting 1.7% improvements over the BAU demand.
3	AFFORDABILITY	- domestic investment cost for oil sector development will increase by 56.1% over 5 years, about 4% above BAU. - domestic investment cost for gas sector development will increase by 33.1% over 5 years, about 5% above BAU. - investment in renewable energy is set to increase by 50% over the period, denoting significant rise in cost of renewable energy development, with overall impact on final end use energy prices. - end use gasoline price increases from US $0.4/litre to US $0.6/litre, denoting 50% increase in fuel price over 5 years.
4	ACCEPTABILITY	- GDP energy intensity under this policy will decrease by 24.4% over the 5 year period, about 5.5% less than BAU. - GDP electricity intensity is set to decrease by more than 9% over 5 year period, about 1.6% lower than BAU. - pollution index changes from 15.34 – 31.01, indicating more than 100% increase in oil and gas pollution, about 1% above BAU. - CO_2 emission and CO_2 emissions per capita will increase in accordance with BAU assumptions.

The LOCAL CONTENT policy also has direct impact on energy use, especially on energy availability, affordability and acceptability, as well as a significant influence other critical areas within the social, economic and environmental domains. The E-PAM has represented these sectors to include variables such as: cohorts' births and death rates, labour supply, GDP electricity intensity, domestic investment and income per capita. Others are oil and gas pollution, pollution abatement and regulation cost.

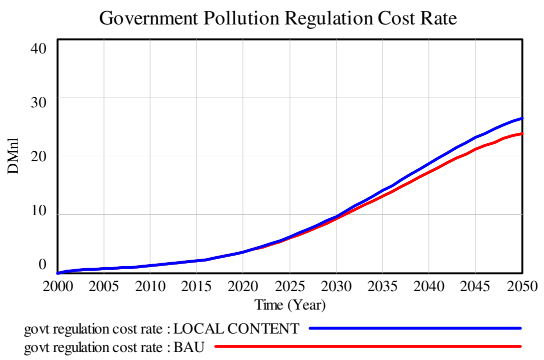
The overall focus of the LOCAL CONTENT policy is to *"green"* the economy through energy efficiency measures using improvements in energy technologies. It is however, important to note as in Figure 6.6, that overall oil and gas industry pollution from 'oil spills' and 'gas flares' will continue into the future. This is due to expected higher oil and gas production over the short and medium term.



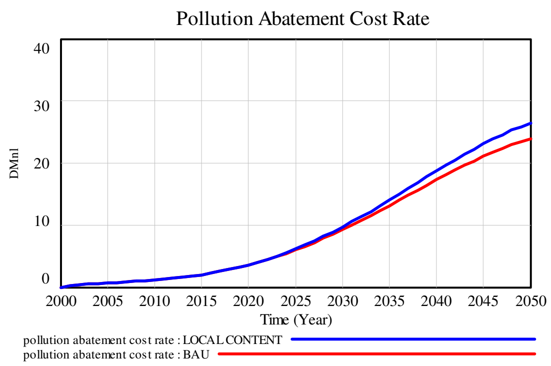
(a) pollution from oil spill



(b) pollution from gas flaring



(c) pollution regulation cost rate



(d) pollution abatement cost rate

Figure 6.6: Pollution and Pollution Control Measures.

It is evident in Figure 6.6 (a) that pollution from oil spill—driven in the model by 'technology' and 'oil production', will rise from 4.161 billion (pollution unit/Year) in 2015 to 7.898 billion (pollution unit/Year) by 2020. This represents around 89.8% increase over a 5 year period and about 3.3% above BAU scenario. Pollution from oil spills is expected to peak around year 2045. This is in line with projected decline in oil production activities in the country over the next four decades (2010 – 2050).

Similarly, pollution from gas flare shown in Figure 6.6 (b), is projected to rise from 580 million (pollution unit/Year) to 983 million (pollution unit/Year), indicating 69% increase and about 3.3% rise above BAU. Gas flare is expected to peak by 2040. This is due to a combination of factors such as: 1) increased investment in 'gas flare out' projects, 2) gas capture and re-injection and 3) decline in gas production yield.

In view of increased overall oil and gas industry pollution, it is expected that government will adopt appropriate measures to deal with the pollution challenges. To this end, two cost measures: 1) 'pollution regulation cost' and 2) 'pollution abatement cost' are configured in the E-PAM to examine this purpose. As shown in Figure 6.6 (c) and (d), it is expected that pollution regulation cost rate and pollution abatement cost rate—the key measures to pollution control, will increase in accordance with oil industry pollution trend. Both are projected to increase by 77% over the 5 year period (2015 – 2020). This indicates annual increase of 15% and 1% increase above BAU.

It is expected that increased investment in pollution control will not only improve the chances of attaining SED in the country, but it will equally enhance environmental Sustainability from the energy use *"acceptability"* objective. In addition, the attainment of a reasonable level of energy efficiency through improvements in technology will have a positive impact on climate change mitigation and non-renewable energy resource conservation.

6.4.4 Metrics for Comparison of Energy Scenarios

In this section, we present a combined result of our four energy scenarios: 1) Energy Poverty (EP), 2) Energy Sufficiency (ES), 3) Energy Diversity (ED) and 4)

Energy Efficiency (EE). The quantification and comparison of the scenarios is based on the Energy Sustainability Indicators (ESI) defined in Section 6.2 of this chapter. The four energy scenarios are compared over a 10 year timescale (2010 – 2020). Years 2010, 2015 and 2020 are chosen as policy reference years because, it is in 2010 and 2015 that proposed policy changes are expected to commence, and the government anticipates that all policy changes will show impact by year 2020. A summary of the metrics quantifying the impacts is shown in Table 6.7.

Table 6.7: Energy Scenario Metrics for Nigeria.

ENERGY OBJECTIVE & INDICATORS	**SCENARIO COMPARISON FOR THE PERIOD (2010 – 2020)**											
	2010				**2015**				**2020**			
	EP	**ES**	**ED**	**EE**	**EP**	**ES**	**ED**	**EE**	**EP**	**ES**	**ED**	**EE**
AVAILABILITY												
-petroleum reserve *(Billion metric tonnes)*	5.43	5.43	5.43	5.43	6.08	6.08	6.08	6.08	6.48	6.46	6.46	6.47
-petroleum production *(Million metric tonnes)*	122	122	122	122	141	142	141	141	151	151	151	153
-petroleum reserve-to-production ratio *(Year)*	44.5	44.5	44.5	44.5	43.1	42.8	43.1	42.9	42.8	42.8	42.6	42.3
-natural gas reserve *(BTOE)*	4.44	4.44	4.44	4.44	4.90	4.90	4.90	4.90	5.19	5.20	5.19	5.20
-natural gas production *(MTOE)*	26.6	26.6	26.6	26.6	28.9	29.0	28.9	31.1	31.2	31.1	31.1	31.6
-gas reserve-to-production ratio *(Year)*	167	167	167	167	169	168	169	169	166	167	167	165
-coal reserve *(MTOE)*	511	511	490	511	683	683	642	683	841	841	775	841
-coal production *(MTOE)*	0	0	3.43	0	0	0	4.49	0	0	0	5.43	0
-coal reserve-to-production ratio *(Year)*	∞	∞	142	∞	∞	∞	143	∞	∞	∞	143	∞
-tar sands reserve *(BTOE)*	6.37	6.37	6.35	6.37	7.62	7.62	7.58	7.62	8.66	8.66	8.59	8.66
-tar sands production *(MTOE)*	0	0	3.17	0	0	0	3.79	0	0	0	4.29	0
-tar sands reserve-to-production ratio *(Year)*	∞	∞	203	∞	∞	∞	200	∞	∞	∞	202	∞
-renewable energy total capacity *(MTOE)*	23.9	23.9	28.3	23.9	28.7	28.7	33.9	28.7	33.6	33.6	39.5	33.6
-petroleum products import *(MTOE)*	7.55	7.55	7.55	7.55	7.77	7.77	7.77	7.77	7.99	7.99	3.44	7.99
ACCESSIBILITY												
-total primary energy demand *(MTOE/Year)*	31.7	31.7	31.7	31.7	35.9	37.5	35.9	35.9	38.8	40.5	39.8	36.8
-energy demand per capita *(TOE/Year/Person)*	0.20	0.20	0.20	0.20	0.20	0.21	0.20	0.20	0.19	0.20	0.20	0.18
-electricity total demand *(BkWh/Year)*	22.4	22.4	22.4	22.4	28.5	30.5	28.5	28.5	33.9	36.2	33.9	33.3
-electricity demand per capita *(kWh/Year/Person)*	141	141	141	141	160	172	160	160	170	184	170	167
-oil domestic consumption *(Mmt)*	13.9	13.9	13.9	13.9	14.7	14.7	14.7	14.7	15.5	15.5	16.8	15.5
-gas domestic consumption *(MTOE)*	4.39	4.39	4.39	4.39	4.67	4.67	4.67	4.67	4.96	4.96	5.31	4.96
-coal domestic consumption *(MTOE)*	0	0	0	0	0	0	4.69	0	0	0	5.43	0
-tar sands domestic consumption *(MTOE)*	0	0	0	0	0	0	3.90	0	0	0	4.29	0

-renewable energy production *(MTOE)*	23.9	23.9	28.3	23.9	28.7	28.7	33.9	28.7	33.6	33.6	39.5	33.6
AFFORDABILITY												
-end use gasoline price *(US$/litre)*	0.40	0.40	0.40	0.40	0.40	0.40	0.60	0.40	0.60	0.60	0.87	0.60
-income per capita (10^2)*(US95$/Year/Person)*	12.2	12.2	12.2	12.2	15.0	16.2	15.0	15.0	17.1	18.6	17.1	17.1
-population dependency ratio*(Dml)*	0.96	0.96	0.96	0.96	0.97	0.96	0.97	0.97	0.97	0.96	0.97	0.97
-unemployment rate *(%)*	17.3	17.3	17.3	17.3	22.0	21.7	22.0	22.0	22.2	20.9	22.2	22.2
-oil and gas investment *(B US95$/Year)*	0.61	0.61	0.61	0.61	1.16	1.24	1.16	1.16	1.95	2.09	1.95	1.95
-power sector investment *(B US95$/Year)*	0.60	0.60	0.60	0.60	1.28	1.37	1.28	1.28	2.33	2.50	2.33	2.33
-renewable investment *(M US95$/Year)*	13.9	13.9	13.9	13.9	34.9	37.3	34.9	34.9	70.2	75.3	70.2	70.2
-energy total investment cost *(B US95$/Year)*	3.80	3.80	3.80	3.80	6.41	6.86	6.41	6.41	9.73	10.4	9.73	9.73
-total domestic investment *(B US95$/Year)*	47.7	47.7	47.7	47.7	67.5	72.2	67.5	67.5	88.1	94.5	88.1	88.1
ACCEPTABILITY												
-CO_2 total emissions *(M TonC/Year)*	40.5	40.5	40.5	40.5	43.5	43.5	65.9	43.5	45.5	45.5	70.6	45.5
-CO_2 emission per capita *(TonC/Year/Person)*	0.25	0.25	0.25	0.25	0.23	0.24	0.36	0.23	0.22	0.23	0.35	0.22
-GHG total emissions *(B kg/Year)*	40.7	40.7	40.7	40.7	43.7	43.7	66.3	43.7	45.7	45.7	71.0	45.7
-GHG emissions intensity *(kg/US95$)*	0.21	0.21	0.21	0.21	0.15	0.14	0.23	0.15	0.13	0.12	0.20	0.13
-GDP energy intensity (10^{-4})*(TOE/US95$)*	1.63	1.63	1.63	1.63	1.29	1.26	1.32	1.28	1.13	1.10	1.16	1.08
-GDP electricity intensity (10^{-2})*(kWh/US95$)*	11.6	11.6	11.6	11.6	10.5	10.5	10.5	10.4	9.93	9.91	9.93	9.97
-pollution from oil spill *(B pollution unit/Year)*	1.93	1.93	1.93	1.93	4.16	4.21	4.16	4.16	7.64	7.88	7.64	7.89
-pollution from gas flaring *(B pollution unit/Year)*	0.30	0.30	0.30	0.30	0.58	0.59	0.58	0.58	0.95	0.98	0.95	0.98

6.5 Sensitivity Analysis

In this section, we present the results of sensitivity testing using a process known as Monte Carlo Simulation [88]. A general introduction to sensitivity analysis is already presented in (Section 4.5 Chapter 4). In this section, model outputs from the procedure are analysed. The purpose of sensitivity analysis here is to address uncertainty of the most critical model variables. The approach involved automated varying of model assumptions about the value of ‘Constants’—the non-changing parameters in the E-PAM. The aim is to examine response to uncertainty of selected variables. A five-step procedure was adopted in the overall testing and analyses. These are: 1) definition of model parameters to be varied, 2) definition of parameter range to be sampled, 3) definition of sampling methodology, 4) multivariate sensitivity simulation of selected parameters and 5) analysis of sensitivity output.

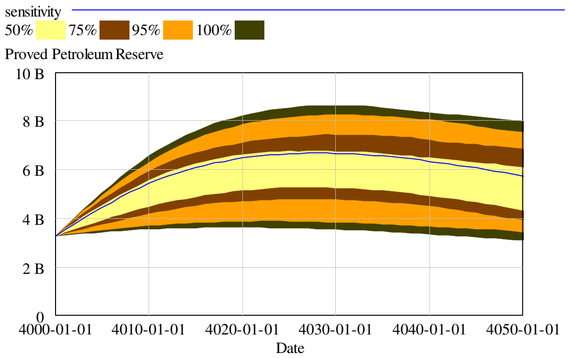
Sensitivity Analysis can be done on all the 999 elements that constitute the E-PAM. However, depending on the need, such a level of assessment of value can become counterproductive and unwarranted. For the purpose of this report, we varied less than a dozen (eight) model parameters. These are parameters that demonstrate significant influence on the most sensitive model variables (thirty eight), within the energy sector and the three sustainability domains. We refer to the procedure for identifying parameters together with sensitivity range and sampling methodology as *"parameter encoding"* for sensitivity analysis. The eight parameters defined for sensitivity analysis in this study are summarised as shown in Table 6.8.

Table 6.8: Parameter Encoding for Sensitivity Analysis.

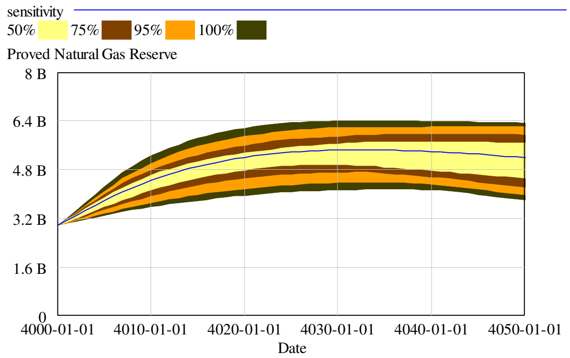
	MODEL PARAMETER	MODEL ACTUAL VALUE	SENSITIVITY RANGE		SAMPLING METHOD
			MIN	MAX	
1	Initial Total Fertility	5.5	4.5	6.5	Random Uniform Distribution
2	Initial GDP growth rate	7.0	3.5	13.8	Random Uniform Distribution
3	Initial technology progression rate	0.09	0.02	0.5	Random Uniform Distribution
4	Base oil discovery fraction	0.025	0.01	0.035	Random Uniform Distribution
5	Base oil production fraction	0.015	0.01	0.025	Random Uniform Distribution
6	Base gas discovery fraction	0.036	0.02	0.05	Random Uniform Distribution
7	Base gas production fraction	0.005	0.001	0.009	Random Uniform Distribution
8	Initial petroleum product import	$7.1e^{+006}$	$2e^{+006}$	$8e^{+006}$	Random Uniform Distribution

The eight parameters were subjected to 'extreme model conditions' by assigning 'minimum' and 'maximum' values relative to the model actual value (i.e. BAU value) as a reference. Using a Random Uniform Distribution (RUD) probability to sample the parameters, 500 scenarios were automatically simulated. The model outputs for the Multivariate Sensitivity Simulation (MVSS) are discussed in the following subsections. They are presented in terms of Confidence Bounds and Histograms [88].

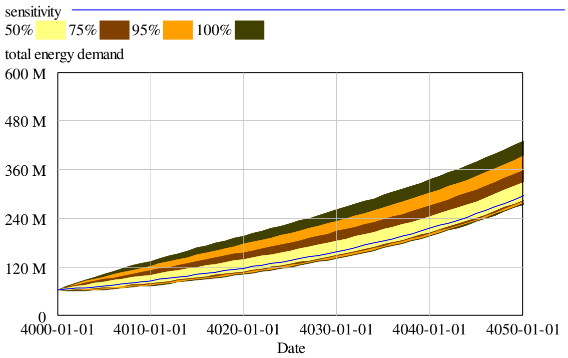
6.5.1 Energy Sector Sensitivity Analysis



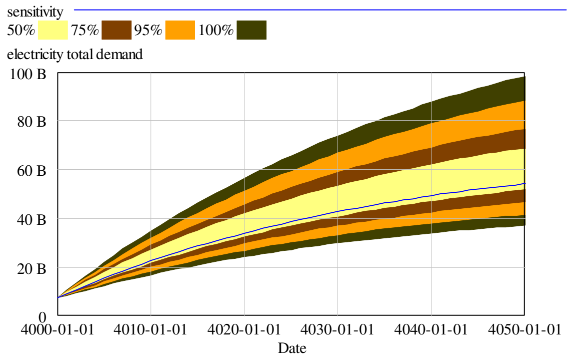
(a) sensitivity for proved petroleum reserve



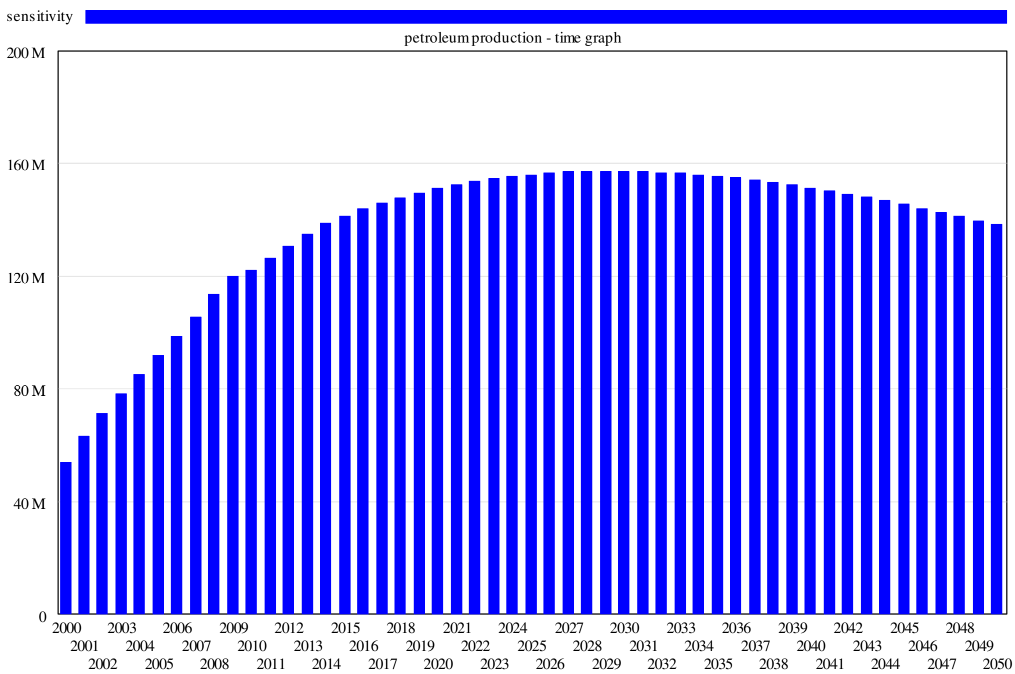
(b) sensitivity for proved natural gas reserve



(c) sensitivity for total primary energy demand



(d) sensitivity for electricity total demand



(e) sensitivity for petroleum production

Figure 6.7: Energy Sector Sensitivity Output.

In Figure 6.7, model output indicating the degree of uncertainty of critical energy variables to changes in technology progression, oil and gas discovery and production rates are presented. The 50%, 70%, 95% and 100% represent level of confidence. In Figure 6.7 (a) and (b), the outer bounds of uncertainty (100%) show the maximum oil and gas reserves, we think Nigeria might be able to achieve by year 2050. It is important to note the possibility of declining reserves capability for both fuels.

Petroleum reserve for example, is likely to be on the path of decline from 2028—depleting from 6.670 Bmt to 5.739 Bmt by 2050. This indicates 16% decline in 22 years. A similar pattern can be seen in petroleum production as evidenced in Figure 6.7 (e). Oil production is expected to peak around 2030, beyond which, production will follow a terminal decline. Similar analyses can be made for natural gas reserve and production, which are expected to start declining by year 2033 and 2035 respectively.

It is also important to note that despite expected decline in oil and gas supply as revealed in the above discussion, total primary energy demand and electricity demand are expected to maintain upward growth trend as in Figure 6.7 (c) and (d). This is in view of significant growth in population and economy—the major drivers of energy demand. It is also evident in the change in 'asymmetry' of Figure 6.7 (c), that a significantly raising energy demand (due to population and economic growth), and a declining supply has shown a high degree of uncertainty. In addition, these changes are expected to have significant impact on investment in energy imports and domestic energy development activities. In view of space limitations, only sensitivity outputs for the energy sector are discussed in this report.

Based on the RUD probability function over which the parameters were sampled, a statistical output of sensitivity analysis for the four domains is summarised in Table 6.9. The key outputs presented are: 1) minimum and maximum values for the sampled parameters; 2) the median value ($\bar{x}$); 3) the mean value (**μ**) and 4) the standard deviation (**σ**) [88]. These outputs are also considered as new set of metrics for evaluating uncertainty in the energy sector and the three sustainability domains.

Table 6.9: Metrics for Sensitivity Analysis.

MODEL VARIABLE	COUNT	MIN (2050)	MAX (2050)	MEDIAN ($\bar{x}$)	MEAN (μ)	StDev (σ)
ENERGY SECTOR SENSITIVITY						
Proved petroleum reserve *(Bmt)*	51	3.285	6.670	6.237	5.904	0.889
Petroleum production *(Mmt/Year)*	51	54.44	157.7	148.3	137.0	26.76
Petroleum investment *(US$/Bmt/Year)*	51	4.364	370.4	177.8	179.3	118.9
Natural gas reserve *(BTOE)*	51	2.976	5.451	5.257	4.924	0.690
Natural gas production *(MTOE/Year)*	51	14.15	34.29	32.66	30.31	5.032
Natural gas investment *(US$/BTOE/Year)*	51	0.244	2.916	1.636	1.676	0.741
Petroleum products import *(MTOE/Year)*	51	7.117	9.302	8.209	8.209	0.643
Total energy demand *(MTOE/Year)*	51	63.47	295.4	136.4	150.8	66.43
Energy demand per capita *(TOE/Person/Year)*	51	0.513	0.759	0.613	0.620	0.072
Electricity total demand *(BkWh/Year)*	51	7.546	54.22	38.57	35.95	13.60
Electricity demand per capita *(kWh/Person/Year)*	51	60.01	173.5	158.4	149.8	27.17
SOCIAL DOMAIN SENSITIVITY						
Total population *(MPeople)*	51	123.7	389.2	222.3	234.3	76.98
Population growth rate *(Dml)*	51	2.376	117.0	61.02	60.76	33.34
Net migration *(MPeople/Year)*	51	-63.68	-20.16	-54.34	-50.23	12.35
Total labour demand *(MPeople/Year)*	51	29.96	170.7	63.45	77.06	42.14
Total labour supply *(MPeople/Year)*	51	37.15	188.5	79.67	90.46	45.24
Dependency ratio *(Dml)*	51	0.864	0.983	0.981	0.969	0.027
Unemployment rate *(Dml)*	51	0.095	0.225	0.157	0.164	0.042
ECONOMIC DOMAIN SENSITIVITY						
Real GDP *(BUS95$/Year)*	51	45.98	784.0	415.0	415.0	217.3
Real GDP growth rate *(Dml)*	51	0.856	30.64	15.75	15.75	8.769
Income per capita *(US95$/Person/Year)*	51	371.8	2046	1866	1638	484.2
Energy sector investment *(BUS95$/Year)*	51	0.455	46.60	13.79	17.18	13.71
Government total revenue *(BUS95$/Year)*	51	19.00	241.8	104.2	115.3	64.67
Government total expenditure *(BUS95$/Year)*	51	16.63	308.6	114.1	133.3	85.49
R&D investment *(BUS$/Year)*	51	0.836	12.47	3.609	4.517	3.828
Technology progression *(Dml)*	51	1.100	2.677	2.254	2.172	0.387
Domestic total investment *(BUS95$/Year)*	51	9.283	230.1	109.6	113.4	64.56
ENVIRONMENTAL DOMAIN SENSITIVITY						
Pollution from gas flaring *(BPollution Unit/Year)*	51	0.121	1.938	1.332	1.144	0.674
Pollution from oil spill *(BPollution Unit/Year)*	51	0.603	25.42	11.96	12.63	9.365
GDP electricity intensity *(kWh/US95$)*	51	0.069	0.164	0.093	0.098	0.023
GHG emission intensity *(kg/US95$)*	51	0.274	2.853	0.634	0.803	0.542
CO_2 emission per capita *(TonC/Person/Year)*	51	0.548	1.344	1.128	1.056	0.253
Industry water demand *(Bkg/Year)*	51	5.891	92.21	54.88	52.54	31.75
Municipal water demand *(Bkg/Year)*	51	7.545	23.74	13.56	14.29	4.695
Agric water demand *(Bkg/Year)*	51	5.396	11.32	10.80	9.672	1.911
Total water demand *(Bkg/Year)*	51	32.05	206.8	132.7	127.5	63.10

6.6 Conclusion

In this Chapter, we simulated a variety of government energy policy interventions, and examined their impacts on economic, social and environmental dimensions of sustainability. We also presented in this chapter, the concept of a working definition of SED. The approach was employed, to evaluate energy usage in Nigeria from four standpoints: availability, accessibility, affordability and acceptability—termed the 'four grand energy objectives'. The concept was found to provide a useful 'platform' for defining the metrics needed to assess targets and progress towards SED.

This chapter further examined in much detail, the three proposed government policies and the key considerations around which different energy scenarios were explored. This provided insights into the different energy policy targets and their expected impact on the three sustainability domains, based on model predictions. Three new sets of energy scenarios resulted from the analyses. These are 1) Energy Sufficiency in a Thriving Economy, 2) Energy Diversity in a Transitional Economy and 3) Energy Efficiency in a Green Economy. The policies were explored in comparison with the BAU case—a scenario of Energy Poverty in a Developing Economy.

It was found in the analyses made on the three energy scenarios, that none of the three government policy interventions is able to satisfy the 'four grand energy objectives' as a standalone policy. Each policy maximises a particular energy objective and a particular sustainability dimension. Sensitivity analyses were also conducted, to examine variations on the key scenario assumptions. It was also found that critical energy variables such as petroleum and natural gas reserves, and other economic, social and environmental-based variables such as real GDP, labour demand and supply and GHG emissions were highly sensitive to policy changes and future uncertainties.

Chapter 7

Optimal Policy Selection: A Multi-Criteria Evaluation

7.1 Introduction

This chapter deals with the second part of the thesis argument which focuses on multi-criteria, multidimensional and multi-stakeholder evaluation of alternative government policies and the selection of 'optimal policy' according to stakeholders viewpoints. The chapter employs SMART—Simple Multi-Attribute Rating Technique [8] as its main evaluation methodology. SMART, a multi-attribute utility theory (MAUT) procedure is used to assign weights to defined assessment criteria according to their relative importance. This helps us to explicitly spell out what the different policy values are, how much they differ, and which one is the most preferred.

The discussion in this chapter is structured around one case study example on 'Sustainable Energy Development in Nigeria', with specific focus on assessment of alternative policy impact on the four 'grand energy objectives' discussed in Chapter 5 and Chapter 6. The evaluation of the policies is done using E-PAM output and fieldwork data from Nigeria as a combined *"front end"* to SMART [10]. The chapter aims to examine in much detail, the impacts of proposed government policies, and to determine which policy run is the most desirable according to stakeholder preferences.

Section 7.2 presents a decision matrix, which serves as a hierarchical value judgement model for the evaluation process. Section 7.3 focuses on constructing stakeholder value models using a ten-step SMART evaluation procedure. Section 7.4 discusses the outcome and implications of the evaluation—including a discussion on the most desirable alternative policy. Section 7.5 concludes the chapter.

7.2 The Decision Matrix

According to Edwards [17], public-based policies should explicitly be designed and implemented with *"maximum efficiency"* and *"minimum ambiguity"*. This requires the focus of a decision making process to shift from *"specific actions"* to *"specific values"* that these actions aim to serve [10]. Moreover, such unambiguous policies Gardiner and Ford [10] suggest can be easily managed when responding to emerging changes in the value system. The overall idea is to ensure that 'quantities' used for decision making are not unilateral, but are based on *"some kind of social consensus and aggregation of individual or group views"* [8].

In the context of this research, the overarching question the working definition of SED proposed in Chapter 6 aims to satisfy is: *"how will the impacts of different policy initiatives on the emerging economic, social and environmental challenges of achieving SE results that are consistent with the defined energy objectives be measured?"* In addition to satisfying the core energy objectives, this question underpins a 3-dimensional value system that public-based policies are expected to address.

In order to assess, whether the proposed government policies address these energy objectives as well as the underpinning value system, requires us to define the essential evaluation parameters. For this study, these include: 1) *"the overall objective"*—which defines major issues such as stakeholders, the value system, as well as the expected benefits and any associated costs, 2) *"the impact dimensions"*—which defines issues such as assessment criteria, sustainability focus and alignment of criteria with objectives and the sustainability focus and 3) *"the impact measures"*—which defines the evaluation metrics in accordance with experts or stakeholders viewpoints. We term these 'the key decision variables'. A framework that encapsulates this idea in a logical sequence is illustrated in Figure 7.1. The hierarchical structure depicts a decision matrix that serves as a value judgement model for evaluation of *"utilities"* (defined in subsection 2.5.4 of Chapter 2). The approach helps us to decide on the choice of an appropriate evaluation methodology that is not only suitable in terms of transparency and reliability, but can also produce results that *"reflect real preferences"* [10].

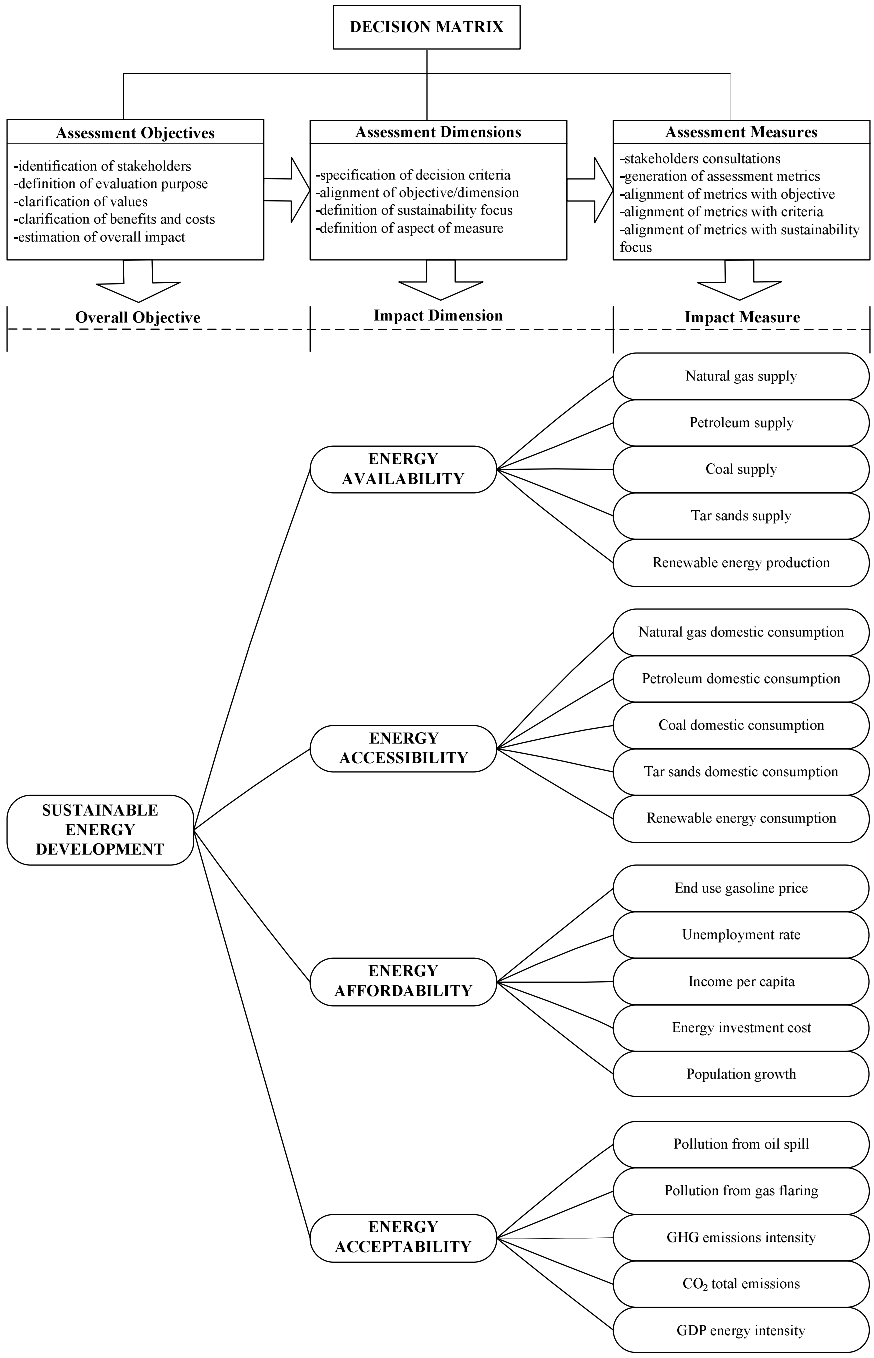


Figure 7.1: A Hierarchical Value Judgement Model.

7.3 Evaluation of Alternative Policies

This section focuses on constructing SMART value models, for evaluating SED policies relative to a BAU case as discussed in Chapter 6. These policies are 1) VISION 2020; 2) SUBSIDY TRANSFER and 3) LOCAL CONTENT [13, 14, 191]. Each of these policies has a storyline that reflects the type of energy future it seeks to represent. These energy scenarios are 1) Energy Sufficiency in a Thriving Economy; 2) Energy Diversity in a Transitional Economy and 3) Energy Efficiency in a Green Economy.

In line with government targets, each of these policies aims to satisfy the four energy objectives of availability, accessibility, affordability and acceptability. While we establish that the proposed policies aim to serve public values, we are on the other hand, not able to readily specify if each policy will satisfy the four objectives on a standalone basis. The key question to examine here is: *"which of these policies, based on stakeholder preferences is most desirable in achieving the defined energy objectives?"*

To deal with the above question, we employ SMART, which is flexible in uncovering stakeholder values using suitable *"aggregation rule"* and *"weighting procedure"* in accordance with the impact dimension being assessed [8]. For this evaluation, the aggregation rule and weighting procedure adopted is the *"weighted linear average"* [10]. Other aggregation rules such as the "*multiplicative rules"* proposed by Keeney [151] are also available in practical use. However, the choice of our preferred approach is in consideration, that it produces closer approximations to the desired value, and it is easier to elicit and understand [199-201].

In this case, our 'four grand energy objectives' are used as assessment criteria. They are evaluated using the five indicators defined under each criterion. As earlier mentioned, these indicators are selected from a list compiled during fieldwork in

Nigeria. They are based on stakeholder responses to research questions shown in (Section A of Appendix B). Our model outputs for these indicators are used as *"front end"* to SMART, and are evaluated through a ten-step process shown in Figure 7.2. Each of the evaluation steps are further considered in the following subsections.

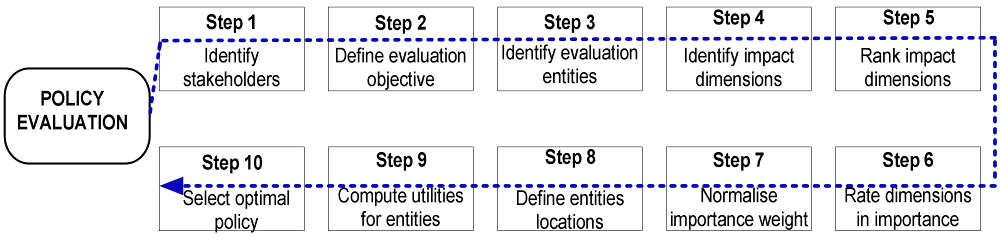


Figure 7.2: SMART Policy Evaluation Cycle. After [8].

7.3.1 Step 1: Identification of Stakeholders

The first step of the SMART evaluation involves identification of stakeholders. It requires identifying *"the person or organisation whose utilities (values) are to be maximised"* [17]. In our case, the approach was used in a slightly different mode. It involved identifying the policymakers that would provide inputs to the evaluation. This was done in consideration that the policies under evaluation aim to maximise public values in a national context. For this reason, we utilised a fieldwork approach to consult and collate opinions of energy, economic, national planning and environmental management policymakers in Nigeria. The aim was to obtain information from decision makers with the right expertise and experience necessary to provide useful insights that would yield the desired outcome of the evaluation.

A total of fifty 'top-management' and 'operational-level' policymakers from five government ministries were consulted during fieldwork in Nigeria. The fieldwork methodology and part of the results obtained from the process is already discussed in Chapter 3 and Chapter 4 of this report. Here, we only categorise the stakeholders consulted during the fieldwork as summarised in Table 7.1. The aim is to provide the basis for defining 'stakeholder viewpoints' required for discussion in this chapter.

Table 7.1: List of Policymakers Consulted during Fieldwork in Nigeria.

	GOVERNMENT MINISTRY	NUMBER OF POLICYMAKERS CONSULTED	LEVEL IN MINISTRY	TOTAL
1	Ministry of Petroleum Resources	Three	Director	**10**
	Ministry of Petroleum Resources	Three	Deputy Director	
	Ministry of Petroleum Resources	Four	Assistant Director	
2	Nigerian National Petroleum Corporation	One	Executive Director	**10**
	Nigerian National Petroleum Corporation	Five	Senior Manager	
	Nigerian National Petroleum Corporation	Four	Deputy Manager	
3	Energy Commission of Nigeria	Two	Chief Scientific Officer	**10**
	Energy Commission of Nigeria	Eight	Senior Scientific Officer	
4	National Planning Commission	Four	Director	**10**
	National Planning Commission	Two	Deputy Director	
	National Planning Commission	Four	Chief Planning Officer	
5	Federal Ministry of Environment	One	Director	**10**
	Federal Ministry of Environment	Three	Assistant Director	
	Federal Ministry of Environment	Six	Senior Scientific Officer	
6				**50**

7.3.2 Step 2: Definition of Evaluation Purpose

This phase of the evaluation process defines the purpose for which the evaluation is being carried out. This purpose is already discussed in Chapter 4 and Chapter 6 of this report. However, it is important to reiterate here, that we intend to assess public values of three proposed government policies over the four energy objectives illustrated in Figure 7.1. The assessment criteria are based on government energy targets to year 2020 (summarised in Table 7.2). Our goal is to evaluate the policies against these criteria, and based on stakeholders' viewpoints, select from amongst the three alternative policies and the BAU case, the most preferred policy option. This is also termed in this study as 'optimal policy'. An excerpt of these short-medium term government energy targets used as assessment criteria in this evaluation is shown in Table 7.2. It is important to note the link between these energy targets and the evaluation metrics already defined in Figure 7.1.

Table 7.2: Short-Medium Term Energy Targets for SED in Nigeria.

EXCERPT OF GOVERNMENT ENERGY TARGETS TO YEAR 2020
-increase petroleum reserves from 5.43 *(Bmt)* in 2010 by 20% in year 2020
-increase natural gas reserves from 4.4 *(BTOE)* in 2010 by 15% in year 2020
-reintroduce coal production by year 2015, contributing >5% to total primary energy supply in the country by 2020
-start production of tar sands by year 2015, contributing about 4% to total primary energy use in the country
-introduce solar and wind energy use by 2015, contributing 7% and 4% respectively, to total renewable energy use
-reduce dependence on petroleum products importation from 7.55 *(MTOE)* in 2010 by 45% in year 2020
-increase gas domestic consumption from 4.96 *(MTOE)* in 2010 by 30% in year 2020
-increase total primary energy domestic consumption from 31.72 *(MTOE)* in 2010 by 30% in year 2020
-reintroduce coal consumption, contributing about 7% to electricity generation by year 2015
-introduce tar sands consumption in domestic energy supply, contributing about 5% by year 2015
-increase share of renewable energy in total energy supply from 8.410 *(MTOE)* in 2010 by 20% in year 2020
-reduce end use gasoline price from 0.6 *(US$/litre)* in 2010 by 50% in year 2020.
-increase income per capita from 1220 *(US95$/Year/Person)* in 2010 to 4000 *(US95$/Year/Person)* by year 2020
-reduce unemployment rate in the country from 22.25*(%)* in 2010 to 15% by year 2020
-reduce population growth and dependence through reduction in total fertility from 5.5 in 2010 to 4.5 by 2020
-increase energy sector total investment from 3. 806 *(B US95$/Year) in 2010* by >100% in year 2020
-reduce fossil fuels CO_2 emissions from current 40.55 *(MTonC/Year)* by 5% in year 2020
-reduce GHG total emissions from current 40.78 *(B kg/Year)* by 2% in year 2020
-reduce GDP energy intensity through energy efficiency and energy saving measures by >5% *in* year 2020
-reduce pollution from oil spill from current 1.938 *(B PU/Year)* by 50% in year 2020
-bring pollution from gas flaring to 0% by year 2020

Source: [13, 14, 123, 191].

7.3.3 Step 3: Definition of Evaluation Entities

Step 3 of the evaluation process focuses on defining the *"entities"* whose values are to be evaluated. In our case study, the entities are the three alternative policies for SED in Nigeria and the BAU scenario. The three policies as already mentioned in Section 7.3 are 1) VISION 2020; 2) SUBSIDY TRANSFER and 3) LOCAL CONTENT. The policies were simulated with the E-PAM in accordance with the government targets in Table 7.2, to examine their relative impacts on energy availability, accessibility, affordability and acceptability. Our model outputs for three policy projections to year 2020 will be evaluated with SMART, to determine which one of the three policies relative to the BAU is more desirable from stakeholders' viewpoints. This implies that the model policy projections (which will be shown to policymakers at a later step), aim to influence stakeholder judgements and decisions in making preferences. This is the major link between E-PAM and SMART. The four policies and the associated energy scenarios are summarised as shown in Table 7.3.

Table 7.3: Proposed Policies and the Associated Energy Scenarios.

	POLICY (ENTITY)	ENERGY SCENARIO
1	BAU	Energy Poverty in a Developing Economy
2	VISION 2020	Energy Sufficiency in a Thriving Economy
3	SUBSIDY TRANSFER	Energy Diversity in a Transitional Economy
4	LOCAL CONTENT	Energy Efficiency in a Green Economy

7.3.4 Step 4: Identification of Impact Dimensions

This step identifies the relevant 'impact dimensions of value' for evaluation. The main issue to consider under this objective is: *"what impacts are important to the evaluation of the alternatives of interest?"* [17]. These 'impact dimensions' together with the 'performance impacts' or 'impact measures' [17] are already highlighted in Section 7.2 of this chapter in form of hierarchical value judgement goals. According to Raiffa [152], evaluation goals are usually structured in hierarchies, but in practice, the hierarchical structure is often ignored. This, Gardiner and Ford [10] suggest is to avoid *"considering evaluation outcomes as opportunities for further decisions"*.

In view of the foregoing, we only consider in this study, four impact dimensions, which represent our 'four grand energy objectives'. In addition, twenty performance impacts (i.e. impact measures)—representing our Energy Sustainability Indicators (ESI) is defined. Their initial evaluation and ranking (shown in Table 7.4) is based on stakeholders' opinions and preferences on the energy targets listed in Table 7.2. Here, the stakeholders (identified in Step 1) were first, presented with an excerpt of government energy targets (Table 7.2). They were asked to use the information, and based on their own opinion and preference; map the targets (i.e. twenty performance impacts) to each of the four impact dimensions (i.e. 'four grand energy objectives').

Policymakers were also encouraged to make an initial ranking of their preferences for the impact dimensions and impact measures *"in order of importance"* [17]. In line with the total number of impact measures, the ranking was done on a scale of 1 to 20, where '1' was considered the most important and '20' the least important in rank respectively [10]. It is important to emphasise that the initial evaluation and ranking of impact dimensions and measures was done solely on the basis of information relating to the government energy targets (and not yet on model projections). The aim was to determine if the model predictions when later shown to policymakers, will influence their previous judgements, and whether this will reform their subsequent opinions.

As illustrated in Figure 7.1, the four impact dimensions are defined as sub goals under the overall objective of SED. This is followed by five impact measures defined as sub-goals under each of the impact dimensions. These bring the total number of impact dimensions to four and impact measures to twenty. Stakeholders' initial definition and ranking of these impact dimensions and measures, based on their opinions on government energy targets (without seen model projections) is summarised in Table 7.4.

Table 7.4: Stakeholders Initial Ranking of Impact Dimensions and Measures.

INITIAL RANKING	**IMPACT DIMENSIONS AND MEASURES (based on government energy targets)**
	ENERGY AVAILABILITY
1	Petroleum domestic supply *(Mmt)*
2	Natural gas domestic supply *(MTOE)*
3	Tar sands domestic supply *(MTOE)*
4	Coal domestic supply *(MTOE)*
5	Renewable energy production (MTOE)
	ENERGY ACCESSIBILITY
6	Petroleum domestic consumption *(Mmt)*
7	Natural gas domestic consumption *(MTOE)*
8	Tar sands domestic consumption *(MTOE)*
9	Coal domestic consumption *(MTOE)*
10	Renewable energy consumption *(MTOE)*
	ENERGY AFFORDABILITY
11	Population growth *(Million)*
12	Income per capita *(US95$/Year/Person)*
13	End use gasoline price *(US$/litre)*
14	Unemployment rate *(%)*
15	Energy investment cost *(B US95$/Year)*
	ENERGY ACCEPTABILITY

16	CO_2 emissions *(MTonC/Year)*
17	GHG total emissions *(B kg/Year)*
18	GDP energy intensity *(TOE/US95$)*
19	Pollution from oil spill *(B PU/Year)*
20	Pollution from gas flare *(B PU/Year)*

7.3.5 Step 5: Ranking of Impact Dimensions

In this step, the impact dimensions and the performance impacts discussed in Step 4 were re-evaluated and re-ranked *"in order of importance"* [17] on the same scale of 1 to 20. The re-evaluation and re-ranking is based on how the model outputs shown to policymakers at this stage have influenced their opinions. It is important to note in Table 7.5, a reordering of the impact measures according to stakeholder preferences, in comparison with initial elicitation shown in Table 7.4. It is glaring that the model projections for the four alternative policies (shown in columns 3 to 6) in Table 7.5 has significantly influenced stakeholders' opinion and judgement in preferences.

For example, it is interesting to see how stakeholders expressed strongest opinion for domestic supply and consumption of natural gas (now ranked first in Table 7.5) as opposed to petroleum, as it were in Table 7.4. Similarly, indicators such as coal and tar sands domestic supply, end use energy price and population growth as well as unemployment rate and income per capita have all 'swapped' ranking positions following changes in stakeholder preferences. Other such changes in ranking positions based on changes in opinions can be seen between pollution from oil spill and pollution from gas flare and CO_2 emissions and GHG total emissions respectively.

Table 7.5: Stakeholders Final Ranking of Impact Dimensions and Measures.

FINAL RANKING	IMPACT DIMENSIONS AND MEASURES (based on model output)	BAU	VISION 2020	SUBSIDY TRANSFER	LOCAL CONTENT
	ENERGY AVAILABILITY				
1	Natural gas domestic supply *(MTOE)*	4.963	4.963	5.310	4.963
2	Petroleum domestic supply *(Mmt)*	15.57	15.57	16.82	15.57
3	Coal domestic supply *(MTOE)*	0	0	5.431	0
4	Tar sands domestic supply *(MTOE)*	0	0	4.299	0
5	Renewable energy production (MTOE)	11.79	11.79	12.76	11.79

	ENERGY ACCESSIBILITY				
6	Natural gas consumption *(MTOE)*	4.963	4.963	5.310	4.963
7	Petroleum consumption *(Mmt)*	15.57	15.57	16.82	15.57
8	Coal consumption *(MTOE)*	0	0	5.431	0
9	Tar sands consumption *(MTOE)*	0	0	4.299	0
10	Renewable energy consumption *(MTOE)*	11.79	11.79	12.76	11.79
	ENERGY AFFORDABILITY				
11	End use gasoline price *(US$/litre)*	0.60	0.60	0.87	0.60
12	Unemployment rate *(%)*	22.25	20.91	22.25	22.25
13	Income per capita *(US95$/Year/Person)*	1716	1862	1716	1716
14	Energy investment cost *(B US95$/Year)*	9.734	10.44	9.734	9.734
15	Population growth (*Million)*	198.7	196.5	198.7	198.7
	ENERGY ACCEPTABILITY				
16	Pollution from oil spill *(B PU/Year)*	7.643	7.888	7.643	7.898
17	Pollution from gas flare *(B PU/Year)*	0.952	0.982	0.952	0.983
18	GHG total emissions *(B kg/Year)*	45.79	45.79	71.03	45.79
19	CO_2 emissions *(MTonC/Year)*	45.53	45.53	70.64	45.53
20	GDP energy intensity *(TOE/US95$)*	0.000114	0.000111	0.000117	0.000108

7.3.6 Step 6: Rating of Impact Dimensions

In this step, the impact ‘dimensions’ and ‘measures’ are rated in *“importance, preserving ratio”* [10]. This means that a weighting system is employed to assign numerical value to each measure according to order of importance [17]. According to [17], weight equal to ‘1’ or ‘10’ can be assigned to the least important dimension, depending on one’s preference. However, it is usually good practice to start with ‘10’, to *“permit subsequent judgements to be finely graded and made in integers”* [17]. In such a case, the next least important measure can be assigned a weight of ‘20’. This implies that the measure with ‘10’ is ½ as important as the one with ‘20’. The *“preserving ratio”* of ½ indicates the relative importance of the two measures. This approach can be used to rate all impact measures in each dimension being considered.

In our case, the fifty stakeholders (identified in Step 1) were asked to rate their responses in Table 7.5 on a scale of 1 – 20, with ‘1’ being the least important and ‘20’ the most important. A ‘0’ could be assigned to a measure where there is no mention of it. It is useful to point out here, that this weighting scale is a direct reserve of the ranking order used in ranking the impact dimensions and measures in Table 7.4 and

Table 7.5. The scale of 1 – 20 is chosen in consideration of the total number of impact measures defined under each of the impact dimensions. It is also important to note, that the purpose of the rating is to define the *"importance weights"* that would be used at a later stage, to evaluate and compare the four alternative policies.

To simplify the rating approach, responses from these fifty policymakers were not treated as fifty individual responses, but were condensed into five groups according to the five ministries listed in Step 1. This means, that stakeholder responses according to the five ministries consulted are treated as five *"viewpoints"*—denoted in this study as (VP). A summary of *"importance weights"* according to the five viewpoints is given in Table 7.6. As revealed in the table, policymakers from five ministries made their importance weight judgements as to what they would like to see more or less of the policy impacts. It is evident how each ministry *"rate the relative importance of the dimensions and measures and, in effect, make their impact trade-offs"* [10]. It is also worth noting that the five viewpoints were not labelled with names of individuals or the responding ministries, as it is a way of preserving anonymity of the respondents [10].

Table 7.6 Importance Weights According to Five Viewpoints.

RANKING	**IMPACT DIMENSION**	**IMPORTANCE WEIGHT BY VIEWPOINT**				
		VP1	**VP2**	**VP3**	**VP4**	**VP5**
	ENERGY AVAILABILITY					
1	Natural gas domestic supply *(MTOE)*	15	14	7	11	10
2	Petroleum domestic supply *(Mmt)*	12	13	8	8	8
3	Coal domestic supply *(MTOE)*	7	8	8	7	4
4	Tar sands domestic supply *(MTOE)*	5	9	9	9	5
5	Renewable energy production (MTOE)	8	11	4	5	15
	ENERGY ACCESSIBILITY					
6	Natural gas consumption *(MTOE)*	15	14	7	11	9
7	Petroleum consumption *(Mmt)*	12	13	8	8	7
8	Coal consumption *(MTOE)*	7	8	8	7	2
9	Tar sands consumption *(MTOE)*	5	9	9	9	5
10	Renewable energy consumption *(MTOE)*	8	11	5	5	13
	ENERGY AFFORDABILITY					
11	End use gasoline price *(US$/litre)*	12	17	16	18	13
12	Unemployment rate *(%)*	20	19	19	19	20
13	Income per capita *(US95$/Year/Person)*	9	19	17	20	18
14	Energy investment cost *(B US95$/Year)*	11	15	14	18	19
15	Population growth (*Million)*	1	2	1	1	2
	ENERGY ACCEPTABILITY					

16	Pollution from oil spill *(B PU/Year)*	7	9	7	9	12
17	Pollution from gas flaring *(B PU/Year)*	6	9	7	13	12
18	GHG total emissions *(B kg/Year)*	4	7	9	11	9
19	CO_2 total emissions *(MTonC/Year)*	2	7	8	9	9
20	GDP energy intensity *(TOE/US95$)*	2	5	5	3	7

7.3.7 Step 7: Normalisation of Importance Weight

Normalisation is a process of organising data in such a way as to minimise or eliminate data redundancy and inconsistent dependencies [202]. The purpose of normalising data in most cases, is to adjust the rated values, which often are measured on different scales to a common scale [203]. In a normal SMART evaluation process, the importance weights developed in Step 6 are normalised. This is done by converting rated values of the 'viewpoints' to a common scale. Depending on the data range, the normalising scale could be in the range of say 1 – 20, where '1' is the minimum value and '20' the maximum value on the scale. Stewart [204] and Andersen and Rohrbaugh [85], argue that a 20-point rating scale is conventionally used for *"social judgement analysis when the task is novel and lacks an otherwise established rating format"*. The normalisation of rated values could be done using the following formulation:

$$\mathbf{X_n} = \frac{\mathbf{a+(X-A)*(b-a)}}{\mathbf{(B-A)}} \qquad \textbf{(6)}$$

Where, $\mathbf{X_n}$ is the normalised value, **X** is the original rated value for each viewpoint, **A** is the smallest rated value in the original dataset, **B** is the largest rated value in the original dataset, **a** is the smallest number on the normalising scale and **b** is the largest number on the normalising scale.

In our study, the normalisation step was not needed because the original data from Step 6 were already set in a common scale of 1 – 20, and no zeros were assigned in the original dataset that could be eliminated through the normalisation process.

7.3.8 Step 8: Definition of Entities Locations

Entities Location refers to a *"measure of the location of each entity being evaluated on each dimension"* [17]. The approach can be used to reveal *"conflict of opinion over the attribute"* being measured [10]. According to [17], three classes of dimensional measures can be considered; these are 1) purely subjective, 2) partly subjective and 3) purely objective.

A 'purely subjective' dimension is one where an entity location can simply be estimated by an expert on a scale of say 1 – 100, without recourse to any form of objectivity [17]. A 'partly subjective' dimension is one in which the units of measurements are objectively determined, but the locations of the entities are subjectively considered [17]. In a 'purely objective' dimensional analysis, both the units of measurements and the entities locations are determined nonjudgmentally [17]. This means, their consideration is entirely based on some forms of measure.

Different opinions exist among users of MAUT[12], as to which of the above defined approaches is most suited to a particular case. While authors such as Edwards [8] are *"content"* with simple connection of a straight line through the 'minimum' and the 'maximum' plausible values to determine an entity location, others such as Raiffa [152] propose more sophisticated methods such as the development of 'dimension-by-dimension' utility curves. In such a case, *"the x-axis of such curves represents plausible range of values under consideration"*, while "*the y-axis represents the range of values or utilities associated with the corresponding x-axis values"* [17].

In our study, the locations for the four entities (policies), based on development of a dimension-by-dimension utility or value curve is preferred. This is in consideration

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[12] Multi-Attribute Utility Theory

of the 'objective' and 'transparent' manner in which conflict of opinions for each attribute under scrutiny are captured and represented with this approach. Here, stakeholders (defined in Step 1) were asked to make rough plots of their own judgements over each of the twenty impact measures for the four alternative policies: BAU, VISION 2020, SUBSIDY TRANSFER and LOCAL CONTENT. This implies a representation of value curves of 5 stakeholder viewpoints along 20 impact measures for 4 entities. The plots were done on a scale of 0 – 100, where '0' represents the lowest and '100' the highest relative values along the y-axis respectively; the x-axis represents the impact measures according to five *"viewpoints"*. Overall, the value curves aim to represent *"entity locations"*, through the use of straight lines to connect discrete points. Standardised versions of these stakeholder value curves along the twenty impact measures for the four policies (entities) are shown in Figure 7.3 (a) – (d).

i) Stakeholder Value Curves for the BAU Case

Figure 7.3 (a) reveals stakeholders' (VP_1 – VP_5) conflicting values over the BAU policy case. In terms of *"energy availability"* in the country by 2020, it is glaring in Figure 7.3 (a) that VP_1 and VP_2 express strongest opinions for domestic supply of natural gas, while VP_5 prefers more of government commitment to renewable energy development. Coal domestic supply appears to be the least preferred, as it receives low preference ratings—particularly from VP_4 and VP_5. Despite these, conflicting values did not emerge along all the impact measures. For example, VP_2 – VP_5 are unanimous in their preference for domestic oil supply, behind natural gas supply and ahead of others.

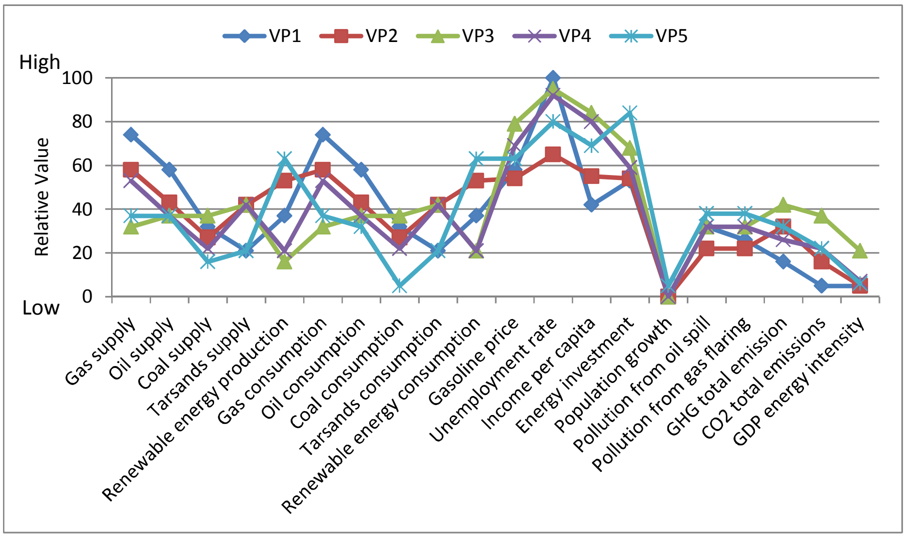

Figure 7.3 (a): Value Curves for BAU Case Based on Five Viewpoints.

ii) Stakeholder Value Curves for the Vision 2020 Policy

The Vision 2020 policy has also shown interesting dynamics in stakeholder values system. For instance, as shown in Figure 7.3 (b), VP_1 believes increasing natural gas domestic use is a better way of improving *"energy access"* to Nigerians. However, VP_3 expresses strongest opinion for oil use, while VP_2 did not at all support the planned reintroduction of coal use in the country. VP_1 and VP_3 also thought access to energy can be enhanced with development of renewable energy sources in a decentralised manner.

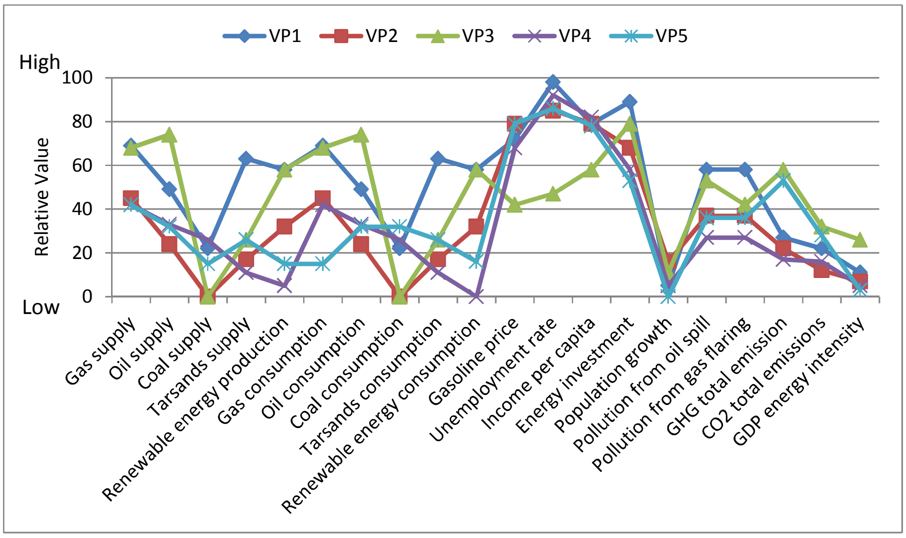

Figure 7.3 (b): Value Curves for Vision 2020 Policy Based on Five Viewpoints.

iii) Stakeholder Value Curves for the Subsidy Transfer Policy

In terms of *"energy affordability"*, majority of stakeholders (VP_2 – VP_4) in Figure 7.3 (c) are of the opinion that curbing unemployment and raising income per capita remains a high priority, as the need to lower end-use energy prices. Stakeholders are almost unanimous in their opinion that population growth is not a major barrier to energy affordability, especially if priority areas are tackled. All the stakeholders are in agreement that reducing investment costs would also make energy more affordable.

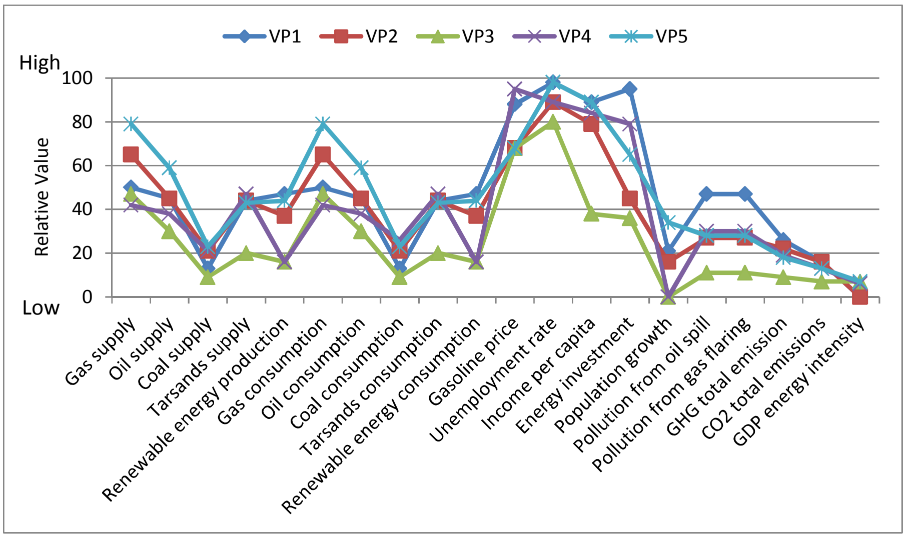

Figure 7.3 (c): Value Curves for Subsidy Transfer Policy Based on Five Viewpoints.

iv) Stakeholder Value Curves for the Local Content Policy

The Local Content policy of government aims to ensure *"energy use acceptability"* through improvements in energy efficiency. Yet, it is evident in Figure 7.3 (d) that compared to the other areas of impact, environmental impact of energy usage in the country is yet a major concern to stakeholders. For example, all the five indicators targeting assessment of environmental improvement measures receive the least rating in terms of preference. None of the indicators receive even 50% of the maximum rating of 100 (on a scale of 0 – 100).

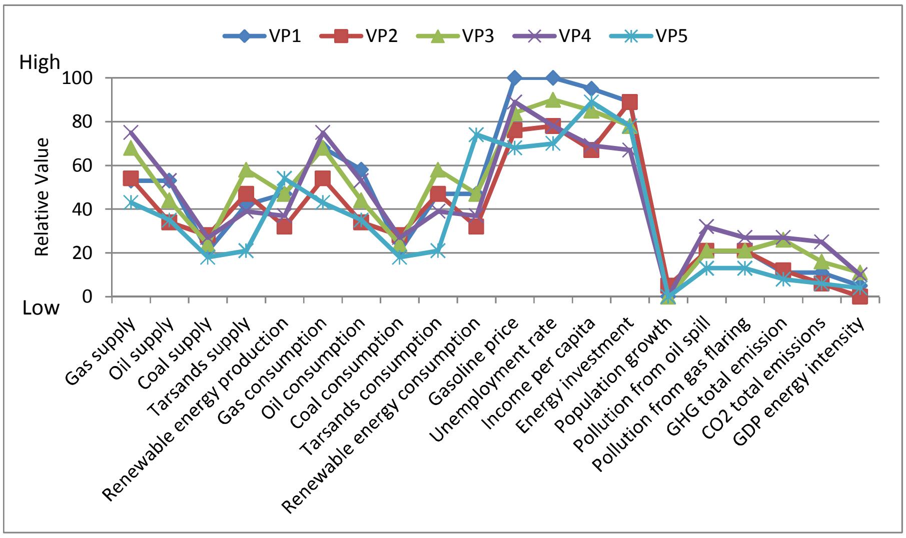

Figure 7.3 (d): Value Curves for Local Content Policy Based on Five Viewpoints.

Based on development of the value curves shown in Figure 7.3 (a) – (d), the following entity locations (v) were defined for each of the four policies as summarised in Table 7.7 to Table 7.10.

Table 7.7: Value Locations for the Base Case (BAU) Policy.

RANKING	IMPACT DIMENSIONS AND MEASURES	ENTITY LOCATION (Scale: 0 – 100)				
		$VP1_{v1}$	$VP2_{v1}$	$VP3_{v1}$	$VP4_{v1}$	$VP5_{v1}$
	ENERGY AVAILABILITY					
1	Natural gas domestic supply *(MTOE)*	74	58	32	53	37
2	Petroleum domestic supply *(Mmt)*	58	43	37	37	37
3	Coal domestic supply *(MTOE)*	32	27	37	22	16
4	Tar sands domestic supply *(MTOE)*	21	42	42	42	21
5	Renewable energy production (MTOE)	37	53	16	21	63
	ENERGY ACCESSIBILITY					
6	Natural gas consumption *(MTOE)*	74	58	32	53	37
7	Petroleum consumption *(Mmt)*	58	43	37	37	32
8	Coal consumption *(MTOE)*	32	27	37	22	5
9	Tar sands consumption *(MTOE)*	21	42	42	42	21
10	Renewable energy consumption *(MTOE)*	37	53	21	21	63
	ENERGY AFFORDABILITY					
11	End use gasoline price *(US$/litre)*	58	54	79	69	63
12	Unemployment rate *(%)*	100	65	95	92	80
13	Income per capita *(US95$/Year/Person)*	42	55	84	80	69
14	Energy investment cost *(B US95$/Year)*	53	54	68	59	84
15	Population growth *(Million)*	0	0	0	0	5
	ENERGY ACCEPTABILITY					
16	Pollution from oil spill *(B PU/Year)*	32	22	32	32	38
17	Pollution from gas flaring *(B PU/Year)*	26	22	32	32	38
18	GHG total emissions *(B kg/Year)*	16	32	42	26	32
19	CO_2 total emissions *(MTonC/Year)*	5	16	37	22	22
20	GDP energy intensity *(TOE/US95$)*	5	5	21	7	6

Table 7.8: Value Locations for VISION 2020 Policy.

RANKING	IMPACT DIMENSIONS AND MEASURES	ENTITY LOCATION (Scale: 0 – 100)				
		$VP1_{v2}$	**$VP2_{v2}$**	**$VP3_{v2}$**	**$VP4_{v2}$**	**$VP5_{v2}$**
	ENERGY AVAILABILITY					
1	Natural gas domestic supply *(MTOE)*	69	45	68	42	42
2	Petroleum domestic supply *(Mmt)*	49	24	74	33	32
3	Coal domestic supply *(MTOE)*	22	0	0	26	15
4	Tar sands domestic supply *(MTOE)*	63	17	26	11	26
5	Renewable energy production (MTOE)	58	32	58	5	15
	ENERGY ACCESSIBILITY					
6	Natural gas consumption *(MTOE)*	69	45	68	42	15
7	Petroleum consumption *(Mmt)*	49	24	74	33	32
8	Coal consumption *(MTOE)*	22	0	0	26	32
9	Tar sands consumption *(MTOE)*	63	17	26	11	26
10	Renewable energy consumption *(MTOE)*	58	32	58	0	16
	ENERGY AFFORDABILITY					
11	End use gasoline price *(US$/litre)*	72	79	42	68	79
12	Unemployment rate *(%)*	98	85	47	92	86
13	Income per capita *(US95$/Year/Person)*	79	79	58	82	78
14	Energy investment cost *(B US95$/Year)*	89	68	79	58	53
15	Population growth *(Million)*	5	16	11	5	0
	ENERGY ACCEPTABILITY					
16	Pollution from oil spill *(B PU/Year)*	58	37	53	27	36
17	Pollution from gas flaring *(B PU/Year)*	58	37	42	27	36
18	GHG total emissions *(B kg/Year)*	27	22	58	17	53
19	CO_2 total emissions *(MTonC/Year)*	22	12	32	16	28
20	GDP energy intensity *(TOE/US95$)*	11	7	26	5	3

Table 7.9: Value Locations for SUBSIDY TRANSFER Policy.

RANKING	IMPACT DIMENSIONS AND MEASURES	ENTITY LOCATION (Scale: 0 – 100)				
		$VP1_{v3}$	**$VP2_{v3}$**	**$VP3_{v3}$**	**$VP4_{v3}$**	**$VP5_{v3}$**
	ENERGY AVAILABILITY					
1	Natural gas domestic supply *(MTOE)*	50	65	47	42	79
2	Petroleum domestic supply *(Mmt)*	45	45	30	38	59
3	Coal domestic supply *(MTOE)*	13	21	9	21	23
4	Tar sands domestic supply *(MTOE)*	44	44	20	47	43
5	Renewable energy production (MTOE)	47	37	16	16	44
	ENERGY ACCESSIBILITY					
6	Natural gas consumption *(MTOE)*	50	65	47	42	79
7	Petroleum consumption *(Mmt)*	45	45	30	38	59
8	Coal consumption *(MTOE)*	13	21	9	26	23
9	Tar sands consumption *(MTOE)*	44	44	20	47	43
10	Renewable energy consumption *(MTOE)*	47	37	16	16	44
	ENERGY AFFORDABILITY					
11	End use gasoline price *(US$/litre)*	88	68	68	95	68
12	Unemployment rate *(%)*	98	89	80	89	98
13	Income per capita *(US95$/Year/Person)*	89	79	38	84	89
14	Energy investment cost *(B US95$/Year)*	95	45	36	79	65
15	Population growth *(Million)*	21	16	0	0	34
	ENERGY ACCEPTABILITY					
16	Pollution from oil spill *(B PU/Year)*	47	27	11	30	28
17	Pollution from gas flaring *(B PU/Year)*	47	27	11	30	28
18	GHG total emissions *(B kg/Year)*	26	22	9	19	18
19	CO_2 total emissions *(MTonC/Year)*	16	16	7	13	13
20	GDP energy intensity *(TOE/US95$)*	0	0	7	6	7

Table 7.10: Value Locations for LOCAL CONTENT Policy.

RANKING	IMPACT DIMENSIONS AND MEASURES	ENTITY LOCATION (Scale: 0 – 100)				
		$VP1_{v4}$	$VP2_{v4}$	$VP3_{v4}$	$VP4_{v4}$	$VP5_{v4}$
	ENERGY AVAILABILITY					
1	Natural gas domestic supply *(MTOE)*	53	54	68	75	43
2	Petroleum domestic supply *(Mmt)*	53	34	44	53	35
3	Coal domestic supply *(MTOE)*	21	28	24	27	18
4	Tar sands domestic supply *(MTOE)*	42	47	58	39	21
5	Renewable energy production (MTOE)	47	32	47	37	54
	ENERGY ACCESSIBILITY					
6	Natural gas consumption *(MTOE)*	68	54	68	75	43
7	Petroleum consumption *(Mmt)*	58	34	44	53	35
8	Coal consumption *(MTOE)*	21	28	24	27	18
9	Tar sands consumption *(MTOE)*	47	47	58	39	21
10	Renewable energy consumption *(MTOE)*	47	32	47	37	74
	ENERGY AFFORDABILITY					
11	End use gasoline price *(US$/litre)*	100	76	84	89	68
12	Unemployment rate *(%)*	100	78	90	78	70
13	Income per capita *(US95$/Year/Person)*	95	67	85	69	89
14	Energy investment cost *(B US95$/Year)*	89	89	78	67	78
15	Population growth *(Million)*	0	5	0	0	0
	ENERGY ACCEPTABILITY					
16	Pollution from oil spill *(B PU/Year)*	21	21	21	32	13
17	Pollution from gas flaring *(B PU/Year)*	21	21	21	27	13
18	GHG total emissions *(B kg/Year)*	11	12	26	27	8
19	CO_2 total emissions *(MTonC/Year)*	11	6	16	25	6
20	GDP energy intensity *(TOE/US95$)*	5	0	11	10	4

7.3.9 Step 9: Computation of Utilities for Entities

This step involves computing the aggregate values for each of the four entities (policy runs) under evaluation. The calculations are done using the following equation:

$$\mathbf{U}_{ij} = \sum_{k=1}^{K} \mathbf{w}_{ijk}\ \mathbf{v}_{ijk},\ i = 1, 2, \ldots, 4;\ j = 1, 2, \ldots, 5;\ k = 1, 2, \ldots, 20 \qquad (7)$$

Where, $\mathbf{U}_{ij}$ is overall value of $\mathbf{i}^{th}$ alternative policy according to $\mathbf{j}^{\mathbf{th}}$ viewpoint, $\mathbf{w}_{ijk}$ is importance weight given to $\mathbf{i}^{\mathbf{th}}$ policy by $\mathbf{j}^{\mathbf{th}}$ viewpoint along $\mathbf{k}^{\mathbf{th}}$ the impact measure and $\mathbf{v}_{ijk}$ is the location of $\mathbf{i}^{th}$ policy according to $\mathbf{j}^{th}$ viewpoint along the $\mathbf{k}^{th}$ impact measure.

Following the above computations, a set of weighted values are obtained for each of the four entities, in accordance with the five stakeholder viewpoints. This means that for each policy run, aggregate values reflecting the worth of that policy based on viewpoints (VP_1 – VP_5) are presented. These evaluation results are presented in this report as shown in Tables 7.11 – 7.14.

Table 7.11 (a): Evaluation Results for Base Case Policy (BAU) of VP_1.

BASE CASE (BAU) POLICY WORTH BASED ON VP_1				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	15	4.963 (MTOE)	74	1110
2	12	15.57 (Mmt)	58	696
3	7	0 (MTOE)	32	224
4	5	0 (MTOE)	21	105
5	8	11.79 (MTOE)	37	296
6	15	4.963 (MTOE)	74	1110
7	12	15.57 (Mmt)	58	696
8	7	0 (MTOE)	32	224
9	5	0 (MTOE)	21	105
10	8	11.79 (MTOE)	37	296
11	12	0.6 (US$/litre)	58	696
12	20	22.25 (%)	100	2000
13	9	1716 (US95$/Year/Person)	42	378
14	11	9.73 (B US95$/Year)	53	583
15	1	198.7 (Million)	0	0
16	7	7.643 (B PU/Year)	32	224
17	6	0.952 (B PU/Year)	26	156
18	4	45.79 (B kg/Year)	16	64
19	2	45.53 (MTonC/Year)	5	10
20	2	0.000114 (TOE/US95$)	5	10
Values Total				**8983**

Table 7.11 (b): Evaluation Results for Base Case Policy (BAU) of VP_2.

BASE CASE (BAU) POLICY WORTH BASED ON VP_2				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	14	4.963 (MTOE)	58	812
2	13	15.57 (Mmt)	43	559
3	8	0 (MTOE)	27	216
4	9	0 (MTOE)	42	378
5	11	11.79 (MTOE)	53	583
6	14	4.963 (MTOE)	58	812
7	13	15.57 (Mmt)	43	559
8	8	0 (MTOE)	27	216
9	9	0 (MTOE)	42	378
10	11	11.79 (MTOE)	53	583
11	17	0.6 (US$/litre)	54	918
12	19	22.25 (%)	65	1235
13	19	1716 (US95$/Year/Person)	55	1045
14	15	9.73 (B US95$/Year)	54	810
15	2	198.7 (Million)	0	0
16	9	7.643 (B PU/Year)	22	198
17	9	0.952 (B PU/Year)	22	198
18	7	45.79 (B kg/Year)	32	224
19	7	45.53 (MTonC/Year)	16	112
20	5	0.000114 (TOE/US95$)	5	25
Values Total				**9861**

Table 7.11 (c): Evaluation Results for Base Case Policy (BAU) of VP_3.

BASE CASE (BAU) POLICY WORTH BASED ON VP_3				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	7	4.963 (MTOE)	32	224
2	8	15.57 (Mmt)	37	296
3	8	0 (MTOE)	37	296
4	9	0 (MTOE)	42	378
5	4	11.79 (MTOE)	16	64
6	7	4.963 (MTOE)	32	224
7	8	15.57 (Mmt)	37	296
8	8	0 (MTOE)	37	296
9	9	0 (MTOE)	42	378
10	5	11.79 (MTOE)	21	105
11	16	0.6 (US$/litre)	79	1264
12	19	22.25 (%)	95	1805
13	17	1716 (US95$/Year/Person)	84	1428
14	14	9.73 (B US95$/Year)	68	952
15	1	198.7 (Million)	0	0
16	7	7.643 (B PU/Year)	32	224
17	7	0.952 (B PU/Year)	32	224
18	9	45.79 (B kg/Year)	42	378
19	8	45.53 (MTonC/Year)	37	296
20	5	0.000114 (TOE/US95$)	21	105
Values Total				**9233**

Table 7.11 (d): Evaluation Results for Base Case Policy (BAU) of VP_4.

BASE CASE (BAU) POLICY WORTH BASED ON VP_4				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	11	4.963 (MTOE)	53	583
2	8	15.57 (Mmt)	37	296
3	7	0 (MTOE)	22	154
4	9	0 (MTOE)	42	378
5	5	11.79 (MTOE)	21	105
6	11	4.963 (MTOE)	53	583
7	8	15.57 (Mmt)	37	296
8	7	0 (MTOE)	22	154
9	9	0 (MTOE)	42	378
10	5	11.79 (MTOE)	21	105
11	18	0.6 (US$/litre)	69	1242
12	19	22.25 (%)	92	1748
13	20	1716 (US95$/Year/Person)	80	1600
14	18	9.73 (B US95$/Year)	59	1062
15	1	198.7 (Million)	0	0
16	9	7.643 (B PU/Year)	32	288
17	13	0.952 (B PU/Year)	32	416
18	11	45.79 (B kg/Year)	26	286
19	9	45.53 (MTonC/Year)	22	198
20	3	0.000114 (TOE/US95$)	7	21
Values Total				**9893**

Table 7.11 (e): Evaluation Results for Base Case Policy (BAU) of VP_5.

BASE CASE (BAU) POLICY WORTH BASED ON VP_3				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	10	4.963 (MTOE)	37	370
2	8	15.57 (Mmt)	37	296
3	4	0 (MTOE)	16	64
4	5	0 (MTOE)	21	105
5	15	11.79 (MTOE)	63	945
6	9	4.963 (MTOE)	37	333
7	7	15.57 (Mmt)	32	224
8	2	0 (MTOE)	5	10
9	5	0 (MTOE)	21	105
10	13	11.79 (MTOE)	63	819
11	13	0.6 (US$/litre)	63	819
12	20	22.25 (%)	80	1600
13	18	1716 (US95$/Year/Person)	69	1242
14	19	9.73 (B US95$/Year)	84	1596
15	2	198.7 (Million)	5	10
16	12	7.643 (B PU/Year)	38	456
17	12	0.952 (B PU/Year)	38	456
18	9	45.79 (B kg/Year)	32	288
19	9	45.53 (MTonC/Year)	22	198
20	7	0.000114 (TOE/US95$)	6	42
Values Total				**9978**

Table 7.12 (a): Evaluation Results for VISION 2020 of VP_1.

VISION 2020 POLICY WORTH BASED ON VP_1				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	15	4.963 (MTOE)	69	1035
2	12	15.57 (Mmt)	49	588
3	7	0 (MTOE)	22	154
4	5	0 (MTOE)	63	315
5	8	11.79 (MTOE)	58	464
6	15	4.963 (MTOE)	69	1035
7	12	15.57 (Mmt)	49	588
8	7	0 (MTOE)	22	154
9	5	0 (MTOE)	63	315
10	8	11.79 (MTOE)	58	464
11	12	0.6 (US$/litre)	72	864
12	20	20.91 (%)	98	1960
13	9	1860 (US95$/Year/Person)	79	711
14	11	10.40 (B US95$/Year)	89	979
15	1	196.5 (Million)	5	5
16	7	7.888 (B PU/Year)	58	406
17	6	0.982 (B PU/Year)	58	348
18	4	45.79 (B kg/Year)	27	108
19	2	45.53 (MTonC/Year)	22	44
20	2	0.000111 (TOE/US95$)	11	22
Values Total				**10559**

Table 7.12 (b): Evaluation Results for VISION 2020 of VP_2.

VISION 2020 POLICY WORTH BASED ON VP_2				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	14	4.963 (MTOE)	45	630
2	13	15.57 (Mmt)	24	312
3	8	0 (MTOE)	0	0
4	9	0 (MTOE)	17	153
5	11	11.79 (MTOE)	32	352
6	14	4.963 (MTOE)	45	630
7	13	15.57 (Mmt)	24	312
8	8	0 (MTOE)	0	0
9	9	0 (MTOE)	17	153
10	11	11.79 (MTOE)	32	352
11	17	0.6 (US$/litre)	79	1343
12	19	20.91 (%)	85	1615
13	19	1860 (US95$/Year/Person)	79	1501
14	15	10.40 (B US95$/Year)	68	1020
15	2	196.5 (Million)	16	32
16	9	7.888 (B PU/Year)	37	333
17	9	0.982 (B PU/Year)	37	333
18	7	45.79 (B kg/Year)	22	154
19	7	45.53 (MTonC/Year)	12	84
20	5	0.000111 (TOE/US95$)	7	35
Values Total				**9344**

Table 7.12 (c): Evaluation Results for VISION 2020 of VP_3.

VISION 2020 POLICY WORTH BASED ON VP_3				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	7	4.963 (MTOE)	68	476
2	8	15.57 (Mmt)	74	592
3	8	0 (MTOE)	0	0
4	9	0 (MTOE)	26	234
5	4	11.79 (MTOE)	58	232
6	7	4.963 (MTOE)	68	476
7	8	15.57 (Mmt)	74	592
8	8	0 (MTOE)	0	0
9	9	0 (MTOE)	26	234
10	5	11.79 (MTOE)	58	290
11	16	0.6 (US$/litre)	42	672
12	19	20.91 (%)	47	893
13	17	1860 (US95$/Year/Person)	58	986
14	14	10.40 (B US95$/Year)	79	1106
15	1	196.5 (Million)	11	11
16	7	7.888 (B PU/Year)	53	371
17	7	0.982 (B PU/Year)	42	294
18	9	45.79 (B kg/Year)	58	522
19	8	45.53 (MTonC/Year)	32	256
20	5	0.000111 (TOE/US95$)	26	130
Values Total				**8367**

Table 7.12 (d): Evaluation Results for VISION 2020 of VP_4.

VISION 2020 POLICY WORTH BASED ON VP_4				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	11	4.963 (MTOE)	42	462
2	8	15.57 (Mmt)	33	264
3	7	0 (MTOE)	26	182
4	9	0 (MTOE)	11	99
5	5	11.79 (MTOE)	5	25
6	11	4.963 (MTOE)	42	462
7	8	15.57 (Mmt)	33	264
8	7	0 (MTOE)	26	182
9	9	0 (MTOE)	11	99
10	5	11.79 (MTOE)	0	0
11	18	0.6 (US$/litre)	68	1224
12	19	20.91 (%)	92	1748
13	20	1860 (US95$/Year/Person)	82	1640
14	18	10.40 (B US95$/Year)	58	1044
15	1	196.5 (Million)	5	5
16	9	7.888 (B PU/Year)	27	243
17	13	0.982 (B PU/Year)	27	351
18	11	45.79 (B kg/Year)	17	187
19	9	45.53 (MTonC/Year)	16	144
20	3	0.000111 (TOE/US95$)	5	15
Values Total				**8640**

Table 7.12 (e): Evaluation Results for VISION 2020 of VP_5.

VISION 2020 POLICY WORTH BASED ON VP_2				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	10	4.963 (MTOE)	42	420
2	8	15.57 (Mmt)	32	256
3	4	0 (MTOE)	15	60
4	5	0 (MTOE)	26	130
5	15	11.79 (MTOE)	15	225
6	9	4.963 (MTOE)	15	135
7	7	15.57 (Mmt)	32	224
8	2	0 (MTOE)	32	64
9	5	0 (MTOE)	26	130
10	13	11.79 (MTOE)	16	208
11	13	0.6 (US$/litre)	79	1027
12	20	20.91 (%)	86	1720
13	18	1860 (US95$/Year/Person)	78	1404
14	19	10.40 (B US95$/Year)	53	1007
15	2	196.5 (Million)	0	0
16	12	7.888 (B PU/Year)	36	432
17	12	0.982 (B PU/Year)	36	432
18	9	45.79 (B kg/Year)	53	477
19	9	45.53 (MTonC/Year)	28	252
20	7	0.000111 (TOE/US95$)	3	0.21
Values Total				**8603**

Table 7.13 (a): Evaluation Results for SUBSIDY TRANSFER of VP_1.

SUBSIDY POLICY WORTH OF VP_1				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	15	5.310 (MTOE)	50	750
2	12	16.82 (Mmt)	45	540
3	7	5.431 (MTOE)	13	91
4	5	4.299 (MTOE)	44	220
5	8	12.76 (MTOE)	47	376
6	15	5.310 (MTOE)	50	750
7	12	16.82 (Mmt)	45	540
8	7	5.431 (MTOE)	13	91
9	5	4.299 (MTOE)	44	220
10	8	12.76 (MTOE)	47	376
11	12	0.87 (US$/litre)	88	1056
12	20	22.25 (%)	98	1960
13	9	1716 (US95$/Year/Person)	89	801
14	11	9.73 (B US95$/Year)	95	1045
15	1	198.7 (Million)	21	21
16	7	7.643 (B PU/Year)	47	329
17	6	0.952 (B PU/Year)	47	282
18	4	71.03 (B kg/Year)	26	104
19	2	70.64 (MTonC/Year)	16	32
20	2	0.000117 (TOE/US95$)	0	0
Value Totals				**9584**

Table 7.13 (b): Evaluation Results for SUBSIDY TRANSFER of VP_2.

SUBSIDY POLICY WORTH BASED ON VP_1				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	14	5.310 (MTOE)	65	910
2	13	16.82 (Mmt)	45	585
3	8	5.431 (MTOE)	21	168
4	9	4.299 (MTOE)	44	396
5	11	12.76 (MTOE)	37	407
6	14	5.310 (MTOE)	65	910
7	13	16.82 (Mmt)	45	585
8	8	5.431 (MTOE)	21	168
9	9	4.299 (MTOE)	44	396
10	11	12.76 (MTOE)	37	407
11	17	0.87 (US$/litre)	68	1156
12	19	22.25 (%)	89	1691
13	19	1716 (US95$/Year/Person)	79	1501
14	15	9.73 (B US95$/Year)	45	675
15	2	198.7 (Million)	16	32
16	9	7.643 (B PU/Year)	27	243
17	9	0.952 (B PU/Year)	27	243
18	7	71.03 (B kg/Year)	22	154
19	7	70.64 (MTonC/Year)	16	112
20	5	0.000117 (TOE/US95$)	0	0
Values Total				**10739**

Table 7.13 (c): Evaluation Results for SUBSIDY TRANSFER of VP_3.

SUBSIDY POLICY WORTH BASED ON VP_3				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	7	5.310 (MTOE)	47	329
2	8	16.82 (Mmt)	30	240
3	8	5.431 (MTOE)	9	72
4	9	4.299 (MTOE)	20	180
5	4	12.76 (MTOE)	16	64
6	7	5.310 (MTOE)	47	329
7	8	16.82 (Mmt)	30	240
8	8	5.431 (MTOE)	9	72
9	9	4.299 (MTOE)	20	180
10	5	12.76 (MTOE)	16	80
11	16	0.87 (US$/litre)	68	1088
12	19	22.25 (%)	80	1520
13	17	1716 (US95$/Year/Person)	38	646
14	14	9.73 (B US95$/Year)	36	504
15	1	198.7 (Million)	0	0
16	7	7.643 (B PU/Year)	11	77
17	7	0.952 (B PU/Year)	11	77
18	9	71.03 (B kg/Year)	9	81
19	8	70.64 (MTonC/Year)	7	56
20	5	0.000117 (TOE/US95$)	7	35
Values Total				**5870**

Table 7.13 (d): Evaluation Results for SUBSIDY TRANSFER of VP_4.

SUBSIDY POLICY WORTH BASED ON VP_4				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	11	5.310 (MTOE)	42	462
2	8	16.82 (Mmt)	38	304
3	7	5.431 (MTOE)	21	147
4	9	4.299 (MTOE)	47	423
5	5	12.76 (MTOE)	16	80
6	11	5.310 (MTOE)	42	462
7	8	16.82 (Mmt)	38	304
8	7	5.431 (MTOE)	26	182
9	9	4.299 (MTOE)	47	423
10	5	12.76 (MTOE)	16	80
11	18	0.87 (US$/litre)	95	1710
12	19	22.25 (%)	89	1691
13	20	1716 (US95$/Year/Person)	84	1680
14	18	9.73 (B US95$/Year)	79	1422
15	1	198.7 (Million)	0	0
16	9	7.643 (B PU/Year)	30	270
17	13	0.952 (B PU/Year)	30	390
18	11	71.03 (B kg/Year)	19	209
19	9	70.64 (MTonC/Year)	13	117
20	3	0.000117 (TOE/US95$)	6	18
Values Total				**10374**

Table 7.13 (e): Evaluation Results for SUBSIDY TRANSFER of VP_5.

SUBSIDY POLICY WORTH BASED ON VP_5				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	10	5.310 (MTOE)	79	790
2	8	16.82 (Mmt)	59	472
3	4	5.431 (MTOE)	23	92
4	5	4.299 (MTOE)	43	215
5	15	12.76 (MTOE)	44	660
6	9	5.310 (MTOE)	79	711
7	7	16.82 (Mmt)	59	413
8	2	5.431 (MTOE)	23	46
9	5	4.299 (MTOE)	43	215
10	13	12.76 (MTOE)	44	572
11	13	0.87 (US$/litre)	68	884
12	20	22.25 (%)	98	1960
13	18	1716 (US95$/Year/Person)	89	1602
14	19	9.73 (B US95$/Year)	65	1235
15	2	198.7 (Million)	34	68
16	12	7.643 (B PU/Year)	28	336
17	12	0.952 (B PU/Year)	28	336
18	9	71.03 (B kg/Year)	18	162
19	9	70.64 (MTonC/Year)	13	117
20	7	0.000117 (TOE/US95$)	7	49
Values Total				**10935**

Table 7.14 (a): Evaluation Results for LOCAL CONTENT of VP_1.

LOCAL CONTENT POLICY WORTH BASED ON VP_1				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	15	4.963 (MTOE)	53	795
2	12	15.57 (Mmt)	53	636
3	7	0 (MTOE)	21	147
4	5	0 (MTOE)	42	210
5	8	11.79 (MTOE)	47	376
6	15	4.963 (MTOE)	68	1020
7	12	15.57 (Mmt)	58	696
8	7	0 (MTOE)	21	147
9	5	0 (MTOE)	47	235
10	8	11.79 (MTOE)	47	376
11	12	0.6 (US$/litre)	100	1200
12	20	22.25 (%)	100	2000
13	9	1716 (US95$/Year/Person)	95	855
14	11	9.73 (B US95$/Year)	89	979
15	1	198.7 (Million)	0	0
16	7	7.898 (B PU/Year)	21	147
17	6	0.983 (B PU/Year)	21	126
18	4	45.79 (B kg/Year)	11	44
19	2	45.53 (MTonC/Year)	11	22
20	2	0.000108 (TOE/US95$)	5	10
Values Total				**10021**

Table 7.14 (b): Evaluation Results for LOCAL CONTENT of VP_2.

LOCAL CONTENT POLICY WORTH BASED ON VP_2				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	14	4.963 (MTOE)	54	756
2	13	15.57 (Mmt)	34	442
3	8	0 (MTOE)	28	224
4	9	0 (MTOE)	47	423
5	11	11.79 (MTOE)	32	352
6	14	4.963 (MTOE)	54	756
7	13	15.57 (Mmt)	34	442
8	8	0 (MTOE)	28	224
9	9	0 (MTOE)	37	333
10	11	11.79 (MTOE)	32	352
11	17	0.6 (US$/litre)	76	1292
12	19	22.25 (%)	78	1482
13	19	1716 (US95$/Year/Person)	67	1273
14	15	9.73 (B US95$/Year)	89	1335
15	2	198.7 (Million)	5	10
16	9	7.898 (B PU/Year)	21	189
17	9	0.983 (B PU/Year)	21	189
18	7	45.79 (B kg/Year)	12	84
19	7	45.53 (MTonC/Year)	6	42
20	5	0.000108 (TOE/US95$)	0	0
Values Total				**10200**

Table 7.14 (c): Evaluation Results for LOCAL CONTENT of VP_3.

LOCAL CONTENT POLICY WORTH BASED ON VP_3				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	7	4.963 (MTOE)	68	476
2	8	15.57 (Mmt)	44	352
3	8	0 (MTOE)	24	192
4	9	0 (MTOE)	58	522
5	4	11.79 (MTOE)	47	188
6	7	4.963 (MTOE)	68	476
7	8	15.57 (Mmt)	44	352
8	8	0 (MTOE)	24	192
9	9	0 (MTOE)	58	522
10	5	11.79 (MTOE)	47	235
11	16	0.6 (US$/litre)	84	1344
12	19	22.25 (%)	90	1710
13	17	1716 (US95$/Year/Person)	85	1445
14	14	9.73 (B US95$/Year)	78	1092
15	1	198.7 (Million)	0	0
16	7	7.898 (B PU/Year)	21	147
17	7	0.983 (B PU/Year)	21	147
18	9	45.79 (B kg/Year)	26	234
19	8	45.53 (MTonC/Year)	16	128
20	5	0.000108 (TOE/US95$)	11	55
Values Total				**9809**

Table 7.14 (d): Evaluation Results for LOCAL CONTENT of VP_4.

LOCAL CONTENT POLICY WORTH BASED ON VP_4				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	11	4.963 (MTOE)	75	825
2	8	15.57 (Mmt)	53	424
3	7	0 (MTOE)	27	189
4	9	0 (MTOE)	39	351
5	5	11.79 (MTOE)	37	185
6	11	4.963 (MTOE)	75	825
7	8	15.57 (Mmt)	53	424
8	7	0 (MTOE)	27	189
9	9	0 (MTOE)	39	351
10	5	11.79 (MTOE)	37	185
11	18	0.6 (US$/litre)	89	1602
12	19	22.25 (%)	78	1482
13	20	1716 (US95$/Year/Person)	69	1380
14	18	9.73 (B US95$/Year)	67	1206
15	1	198.7 (Million)	0	0
16	9	7.898 (B PU/Year)	32	288
17	13	0.983 (B PU/Year)	27	351
18	11	45.79 (B kg/Year)	27	297
19	9	45.53 (MTonC/Year)	25	225
20	3	0.000108 (TOE/US95$)	10	30
Values Total				**10809**

Table 7.14 (e): Evaluation Results for LOCAL CONTENT of VP_5.

LOCAL CONTENT POLICY WORTH BASED ON VP_5				
Impact Measure (k)	**Importance Weight (w)**	**Projected Policy Impact (i)**	**Entity Location (v)**	**Utility Value (u_{ij})**
1	10	4.963 (MTOE)	43	430
2	8	15.57 (Mmt)	35	280
3	4	0 (MTOE)	18	72
4	5	0 (MTOE)	21	105
5	15	11.79 (MTOE)	54	810
6	9	4.963 (MTOE)	43	387
7	7	15.57 (Mmt)	35	245
8	2	0 (MTOE)	18	36
9	5	0 (MTOE)	21	105
10	13	11.79 (MTOE)	74	962
11	13	0.6 (US$/litre)	68	884
12	20	22.25 (%)	70	1400
13	18	1716 (US95$/Year/Person)	89	1602
14	19	9.73 (B US95$/Year)	78	1482
15	2	198.7 (Million)	0	0
16	12	7.898 (B PU/Year)	13	156
17	12	0.983 (B PU/Year)	13	156
18	9	45.79 (B kg/Year)	8	72
19	9	45.53 (MTonC/Year)	6	54
20	7	0.000108 (TOE/US95$)	4	28
Values Total				**9266**

7.3.10 Step 10: Optimal Policy Selection

This final step of the SMART evaluation involves comparing our four 'entities', to determine which policy is *"best"* according to stakeholder viewpoints [10]. In our case, a combined result is presented as shown in Table 7.15. The table summarises the results of the ten-step evaluation process. This helps us to quickly visualise individual preferences of the five stakeholders (VP_1 – VP_5), and to rank each policy worth in order to choose the most preferred option from amongst the four competing alternatives.

Table 7.15: SMART-Based Evaluation Results for Four Entities (Policies).

VIEWPOINT	**POLICY WORTH**				**INDIVIDUAL PREFERENCES**
	BASE CASE (BAU)	***VISION 2020***	***SUBSIDY TRANSFER***	***LOCAL CONTENT***	
VP_1	8983	10559	9584	10021	VISION 2020
VP_2	9861	9344	10739	10200	SUBSIDY TRANSFER
VP_3	9233	8367	5870	9809	LOCAL CONTENT
VP_4	9893	8640	10374	10809	LOCAL CONTENT
VP_5	9978	8603	10935	9266	SUBSIDY TRANSFER
$\sum$	**47948**	**45513**	**47502**	**50105**	

In Table 7.16, a final ranking of the four policies is shown and an 'optimal policy' is selected. Here, the rule is simply to maximise $\boldsymbol{U_{ij}}$ if a single policy is preferred; but if a subset of $\boldsymbol{i}$ is preferred, *"then the subset for which $\sum_i \boldsymbol{U_i}$ is maximum is the best"* [17]. Since the LOCAL CONTENT policy carries the highest aggregate value, with a numerical policy worth of 50105, this policy is selected as the preferred policy option according to stakeholder viewpoints. This policy can be recommended for adoption and implementation, where such recommendations are required.

Table 7.16: Policy Ranking and Optimal Policy Selection.

POLICY WORTH	**POLICY RANK**	**POLICY PREFERENCE**	**OPTIMAL POLICY**
50105	1	LOCAL CONTENT	LOCAL CONTENT
47948	2	BASE CASE (BAU)	
47502	3	SUBSIDY TRANSFER	
45513	4	VISION 2020	

7.4 Discussion on the Final Policy Decision

The implications of the policy evaluation results shown in Table 7.15 and Table 7.16 are discussed in the following paragraphs. It is useful to recall here, that the evaluation results are based on the viewpoints and preferences of fifty policymakers (stakeholders)—ten each from five ministries in Nigeria. These ministries are 1) Ministry of Petroleum Resources (MPR); 2) Nigerian National Petroleum Corporation (NNPC); 3) Energy Commission of Nigeria (ECN); 4) National Planning Commission (NPC) and 5) Federal Ministry of Environment (FME). The stakeholder viewpoints were represented in the evaluation as (VP_1 – VP_5).

A review of individual stakeholder preferences for the four alternative policies in Table 7.15 reveals that stakeholders representing viewpoint (VP_1) express strongest preference for adoption and implementation of the VISION 2020 policy. This is possibly because the desire for 'Energy Sufficiency in a Thriving Economy' remains paramount to the aspirations of this category of stakeholders. This group also believes that increasing natural gas domestic use in the country through the implementation of this policy is a better way of improving *"energy accessibility"* to the Nigerian public.

Stakeholders representing viewpoints (VP_2 and VP_5) express strongest opinions for adoption and implementation of the SUBSIDY TRANSFER policy. We think these categories of stakeholders are motivated for this policy because the path leads to achievement of 'Energy Diversity in a Transitional Economy'. These stakeholder groups are also of the opinion that curbing unemployment and raising income per capita through this policy remain a high priority, as the need to lower end-use energy prices. This, the stakeholders believe will impact positively on energy affordability in the country. They are also in agreement with other opinions that population growth is not a major barrier to energy affordability, especially if priority areas such as unemployment and poor income levels are tackled.

It is also evident in Table 7.15, that VP_3 and VP_4 prefer the LOCAL CONTENT development policy. Here, the desire to achieve 'Energy Efficiency in a Green Economy' remains the motivation for the choice of this policy. Although, two stakeholder viewpoints have expressed preferences for the 'local content' policy, it is interesting to note the stark contrast between this choice and the results of stakeholder value curves developed in Step 8. It is obvious in the value curves in Step 8, that stakeholders are more concerned about the positive economic and social development impacts of energy usage in Nigeria, as compared to environmental preservation. For example, none of the metrics defined for assessment of environmental improvement measures received even 50% of the maximum rating of 100 (on a scale of 0 – 100).

It is also worth noting, that based on individual results of the five viewpoints in Table 7.16, none of the stakeholders express any preference to see the BAU policy continue. It is evident that everyone desires a change in policy direction. However, this perceived desire for a change in policy direction is not entirely reflected in the final aggregate values of the four policies shown in Table 7.16. Here, the overall policy ranking based on summation of individual policy worth reveals, that the LOCAL CONTENT policy is the most preferred. Despite this overall preference, it is still evident in the same table that the BAU policy ranks second in preference, ahead of SUBSIDY TRANSFER and VISION 2020. It can be inferred therefore, that other stakeholders believe in the BAU policies, and would want to see the existing energy, social, economic and environmental policies continue into the future.

7.5 Conclusion

This chapter adapted the Simple Multi-Attribute Rating Technique (SMART), to evaluate four government policies targeting Sustainable Energy Development (SED) in Nigeria. The aim was to select the *"best"* policy option, which based on stakeholder 'viewpoints' and 'preferences', is likely to yield targeted outcomes on the 'four grand energy objectives' of availability, accessibility, affordability and acceptability.

We introduced in this chapter, the concept of 'decision matrix' in form of a hierarchical value judgement model, which encapsulates the key decision variables. It was found in our analysis that the use of this approach is helpful in: 1) defining the essential evaluation parameters in a transparent manner, 2) highlighting at an early stage, the necessary evaluation steps and 3) deciding on the choice of an appropriate evaluation methodology that can reflect real stakeholder preferences.

Three proposed government policies relative to a BAU case were evaluated in this chapter. It was found during identification and ranking of policies impact dimensions and impact measures that our model projections had significant influence on stakeholder decisions, as policymakers revised their initial ranking after seen the model predictions. Results of stakeholder value curves had also shown that policymakers are more concerned with the positive economic and social impacts of energy use in Nigeria than environmental concerns, as environmental indicators received the lowest rating.

It is evident in the overall ranking of policies in the evaluation results, that the LOCAL CONTENT policy is the most preferred alternative. It can be inferred from the final results, that while majority of the stakeholders believe adoption and implementation of new policies is likely to improve the status quo in Nigeria's energy economy situation, others believe that continuing with existing policies will also suffice.

Chapter 8

Thesis Conclusion

8.1 Discussion

This chapter presents final reflections on the research into the Sustainability Assessment of Energy Policy in Nigeria, which has been based on Scenario Planning and Integrated Modelling. It reflects on study outcomes in the following areas: 1) integration of System Dynamics Simulation (SD) and Multi-Criteria Evaluation (MCE) models, which forms the core of the thesis argument; 2) a case study application, which focuses on analysis of the challenges to Sustainable Energy Development in Nigeria; 3) development of an Energy Policy Assessment Model (E-PAM), which provides an integrated energy planning and analysis tool to support informed decision making in Nigeria and elsewhere; 4) analysis of energy scenarios, which define alternative energy futures for Nigeria, based on government energy objectives and targets; 5) evaluation of proposed energy policies and the selection of an *"optimal"* policy option according to stakeholder viewpoints and 6) a discussion on SD model validation and uncertainty in model projections and its impact on policy choices.

8.1.1 Reflections on Integration of SD Simulation and MCE Models

The main argument defended in this study is that combining System Dynamics (SD) simulation and Multi-Criteria Evaluation (MCE) models provides a practical framework within which the policy environment can be effectively explored. This argument follows from our understanding and identification of the key strengths and weaknesses of SD methodology and diverse multi criteria evaluation methods, based on review of existing literature. This helped us to determine the needs for their integration.

We found in our reviews, that SD methodology utilises a dynamic modelling approach, to provide the quantitative basis for rigorous policy analysis [7]. This helps in predicting the effectiveness of diverse policies [9]. Despite providing the quantitative rigour, we also found that the SD methodology does not explicitly deal with evaluation of policies [10]. One major problem uncovered in this study about SD methodology, is that the patterns of behaviour highlighted in SD models are not sufficient to aid policymakers judge policies and determine a particular course of action that would truly serve as *"best"* alternative. This implies that policy recommendations, based on the approach alone are unlikely to represent diverse perspectives, as model representation and interpretations are usually left to the intuition of the modeller or analyst.

In spite of the issues uncovered about SD, the approach was adopted as the preferred methodology in our project, above similar approaches such as Agent-Based Modelling (ABM). Our main motivation for the choice of SD was based on the consideration, that the SD methodology has shown a better capability of exposing 'whole' system behaviour and the 'cause' and 'effect' relationships amongst system variables, when compared to alternatives like ABM. A review of the ABM approach revealed that ABM is a robust, non-linear modelling technique. However, its major limitation was found to be its focus on mainly examining the dynamic behaviour of 'agents' (i.e. individual or collective entities), as opposed to entire system behaviour—which is the 'thrust' of our work. The SD approach on the other hand, was found to be effective in representing and interpreting 'whole' system behaviour. This helps our understanding of overall system behaviour and potential consequences. Thus, SD was found to be the best option for our project, as it helps us to better recognise a particular pattern of system behaviour, understand causes and predict future consequences.

However, this study focused on evaluating real values and real judgement preferences that touch directly on stakeholder aspirations. Therefore, to ensure a transparent evaluation of stakeholder values and trade-offs, and in judging the effectiveness of proposed government policies based on stakeholder perspectives, an appropriate MCE model was needed to combine with the SD model proposed in this study. The aim was to counterbalance the weaknesses identified in both approaches.

Different MCE methods were reviewed, for ‘transparency’ and ease in handling stakeholder inputs, and effectiveness in dealing with issues of trade-offs. It was found, that the Outranking Methods (within the family of MAUT) are the most sophisticated, yet, they were confirmed to lack the flexibility needed to deal with stakeholder issues highlighted above. For this reason, we selected a MCE method known as SMART—Simple Multi-Attribute Rating Technique [17]. It was chosen to combine with SD, for its transparency and ease in handling stakeholder inputs. Since our evaluation approach focused largely on wider stakeholder participation—with a high degree of transparency, the SMART approach became the most practical approach to use in our study.

Based on the work done in this study on SD policy modelling and multi criteria evaluation of alternative policies, and our understanding of the issues uncovered under these themes, we can conclude here, that for an effectual assessment of policies, the SD methodology needs to be combined with an appropriate evaluation method such as SMART. It was evident in our study, that the SMART evaluation model, just like the output of the SD model, aids our understanding of the proposed government policies. They were found to differ significantly, in that the SMART model aid an understanding that leads to appropriate and justifiable choices in the face of competing and conflicting alternative policies—hence, the needs to integrate both approaches for better results.

8.1.2 Reflections on Case Study Application

It was found in our analyses of the case study area, that Nigeria, though an 'energy-rich' country, falls within the category of countries experiencing *"energy-poverty"* [11]. A study of government's strategic documents [12-14] for example, revealed two important perspectives: 1) that one of the key challenges Nigeria currently faces is ineffective energy policy formulation and implementation and 2) there is a general lack of structured tools to aid planning and evaluation of effective policies; tools that will bring about the process of informed decision making in the country.

The Nigerian case study analyses, which were carried out from three standpoints: 1) geography, 2) energy economy challenges and 3) current policy responses and reforms, conveyed a detailed description of the current situation in the nation's energy sector and the three sustainability domains: society, economy and environment. These analyses have helped us to identify the most problematic areas, and the key issues that were investigated in this research.

Analyses of the social domain have shown that burgeoning population, raising unemployment and lack of skilled labour supply resulting from poor quality of education and training are the major issues affecting the country in this area. Under the economic domain, it was discovered that the lack of domestic investment, *"unrealistic"* GDP growth and misplacement of government priorities in expenditure are the key issues needing urgent attention. The environmental impacts of oil and gas pollution, desertification and increasing GHG emissions from energy use, were identified by this study as major environmental concerns in Nigeria.

It was inferred from fieldwork data based on stakeholder opinions, that despite possessing huge energy potential, Nigeria is still likely to face significant energy crisis in the near future. This, stakeholders thought will be the case, if there are no significant changes in existing energy policies. In view of these concerns, a thorough review of current policy responses in the aforementioned domains and the on-going challenges with the reform agenda of government was undertaken in this study. An understanding of the main issues (highlighted in paragraph one of this subsection), helped us to identify the needs to develop an integrated policy assessment tool—the E-PAT.

We developed the E-PAT and demonstrated its practical application on Nigeria, as a case study example. We tested the robustness and real life usage of the tool with proposed government policies for Sustainable Energy Development (SED). Three alternative policies were modelled and evaluated using the framework. The evaluation procedure utilised simulation output from our model and fieldwork data from Nigeria—based on stakeholder inputs, to serve as *"front end"* [8]. The process resulted in the selection of an 'optimal' or 'most preferred' alternative policy based on stakeholder preferences. The E-PAT itself was found to be a useful and practical tool for modelling and evaluation of diverse policies.

8.1.3 Reflections on Development of the E-PAM

Our first research question on provision of a policy assessment tool was tackled through development and representation of the Energy Policy Assessment Model (E-PAM). This is proposed to serve as a tool to aid policymakers in the planning and analysis of energy policies in a national context. The E-PAM specifically seeks to be an integrated tool for examining the dynamic interplay, and long term impacts of the energy sector on the Nigerian economy, society and the environment, and it can be customised for use elsewhere.

The model development process provided significant insights into the challenges to Sustainable Energy Development (SED) in Nigeria. Some of the key insights drawn from the process are already highlighted in the previous section. However, it is important to recall here, that these issues include: 1) ineffective energy policy formulation and implementation and 2) lack of structured tools to aid planning and evaluation of policies. It was also found, that stakeholder consultations through fieldwork in Nigeria proved to be an essential part of the process. This helped us in gaining valuable insights and inputs for the development and modelling of the E-PAM.

It was also evident from the analyses made under this theme, that energy supply in Nigeria is characterised by inefficient and unreliable energy systems. Some of the key issues uncovered, to support development of the E-PAM were issues of weak governance and poor energy policy, infrastructural and technical problems, poor management of finance, and the challenges of a growing population and the supply of skilled manpower. In view of these challenges, the government has embarked on vigorous reforms to improve the situation. One of the desired outcomes is to provide sustainable energy access to the people through development of renewable energy resources—hence, the needs for a structured planning and evaluation tool.

Key features of the tool developed for this purpose include ‘dynamism’ and ‘holism’. This means, that the E-PAM supports policy planning and analysis in an integrated and comprehensive manner. We found in our review of its structure, that the system feedback loops (i.e. the ‘positive’ (reinforcing) and the ‘negative’ (balancing) feedback structures [153], proved to be an important part of the model. These help us to understand what is causing a particular pattern of behaviour in a policy system [7]. Such behaviour can be thoroughly examined through simulation of the model [9].

Within the integrated E-PAM comprising four domains (energy, society, economy and environment), are specific variables that make up each domain. It is important to note here, that it is the 'cause' and 'effect' relationships amongst these key domain variables that produce a particular pattern of behaviour that reveals interesting dynamics about the model. These dynamic interactions and the characteristic behaviour altogether depict what the E-PAM represents. It is essential to conclude here, that the 'composite validation' procedure used to validate our model remains very effective. The approach proved to be a useful way of ensuring a holistic representation and verification of a formal model. This helps in ensuring the credibility and acceptability of a model not only to experts but to target users of the tool as well.

8.1.4 Reflections on Energy Scenarios

Analyses of the E-PAM's 'Reference Behaviour', also known as 'Baseline Scenario' or 'Business-As-Usual' (BAU) case were done. The BAU scenario was based on two main considerations (assumptions): 1) that no new government interventions are expected to existing energy, social, economic and environmental policies and 2) that 2000 – 2010 trends in activities within the energy sector and the three sustainability domains will continue to year 2050.

The following key insights were drawn from these analyses. It was found under BAU, that existing technologies for fossil fuels discovery in Nigeria will prevail to 2050. This implies that oil and gas reserves will continue to grow at annual rate of 0.14% and 0.39% respectively. Total primary energy demand will continue to grow at the rate of 2.35% per annum. It was also found that the country's total population will continue to grow at the rate of 2.37% per year to 2050. This is based on a Constant Fertility variant of 5.5 births per woman and a female reproductive age of 30 years.

Our analyses also revealed that the Nigerian economy will remain dependent on oil revenue to year 2050. The implication is that government operational costs will also remain dominant over capital expenditure. Both are predicted to grow at an annual rate of 0.3% and 0.25% respectively. For the environment domain, it was found that oil industry pollution from gas flares and oil spills will continue to rise at annual growth rate of 10% and 13% respectively. Total GHG emission will also rise into the future, growing at the rate of 1.47% per year to 2050. The key conclusion under this scenario is that energy crisis, as well as the economic, social and environmental challenges of bringing about SED in Nigeria will remain unabated in this case.

In addition to the BAU case, 'plausible' energy scenarios were screened against the government's declared policy to achieve SED in Nigeria. The analyses focused on the impact of different government initiatives within the energy sector and their economic, social and environmental implications. Also, the long-term perspectives that underpin *"actions"* and *"measures"* aimed at achieving targeted SED results over the timescale under consideration were examined. Here, the concept of a working definition of SED introduced in this study was used, to evaluate energy usage in Nigeria from four standpoints: availability, accessibility, affordability and acceptability—termed the 'four grand energy objectives'. The concept was found to provide a useful 'platform' for defining the metrics needed to assess targets and progress towards SED.

We further examined in much detail, three proposed government policies and the key considerations around which different energy scenarios were explored. This provided insights into the different energy policy targets and their expected impact on the three sustainability domains, based on model predictions. Three new sets of energy scenarios resulted from these analyses. These are: 1) Energy Sufficiency in a Thriving

Economy, 2) Energy Diversity in a Transitional Economy and 3) Energy Efficiency in a Green Economy. The policies were explored in comparison with the BAU case—a scenario of Energy Poverty in a Developing Economy.

As a key conclusion to the analyses done under this theme, it is worthy to emphasise here, that none of the three government policy interventions was found to be able to satisfy the 'four grand energy objectives' as a standalone policy. Each policy maximises a particular energy objective and a particular sustainability dimension. Similarly, results of sensitivity analysis conducted on critical model parameters, to examine variations on the key scenario assumptions, showed that critical energy variables such as petroleum and natural gas reserves and other economic, social and environmental-based variables such as real GDP, labour demand and supply and GHG emissions are highly sensitive to policy changes and future uncertainties.

8.1.5 Reflections on Policy Evaluation

The second part of this thesis argument focused on multi-criteria, multidimensional and multi-stakeholder evaluation of alternative government policies, and the selection of an 'optimal policy' according to stakeholder viewpoints. Here, the study employed SMART [8] as its main evaluation methodology. SMART, a MAUT procedure was used to assign weights to defined assessment criteria according to their relative importance. This helped us to explicitly spell out what the different policy values were, how much they differ, and which one was the most preferred.

The discussion was structured around one case study example on SED in Nigeria', with specific focus on assessment of alternative policy impacts on the 'four grand energy objectives' previously mentioned. The evaluation process utilised E-PAM output and fieldwork data from Nigeria as a combined *"front end"* to SMART [10]. We examined in detail the impacts of proposed policies, and determined which policy was likely to yield targeted outcomes on the 'four grand energy objectives' of availability, accessibility, affordability and acceptability, according to stakeholder preferences.

Here, the concept of a 'decision matrix' developed in this study, in form of a 'hierarchical value judgement model' was found to be a useful approach to structuring a policy problem evaluation. The matrix encapsulated key decision variables. It was found in our analysis, that the use of this approach helped us to achieve the following: 1) define the essential evaluation parameters in a transparent manner, 2) highlight at an early stage, the necessary evaluation steps and 3) decide on the choice of an appropriate evaluation methodology that could reflect real stakeholder preferences.

Three proposed government policies relative to a BAU case were evaluated. It was found during identification and ranking of policies impact dimensions and impact measures that our model projections have significant influence on stakeholder judgement and decisions. For example, policymakers were able to revise their initial decision on ranking of the impact dimensions after seen the model predictions. Results of stakeholder value curves had also shown that policymakers are more concerned with the positive economic and social impacts of energy use in Nigeria than environmental concerns, as environmental indicators received the lowest rating.

It was evident in the overall ranking of the four policies in the evaluation results, that the LOCAL CONTENT is the most preferred alternative policy. The following are worth noting as key conclusion to the evaluation: it was inferred from the final results, that while majority of the stakeholders believe adoption and implementation of new policies is likely to improve the status quo in the Nigerian energy economy situation, others believe that continuing with the existing policies will also suffice.

8.1.6 Reflections on SD Model Validation and Uncertainty

This study found that model validation and a true assessment of uncertainty in model projections and its impact on policy choices is an essential part of model development, and yet, a difficult task to undertake. Model validation and assessment of uncertainty was found in our case to be particularly difficult because of our inability to adequately demonstrate what actually constitutes a good model, and whether our model projections about uncertainty of some parameters truly reflect such uncertainties.

Despite these concerns, there was still the need to define and develop procedures that could potentially, enhance 'credibility' and 'acceptability' of our model. For this reason, a composite validation approach was developed as a means to check the structural robustness and dimensional consistency of the E-PAM, while sensitivity analysis was conducted on a range of model parameters, to address key uncertainties.

We found that our model projections about the uncertainty of the energy sector and the sustainability domains influenced policymakers' decisions during fieldwork in Nigeria. These uncertainty projections help them to determine the critical variables that were used during policy evaluation and selection. Yet, it was difficult to ascertain if these truly possess a high level of uncertainty, as some of the parameters (such as initial total fertility and initial GDP growth rate) for example, were based on factual data. These altogether reduce our level of confidence even in sensitivity analysis.

Despite the difficulty to explicitly infer, if validation results and the techniques used in validations are truly sufficient and accurate enough, to ensure credibility and acceptability of structured models, we suggest that more activities can be undertaken to improve the uncertainty outlook of formal models. Such areas of improvements could include further optimisation and the use of additional historical and other country data.

8.2 Study Conclusions

This thesis presents a novel integrated policy assessment tool that serves as a decision support framework for analysis of energy policy problems involving multilevel, multidimensional, and multi-stakeholder complexity. The new approach termed The Energy Policy Assessment Technique (E-PAT), integrates System Dynamics Simulation and Multi-Criteria Evaluation models into a unified assessment framework. The E-PAT doubles as a systems-thinking model and a multi-criteria evaluation archetype. The E-PAT is practical for use in assessing policy issues, particularly those relating to energy planning in a national context. It is a suitable tool for evaluation and selection of optimal policies from amongst competing and conflicting alternatives, based on stakeholder perspectives.

The overall objective of the study was to develop an integrated technique for assessing policy initiatives, particularly those relating to energy planning in a national context. The aim is to provide energy policymakers with a planning and evaluation tool to support informed decision making process. The main hypothesis defended in this study is that combining a structured computer simulation model with a social-oriented evaluation model provides a more practical approach to explore the policy environment.

The research shows that a novel framework that combines System Dynamics (SD) simulation model and Multi-Criteria Evaluation (MCE) model results in a powerful assessment technique. A robust technique that has the capability for exploring diverse policies has been tested. In addition to assessing policies from a nonlinear approach, the new technique is practical for evaluating and selecting an ‘optimal’ or ‘best’ policy case from amongst multiple alternatives. It is also an appropriate integrated tool for use in preliminary policy assessment before adoption and implementation and in the full evaluation of policies after implementation.

In this study, the use of Simple Multi-Attribute Rating Technique (SMART) [8], and other social-oriented MCE models—which are flexible in incorporating stakeholder viewpoints is recommended. To test the robustness and practical application, a case study evaluation of proposed policies is also recommended. In our case, three proposed government energy policies for Sustainable Energy Development in Nigeria were evaluated relative to a Business-As-Usual case. The evaluation process resulted in the selection of 'best' policy option according to stakeholder viewpoints.

The original contribution made by this study is the creation of an integrated, transparent, and comprehensive assessment tool to aid policymakers in diverse policy analysis. The new tool is intended to support assessment of energy policies in relation to impacts on the economy, society and environment. The tool is developed in recognition of the needs for Sustainability Assessments—particularly; those relating to polices, to accommodate multilevel, multi-domain and multi-stakeholder complexity.

The study concludes that the SD methodology benefits from its ability to expose 'cause and effect' relationships among system variables [7]. It also helps in our understanding of behaviour patterns and potential consequences [9]; but it is not able to explicitly, deal with evaluation of potential consequences [10]. Therefore, to ensure a transparent evaluation of policy impacts and trade-offs based on stakeholder perspectives, the choice of an appropriate MCE model to combine with SD simulation model remains essential [10].

8.3 Future Work

It is demonstrated in the preceding discussions that: 1) the E-PAT doubles as a systems-thinking model and a multi-criteria evaluation archetype; 2) it is practical for use in assessing policy issues, particularly those relating to energy planning in a national context and 3) it is suitable for evaluation and selection of optimal policy from amongst competing and conflicting alternatives, based on stakeholder perspectives.

Despite these important contributions, there are still some limitations with the E-PAT as currently configured. This means, opportunities to advance further research on the tool still exist. First of all, the focus of the E-PAT in its current form is to deal mainly with issues of energy policy planning in a national context. However, an important question one would reasonably ask is: *"what about the possibility of using the E-PAM for other problems?"* Furthermore, the E-PAM provides a standardised framework for decision making—thereby making the decision-making process more efficient. Yet, it is worth noting that the E-PAM cannot in any way replace the need for human involvement in the decision making process.

We note that the E-PAT framework in itself, only avails policymakers an understanding of the important aspects of the decision, of which some may not have received any attention due to the lack of evidence, and a structured approach to support such understanding—including the future implications. It is essential therefore; that research on development and use of the E-PAT framework continue such as to accomplish at least three important objectives: 1) that other problem areas of interest can be explored with the tool, 2) that stakeholder priorities are always understood, captured and well represented within the framework through active engagements and 3) that other options to better integrate the E-PAM and MCE models be explored.

The need to improve the E-PAT framework from a standpoint of the above three objectives is based on our understanding of what constitutes the key limitations to this study. For example, despite being an integrated tool, the overall focus of the E-PAM as is to mainly deal with the dynamics of the energy sector and the three Sustainability domains: society, economy and environment. However, problems in other areas such as business development, supply chain management, climate change mitigation and adaptation and many others areas can benefit from the use of this tool through future expansion of the framework. To this end, we recommend further work aimed at expanding the development and use of the E-PAT to include diverse areas of interest.

Also, as represented in Section 4.4 of this report, stakeholder engagements occurred during the E-PAM development process. However, their inputs were only received in only two of the seven model development phases. The implication is that stakeholder understanding of the E-PAM mechanisms, might be constrained by limited participation—which in this case, was due to time and financial constraints. Therefore, we recommend more stakeholder engagements in future expansion of the framework, to maximise their input, and enhance their understanding of the process.

It also became apparent in our final review of the E-PAM development that stakeholder involvement in every stage of the model development process is the only way to guarantee that their priorities are clearly understood and adequately represented. As discussed in Chapter 2 of this thesis, the advantages of stakeholder engagements are many. They include the following: 1) stakeholders provide useful information by adding new ideas and insights to the process; 2) stakeholder engagements yield higher-quality output from the process and 3) stakeholder engagements remain the only way to build confidence that their priorities are understood—hence, the needs for their engagements.

List of References

1. Nagel, S.S., ed. *Policy Analysis Methods* 1999, Nova Science Publishers Inc: Commack, New York.

2. Buhrs, T. and R.V. Bartlett, *Environmental Policy in New Zealand: The Politics of Clean and Green?* . 1993, USA: Oxford University Press.

3. Rath-Nagel, S. and A. Voss, *Energy Models for Planning and Policy Assessment.* European Journal of Operational Research, 1981. **8**(2): p. 99-114.

4. Benson, J.F., *What is the Alternative? Impact Assessment Tools and Sustainable Planning.* Impact Assessment and Project Appraisal, 2003. **21**(4): p. 261-280.

5. Millennium Institute. *Integrated Planning Tools: Threshold 21 Model.* 2013 [cited 2013 1st March]; Available from: http://www.millennium-institute.org/integrated_planning/tools/T21/index.html.

6. Bassi, A.M., J.D. Shilling, and H.R. Herren, *Informing the US Energy Policy Debate: How can We Deal with Rising Demand and Constrained Supply*, 2007, Millennium Institute: Arlington VA. p. 65.

7. Forrester, J.W., *Industrial Dynamics*. Vol. 2. 1961, Cambridge, MA: MIT Press

8. Edwards, W., *Social Utilities.* The Engineering Economist, Summer Symposium Series, 1971. **6**: p. 119-129.

9. Sterman, J.D., *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Vol. 19. 2000: Irwin/McGraw-Hill New York.

10. Gardiner, P.C. and A. Ford, *Which Policy Run is Best and Who Says So?*, in *TIMS Studies in the Management Science*, A.A. Legasto, J.W. Forrester, and J.M. Lyncis, Editors. 1980, North-Holland Publishing Company. p. 241-257.

11. United Nations Economic and Social Council, *Sustainable Production, Distribution and Use of Energy: Trends in National Implementation*, in *Commission on Sustainable Development Report of the Ninth Session*2001, Commission on Sustainable Development: New York.

12. Central Bank of Nigeria, *Annual Report and Statement of Accounts*, 2009: Abuja, Nigeria. p. 344.

13. Nigerian National Petroleum Corporation, *The Petroleum Industry Draft Bill 2009*, Federal Ministry of Petroleum Resources, Editor 2009: Abuja, Nigeria. p. 189.

14. Federal Ministry of National Planning, *Vision 20:2020 First Implementation Plan (2010 - 2013)*, 2010: Abuja, Nigeria.

15. Sambo, A.S., et al., *Nigeria's Experience on the Application of IAEA's Energy Models*, in *Exchange of Experience in Using IAEA's Energy Models*2006: Korea Atomic Energy Research Institute, Daejon, Korea.

16. Bassi, A.M. and J.D. Shilling, *Informing the US Energy Policy Debate with Threshold 21.* Technological Forecasting and Social Change, 2010. **77**(3): p. 396-410.

17. Edwards, W., *How to Use Multiattribute Utility Measurement for Social Decisionmaking.* Systems, Man and Cybernetics, IEEE Transactions on, 1977. **7**(5): p. 326-340.

18. Goldman Sachs. *Beyond BRIC - The Next 11*. Reasons to Invest in the Goldman Sachs N-11 Equity Fund 2005 [cited 2013 1st May]; Available from: http://www.goldmansachs.com/gsam/individuals/products/growth_markets/n11/n11-equity-fund/index.html.

19. World Commission on Environment and Development, *Our Common Future*. 1987, Oxford: Oxfrod University Press.

20. Mbasuen, S.T. and P.M. Guthrie, *Peak Oil and Climate Change: How Prepared is Nigeria?*, in *Engineering Department,*2010, University of Cambridge: Cambridge. p. 62.

21. Hotelling, H., *The Economics of Exhausible Resources.* Journal of Poilitical Economics, 1931. **39**: p. 137–175.

22. Malthus, T.R., *An Essay on the Principle of Population*. 1798, London: J. Johnson.

23. Meadows, D.H., et al., *The Limits to Growth*. 1972, New York: Universe Books.

24. Elkington, J., *Cannibals with Folks: The Triple Bottom Line of 21st Century Business*. 1998, London: Capstone.

25. The World Conservation Union, *The Future of Sustainability: Re-thinking Environment and Development in the Twenty-first Century*, W.M. Adams, Editor 2006.

26. International Atomic Energy Agency, *Indicators of Sustainable Energy Development*, in *Progress Report of the International Workshop on CSD Indicators of Sustainable Development*1999: Bridgetown.

27. Seghezzoa, L., *The Five Dimensions of Sustainability.* Environmental Politics, 2009. **18**(4): p. 539 — 556.

28. Barrett, C.B. and R.E. Grizzle, *A Holistic Approach to Sustainability Based on Pluralistic Stewardship.* Environmental Ethics, 1999. **21**: p. 23-42.

29. Bond, A.J. and A. Morrison-Saunders, *Re-evaluating Sustainability Assessment: Aligning the Vision and the Practice.* Environmental Impact Assessment Review, 2011. **31**(1): p. 1-7.

30. George, C., *Testing for Sustainable Development through Environmental Assessment.* Environmental Impact Assessment Review, 1999. **19**(2): p. 175-200.

31. Pearce, D. and J. Warford, *World without End: Economics, Environment, and Sustainable Development.* 1994. **104**(425).

32. Ayres, R.U., J.C.J.M. van den Bergh, and J.M. Gowdy, *Viewpoint: Weak versus Strong Sustainability*. Discussion Paper. 1998, Rotterdam: Tinbergen Institute.

33. Devkota, S.R., *Is Strong Sustainability Operational? An Example from Nepal.* Sustainable Development and Integrated Appraisal in a Developing World, 2005. **13**(5): p. 297.

34. Becker, B., *Sustainability Assessment: A Review of Values, Concepts and Methodological Approaches*. Issues in Agriculture. Vol. 10. 1997, Washington D.C: Consultative Group on International Agriculture Research.

35. Williams, C.C. and A.C. Millington, *The Diverse and Contested Meanings of Sustainable Development.* Geographical Journal, 2004. **170**(2): p. 99-104.

36. Howarth, B.R. *Sustainability and the Fair-Sharing Principle*. Environmental Studies Program, 2007.

37. Carter, N., *The Politics of the Environment*. 2001, Cambridge: Cambridge University Press.

38. Bond, A.J. and A. Morrison-Saunders, *Sustainability Appraisal: Jack of all Trades, Master of None?* Impact Assessment and Project Appraisal, 2009. **27**(4): p. 321-329.

39. Costanza, R., *The Dynamics of the Ecological Footprint Concept.* Ecological Economics, 2000. **32**: p. 341-345.

40. Cashmore, M., *The Role of Science in Environmental Impact Assessment: Process and Procedures versus Purpose in the Development of Theory.* Environmental Impact Assessment Review, 2004. **24**: p. 403-426.

41. Gasparatos, A., M. Mohamed El-Haram, and M. Horner, *The Argument against a Reductionist Approach for Measuring Sustainable Development Performance and the need for Methodological Pluralism.* Accounting Forum, 2009. **33**: p. 245-256.

42. Morrison-Saunders, A. and J. Bailey, *Transparency in Environmental Impact Assessment Decision-making: Recent Developments in Western Australia.* Impact Assessment and Project Appraisal, 2000. **18**: p. 260-270.

43. Govender, K., R. Hounsome, and A. Weaver, *Sustainability Assessment: Dressing up SEA? Experience from South Africa.* Environmental Assessment Policy and Management, 2006. **8**(3): p. 321-340.

44. Pope, J., D. Annandale, and A. Morrison-Saunders, *Conceptualising Sustainability Assessment.* Environmental Impact Assessment Review, 2004. **24**(6): p. 595-616.

45. Ness, B., et al., *Categorising Tools for Sustainability Assessment.* Ecological Economics, 2007. **60**(3): p. 498-508.

46. Singh, R.K., et al., *An Overview of Sustainability Assessment Methodologies.* Ecological Indicators, 2009. **9**(2): p. 189-212.

47. Tamborra, M. *Developing Tools for Sustainability Impact Assessment: The Role of Socioeconomic Research in the EU*. 2011.

48. Gluch, P. and H. Baumann, *The Life Cycle Costing Approach: A Conceptual Discussion of its Usefulness for Environment Decision-making.* Building and Environment, 2004. **39**: p. 571-580.

49. Royal Society of Chemistry, ed. *Sustainable Solution for Modern Economics*. ed. R. Hofer. 2009, RSC Publishing.

50. Azapagic, A. and R. Clift, *Life Cycle Assessment and Multiobjective Optimisation.* Journal of Cleaner Production, 1999. **7**(2): p. 135-143.

51. Hertwich, E.G., *Consumption and the Rebound Effect: An Industrial Ecology Perspective.* Journal of Industrial Ecology, 2005. **9**(1-2): p. 85-98.

52. Jeswani, H.K., et al., *Options for Broadening and Deepening the LCA Approaches.* Journal of Cleaner Production, 2010. **18**(2): p. 120-127.

53. Chee Tahir, A. and R.C. Darton, *The Process Analysis Method of Selecting Indicators to Quantify the Sustainability Performance of a Business Operation.* Journal of Cleaner Production, 2010. **18**(16-17): p. 1598-1607.

54. Odum, H.T., *Environmental Accounting: EMERGY and Decision Making*. 1996, New York: John Wiley.

55. Rant, Z., *Exergy, a New Word for Technical Available Work.* Forsch. Ing. Wis, 1956. **22**(1): p. 36-37.

56. Odum, H.T., ed. *Emergy in Ecosystems*. Environmental Monographs and Symposia, ed. N. Polunin. 1986, John Wiley: New York. 337-369.

57. Odum, H.T., ed. *Energy Analysis of the Environmental Role in Agriculture*. Energy and Agriculture, ed. G. Stanhill. 1984, Springer-Verlag: Berlin. 192.

58. Månsson, B. and J. McGlade, *Ecology, Thermodynamics and HT Odum's Conjectures.* Oecologia, 1993. **93**(4): p. 582-596.

59. Wrisberg, N., et al., *Analytical Tools for Environmental Design and Management in a Systems Perspective: the Combined use of Analytical Tools*. 2002: Kluwer Dordrecht, The Netherlands.

60. Brans, J.P., et al., *Combining Multicriteria Decision Aid and System Dynamics for the Control of Socio-economic Processes. An Iterative Real-time Procedure.* European Journal of Operational Research, 1998. **109**(2): p. 428-441.

61. Hjorth, P. and A. Bagheri, *Navigating Towards Sustainable Development: A System Dynamics Approach.* Futures, 2006. **38**(1): p. 74-92.

62. Beierle, T.C. and J. Cayford, *Democracy in Practice: Public Participation in Environmental Decisions*. 2002: RFF Press.

63. Rotmans, J., *Tools for Integrated Sustainability Assessment: A Two-Track Approach.* The Integrated Assessment Journal, 2006. **6**(4): p. 35–57.

64. Rebitzer, G., et al., *Life Cycle Assessment: Part 1: Framework, Goal and Scope Definition, Inventory Analysis, and Applications.* Environment International, 2004. **30**(5): p. 701-720.

65. Pinfield, G., *Beyond Sustainability Indicators.* Local Environment, 1996. **1**(2): p. 151-163.

66. Bell, S. and S. Morse, *Experiences with Sustainability Indicators and Stakeholder Participation: A Case Study Relating to a 'Blue Plan'Project in Malta.* Sustainable Development, 2004. **12**(1): p. 1-14.

67. Besleme, K. and M. Mullin, *Community Indicators and Healthy Communities.* National Civic Review, 1997. **86**(1): p. 43-52.

68. Meppem, T. and R. Gill, *Planning for Sustainability as a Learning Concept.* Ecological Economics, 1998. **26**(2): p. 121-137.

69. Balkema, A.J., et al., *Indicators for the Sustainability Assessment of Wastewater Treatment Systems.* Urban Water, 2002. **4**(2): p. 153-161.

70. Van der Voet, E., et al., *Predicting Future Emissions based on Characteristics of Stocks.* Ecological Economics, 2002. **41**(2): p. 223-234.

71. Suh, S., *Theory of Materials and Energy Flow Analysis in Ecology and Economics.* Ecological Modelling, 2005. **189**(3): p. 251-269.

72. Bebbington, J., J. Brown, and B. Frame, *Accounting Technologies and Sustainability Assessment Models.* Ecological Economics, 2007. **61**(2-3): p. 224-236.

73. Sinden, J., et al., *The Economic Impact of Weeds in Australia.* Technical Series, 2004. **8**.

74. Pohl, C., *From Science to Policy through Transdisciplinary Research.* Environmental Science & Policy, 2008. **11**(1): p. 46-53.

75. Taeihagh, A., R. Bañares-Alcántara, and C. Millican, *Development of a Novel Framework for the Design of Transport Policies to Achieve Environmental Targets.* Computers & Chemical Engineering, 2009. **33**(10): p. 1531-1545.

76. Bañares-Alcántara, R., *Perspectives on the Potential Roles of Engineers in the Formulation, Implementation and Enforcement of Policies.* Computers & Chemical Engineering, 2010. **34**(3): p. 267-276.

77. Bassi, A.M. and J.S. Yudken, *Climate Policy and Energy-Intensive Manufacturing: A Comprehensive Analysis of the Effectiveness of Cost Mitigation Provisions in the American Energy and Security Act of 2009.* Energy Policy, 2011. **39**(9): p. 4920-4931.

78. Bauer, V., A. Gebert, and J. Meise, *Urban Systems Studies: Report*. 1973: Battelle-Inst.

79. Hammond, K.R., J.L. Mumpower, and T.H. Smith, *Linking Environmental Models with Models of Human Judgment: A Symmetrical Decision Aid.* Systems, Man and Cybernetics, IEEE Transactions on, 1977. **7**(5): p. 358-367.

80. Hammond, K.R., J.K. Klitz, and R.L. Cook, *How Systems Analysts can Provide more Effective Assistance to the Policymaker*. 1978, Laxenburg, Austria: International Institute for Applied Systems Analysis.

81. Mumpower, J., V. Veirs, and K.R. Hammond, *Scientific Information, Social Values, and Policy Formation: The Application of Simulation Models and Judgment Analysis to the Denver Regional Air Pollution Problem.* Systems, Man and Cybernetics, IEEE Transactions on, 1979. **9**(9): p. 464-476.

82. Dennis, R.L., et al., *Integration of Technical and Value Issues in Air Quality Policy Formation: A Case Study.* Socio-Economic Planning Sciences, 1983. **17**(3): p. 95-108.

83. Gruver, W.A., A. Ford, and P.C. Gardiner, *Public Policy Analysis Using Three Systems Science Techniques.* IEEE Transactions on Systems, Man and Cybernetics, 1984. **SMC-14**(2): p. 355-361.

84. Reagan-Cirincione, P., et al., *Decision Modeling: Tools for Strategic Thinking.* Interfaces, 1991. **21**(6): p. 52-65.

85. Andersen, D.F. and J. Rohrbaugh, *Some Conceptual and Technical Problems in Integrating Models of Judgment with Simulation Models.* Systems, Man and Cybernetics, IEEE Transactions on, 1992. **22**(1): p. 21-34.

86. Kunsch, P.L., J. Springael, and J.P. Brans, *An Adaptive Multicriteria Control Methodology in Sustainable Developement-Case Study: a CO2-ecotax.* JORBEL: Belgian Journal of Operations Research, Statistics and Computer Science, 1999. **39**: p. 109-143.

87. Macharis, C., *Hybrid Modeling: System Dynamics combined with Multi-criteria Analysis*, in *International Conference of the System Dynamics Society,*1999.

88. Ventana Systems Inc, *User's Guide: Sensitivity Testing*, in *Vensim Version 5 User's Guide*, Ventana Systems Inc., Editor 2009, Ventana Systems Inc.,: Harvard, MA, USA.

89. Macal, C.M. and M.J. North, *Tutorial on Agent-based Modelling and Simulation.* Journal of Simulation, 2010. **4**(3): p. 151-162.

90. Bonabeau, E., *Agent-based Modeling: Methods and Techniques for Simulating Human Systems.* Proceedings of the National Academy of Sciences of the United States of America, 2002. **99**(Suppl 3): p. 7280-7287.

91. Meadows, D.L., et al., *Dynamics of Growth in a Finite World*. 1974: Wright-Allen Press Cambridge, MA.

92. Buchman, T.A. and J.A. Tracy, *Obtaining Responses to Sensitive Questions: Conventional Questionnaire versus Randomized Response Technique.* Journal of Accounting Research, 1982. **20**(1): p. 263-271.

93. Neuman, W.L., *Social Research Methods: Quantitative and Qualitative Approaches*. 2005: Allyn and Bacon.

94. Johnson, B. and L.A. Turner, *Data Collection Strategies in Mixed Methods Research.* Handbook of Mixed Methods in Social and Behavioral Research, 2003: p. 297-319.

95. Denzin, N.K. and Y.S. Lincoln, *The Sage Handbook of Qualitative Research*. 2005: Sage Publications, Incorporated.

96. Oppenheim and A. Naftali, *Questionnaire Design, Interviewing and Attitude Measurement*. 2000: Continuum.

97. Foddy, W., *Constructing Questions for Interviews and Questionnaires: Theory and Practice in Social Research*. 1994: Cambridge University Press.

98. Presser, S., et al., *Methods for Testing and Evaluating Survey Questions.* Public Opinion Quarterly, 2004. **68**(1): p. 109-130.

99. Cohen, L., L. Manion, and K. Morrison, *Research Methods in Education*. 2000: Routledge.

100. Central Intelligence Agency. *The World Factbook*. Africa:Nigeria 2010 [cited 2010 15th December]; Available from: https://www.cia.gov/library/publications/the-world-factbook/geos/countrytemplate_ni.html.

101. Central Intelligence Agency. *The World Factbook, Country Comparison: Population*. 2010 [cited 2011 14 January]; Available from: https://www.cia.gov/library/publications/the-world-factbook/rankorder/2119rank.html.

102. United Nations Development Programme, *UNDP Human Development Report*, 2010: Washington D.C. p. 238.

103. United Nations, *World Population Prospects: The 2010 Revision*, 2011, Department of Economic and Social Affairs, Population Division.

104. Wikipedia. *Population Density Map of Nigerian States - English*. 2013 [cited 2013 14th February]; Available from: http://en.wikipedia.org/wiki/File:Population_density_map_of_Nigerian_states_-_English.png.

105. Trading Economics. *Nigeria Unemployment Rate*. 2013 [cited 2013 14th February]; Available from: http://www.tradingeconomics.com/nigeria/unemployment-rate.

106. Central Bank of Nigeria, *Annual Report and Statement of Accounts*, 2010: Abuja, Nigeria.

107. National Bureau of Statistics, *Statistical News: Labour Force Statistics*, 2010: Abuja, Nigeria. p. 13.

108. United Nations Children's Fund. *Nigeria: Education*. 2005 [cited 2013 14th February]; Available from: http://www.unicef.org/nigeria/children_1937.html.

109. International Bank for Reconstruction and Development/The World Bank Group, *Africa Development Indicators 2010*, 2010: Washington, DC. p. 45.

110. World Bank, *Country Factsheet: Nigeria*, 2009, The World Bank Group: Washington, DC.

111. International Monetary Fund, *IMF Annual Report 2010: Supporting a Balanced Global Recovery*, in *International Development,*2010: Washington, DC. p. 84.

112. National Bureau of Statistics, *Statistical News: Trade Statisticsc*, 2010: Abuja, Nigeria. p. 10.

113. National Planning Commission, *Nigeria Vision 20: 2020*, NPC Economic Planning, Editor 2010, National Planning Commission: Abuja. p. 250.

114. Sambo, A.S., *Renewable Energy For Rural Development : The Nigerian Perspective.* ISESCO Science and Technology Vision, 2005. **1**: p. 12-22.

115. United Nations Conference on Trade and Development, *World Investment Report 2010*. 20th Anniversary ed. Investing in a Low-Carbon Economy. 2010, Newyork and Geneva: United Nations. 220.

116. World Resource Institute. *Climate, Energy and Transport*. 2013 [cited 2013 14th February]; Available from: http://www.wri.org/publications/climate.

117. US Energy Information Administration. *Country Analysis Briefs: Nigeria*. 2010 [cited 2010 17th December]; Available from: http://www.eia.doe.gov/emeu/cabs/Nigeria/Background.html.

118. National Bureau of Statistics. *Nigeria Environmental Statistics*. 2007; Available from: http://www.nigerianstat.gov.ng/.

119. Ajaero, C.K. and A.T. Mozie. *The Agulu-Nanka Gully Erosion Menace in Nigeria : What does the Future Hold for Population at Risk?* 2008 [cited 2012 5th May]; 1-22]. Available from: http://www.ehs.unu.edu/file/get/5395.

120. Nwilo, P.C., et al., *An Assessment and Mapping of Gully Erosion Hazards in Abia State: A GIS Approach.* Journal of Sustainable Development, 2011. **4**(5): p. 16.

121. Food and Agriculture Organisation of the United Nations, *Workshop on Tropical Secondary Forest Management in Africa: Reality and Perspectives*, 2002, FAO: Nairobi, Kenya.

122. National Petroleum Investment Management Services. *Crude Oil Reserves and Production*. 2010 [cited 2010 17th December]; Available from: http://www.napims.com/crude.html.

123. Energy Commission of Nigeria, *National Energy Policy*, The Presidency, Editor 2003, Energy Commission of Nigeria: Abuja, Nigeria. p. 89.

124. Sambo, A.S., *Matching Electricity Supply with Demand in Nigeria.* 2008: p. 32-36.

125. Sambo, A.S., *The Challenges of Sustainable Energy Development in Nigeria*, in *Nigerian Society of Engineers Forum,*2009: Shehu Yar'Adua Centre, Abuja. p. 39.

126. Sambo, A.S., *Prospects of Coal for Power Generation in Nigeria*, in *International Workshop on Promotion of Coal for Power Generation*2009: Nike Lake Resort Hotel, Enugu State, Nigeria. p. 46.

127. Dayo, F.B., *Clean Energy Investment in Nigeria: The Domestic Context*, in *A Country Case Study Completed for IISD's Clean Energy Investment Project*2008, International Institute for Sustainable Development: Manitoba, Canada. p. 110.

128. Nigerian National Petroleum Corporation, *NNPC Annual Statistical Bulletin*, in *Annual Bulletin*2009, Corporate Planning and Strategy Division: Abuja, Nigeria. p. 68.

129. US Energy Information Administration. *International World Energy Data and Analysis*. 2010 [cited 2010 16th December]; Available from: http://www.eia.doe.gov/oiaf/aeo/index.html.

130. Okoro, O.I., P. Govender, and E. Chikuni. *Power Sector Reforms in Nigeria: Opportunities and Challenges*. 2006 [cited 2011 28th August]; Available from: http://active.cput.ac.za/energy/web/due/papers/2006/O%20Okoro1.pdf.

131. Sambo, A.S., *Renewable Energy Policy and Regulation in Nigeria*, in *International Renewable Energy Conference,*2008: Rockview Hotel, Abuja, Nigeria. p. 35.

132. Sambo, A.S., *Renewable Energy Options for the Environment and Sustainable Development in Nigeria*, in *National Workshop on Energy Investment and Private Sector Participation,*2008: Petroleum Training Institute, Warri, Delta State, Nigeria. p. 41.

133. Sambo, A.S., *Energy Commission of Nigeria: Achievements so Far, Challenges and the Way Forward*, 2009: Abuja, Nigeria.

134. Mbasuen, S.T. and R.C. Darton. *Application of System Dynamics as a Policy Evaluation Tool: The Nigerian Perspective*. in *The 30th International Conference of the System Dynamics Society*. 2012. St. Gallen, Switzerland: System Dynamics Society.

135. UNDP, UNDESA, and WEC, *World Energy Assessment-Energy and the Challenge of Sustainability.* United Nations Development Programme, New York, 2000.

136. US Energy Information Administration. *Country Analysis Briefs: Nigeria*. 2011 23rd March 2011 [cited 2011 23rd March]; Available from: http://tonto.eia.doe.gov/countries/cab.cfm?fips=NI.

137. British Petroleum. *BP Energy Outlook 2030*. 2011 [cited 2013 28th February]; Available from: http://www.bp.com/sectiongenericarticle800.do?categoryId=9037130&contentId=7068669.

138. Mbasuen, S.T. and R.C. Darton. *The Transition to an Energy Sufficient Economy*. in *3rd Student Conference on Operational Research, SCOR 2012*. 2012. Nottingham, UK: Schloss Dagstuhl.

139. World Bank, *Energy and Mining Report*, 2010, The World Bank Group: Washington, DC.

140. Forrester, J.W., *System Dynamics, Systems Thinking, and Soft OR.* System Dynamics Review, 1994. **10**(2-3): p. 245-256.

141. Schwaninger, M., S. Ulli-Beer, and R. Kaufmann-Hayoz, *Policy Analysis and Design in Local Public Management: A System Dynamics Approach*, in *Handbook of Transdisciplinary Research*. 2008, Springer. p. 205-221.

142. Heckman, J.J., *Dummy Endogenous Variables in a Simultaneous Equation System*, 1977, National Bureau of Economic Research Cambridge, Mass., USA.

143. Bassi, A.M., *Evaluating the Use of an Integrated Approach to Support Energy and Climate Policy Formulation and Evaluation.* Energies, 2010. **3**(9): p. 1604-1621.

144. Bassi, A.M. and A.E. Baer, *Quantifying Cross-sectoral Impacts of Investments in Climate Change Mitigation in Ecuador.* Energy for Sustainable Development, 2009. **13**(2): p. 116-123.

145. Forrester, J.W. and P.M. Senge, *Tests for Building Confidence in System Dynamics Models*. 1978: System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology.

146. Abdel-Hamid, T.K., *The Dynamics of Software Development Project Management: An Integrative System Dynamics Perspective*, 1984, Massachusetts Institute of Technology.

147. Cooksey, R.W., *What is Complexity Science? A Contextually Grounded Tapestry of Systemic Dynamism, Paradigm Diversity, Theoretical Eclecticism.* Emergence, A Journal of Complexity Issues in Organizations and Management, 2001. **3**(1): p. 77-103.

148. Osorio, L.A.R., M.O. Lobato, and X.A. Del Castillo, *Debates on Sustainable Development: Towards a Holistic View of Reality.* Environment, Development and Sustainability, 2005. **7**(4): p. 501-518.

149. Radzicki, M. and R. Taylor, *Introduction to System Dynamics: a Systems Approach to Understanding Complex Policy Issues.* US Department of Energy's, 1997.

150. Keeney, R.L. and H. Raiffa, *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. 1976, New York: Wiley.

151. Keeney, R.L., *Utility Functions for Multiattributed Consequences.* Management Science, 1972. **18**(5): p. 276-287.

152. Raiffa, H., *Decision Analysis: Introductory Lectures on Choices Under Uncertainty* 1986, Reading, MA: Addison-Wesley.

153. Kirkwood, C.W., *System Dynamics Methods: A Quick Introduction*, 2001, College of Business, Arizona State University. p. 124.

154. Greenberger, M., M.A. Crenson, and B.L. Crissey, *Models in the Policy Process: Public Decision Making in the Computer Era*. 1976: Russell Sage Foundation New York.

155. Oreskes, N., K. Shrader-Frechette, and K. Belitz, *Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences.* Science, 1994. **263**(5147): p. 641-646.

156. Mbasuen, S.T. and R.C. Darton, *Renewable Energy Resources and the Challenges of Decentralised Energy Options in Developing Countries: A Case Study of Nigeria*, in *DocLinks-Commonwealth African European Residential School: "Post COP 17: Climate Change and Livelihoods in Africa"*2012: Gabrone, Botswana.

157. World Bank, *World Development Report 2010: Development and Climate Change*, 2010, The World Bank Group: Washington, DC.

158. British Petroleum, *BP Statistical Review of World Energy.* 2010: p. 50.

159. World Energy Council, ed. *2010 Survey of Energy Resources*. ed. J. Trinnaman and A. Clarke. 2010: London. 618.

160. Ministry of Mines and Steel Development. *The Changing Face of Nigeria's Mining Sector*. 2013 [cited 2013 16th May]; Available from: http://mmsd.gov.ng/publications/publications.asp.

161. Sambo, A.S., *Renewable Energy Electricity in Nigeria: The Way Forward*, in *Renewable Electricity Policy Conference,*2006: Shehu Musa Yar'adua Centre, Abuja, Nigeria. p. 42.

162. Sambo, A.S., *The Place of Renewable Energy in the Nigerian Energy Sector*, in *The World Future Council Workshop on Renewable Energy Policies,*2009: Addis Ababa, Ethiopia.

163. Sambo, A.S., *Creating Enabling Environment for Energy Efficiency and Conservation Programmes in Nigeria*, in *WEC-AFRICA Forum on Energy Efficiency,*2007: Transcop Hilton Hotel, Abuja, Nigeria. p. 19.

164. US Energy Information Administration, *International Energy Outlook 2010*, 2010: Washington, DC. p. 338.

165. National Bureau of Statistics, *Social Statistics in Nigeria*, 2009: Abuja, Nigeria. p. 418.

166. Energy Futures Lab-Imperial College London. *What is Sustainable Energy*. The Difference between Renewable and Sustainable Energy, 2013 [cited 2013 1st

May]; Available from: http://www3.imperial.ac.uk/energyfutureslab/about/sustainableenergy.

167. Oxford Future Energy. *Smart Metering*. 2013 [cited 2013 1st May]; Available from: http://www.futureenergy.ox.ac.uk/research/smart-metering.

168. World Energy Council, *Deciding the Future: Energy Policy Scenarios to 2050*. 2007, London: World Energy Council. 104.

169. Asia Pacific Energy Research Centre, *A Quest for Energy Security in the 21st Century*, A.A. Aponte, Editor 2007: Japan.

170. International Energy Agency, *World Energy Outlook 2007 Edition*, 2007, International Energy Agency (IEA): Paris. p. 674.

171. Kruyt, B., et al., *Indicators for Energy Security.* Energy Policy, 2009. **37**.

172. International Energy Agency, *Energy Technology Analysis:CO2 Capture and Storage-a Key Carbon Abatement Option*. 2008, Paris: IEA.

173. United Nations Framework Convention on Climate Change. *Current Evidence of Climate Change*. 2011 [cited 2011 13th April]; Available from: http://unfccc.int/essential_background/feeling_the_heat/items/2904.php.

174. Jefferson, M., *Sustainable Energy Development: Performance and Prospects.* Renewable Energy, 2006. **31**(5): p. 571-582.

175. Soytas, U. and R. Sari, *Energy Consumption, Economic Growth, and Carbon Emissions: Challenges Faced by an EU Candidate Member.* Ecological Economics, 2009. **68**(6): p. 1667-1675.

176. Turton, H. and L. Barreto, *Long-Term Security of Energy Supply and Climate Change.* Energy Policy, 2006. **34**(15): p. 2232-2250.

177. Cox, P.M., et al., *Acceleration of Global Warming due to Carbon-Cycle Feedbacks in a Coupled Climate Model.* Nature, 2000. **408**(6809): p. 184-187.

178. Scheffer, M., V. Brovkin, and P.M. Cox, *Positive Feedback between Global Warming and Atmospheric CO2 Concentration Inferred from Past Climate Change.* Geophysical Research Letters, 2006. **33**(10).

179. Lashof, D.A. and D.R. Ahuja, *Relative Contributions of Greenhouse Gas Emissions to Global Warming.* 1990.

180. NASA Earth Observatory. *Temperature Anomaly*. Global Temperatures (1880 - 2009) 2013 [cited 2013 1st May]; Available from: http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php.

181. International Energy Agency, *World Energy Outlook*, 2006: Paris.

182. Kramer, P.J., *Carbon dioxide Concentration, Photosynthesis, and Dry Matter Production.* BioScience, 1981: p. 29-33.

183. Manabe, S. and R.J. Stouffer, *Sensitivity of a Global Climate Model to an Increase of CO2 Concentration in the Atmosphere.* Journal of Geophysical Research: Oceans (1978–2012), 1980. **85**(C10): p. 5529-5554.

184. Walker, J.C., P. Hays, and J.F. Kasting, *A Negative Feedback Mechanism for the Long-term Stabilization of Earth's Surface Temperature.* Journal of Geophysical Research: Oceans (1978–2012), 1981. **86**(C10): p. 9776-9782.

185. Cane, M.A., et al., *Twentieth-Century Sea Surface Temperature Trends.* Science, 1997. **275**(5302): p. 957-960.

186. Lean, J.L. and D.H. Rind, *How will Earth's Surface Temperature Change in Future Decades?* Geophysical Research Letters, 2009. **36**(15): p. L15708.

187. Choi, K.-H. and B.W. Ang, *A Time-Series Analysis of Energy-Related Carbon Emissions in Korea.* Energy Policy, 2001. **29**(13): p. 1155-1161.

188. Zhang, X.-P. and X.-M. Cheng, *Energy Consumption, Carbon Emissions, and Economic Growth in China.* Ecological Economics, 2009. **68**(10): p. 2706-2712.

189. Bond, T.C., et al., *Historical Emissions of Black and Organic Carbon Aerosol from Energy-related Combustion, 1850–2000.* Global Biogeochemical Cycles, 2007. **21**(2).

190. Schipper, L., L. Scholl, and L. Price, *Energy Use and Carbon Emissions from Freight in 10 Industrialized Countries: An Analysis of Trends from 1973 to 1992.* Transportation Research Part D: Transport and Environment, 1997. **2**(1): p. 57-76.

191. Petroleum Products Pricing Regulatory Agency. *PPPRA Product Pricing Template*. 2012 [cited 2013 1st May]; Available from: http://www.pppra-nigeria.org/pms.htm.

192. Moyo, N. and V. Songwe *Removal of Fuel Subsidies in Nigeria: An Economic Necessity and a Political Dilemma*. Global Economy and Development, 2012.

193. International Monetary Fund, *Case Studies on Energy Reform: Lessons and Implications*, 2013, IMF: Washington, DC. p. 118.

194. Kolo, A. *World Bank: Nigeria Should Divert Fuel Subsidy Funds To Poor People*. The Herald-Business 2013 [cited 2013 1st May]; Available from: http://www.theheraldng.com/world-bank-nigeria-should-divert-fuel-subsidy-funds-to-poor-people/.

195. Ogbu, O. *Toward Inclusive Growth in Nigeria*. Global Views, 2012. **2012-03**, 7.

196. Energy Saving Trust. *Solar Panels (PV): Costs, Savings and Maintenence*. 2013 [cited 2013 23rd April]; Available from: http://www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Solar-panels-PV.

197. ENVIKO Renewable Energy Solutions. *Wind Costs and Outputs*. 2013 [cited 2013 23rd April]; Available from: http://www.enviko.com/technology/wind-turbines/wind-turbine-costs-and-outputs.

198. Burton, T., et al., *Wind Energy Handbook*. 2011: Wiley.

199. Dawes, R.M. and B. Corrigan, *Linear Models in Decision Making.* Psychological Bulletin, 1974. **81**(2): p. 95.

200. Einhorn, H.J. and R.M. Hogarth, *Unit Weighting Schemes for Decision Making.* Organizational Behavior and Human Performance, 1975. **13**(2): p. 171-192.

201. Wilks, S.S., *Weighting Systems for Linear Functions of Correlated Variables when there is no Dependent Variable.* Psychometrika, 1938. **3**(1): p. 23-40.

202. Codd, E.F. *Normalized Data Base Structure: A Brief Tutorial*. in *Proceedings of the 1971 ACM SIGFIDET (now SIGMOD) Workshop on Data Description, Access and Control*. 1971. ACM.

203. Codd, E., *A Relational Model of Data for Large Shared Data Banks. 1970.* MD Computing: Computers in Medical Practice, 1998. **15**(3): p. 162.

204. Stewart, T.R., *Judgment Analysis: Procedures.* Human Judgment: The SJT View, 1988: p. 41-74.

205. Adaramola, M.S. and O.M. Oyewola, *On Wind Speed Pattern and Energy Potential in Nigeria.* Energy Policy, 2011. **39**(5): p. 2501-2506.

206. ZARMA, I.H., *Hydro Power Resources in Nigeria*, in *International Centre on Small Hydro Power (IC-SHP),*2006, Energy Commission of Nigeria: Hangzhou, China. p. 17.

207. Society of Petroleum Engineers. *Unit Conversion Factors*. 2013 [cited 2013 18th June]; Available from: http://www.spe.org/industry/docs/UnitConversion.pdf.

Appendix A

Major Sources of Research Data

A.1 National Data Sources

	INSTITUTION	DATA TYPE/SOURCE
1	Central Bank of Nigeria (CBN)	Secondary/online database
2	Energy Commission of Nigeria (ECN)	Primary/fieldwork data
3	Federal Ministry of Environment (FME)	Primary/fieldwork data
4	Ministry of Mines and Steel Development (MMSD)	Secondary/online database
5	Ministry of Petroleum Resources (MPR)	Primary/fieldwork data
6	National Bureau of Statistics (NBS)	Secondary/online database
7	National Planning Commission (NPC)	Primary/fieldwork data
8	Nigerian National Petroleum Corporation (NNPC)	Primary/fieldwork data
9	Petroleum Products Pricing Regulatory Agency (PPPRA)	Secondary/online database

A.2 International Data Sources

	INSTITUTION	DATA TYPE/SOURCE
1	British Petroleum Plc (BP)	Secondary/online database
2	Central Intelligence Agency (CIA)	Secondary/online database
3	Food and Agriculture Organisation of the UN (FAO)	Secondary/online database
4	International Atomic Energy Agency (IAEA)	Secondary/online database
5	International Energy Agency (IEA)	Secondary/online database
6	International Monetary Fund (IMF)	Secondary/online database
7	Millennium Institute (MI)	Secondary/online database
8	The World Bank Group (WB)	Secondary/online database
9	UN Department of Social Affairs (UNDESA)	Secondary/online database
10	United Nations Development Programme (UNDP)	Secondary/online database
11	US Energy Information Administration (EIA)	Secondary/online database
12	World Resource Institute (WRI)	Secondary/online database

Appendix B

Data Collection Instrument: Questionnaire

Research on Development of an Energy Policy Assessment Model (E-PAM)

Dear Respondent,

I am a doctoral researcher in Engineering Science at University of Oxford, England. In my study, I am developing a computer-based model to aid policy analysis in diverse settings. The tool aims to support a structured approach to policy planning and evaluation and decision making in Nigeria. Part of the overall research aim is to use the tool to evaluate government policies for Sustainable Energy Development in Nigeria, and to assess the impacts of energy usage in specific sectors within the three Sustainability domains: *society*, *economy* and *environment*. Your comments are highly valuable in enhancing the study, and I do hope you will provide your candid opinion to the simple questions provided below. Thank you for your time and efforts in supporting the research (***it is very helpful if you answer all the questions***).

Please state your: **organisation**: ----------------------------------**position**:----------------------------

SECTION A: ENERGY SECTOR

A1) What is your level of **satisfaction** with the current progress in energy development in Nigeria (for both oil and gas and the power sector)?

Oil and gas: Very satisfied ☐ Somewhat satisfied ☐ Not at all satisfied ☐

Power sector: Very satisfied ☐ Somewhat satisfied ☐ Not at all satisfied ☐

A2) Please, mention any **4 factors**, in your opinion are the **major barriers** to Sustainable Energy Development in Nigeria.

I:---

II:--

III:---

VI:--

A3a) Are there any government policy plans and targets to develop **renewable energy** sources in the country by year 2025?

Yes ☐ **No** (Go to QA5) ☐

A3b) If yes, what is the government's **objective** in promoting the use of renewable energy technologies in the country?

Increase power from Grid ☐ **Decentralise rural electrification** ☐

Other objectives ☐ (*please state*):---

A4) If pursued, what do you consider the most realistic **target** annual **capacity growth** for solar, wind, small hydro, and biomass to year 2025?

Solar: 0-4% ☐ 5-9% ☐ >9% ☐

Wind: 0-4% ☐ 5-9% ☐ >9% ☐

Hydro: 0-4% ☐ 5-9% ☐ >9% ☐

Biomass: 0-4% ☐ 5-9% ☐ >9% ☐

A5) Nigeria has huge reserves of **coal** and **tar sands** that are currently untapped. What share of the **total primary energy supply** do you think these might take by year 2025?

Coal: None ☐ 5%-10% ☐ 10%-30% ☐ >30% ☐

Tar sands: None ☐ 5%-10% ☐ 10%-30% ☐ >30% ☐

SECTION B: ECONOMIC DOMAIN

B1) Nigeria's GDP growth is currently (*at end of 2011*) 7%, what is your expected **annual growth** to year 2025 for **optimistic** and **pessimistic** growth scenarios?

Optimistic (high growth): 5% - 7% ☐ 7% - 12% ☐ >12% ☐

Pessimistic (low growth): 2.5% - 5% ☐ 5% - 7% ☐ >7% ☐

B2) Which of these **economic sectors** are you expecting to contribute most to **real GDP growth** by year 2025?

Agriculture ☐ **Oil & gas** ☐ **Other industries** ☐ **Services** ☐

B3) According to IMF (2012) and Central Bank of Nigeria-CBN (2011), the oil sector currently accounts for over 95% of exports earnings, more than 50% of government revenue and less than 20% of GDP. In your opinion, what are **two major barriers** that **constrict GDP** contribution from oil sector?

(i):---**(ii):**---

B4) Nigeria as the world's 7th oil exporter (as at 2010), also imports more than 50% of its daily fuel needs CBN (2010). What do you think are the **chief economic factors** responsible for this anomaly? (*Please mention only three*).

(i) :----------------------------------**(ii):**----------------------------**(iii)**------------------------------

B5) Over what timescale do you foresee a **definite turnaround** in the Nigerian **energy economy situation**, such that at least 85% of the energy requirements will be met in-country as opposed to importation?

10 years' time ☐ **20 years' time** ☐ **Beyond 30 years' time** ☐

SECTION C: SOCIAL DOMAIN

C1) How do you see the **population structure** of Nigeria over the following timescales?

Year 2025: Rising population ☐ Steady population ☐ Declining population ☐

Year 2040: Rising population ☐ Steady population ☐ Declining population ☐

Beyond 2040: Rising population ☐ Steady population ☐ Declining population ☐

C2) The Central Bank of Nigeria in 2011 reported that **labour supply** in the country is significantly higher than **labour demand** (particularly for the youths). However, different official sources report different figures for **unemployment rate.** What do you think is the current **unemployment level** in the country?

15 – 25% ☐ **25 – 35%** ☐ **>35%** ☐

C3) When do you anticipate **single digit unemployment** in Nigeria?

Year 2020 ☐ **Year 2025** ☐ **Beyond 2030** ☐

C4) Statistics from the World Bank (2010) has shown a systematic rise in **school dropout rates** from primary to tertiary institutions in Nigeria. What do you think are the **major causes**?

(i):------------------------------**(ii):**---------------------------**(iii):**--------------------------------

C5) It is evident from different official sources CBN (2010), NBS (2010) that there are significantly more Nigerian graduates in **arts and commercial** subjects than in **science and engineering** courses. What do you think are the **main reasons** for this phenomenon?

(i) :--------------------------------**(ii) :**-----------------------------**(iii):**------------------------

---

SECTION D: ENVIRONMENT DOMAIN

D1a) Do you believe climate change (CC) is a **threat** to Nigeria?

Yes ☐ **No** ☐ **Not sure** ☐

D1b) If yes, what is your **level of satisfaction** to government's current responses to climate change issues in Nigeria and globally?

Quite satisfied ☐ **Slightly satisfied** ☐ **Not satisfied** ☐

D2) According to the UNFCCC (2011), Nigeria is among the developing countries facing **severe climate change threats**. Based on your knowledge of climate change in Nigeria, which of these **strategies** do you expect government to focus more in combating CC impacts in Nigeria?

Mitigation strategies ☐ **Adaptation strategies** ☐ **Both** ☐

D3) **Gas flare** and **oil spill** remain some of the major environmental challenges in Nigeria, particularly in the Southern oil and gas producing regions. What **environmental improvement measures** do you suggest in these contexts?

Gas flaring: **(i):**--------------------------------------**(ii):**---

Oil spills: **(i):**---**(ii):**--

D4) In the far arid Northern part of the country, **desert encroachment** is threatening sustainable agriculture, causing loss of arable land at the rate of about 6 km^2 per year. In your opinion, what **actions** should government take to achieve the following?

Combat desertification: **(i) :**-------------------------------------**(ii):**----------------------------

Restore soil fertility: **(i) :**---**(ii):**----------------------------

D5a) Are you anticipating any **shortage to water supply** in the country in the near future?

Yes, by 2030 ☐ **Yes, by 2050** ☐ **No, things will normalise** ☐

D5b) If yes, what do you think are the **major factors** likely to trigger water security challenges in the country within the time scale chosen?

(i) :--------------------------------**(ii) :**-----------------------------**(iii) :**-------------------------

SECTION E: THE POLICY/DECISION SUPPORT TOOL

E1) Do you think the use of structured **policy support tools** is relevant and useful to your ministry?

Very relevant/useful ☐ **Somewhat relevant/useful** ☐ **Not relevant/useful** ☐

You have been shown a System Dynamics-based model developed to serve as a structured policy planning and evaluation tool, to support informed decision making process in specified sectors in Nigeria.

E2) Did you understand the information the **structure** and **output** of the model conveyed?

Fully understood ☐ **Slightly understood** ☐ **Did not understand** ☐

E3) Does the **model** include issues that are **relevant** and of **interest** to you or your organisation?

Very much agree ☐ **Somewhat agree** ☐ **Don't agree** ☐

E4) If made available, are you **willing** to use this **tool or similar tool** to support policy planning and evaluation in your ministry?

Very willing ☐ **Slightly willing** ☐ **Not willing** ☐

E5) Please, state any other **opinions** or any **suggestions** on issues you feel relevant to improve the model.

I:---

II:--

III:---

Thank you once again, for your time to take part in this study.

Appendix C

Detail Calculations for Renewable Energy Potential

C.1 Calculations for Biomass Potential

Biomass production in Nigeria is consistent with the spread of natural vegetation cover and agricultural practice. Major biomass sources are fuel wood, crop residue and animal 'waste'. These are predominantly found in the Southern, Central and Northern parts of Nigeria respectively.

FUELWOOD ESTIMATION

Fuel wood potential in Nigeria for *"sustainable"* and *"unsustainable"* wood harvesting is estimated based on the following considerations:

- Estimated Forest Area (A) of 11 x 10^6 (ha).
- Mean Stock Density (D) of 40 (m^3/ha), which is the average total volume of wood.
- Mean Annual Increment (MAI) of 2.5% of forest stock density, which is the total increase in volume of wood per hectare per year (i.e. m^3/ha/yr).
- Allowable Cut (AC) of 50 (m^3/ha/year) or 0.5, which is the amount of wood that can be harvested annually per hectare.
- Accessible Area Fraction (AF) of 80% or 0.8, which is the share of forest area accessible for wood exploitation.
- Fuel wood Fraction (FF) of 100% or 1.0, which is the share of wood volume destined for wood fuel production.
- Harvest Fraction (HF) of 90% or 0.9, which is the volume of harvested wood, after deduction of percentage losses (which is about 10% of the Allowable Cut).

Source: [103, 154]; Author's Computations.

Therefore, for clear felling of wood, which we assume here to be 100% accessibility to forest, volume (v) of Fuel Wood Harvest (FWH) in (m^3) can be determined as follows:

FWH = A x D x FF x HF **(8)**

► FWH = 11 x 10^6 x 40 x 1.0 x 0.9 = 396 x 10^6 m^3

Assuming wood density (specific mass-ρ) of 750 kg/m^3

► Mass (m) of wood harvested in (kg) = ρ x v = 750 x (396 x 10^6) = 2.97 x 10^{11} kg

(1000 kg = 1 tonne)

► 2.97 x 10^{11} kg = 297 x 10^6 tonnes or **297 Mt** of fuel wood per year, which is unsustainable harvesting.

For sustainable harvesting, volume of Fuel Wood Harvest (FWH) per year in (m^3) can be determined as follows:

FWH = A x AC x AF x FF x HF **(9)**

► FWH = 11 x 10^6 x 0.5 x 0.8 x 1.0 x 0.9 = 396 x 10^4 m^3

At 750 kg/m^3 specific mass:

► Mass of wood harvested = 750 x (396 x 10^4) = 297 x 10^7 kg

► 297 x 10^7 kg = 297 x 10^4 tonnes/year or **2.97 Mt/year** of fuel wood harvested per year, which is assumed to be sustainable harvesting.

AGRIC RESIDUE ESTIMATION

Estimation for agric. residue as a source of biomass is based on the following considerations:

- Estimated Land Area (LA) of 72 million hectares (Mha) of arable land for crop production.
- Average annual agric. residue production (ARP) of 4.5 tonnes per hectare of land use.
- Average moisture content (AMC) of 25%

Source: [103, 154]; Author's Computations.

This implies that total Average Agric. Residue (AAR) produced per year will be:

AAR = LA x ARP x AMC **(10)**

► AAR = 72 x 10^6 x 4.5 x 0.25 = 81 x 10^6 tonnes or 81 Mt of total agric. residue per year. If only 80% of total agric. residue is destined for biomass use:

► AAR = 81 x 10^6 x 0.8 = 64.8 x 10^6 tonnes/year or approximately **65 Mt/year** of agric. residue used as biomass.

ANIMAL WASTE ESTIMATION

Estimation for animal waste as a source of biomass is based on the following considerations:

- Estimated 211 x 10^6 total assorted animals (TAA).
- 25 kg of waste produced per day (WPPD).
- Waste is produced over only 50% of the year.
- Only 5% of the animal waste is collected (AWC) for use as biomass.

Source: [103, 154]; Author's Computations.

Therefore, total Annual Animal Waste Production is calculated as:

AAWP = TTA x (WPPD (kg)/1000) x (365/2) x AWC **(11)**

► AAWP = 211 x 10^6 x (25/1000) x 182.5 x 0.05 = 211 x 10^6 x 0.025 x 182.5 x 0.05

► AAWP = 48.1 x 10^6 tonnes/year or approximately **50 Mt/year** of animal waste used as biomass.

Hence, annual total biomass production in the country in this case is the summation of fuel wood production, agric. residue production and animal waste production.

► Annual Total Biomass Production = 2.97 + 65 + 50 = 117.97 ≈ **118 Mt/year**

C.2 Calculations for Wind Potential

Wind energy potential is estimated using the following parameters:

- Estimated 2.0 m/s wind speed in the coastal region of Southern Nigeria.
- Estimated 4.0 m/s wind speed in the arid far Northern part of the country.
- Air density (ρ) of 1.1 kg/m^3 above sea level.
- Wind speed probability (σ) of 12%.
- Only 0.1% of Nigeria's area of (923,768 km^2) is available as total swept area.
- 60% of Betz theoretical limit of (59.3%) for turbine efficiency (η).

Source: [205]; Author's Computations.

These imply that:

Average national wind speed (V) = 3 m/s

Wind energy intensity perpendicular to wind direction = 4.4 W/m^2 and 35.2 W/m^2 in the coast and arid regions respectively.

Power (P) in (Watts) extracted by turbine from moving wind is given by:

$$\mathbf{P_w = (\tfrac{1}{2}\rho A V^3) \times \eta \times \sigma} \qquad \mathbf{(12)}$$

► $P_w = \frac{1}{2} \times 1.1\ (kg/m^3) \times 923.768\ (km^2) \times (3)^3\ (m/s) \times 0.3558 \times 0.12$

► $P_w = 0.5 \times 1.1\ (kg/m^3) \times 9.24 \times 10^8\ (m^2) \times 27\ (m/s) \times 0.3558 \times 0.12 = 5.86 \times 10^8$ W.

► P_w = 585.8 MW, or approximately **600 MW** of wind power can be harnessed in the country per year.

C.3 Calculations for Solar Potential

Solar energy potential is estimated using the following parameters:

- Estimated mean annual total solar radiation of 3.5 $kWh/m^2/day$ in the coastal, Southern regions.
- Estimated mean annual total solar radiation of 7.5 $kWh/m^2/day$ in the arid, Northern areas.
- Only 1% of Nigeria's area of (923,768 km^2) is used to build solar collectors.
- Assuming 10% efficiency for solar photovoltaics.

Source: [111]; Author's Computations.

These imply that:

Average national solar radiation R_s = 5.5 $kWh/m^2/day$.

► $R_s = 5.5 \times 10^{-3}$ MWh/m^2/day

► $R_s = 5.5 \times 10^{-3}$ (MWh) x (9.24×10^9) (m^2) x 365 x (10/100)

► $R_s = 5.5 \times 10^{-3}$ (MWh) x (9.24×10^9) (m^2) x 365 x 0.1 = 1.85×10^9 MWh.

► $R_s = 1850 \times 10^3$ GWh or approximately 2000 GWh of solar electricity per year.

C.4 Calculations for Hydro Potential

- Hydro is already an established form of renewable energy in Nigeria.
- Hydropower is used in the country primarily for electricity generation, based on commissioned large conventional hydroelectric dams.

C.4$_1$ Commissioned (Large) Hydroelectric Schemes

LOCATION/TYPE	INSTALLED CAPACITY (MW)	COMMSSIONED DATE
Kainji-dam	760	1968
Jebba-dam	570	1984
Shiroro-dam	600	1990

Source: [206].

- Additional hydro potential for Nigeria is estimated in this study; it is evaluated by its available power $\mathbf{P_h}$ (Watt), which is a function of hydraulic head **H** (meters)—the energy per unit weight and the rate of fluid flow **Q** (cubic metre/second). This is based on existing identified large/small hydropower sites.
- The hydropower potential $\mathbf{P_h}$ is obtained by the following formulation:

  $$\mathbf{P_h = \eta \rho g Q H} \qquad \mathbf{(13)}$$

  Where, $\boldsymbol{\eta}$ is dimensionless efficiency of water turbine (80 – 90% for large hydro and 60 – 80% for small hydro), $\boldsymbol{\rho}$ is density of water (kg/m^3) and **g** is the local acceleration due to gravity (m/s^2).
- Electricity generation by hydro **E** (kWh/year) is determined by:

  $$\mathbf{E = P_h\ (kW) \times CF \times 8760} \qquad \mathbf{(14)}$$

- **CF** is the plant Capacity Factor (%), which is given by:

CF = E (kWh/year)/(Installed Capacity (kW) x 8760 (h/year)) **(15)**

- Potential large hydro sites of varying 'Head' and 'Discharge' have already been identified by other studies elsewhere, see (Table C.4_2).
- Assuming $\boldsymbol{\eta}$ = 80%, $\boldsymbol{\rho}$ = 1000 kg/m^3 and **g** = 9.81 m/s^2, and using defined parameters in (Table C.4_2); hydro potential capacity in (MW) is estimated.
- We compute additional exploitable large hydro potential in excess of 5,000 MW.
- Overall exploitable large hydro potential is estimated to be around **11,000 MW.**

C.4_2 Large Hydropower Sites and Potential in Nigeria

LOCATION	RIVER	AVERAGE DISCHARGE (m^3/s)	MAXIMUM HEAD (m)	CAPACITY ESTIMATE (MW)
Donko	Niger	1650	17	220.1
Jebba	Niger	1767	27.1	375.8
Zungeru II	Kaduna	343	97.5	262.5
Zungeru I	Kaduna	343	100.6	270.8
Shiroro	Kaduna	294	95	219.2
Zurubu	Kaduna	55	40	17.3
Gwaram	Jamaare	75	50	29.4
Izom	Gurara	55	30	12.9
Gudi	Mada	41.5	100	32.6
Kafachan	Kongum	2.2	100	1.7
Kurra II	Sanga	5.5	430	18.6
Kurra I	Sanga	5	290	11.4
Richa II	Daffo	4	480	15.1
Richa I	Mosari	6.5	400	20.4
Mistakuku	Kurra	2	670	10.5
Kombo	Gongola	128	37	37.2
Kiri	Gongola	154	30.5	36.9
Kramti	Kam	80	100	62.8
Beli	Taraba	266	79.2	165.3
Garin Dali	Taraba	323	36.6	92.8
Sarkin	Suntai	20	180	28.5
Danko	Donga	45	200	70.6
Gembu	Katsina Ala	170	45	60.6
Kasimbila	Katsina Ala	740	49	284.6
Katsina	Benue	3185	25.9	647.4
Ala	Niger	6253	31.4	1540.9
Makurdi	Niger	6635	15.3	796.7
Lokoja	Osse	80	50	31.4
Onitsa	Cross	759	47	280.0
Ifon	Cross	1621	15.5	197.2
Ikom	Cross	1704	10	133.7
Total				**5,983.9**

Source: [203]; Author's Computations.

- A range of Small Hydropower sites from *"run-of-river"* (without dam) and *"waterfalls"* are also available to provide electricity to isolated homes, villages and medium- to- small-scale industries in Nigeria.
- These SHP sites have already been identified by other studies elsewhere, see (Table $C.4_3$).
- As shown in (Table $C.4_3$), these result in exploitable Small Hydropower potential in excess of 700 MW from 278 SHP sites.
- Overall exploitable SHP potential is estimated to be around **3,500 MW.**

$C.4_3$ Small Hydropower Sites and Potential in Nigeria

STATE	RIVER BASIN	NUMBER OF SITES	CAPACITY ESTIMATE (MW)
Sokoto	Sokoto – Rima	22	30.6
Katsina	Sokoto – Rima	11	8
Niger	Niger	30	117.6
Kaduna	Niger	19	59.2
Kwara	Niger	12	38.8
Kano	Hadejea-	28	46.2
Borno	Jama'are	29	20.8
Bauchi	Chad	20	42.6
Gongola	Upper – Benue	38	162.7
Plateau	Upper – Benue	32	110.4
Benue	Lower – Benue	19	69.2
Cross River	Cross – River	18	28.1
Total		**278**	**734.2**

Source: [203].

Appendix D

Stakeholders' Feedback on the E-PAM

Section E Appendix B of this report sought stakeholders' inputs during fieldwork in Nigeria. The aim was to use the feedback received to improve the E-PAM, and to verify policymakers' degree of appreciation of the use of structured planning and evaluation tools. Stakeholders' feedbacks to questions (D1 to D5) are presented here.

D.1 Stakeholders Responses to Question E1

						Total
	NNPC	MPR	ECN	NPC	FME	
Very relevant/useful	10	7	10	10	9	**46**
Somewhat relevant/useful	0	3	0	0	1	**4**
Not relevant/useful	0	0	0	0	0	**0**
Total	**10**	**10**	**10**	**10**	**10**	**50**

D.2 Stakeholders Responses to Question E2

						Total
	NNPC	MPR	ECN	NPC	FME	
Fully understood	10	5	8	6	5	**34**
Slightly understood	0	5	2	3	5	**15**
Did not understand	0	0	0	0	0	**0**
Total	**10**	**10**	**10**	**9/10**	**10**	**49/50**

D.3 Stakeholders Responses to Question E3

						Total
	NNPC	MPR	ECN	NPC	FME	
Very much agree	10	7	10	9	8	**44**
Somewhat agree	0	3	0	0	2	**5**
Don't agree	0	0	0	0	0	**0**
Total	**10**	**10**	**10**	**9/10**	**10**	**49/50**

D.4 Stakeholders Responses to Question E4

						Total
	NNPC	MPR	ECN	NPC	FME	
Very willing	10	8	9	9	9	**45**
Slightly willing	0	2	1	0	1	**4**
Not willing	0	0	0	0	0	**0**
Total	**10**	**10**	**10**	**9/10**	**10**	**49/50**

D.5 Stakeholders Responses to Question E5

Nigerian National Petroleum Corporation (NNPC)	**Ministry of Petroleum Resources (MPR)**
- How do you intend to validate this model? - Where did the data used for this model come from? - How do you account for uncertainties in the model? - This model is novel and can be improved with use. I commend the work. - Try and capture the potential for paradigm shift in the model. - Having a map of Nigeria with present power sites identified and what improvement is required can be a good idea. - Provide comparison with previous works carried out on the power sector. - The model coverage in terms of years should be limited for accuracy. - Iteration of the model be suggested given the peculiarity of the country. - A static model should be built as a guide or test tool for questioning the accuracy of the dynamic model. - Situate the model in specific area of reference in Nigeria. - Create an enabling organ to sensitise government for its use. - Widen circulation to policymakers in Nigeria. - This tool should be used to guide the transformation thrusts of government.	- Environmental impact assessment should be carried out with this tool. - Government should buy into this laudable initiative. - There should be a simulator to generate initial conditions for the simulation. - The dynamism and time dependent of each module should be simulated rather than guessing. - An additional iterative program should be written to solve recycle problems and obtain convergence. - I think we need the theory version of the model. - Please try to compare the model with that of national planning. - After successful completion of the project, I would suggest a stakeholder/public awareness meeting to be organised to enable the usage of the model. - The model should put all other areas into consideration and should not be streamlined to oil and gas /energy alone. - The model to me appears to be adequate.
Energy Commission of Nigeria (ECN)	**National Planning Commission (NPC)**
- Much emphasis should be placed on policy implementation. - The model needs to involve a factor of corruption. - The energy resources to be used should not be just derived from government sources; a lot of issues are made hidden with government data. - The model should be able to capture the informal sector; their consumption at economic and energy sectors is very important. - Attach a way to prosecute anybody violating policies that can come out of this model. - Highlight the effect of insecurity and tribalism in Nigeria to the gain of this model. - Consider the informal sector as the highest consumer of energy. - Extend the future projection of the model to 2050 - Include nuclear energy as a component of the energy mix in the model. - Attention should also be given to other energy technologies in the model. - To me everything is included.	- This is a laudable initiative and a welcome development for Nigeria. - How will you get people to know how to use this model? - The model should be well developed and timely implemented. - Need to put in place a mechanism for fine-tuning the model. - Need for flexibility of the model. - Need for periodic review of the model. - What about implementation process? - What about procurement issues? - How may we know the advantage of this model over a static one? - Is there room for expanding this model to include other issues of interest?
Federal Ministry of Environment (FME)	
- Key government regulators should be involved in different stages of the policy planning, evaluation and implementation. - In-depth studies need be done on the need to encourage renewable energy. - There must be government will power to support this. - This model should be strictly implemented by government as a policy model. - Incorporate the present government programmes on the power sector. - Interface with national policy on environment. - Excessive details should be avoided (2). - It could be made into components to reduce overlaps. - It could be made into two parts, detailed and simple versions. - Practical application of the model should be included. - Top government officials should be involved. - The questions should step down to the stated LCA levels.	

Appendix E

Conversion Factors

E.1 Volume Equivalent Conversions

Unit	Multiply by	Approximate conversion factor	Equals	Unit
Cubic feet (f^3)	x	0.02831685	=	Cubic metres (m^3)
Cubic feet (f^3) of natural gas	x	0.0001767	=	Barrels of oil equivalent (boe)
Tonnes of oil equivalent (toe)	x	7.33	=	Barrel of oil equivalent (boe)
Barrels of oil equivalent (boe)	x	5,658.53	=	Cubic feet (f^3) of natural gas
Barrel of oil (bbl)	x	0.1589873	=	Cubic metres (m^3)
Barrel of oil (bbl)	x	0.136	=	Tonnes of oil equivalent (toe)

Source: [207].

E.2 Mass/Weight Equivalent Conversions

Unit	Multiply by	Approximate conversion factor	Equals	Unit
Short tons	x	0.9071847	=	Metric tonnes (t)
Long tons	x	1.016047	=	Metric tonnes (t)
Metric tonnes (t)	x	1,000	=	Kilograms (kg)
Metric tonnes (t)	x	0.9842	=	Long tons
Metric tonnes (t)	x	1.102	=	Short tons

Source: [204].

E.3 Length Equivalent Conversions

Unit	Multiply by	Approximate conversion factor	Equals	Unit
Miles (mi)	x	1.609344	=	Kilometers (km)
Feet (ft)	x	0.3048	=	Meters (m)
Inches (in)	x	2.54	=	Centimeters (cm)
Kilometers (km)	x	0.62137	=	Miles (mi)

Source: [204].

E.4 Area Equivalent Conversions

Unit	Multiply by	Approximate conversion factor	Equals	Unit
Acres	x	0.40469	=	Hectares (ha)

Square miles (mi^2)	x	2.589988	=	Square kilometers (km^2)
Square feet (ft^2)	x	0.09290304	=	Square meters (m^2)

Source: [204].

E.5 Energy Equivalent Conversions

Multiply by	MJ	GJ	kWh	toe	BTU
Megajoules (MJ)	1	0.001	0.278	24×10^{-6}	948
Gigajoules (GJ)	1000	1	278	0.024	948,000
Kilowatthour (kWh)	3.6	0.0036	1	86×10^{-6}	3,400
Tonnes of oil equivalent (toe)	42,000	42	11,600	1	39.5×10^{6}
British thermal unit (BTU)	1.055×10^{-3}	1.055×10^{-6}	295×10^{-6}	25.3×10^{-9}	1

Source: [204].

E.6 Crude Oil Conversion Factors

Multiply by	t	kl	bbl	Tonnes per year (t/y)
Metric tonnes (t)	1	1.165	7.33	-
Kilolitres (kl)	0.8581	1	6.2898	-
Barrels (bbl)	0.1364	0.159	1	-
Barrels per day (bbl/d)	-	-	-	49.8

Source: [155].

E.7 Natural Gas Conversion Factors

Multiply by	m^3	f^3	toe	million (t) LNG	trillion (BTU)	million (boe)
1 billion cubic metres (m^3) NG	1	35.3	0.90	0.74	35.7	6.60
1 billion cubic feet (f^3) NG	0.028	1	0.025	0.021	1.01	0.19
1 million tonnes of oil equiv (toe)	1.11	39.2	1	0.82	39.7	7.33
1 million tonnes of LNG (t)	1.36	48.0	1.22	1	48.6	8.97
1 trillion British thermal unit (BTU)	0.028	0.99	0.025	0.021	1	0.18
1 million barrels of oil equivalent (boe)	0.15	5.35	0.14	0.11	5.41	1

Source: [155].

Appendix F

Publications and Other

F.1 Publications

Mbasuen, S.T. and R.C. Darton. *The Transition to an Energy Sufficient Economy*. in *3rd Student Conference on Operational Research, SCOR 2012*. 2012. Nottingham, UK: Schloss Dagstuhl.

Mbasuen, S.T. and R.C. Darton. *Application of System Dynamics as a Policy Evaluation Tool: The Nigerian Perspective*. in *The 30th International Conference of the System Dynamics Society*. 2012. St. Gallen, Switzerland: System Dynamics Society.

F.2 Future Publication

Mbasuen, S.T. and R.C. Darton. *The Role of Stakeholders in Sustainability Assessment: The Contrasting Paradigms.* Journal of World Development, [Current Maniscript].

Mbasuen, S.T. and R.C. Darton. *Current Trends in Global Energy Development: Implications for Future Energy Security and Sustainability.* Journal of Energy Policy, [Current Manuscript].

F.3 Paper and Poster Presentations

Mbasuen, S.T. and R.C. Darton, *Renewable Energy Resources and the Challenges of Decentralised Energy Options in Developing Countries: A Case Study of Nigeria*, in *DocLinks-Commonwealth African European Residential School: "Post COP 17: Climate Change and Livelihoods in Africa"* 2012: Gabrone, Botswana.

Mbasuen, S.T. and R.C. Darton, *Development of an Energy Policy Assessment Framework: A System Dynamics and Multi-Criteria Analysis Approach*, in *Poster Presentation for Confirmation of DPhil Status* 2012: Department of Engineering Science, University of Oxford.