Master Thesis
Computer Science
Thesis no: MCS-2008-19
March 2008

DECISION SUPPORT FOR MULTI-CRITERIA ENERGY GENERATION PROBLEM

A REVIEW OF THE NIGERIAN CONTEXT

TEMITAYO ARIKENBI

Department of
Computer Science and Software Engineering
School of Engineering
Blekinge Institute of Technology
Box 520
SE – 372 25 Ronneby
Sweden

This thesis is submitted to the Department of Computer Science and Software Engineering, School of Engineering at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Computer Science. The thesis is equivalent to 40 weeks of full time studies.

Contact Information:
Author(s):
Temitayo Arikenbi
Address: Gymnastikpromenaden 3
SE-37236 Ronneby
E-mail: temitayo@gmail.com

University advisor(s):
Guohua Bai
Department of Interaction and System Design
School of Engineering

Department of
Computer Science and Software Engineering
Blekinge Institute of Technology
Box 520
SE – 372 25 Ronneby
Sweden

Internet : www.bth.se/tek
Phone : +46 457 38 50 00
Fax : + 46 457 102 45

ABSTRACT

In this study, an attempt is made to apply Decision Support Systems (DSS) in planning for the expansion of energy generation infrastructure in Nigeria. There is an increasing demand for energy in that country, and the study will try to show that DSS modelling, using A Mathematical Programming Language (AMPL) as the modelling tool, can offer satisficing results which would be a good decision support resource for motivating how to expend investment for energy generation.

Keywords: Decision support systems, energy, satisficing, efficiency, Nigeria

ACKNOWLEDGEMENT

I would like to express my gratitude to my advisor, Professor Guohua Bai, who accommodated my trouble with time management and firmly insisted that I produce a job of acceptable quality.

I thank my father, Abiodun, and my siblings, Temidire, Olanrewaju and Afolabi, for their support and encouragement.

TABLE OF CONTENTS

INDEX OF TABLES

INDEX OF FIGURES

1 CHAPTER ONE: INTRODUCTION

Decision support models have found utility in the deregulated energy markets of Europe, as is evidenced in research into ways of measuring efficiency and utility of decision support models using stochastic models (Lahdelma et al, 2006)[1]. Some of the uses of Decision Support Systems (DSS) in energy modelling in Europe are for determining the optimum price of energy, and also for determining how much excess energy capacity is required to service periods of peak energy demand. DSS is used for planning not only where to locate energy generating infrastructure, but also for determining how much energy is produced, whether or not to build capacity in excess of the local demand, the environmental costs of building energy infrastructure at specific locations, and so on. However, energy planning in Africa, specifically Nigeria, is not as sophisticated. And to date, there are not many instances of DSS technology in use for the planning of any aspect of electric energy generation.

1.1 ORGANISATION

The study is divided into six chapters. Chapter One gives an introduction of the concept of Decision Support, and shows how it has emerged as a useful resource for enhancing the decision making process.

Chapter Two establishes the background of the study, giving insight into what has been done with decision support in some real world systems, and establishing how DSS can enhance decision making for investing financial resources in energy generation infrastructure. The chapter gives a theoretical framework of what can be done with Decision support in general, and how in particular it can be used for energy decision making.

Chapter Three describes the energy problem in Nigeria, and states what the study is trying to achieve. The chapter also states the restrictions imposed on the study in terms of available information and applicability of the model.

Chapter Four reviews the theory of DSS and describes the methodology for the case study and experiment that is carried out. It gives an overview of the step-by-step processes in the study, how information was collected, how the decision support utility was selected and establishes a basis for the use of the modelling language – AMPL (A mathematical programming language) that is used to optimise the type (source) of energy to be built up in the Nigerian case.

Chapter Five reviews the Nigerian energy experience with data and describes the experiment that was carried out using statistics and data about the Nigerian energy infrastructure, investments and development in the industry over the past 8 years, and the energy aspirations as stated in the strategic policy of Nigeria. The chapter establishes the objective of the model, the criteria affecting the objectives, describes the model and shows the results of testing Nigeria's energy data on the AMPL model.

Chapter Six reviews the results of the experiment, and closes with a summary of what has been done and further areas that may be researched.

1.2 DSS OVERVIEW

Nigeria is a developing nation intent on adopting better and more efficient processes in public service delivery and infrastructure development. One of the planks upon which such an initiative rests is the deregulation and liberalization of public utilities and services, including electric energy generation. Deregulation of the energy industry is only at its infancy in

[1] Lahdelma, R et al, 2006, "Multivariate Guassian Criteria in SMAA", *European Journal of Operations Research,* vol. 120, pp 957 – 970

developing nations, particularly in Africa, and the modalities of how best to enhance productivity and efficiency of the deregulated industry is still an evolving process. The use of decision support systems in modelling the strategic approach to choices to be made in such an industry scenario is one such modality that could yield the desired effect of better efficiency. A decision support model would entail the articulation of the decision problems that would face decision makers, the dimensioning of the problems into criteria expectations and the exploration of alternative approaches to resolving the emergent dilemmas (Turban et al, 2007). Decision support systems underline optimisation, efficiency enhancement and/or cost minimisation. In an economic sense, this would translate to value enhancement to the economic entity, depending on what 'value' constitutes to the particular entity. The object is therefore to review research into decision support modelling, especially for real world, multi-criteria based choices, and to suggest approaches that may offer proper fit and value for an environment such as Nigeria. However, since DSS cannot be described in an exclusively generic sense that fits all circumstances (Wierzbicki et al, 2006), attention will be focused on its application within the context of energy generation infrastructure development, using proven and working models that are in place around the world as templates.

To begin, an overview of Decision Support Systems (DSS) is required. Decision support systems have, since the 1980s, become an established part of mainstream management science (Korhonen and Wallenius, 1990), and the increased sophistication and computational prowess of computer systems make them an ideal tool for the rather complex model requirements that seem best suited for solving decision problems of the present age. Indeed there are many researched and documented instances of decision support systems being critical to decision outcomes in both public and business sector applications (Turban et. al., 2007). Decision support systems can be seen as man-machine cooperation to achieve best-fit outcomes for business problems. To paraphrase Michael Ginzberg (Ginzberg and Stohr, 1982) a decision support system can be described as a "*computer based information system to support decision making activities in a situation where it is not possible or desirable to have an automated system perform the entire decision process*". A layman's definition of the subject term can also be stated as a computer-based system that seeks to add value to the decision making process undertaken by a person (or people) charged with choosing from possible alternatives. As a component business process, decision support seeks to achieve the best possible outcome from any number of alternatives.

The distinction between automation and decision support is important. Even with the passage of time since the earlier postulation and the increased complexities of decision problems, it is still important to distinguish support activities from full-fledged automation. To talk about support means that the ultimate decision resides with a decision maker, who could be a person or a group. The role of DSS is therefore to offer a systemic approach to reaching decisions, and in the event of good decisions with positive feedback, to offer a methodology for the replication of such an approach.

Decisions facing managers and decision makers vary from situation to situation, meaning that there may not be a consistent structure to the problem domain. The outcomes of decisions that are made also offer no guarantees that such decisions will match the expectations or desires of the decision maker. These two concepts – unstructured-ness and uncertainty – are two of the main reasons why DSS have a relevant role to play in the decision making process.

Unstructured-ness and uncertainty are also the principal reasons that the energy generation problem of a nation such as Nigeria has so far defied all the effort and investment targeted at resolving it. An objective of the study therefore is to attempt to apply decision support systems to give structure and form to energy generation decision making. It is intended that such an approach would yield better efficient results with regards to how resources are allocated and utilised for building energy infrastructure in a developing state as Nigeria.

A DSS is traditionally described as having three component areas:

1. Information/Knowledge system
2. Model/Process System
3. Algorithm base/model solver

Further insight into how the above listed areas enhance the decision making process will be given in the section on theoretical framework (chapter four) but for now, suffice to mention that the study will focus more on the use of models to motivate the decision process and enhance the quality of choices that are made. And in developing a model, the study will attempt to deploy a modelling language solution using A Mathematical Programming Language (AMPL) for the as yet intractable energy problem in Nigeria, with a result that is hoped will offer a template for the solving the larger problem of energy management in that country.

Decision support is typically an applied approach, and the body of knowledge built up from the experience of applying its concepts in one area should offer new knowledge that would be found useful in developing a support system for other industry areas. In this regard, DSS constructs and rules from case studies in energy and the environment will offer insights into what can be done with DSS for the Nigerian energy questions that will be posed in this study.

The next section of the study will undertake a review of literature and some previous work done in decision support in different industry areas, and the common aspects of these works that are applicable to a decision support model in the energy terrain of a developing country like Nigeria.

2 CHAPTER TWO: BACKGROUND AND RELATED WORK

2.1 LITERATURE REVIEW

Decision support as a subject of research and study gained relevance through the pioneering work of Herbert Simon. The evolution and adoption of decision support is somewhat connected to the evolution of human social and business practices from the industrial to the information age (Turban et al, 2007).

In literature, decision support models are seen to be mainly targeted at yielding utility maximisation of specified objectives, within the context of the intuitive understanding of what the particular objectives are (Lewandowski and Wierzbicki, 1989). Aligned with studies on decision support have been concurrent studies about the human decision making process. The complex mechanism called the human brain is dimensioned into two hemispheres, each with a proclivity towards a certain behavioural pattern, and each with a role and effect on the nature of human choices (Dreyfus and Dreyfus, 1986). The optimality of the functioning of the brain is dependent on the amount and quality of information that has been immersed and integrated into the thought process. Therefore, for tasks involving decision, an aid to the quality of outcome is not just the amount of information that is available, but also the amount of information that is interpreted. In this guise, decision support can be viewed as an 'information interpreter', presenting different perspectives of what can be done to yield the most optimal results. The decision support system enhances the quality of decisions and does not necessarily define what the decision should be.

In industry, decision support systems have found utility across many business disciplines, from pharmaceuticals, to finance, to logistics and consulting services (Turban et al, 2007). A fundamental aspect of all decision support system applications irrespective of the industry is a need for an enhancement in some value return. That value could be in form of greater profitability, or in form of lower costs and overheads, or in form of better time utility, or higher quality, and so on. This descriptive qualification can in many cases be reduced to a notational or mathematical expression. Such expressions then form a basis for a computation resolution of decision questions, hence the fit between computer systems and decision making.
Another useful definition of DSS in addition to the ones given in the previous section and more relevant to the current study is:

"*A model of information representation, process description and outcome selection for a described undertaking, which is re-usable and replicable at concurrent value yields under different circumstances*"

A number of mathematical theories have been evolved specifically for solving decision questions. Many of these theories have been found useful in real world decision support models. Most of the theories tackle the question of optimisation (Weber, 2005). Linear programming, mixed integer programming, fuzzy sets, bayesian nets, and other probabilistic linear and non-linear modelling procedures consistently recur in decision support system design (Turban et al, 2007). Out of all these, the linear programming approach is the most commonly adopted. However, the pre-eminence of linear optimisation as a basis of formulating the decision model in decision system modelling has come under scrutiny in recent times, because of the singular nature of the objective definition and the complex reality of decision choices in real life application (Wierzbicki, 1997). Indeed, Wierzbicki and Wessel are of the view that optimising systems open the possibility for decision conflicts and vested interests. Rather, a more collaborative and all-engendering arrangement of decision support, reflecting *satisficing interests*, would better serve the needs of a support model. The satisficing basis of decision models can again be traced to the earlier research of Hubert Simon (Simon, 1957). This study will focus more on the satisficing requirement of energy generation in Nigeria. The use of the term 'optimize' will continue, but only because it is more in line will mathematical modelling convention. What is actually meant is a satisficing solution for the objective function.

There are many perspectives to decision support system development and utility, so many in fact that to review them all would constitute an entire large sized volume in itself. This discussion will therefore be limited to the use of a decision support system as an analytical basis for influencing the strategic choices that need to be made in developing electric energy infrastructure in an emerging economy. For this purpose, some related work in the energy industry and other industries are studied, to identify the relevant points of consideration in designing a decision support system. Some examples of real world decision support application are as follows:

a. Integrated Energy Simulation model of FDR (West Germany) (Schmitz and Schwefel, 1977)

b. Lithuania Energy Deregulation (Markandya, 2006)

c. Nitra River base case study (Makowski, 2000)

d. Land use planning case study (Fischer et al, 1998).

2.2 INTEGRATED ENERGY SIMULATION MODEL (W.GERMANY)

Kurt Schmitz and Hans-Paul Schwefel (Schmitz and Schwefel, 1977) presented a seminal paper describing a basis for evolving a national energy model premised on primarily four model fundamentals:

1. The macro-economics of energy
2. Energy demand fundamentals
3. Energy supply fundamentals
4. Environmental impact fundamentals.

The four parts form an integrated model, and each part is premised on the analysis of many different variables and parameters, and also the use of historical information and inferences from other systems. Each area is important in the overall context of energy efficiency, but the degree of importance would vary from one economic entity to another, depending on the level of sophistication of that economy. The model described was a part of an even larger global energy model developed with particular interest in the position of Germany in the dynamics of world energy requirements.

Between the time of the original model and now, the priorities associated with each area have changed, but the dynamics of the interaction between the four still underlie energy generation questions. The summary of the relationship between the different areas is that the macro-economic module reviews the economic performance and economic potential of the country which then serves as an input into the energy demand module, which is further extended to include all aspects of energy requirements including industrial, residential, transportation and any other needs. The energy supply module investigates the sources of energy and the infrastructure requirement to meet the already aggregated demand requirement, while the environmental module considers the emissions due to energy production, conversion and consumption, and aggregates an economic value to the impact on the environment as a way to determining what it would cost to mitigate such harmful effect.

The system is a total and very comprehensive one, and to appreciate the complexities of decision models used for such a complex system, some of the consideration of the modules are detailed as follows:

2.2.1 MACRO-ECONOMIC MODULE

This part of the overall model computed and captured the impact of energy on economic factors like population, financial and capital markets, production output, consumer and commodity markets, and economic investment. The objective was neither to maximise nor minimise any variable, but rather to generate input functions for the other modules. The module involves a lot of analysis and uses historical information in a variety of economic criteria to predict what the future expectations would look like. The module makes use of predictive functions like Cobb-Douglas production function. This aspect of the model shows the importance of economic information on the energy demand and supply of an economic entity. However, for our envisaged energy model to studies the Nigerian energy industry, the economic data will be primarily sourced from available data and statistical information, and will not be based upon computed values.

2.2.2 ENERGY DEMAND MODULE

This part of the model plots the energy demand pattern for the economic entity, and also projects the optimal energy requirements for the future. Energy demand, along with energy supply, forms the important part of the overall model from a point of view of optimization. The overall long-term objective is to minimize the demand and maximize the supply to improve efficiencies in cost and resource management. A very comprehensive analysis and dimensioning of the energy demand within the economic entity is carried out, from the perspectives of industry, petrochemical, commercial, transportation and private household consumption. Each area is analyzed in further detail and some parameters superimposed upon the areas. For example, for industry demand, a gross value added (GVA) is computed as a scalarising function for determining the sustainability of the energy demand trend in the future. The different energy types that are required are matched against the energy resources most suited to meet the requirement. The generated values give the information about optimal demand pattern and also are used as input variables for determining the most efficient supply design system to be utilized.

2.2.3 ENERGY SUPPLY MODULE

The supply generation capacity and growth potential to meet the stated demand is modeled within this module. There is an efficient match between the demand requirement and providing long term sustainable supply for that demand. Issues such as the energy resource availability and sustainability (i.e. nuclear, gas, coal, wind, hydro, etc) and the most efficient and environmentally sustainable manner of converting the resource into energy, as well as the cost now and in the future of utilizing a particular resource compared to others, were analyzed. Also, the ratio of the different resources for energy generation was allocated, and projections made about the appropriate ratio for resources in the future. The modelling approach utilized the data from the previous sections and built it into a FORTRAN-based mathematical program. Also incorporated, but not considered in our own study, were the variables that affect the distribution and delivery of energy to the end users. The satisfaction of demand in excess of supply capacity using imported resources and energy was also aggregated into the model. The results of the model showed that it was projected that energy demand would rise, but at a reduced rate of increase over a 20 year period, and that the supply component would shift from reliance of gas as primary resource to nuclear and gasified coal and lignite as primary resources. The model also plotted the consumption patterns of the various economic sectors in the macro-economic module and showed why it was more efficient to encourage cutbacks in some segments and increases in other segments for the overall objective of a healthy and vibrant economy.

2.2.4 ENVIRONMENTAL MODULE

The environmental module is somewhat a control module that defines the mechanisms for measuring environmental impact with regards to overall energy demand, supply and economic utility. The key environmental measures that are identified are carbon dioxide content, sulfur content, nuclear degradable and fissile content and other chemical and radioactive pollutants. The actual number of chemical and radioactive pollutants that were measured and modeled is nine and four respectively. These factors were built into the cost of the energy resource and were factors in the preference of one resource over the other.

2.2.5 MODEL SUMMARY

The integrated model in particular lays down some of the ground rules that will be adapted for the Nigerian energy model. The areas that are related to the study are:

1. The variables and data for the model are motivated from the macro-economic aspect of the entity. Therefore there is an economic basis for the model and the model objective ultimately seeks to improve the performance in an economically quantifiable manner.

2. The resources that are accounted for are ranked in some way depending on the availability, affordability, sustainability and technology convertibility as a resource for the primary function. For our model the primary function is the generation of electric energy.

3. A mathematical modelling utility is used to build an optimized outcome of energy generated from the different resources. For the integrated energy model, FORTRAN was the primary modelling utility, although other proprietary model support utilities like DYNAMO and RSYSY III are also used (Schmitz and Schwefel, 1977). For this study's modelling task, AMPL will be used.

4 The results and outcomes are projections and suggestions to support policy makers and economic planners in their work. The role of decision support models as support mechanisms and not exact solution providers is maintained.

2.3 ENERGY DEREGULATION (LITHUANIA)

The energy generation problem is a complex one, especially for countries that require rapid improvement to their energy output levels. Decision models for energy generation issues have been utilised to positive effect in Lithuania (Markandya et al, 2006), not for increasing energy output adequacy, but for improving energy usage efficiency and improving energy sustainability and environmental impact. Current electric energy generation in Lithuania is adequate for the population size and industrial needs – indeed excess energy capacity is exported to neighbouring country Estonia.

However, since most of the energy generation is from an outmoded nuclear reactor, the impending shutdown of the reactor in Ignalina (which produces 70% of Lithuania's energy) poses questions of energy management that demand answers.

The loss of the nuclear power generation capacity, which made Lithuania a net exporter of energy after meeting all its energy obligations, has imposed the need for strategies to sustain the energy stability which has catalysed the rapid growth in GDP over the past few years. The efficiency model adopted is borne on three main planks:

1. The implementation of an energy usage reduction scheme for heating energy
2. The implementation of the Lithuanian law of energy, which saw the divestment of central government ownership of energy generation and distribution facilities, and a framework for equal accessibility to energy transmission infrastructure incorporated into the law.
3. The accessibility of energy consumers (categorised as *eligible customers*) to energy producers to directly negotiate supply contracts that is adjusted against the transmission quotas allowable to energy producers.

The important comparative issue between the adopted model and a model approach for other emerging economies is the strategic intent of the various decision choices that were adopted. In (Wessel and Wierzbicki, 1993), the authors reflect that the major aspects under which a decision model may be premised are:

1. The nature of the available information.
2. The relationship between the processes and the actions (or decisions) taken.
3. The complexity of the actual decision.

From 2001, Lithuania began the process of unbundling its energy assets, with the privatization of the energy utility Lietuvos Energija, and the decommissioning of its Ignalina nuclear power plant. The decommissioning would result in a net loss of 70% of energy generation capacity in Lithuania, and the strategy in place for the rapid replacement of lost capacity offers a veritable model that can be adapted to other developing nation's scenarios. Part of the strategy is to reduce the generation/distribution loss ratio, and to reduce the energy capital expended on certain economic activities, like heating, without reducing the efficacy of the economic activities.

The reform is targeted primarily at improving energy efficiency. The decommissioning of the two power reactors that make up the Ignalina plant is to be done in two phases – the first phase was completed in 2005 and the final phase is expected to be completed in 2009. In order to properly understand the impact and dynamics of the decommissioning, a review of the Lithuanian story is in order.

The complex decision making that has resulted in a proven positive outcome in the Lithuanian scenario can be seen to be borne out of considerations spanning various 'data source' outlets, including past energy performance information, economic data and growth indicators, influences from information about nuclear energy value and dangers (the decision to shut down Ignalina was largely premised on European Union pressure due to the fear that the power plant could experience and accident similar to the one which occurred in Chernobyl) (Huang, 1999). The complexity of the choice to be made, from a point of view of long term economic growth (the objective) and sustainability of nationhood and security (a multi-objective) reveals an emerging strategic consideration that reviews information resources within the primary channels (i.e. energy performance indicators, comparative analysis of energy generation and consumption vis-à-vis other emerging nations), and distinctive and peculiar circumstances of the national history and location (situated within the Baltic region, long periods of dominance by larger nations).

Energy generation decisions occur at a strategic and long term level, with the impact evidenced on a 5 years or more basis. Tahir Tahirov states in his paper on energy reforms that the major energy considerations for an emerging economy focused on sustainable growth are energy pricing and efficiency in utility (Tahirov, 2005). These two considerations are reflected in a study of energy generation for Nigeria, but very important for Nigeria is the issue of the efficiency in the generation of energy.

2.4 NITRA RIVER BASIN (SLOVAKIA)

For the river basin case study, the river basin area in Slovakia was chosen for an assessment of pollution levels of various chemical compounds (effluents) at various locations (nodes) along the basin. The strategy was to determine permissible levels of effluents across the basin that would achieve an acceptable effluent percentage for the basin in the most cost effective manner. The review constitutes a multiple objective analysis because various chemical compounds were assigned criteria values, and the optimisation of one criterion would cause some other criteria to return a sub-optimal value. However, multi criteria modelling is by default a negotiating arrangement, in which an allowable range of outcome values determine the optimality or otherwise of a given criteria. In that light, it is not ideal to achieve single criteria optimality, rather what is feasible is a multi-criteria satisficing state (Lewandoski et al, 1985). Therefore, the modelling approach would be to utilise initial criteria values to motivate an optimality formulae, perhaps using a mathematical modelling language like AMPL (Fourer et al, 1993) or HOPDM (Gondzio, 1997), and then iterating the model generated for each criteria through a multi-criteria analysis engine, like MCMA (Makowski, 2000) or a proprietary decision support modelling system design specifically for the task. Important deductions drawn from the Nitra basin illustration and indeed from most of the DSS studies conducted by IIASA are:

1. A notational optimisation objective must be generated for the decision problem, with a representation of each criterion to be satisfied as initial constraints

2. Single objective modelling with hard constraints need to be replaced with an interactive specification of the decision maker's preferences. This means that the criteria would be assigned a satisficing range, from a *pareto optimal (aspiration)* value, to a *nadir (reservation)* value. The maximisation or minimisation of the criteria would be a function of how close to the aspiration or how close to the reservation level is attainable from the model data.

3. The decision maker is not subject to the outcomes of the DSS model; rather the intuitive preferences and value associated to the different criteria should motivate final choice from possible outcomes.

2.5 LAND USE PLANNING (KENYA)

Another interactive and iterative DSS example that was reviewed with a view to proper appreciation of multi-criteria DSS dynamics was the agricultural produce optimisation model developed by the food and agriculture organisation (FAO) and applied in agriculture produce optimisation in Kenya (FAO/IIASA, 1993). Decision making is an exercise in conflict resolution. Available resources of some kind need to be utilised in some beneficial way. However, there might be contending alternatives of ways in which the resource could be used. Decision making is about motivating a basis for the choice to be made, and optimising the benefits from such choices. In the case of land utility, agriculture is an alternative use, whereas the same land could be used for industry, recreation, human accommodation, and so on.

Statistics support the fact that world agricultural output is not increasing in an even and sustainable manner to match population increases. Therefore, the FAO undertook the task of improving the various processes of agricultural output to forestall the worsening of an already inadequate system of food production and distribution. The developing world is most at risk in the land race, as land degradation and desertification is highest in this region. Therefore the challenge was to maintain levels of land productivity for agricultural purposes whilst at the same time ensuring the sustainability of agricultural output and soil quality renewal.

To meet this challenge, a specific model termed the Agro-Ecological Zone methodology (AEZ) was devised and in summary it sought to optimise land utilisation along the following terms:

Food production

a. Food self-sufficiency
b. Cash crop requirements
c. Population supporting capacity
d. Soil fertility guarantee
e. Soil erosion minimisation
f. Land degradation minimisation

These conditions formed the criteria for modelling recommendations for the best approaches to land use. It can be seen from this that the DSS model extends beyond the realms of business choices and pure profit maximisation, and has utility in social, cultural and political dimensions. In addition, the abstraction of the objectives of the AEZ methodology into mathematical notations or programmable solution would logically result in multiple objectives which will not be satisfied by a single objective function. However the traditional approach of resolving linear programming question into single objective functions means that a different optimisation model would be required for each criterion, with each criterion assuming the role of an objective function or a constraint as the need arises. Whilst the computational capacity to achieve this in short order now exists, there might be difficulties in matching the respective outcomes of the different model into a feasible solution. Therefore, an alternative approach to model design is required, one that captures the elements of the different objective functions into a single program solver with a view to reflecting the most *satisficing* outcome.

Other than the core model, another issue that should be of interest is the mechanisms for human-computer interaction in the DSS. For the decision maker, and to some extent also for the analyst, the underlying processes that resolve the modelling question are irrelevant. What is important is an interface that allows for intuitive manipulation of the contending and conflicting aspects of the model in such a way as to accommodate all objectives of the process within a single design block. For this requirement, the interface design of the AEZ methodology offers insight into what should be best approach to multi-criteria DSS design.

2.6 BACKGROUND AND RELATED WORK SUMMARY

The historical basis and relevance of DSS as seen from literature establishes its continued usefulness today for a variety in a variety of decision making scenarios. One such scenario is the energy industry. Specifically, comprehensive decision modelling for national energy infrastructure covers a variety of areas and utilises a variety of mechanisms as seen in section 2.2. More recent decision modelling approaches utilise more interactive mechanisms as well as mathematical optimisation utilities as shown in sections 2.4 and 2.5. Overall, decision modelling relies on the quality of information that is gotten, and the depth of understanding of the requirements within the industry being modelled for, so that objectives and criteria that are real and realisable are plotted and resolved.

3 CHAPTER THREE: PROBLEM DEFINITION AND GOALS

3.1 OVERVIEW OF NIGERIAN ENERGY SITUATION

The long term strategic intent of Nigeria is stated as to become “top 20 world economy in terms of size of gross domestic product (GDP) and gross national product (GNP) by the year 2020”. Whilst this aspiration is long running, the goal post for its attainment has been shifted on a number of occasions (from 2000, to 2010, to 2015, to 2020). Nigeria produced 23.5 billion kWh (kilowatt hours) in 2005 from about 6 GWe (gigawatts electric) of plant and had final consumption of 17 billion GWh (gigawatt hours), giving per capita consumption of only 113 kWh/yr. Current electric energy output is very low, with current installed capacity for energy generation put at 6,200 MW (megawatts), while actual output hovers between 2,500 MW and 3,200 MW. Nigeria’s population size is 140 million, and to put the electric energy generation crisis in perspective, Sweden (population 9 million) generates 32,000MW, South Africa (population 42 million) generates 36,000MW and Lithuania (population 3 million) generates 3,000MW. The government in power has for almost a decade advocated and emphasised the need to drastically improve energy generation output and efficiency of use. The government has backed up its desires by committing huge resources in this quest. However, the results achieved so far beg the issue. The contention is that the choices and decisions made have lacked an important ingredient – information about the potential outcome and value of the choices that have been made.

Decisions on energy infrastructure expansion are strategic and far reaching in consequence. It could be argued that DSS systems should be modelled and applied to the entire energy question, spanning generation, transmission, distribution, marketing, pricing and environmental impact assessment. Such an undertaking would be far beyond the scope and resources of the current exercise. However, an aspect of the entire cycle – generation, will be tested to assess the relevance and value of DSS to improving energy generation efficiency.

3.2 DIMENSIONING THE ENERGY GENERATION PROBLEM

The energy situation in many developing nations leaves a lot to be desired. The fact that the economic systems are evolving and expanding would suggest that energy demand would experience rapid increase over the short haul. Indeed, as can be seen from the ever increasing energy demands of China and India in particular, nations that experience rapid growth are wont to demand larger amounts of energy to sustain such growths.

In the Nigerian scenario, energy demand has not been addressed with the requisite planning that would guarantee concurrent capacity growth. Indeed, there has been a long persisting shortfall especially in electric energy output as compared with the demand in the economy. Available data shows that the effective electric energy demand level at peak utility is in the region of 15,000MW, whereas current energy output level averages at around 2,500MW (World Bank world development indicator, 2006), (EIA -Energy Information Administration,).

The huge shortfall in energy supply is marginally redressed by rather inefficient and comparatively expensive private generation using diesel or petrol powered back-up generating sets. It is estimated that an additional 30% of effective total public utility electricity output (i.e. over 1000MW) of energy is generated using this inefficient means. The additional cost to individuals and businesses arising from this extra expense for energy supply ranges from 200%

to 500% over the retail cost of electricity. The spiral down effect on business and commodity cost in such an environment may be implied.

On the flip side, large amounts of money are invested on improving energy generation on a yearly basis. It is estimated that as much as ten billion dollars ($10B) has been invested over the course of seven years, without any discernible positive implication on the availability of energy in the country Nigeria (Ibitoye and Adenikinju, 2007). Indeed, in their paper on the subject, Ibitoye and Adenikinju project that an annual investment of $10 billion per annum would be required over the next 20 years to achieve optimum power availability at optimum industrial and human capacity growth by the year 2030. The issue of efficiency in planning the use of existing resources is implied but not investigated. Such therefore is the goal of this study.

In addition, energy mix to the national grid system is narrow focused. In spite of many energy generating alternatives available in the country, the primary sources are gas and hydro generating stations. A decision model for energy infrastructure investment should explore the possibilities of expanding the mix to include other sources such as coal, nuclear, solar and wind sources. This is to ensure an overlap of energy resources, and to provide redundant availability should a source-specific problem occur that affects only a particular energy source, as has been known to happen.

The subject of energy efficiency in a country as Nigeria has been widely discussed in social, economic and political terms. The general conclusion of most studies on energy production in Nigeria is that it is an inefficient and inadequate industry (Ikeme and Ebonhor, 2005). However, a systemic resolution to the situation has not, to the knowledge of the author, been previously explored. What has been done to date has been a dimensioning of the problem of energy and a description of the requirements for energy sustenance to support economic growth and development, which was done by the research group from the Energy Commission of Nigeria (ECN) under the auspices of the International Atomic Energy Agency (IAEA), (Sambo et al, 2006).

A lot of industry-based research on decision support system modelling has been undertaken by the International Institute of Applied Systems Analysis (IIASA), beginning from the early 1980s. Much of that work has resulted in a scientifically grounded methodology for decision support model development suited for real world industry adoption. Areas of the methodology's application have centred largely on environmental impact and ecological evaluation decision support (IIASA annual report, 2006). The considerations that were used to create the models at IIASA serve as a template for the model that will be presented in this study. The peculiar requirements of the energy industry are also considered, within the context of the fact that this case study reviews energy modelling for a developing nation and not for a developed and sophisticated nation. The study opines that an adoption of the methodology from IIASA extends the applicability of modelling as a tool for resolving real life industry problems.

3.3 RESEARCH QUESTIONS

Following from the preceding discussion about the energy problems that face the country Nigeria, and in line with the focus of the study being on energy generation, the following questions are posed by the study:

- What are the issues to be considered in determining energy generation requirements for a nation like Nigeria?
- What is the proper mix of energy resources to utilise in meeting the energy demand of the country?
- What is the best approach to adopt for applying investment resources in creating energy generation assets?

- What impact or value does an AMPL modelled DSS have on the efficient use of investment resources for energy generation
- What are the optional scenarios for constituting cost/resource combinations for energy generation, and how efficient are such scenarios?

3.4 SCOPE AND LIMITATIONS

The study focuses on the energy generation aspect of the overall electric energy industry. Other complementary segments of the industry are transmission and distribution. No single segment can be taken in isolation in developing an energy policy or master plan. However, the scope of the study does not cover these other segments on account of time and resource constraints. The study will focus on the energy resources available to the country, the cost of producing energy using the resources, and the optimal mix of energy resources that will best fit the energy needs.

Information on the current size of energy infrastructure in the country, and the ongoing infrastructure development in the energy industry was difficult to gather. There was a lot of contradictory information on the investment valuation and output capacity of energy generating stations, and a lack of information about the energy output projections for some of the energy generating stations that are being constructed. Also, there is no current investment in some of the identified energy resource alternatives, so the contribution quota of some resources to the national energy grid uses assumed figures. The selection and use of AMPL to develop a model does not preclude the use of more GUI-friendly modelling utilities. The AMPL version used is a student version that is license free, but unfortunately bereft of the GUI-functionalities available in the full commercial version.

4 CHAPTER FOUR: THEORETICAL BASIS AND METHODOLOGY

The background section has already detailed a content summary of the subject area, and the problem statement section has described different instances of decision support systems in application. This section will further advance some of the content of both preceding sections, giving a run-through of theoretical aspects of the DSS subject area, and describing the key points of a DSS model. The section will conclude with a review of the method adopted for this study.

4.1 A BASIS FOR DSS

A decision support system can be based on elements that consider three aspects available from the given business or process situation being reviewed:

1. The ordering or the arrangement of the information. For instance, geographical information systems (GIS) are largely dependent on the capability of the system to hold information in formats that support access and retrieval of graphical information and data. The nature of the data being sought would largely influence the support arrangement available for the system.

2. The interaction between basic processes and actions, and the outcomes that are being sought. Wessel and Wierzbicki (Wessel and Wierzbicki, 1993) made the point that decisions are borne not from a single action or activity, but through a coalition of various actions and choices that interact, integrate and influence one another. Therefore, a decision support system will need to accommodate different processes, possibly disparate and unconnected, in a format that is replicable and reproducible in order to qualify as a model. The possibility of decomposing decisions into elemental sub-decisions that can be depicted by notations of a mathematical or programmable nature, whilst retaining a connection to the real world situation being supported, is critical for a qualification as a value adding decision support system.

3. The (complexity of the) decision process itself. Decisions are not taken in isolation. The basic decision model premised on linear programming optimisation presents a slightly deceptive picture. A decision variable x, which seeks to create an outcome $y(x)$ based on satisfying a given criteria $c(x)$, is in reality not very realistic. Variables influencing the choices to be made and the associated possible alternatives do not occur in singular format, but are premised on multiple possibilities, x member of set of possibilities Rn, which could yield outcomes $y(x)$ belonging to an outcome set Rm, aimed at satisfying any number of given criteria $ci(x)$, i belonging to a finite but potentially large number of limiting possibilities. In addition, the decision making is usually not resident in a single person, and the interpretation of a decision support system may not be consistent from decision maker to decision maker. The equity of influence (weight) ascribable to the different members of the decision making group, and the potential for personal biases leaking into the decision process need to be mitigated. Hence effective decision support must engender elements of consistent group communication and collaboration, and negotiation.

A mathematical or program decision support model is not the 'final answer' to the decision making process in real life applications. It is an element in the decision making process, and should be viewed and utilised in that context. A well balanced decision system considers the available information and possible information sources, the arrangement of the information, the interaction between the decision variables, the processes, the actions and the potential outcomes, and the surrounding complexity of the processes undertaken to arrive at the final decision. All these must be given some consideration without over-emphasizing one aspect over the other. This will enhance the quality of the final decision reached.

4.2 THE ROLES OF DSS

The functions and qualities of a DSS can be summarised as follows (Turban et al, 2007):

- Semi-structured and unstructured problems definition and resolution
- Supports managers at all levels
- Supports individuals and groups
- Interdependent or sequential decisions
- Supports intelligence, design, choice, implementation
- Supports a variety of decision processes and styles
- Adaptable and flexible
- Interactive ease of use
- Effectiveness, not efficiency
- Humans control the process
- Ease of development by end users
- Modelling and analysis
- Data access
- Standalone, integration and web-based

The functions of the most interest for the study are the ones dealing with modelling and analysis.

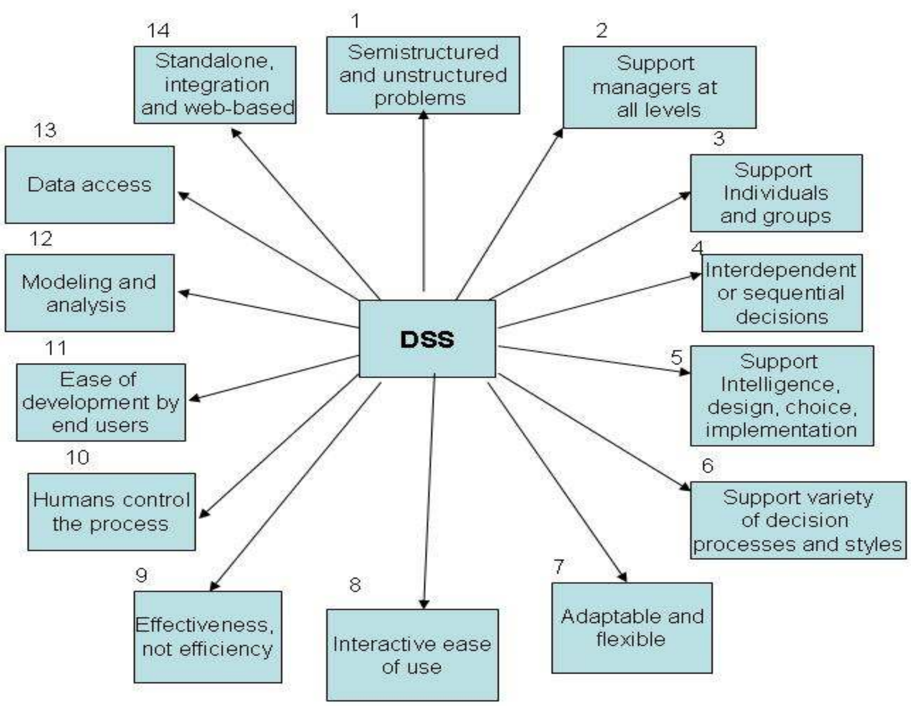

Figure 4-1: Diagram of DSS roles

Source: (Turban, 2007)

4.3 DISCUSSING THE DECISION MAKER

Bounded rationality is another way of expressing the satisficing theory initiated by Herbert Simon.

The metamorphosis of decision making within the information society paradigm – from Simon (satisficing theory 1955) to Lewandowski (decision support in multi-objective situations 1989) shows the impact that research in decision processes has had on organisational management.

Traditionally, the decision maker is seen as the focal point of organisational choices. It therefore becomes very important to understand how decision makers arrive at the choices they make. Simon posits that the solution of a problem is not only a factor of the information available on the subject matter. His position was that *knowledge* from the information, *experience* in resolving similar issues, and *learning ability* were far more important factors in making good decisions rather than the quantum of available information. Literature is strewn with instances of operational, marketing, strategic and tactical failings within businesses with an abundance of information, that were corrected by adopting key decision support systems principles (Turban et al, 2007). The subsystems of a DSS that are most impactful to business outcomes are described as:

a. Data Management Subsystem
b. Model Management Subsystem
c. User Interface (Dialog) Subsystem
d. Knowledge based Management Subsystem

Data management encompasses all the activities geared towards the administration of data systems, the representation of data and the channels of interaction between data and the end user (or model user). A lack of 'good' data, or information could pose major problems to decision making, as the ability of the information available to sustain the decision and to yield a certain projected (positive) outcome is based on the good quality of the information (or the information source).

Model management involves the templates and structures that describe how data, and processes, are utilised for the purpose of achieving targets and goals. The model gives formalisation to the decision process, and removes the arbitrariness and ad hoc representation that would otherwise describe the process. Decisions should not occur in a vacuum, and even in well articulated and thought-out processes, the choices to be made must conform to the underlying objectives that are being pursued. Therefore, with a data subsystem providing the assortment of choices, the model could be likened to a filtration system through which such choices are strained in order to get the most efficient and optimal outcomes.

User interface and dialog subsystem attempts to depict and translate the real world intentions and conceptualisation of the user into computer graphical and textual notation. The effective interface should offer the user perspectives of the real world equivalents connected with the actions being carried out.

Then there is the oft mentioned knowledge based subsystem, which functions as a fulcrum for the other subsystems. It is said that the world today is moving away for an information society towards a knowledge society in which knowledge forms the major component of any human activity. Economic, social, cultural, and all other human activities become dependent on a huge volume of knowledge and distilled information. Knowledge has thus become the major source of creative impetus. The knowledge based subsystem functions on both an intuitive and technical dimension – technical because the available knowledge would influence the programming approach towards designing a model, and intuitive because the information from available data is internalized by decision maker to arrive at what constitutes knowledge in any given instance.

A schematic view of the connection and relationship between the subsystems and other elements of the DSS is shown as follows:

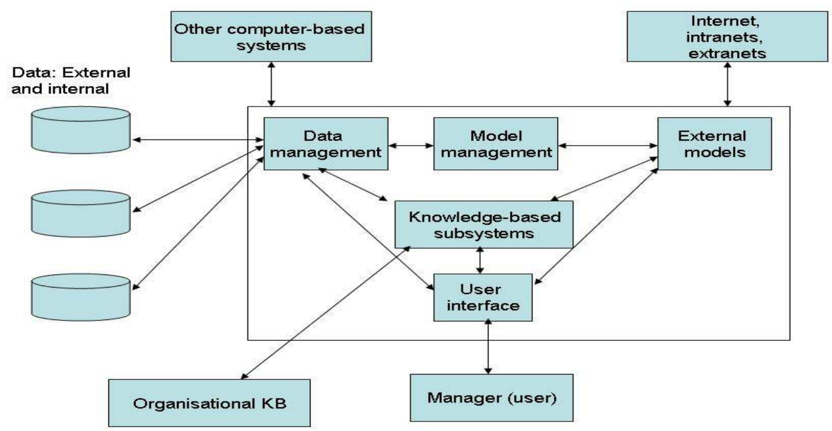

Figure 4-2: Schematics of DSS
Source: (Turban, 2007)

4.4 GROUP WORK AND KNOWLEDGE CREATION

Studies of decision making for complex systems and projects have shown that the process of knowledge acquisition is an important element affecting the quality of decision support that can become available to a project. The process of collaborative effort (i.e. brainstorming – electronic or otherwise, ideas organisation, scoring and ranking) does not by itself guarantee the quality of resultant decision or alternative. But, there is a lot of sense in the truism “two heads are better than one”. Collaboration and cooperation expand the scope of decision choices, and the chances of better alternatives emerging.

More fundamental is the knowledge basis that motivates the decision. An aspect of knowledge creation that can be very useful is identifying all decision considerations. For energy generation model, and one involving the construction of multiple numbered energy stations at multiple locations with environmental and cultural considerations, specific and targeted knowledge gathering should precede the decision support phase.

The question therefore is, what kind of knowledge would add value to the quality of decisions that we make for such a specific task as how to allocate resources for energy infrastructure development? And how does collaborative effort and group cooperation aid the knowledge creation process? Whilst this does not form the crux of the study, it is however still important to mention because group-work as part of DSS, especially in form of collaboration or competition, is beginning to assume very important place.

4.5 DSS INFORMATION/KNOWLEDGE SYSTEM

The three cardinal elements of a decision system – intelligence, design and choice (Simon, 1977) offer the simple view of what happens within DSS. DSS either function as a learning enhancer for the purpose of improving outcome (choices), or as an explicit choice generator

(Wessel, 2006). The basis of either would be the quality of information available, whether it is historical information, referential, research based or from the experience of the modeler. It is pertinent to state here that the optimization objective of a DSS is borne from a set of described criteria which bound the decision process. Arriving at the criteria for optimization is therefore a necessary step in the DSS process, as it indicates the proper recognition of what the problem dimension is, and the description of what needs to be addressed to arrive at an optimized outcome.

Information has a diverse history, and in the context of DSS, it might be better to represent the general notion of information as knowledge base creation. Decision support is basically about using information, which is refined into knowledge, for making better informed choices and achieving better outcomes. As an analogy, the English football team was looking for a new manager for the national team. To achieve the objective of finding a manager "that can deliver results", the decision makers (modelers) have chosen to adopt a search strategy that "avoids the mistakes of past managerial appointments" (Barwick, 2007)[2]. This again further illustrates the learning requirement of the DSS process. The strategy adopted by the English football association (FA) involved extensive consultations with people considered to be experts in the subject domain of soccer. This provides the information that is a basis for the model to be used to aid the decision effort. In (Turban et al., 2007), a further reflection on the knowledge base aspect of a DSS is done, categorizing it as a process-wise venture delineated into the 4 stages of:

a. Knowledge elicitation
b. Knowledge fusion
c. Knowledge base coding (or modelling)
d. Testing and evaluation

Knowledge elicitation and fusion are very important ingredients into the model. The model is the primary generator of the optimized choices or alternatives that are the products of the DSS cycle.

4.6 DSS MODELLING

A model for decision support is a template upon which decision variables are applied so as to derive an optimal result of how certain tasks should be carried out. The objective of many decision support systems is to optimise processes and practices in some ways. This is usually achieved by using techniques like Fuzzy sets, Bayesian nets, mixed integer programming or linear programming to derive better outcomes for a chosen task or activity. However, for decisions that have multiple criteria, then pure optimisation as an objective would be difficult to achieve, because some of the criteria could be contending and conflicting. A better way would be to attempt to achieve a satisficing solution (Simon, 1957). The Nigerian energy scenario is such a case. A decision support system for energy generation would have as criteria the requirement to maximise energy output, to maximise the spread of energy resources used, and to minimise costs. A satisficing solution for a decision model would be one that fits the needs of all the contending criteria as best as possible.

Several modelling tools may be applied in building a decision support system. A lot of research in model building has been done by the International Institute for Applied Systems Analysis (IIASA) but mostly in the area of environmental decision making. The philosophy of model creation that is stated in many of the IIASA research is still relevant to non-environmental decision planning like electric energy generation. One such relevant element of the IIASA models is the description of a reference point for decision support evaluation. The reference point is a quantitative value that serves as the intuitive basis of what the objective outcome of a

[2] Culled from the internet site www.soccernet.com/insight, accessed 17 December 2007.

decision model should be (Wierzbicki, 2000). For a decision question with multiple criteria, it might be impossible to achieve the reference point value, and so alternative values called the utopia and nadir values are plotted. The utopia value is the result value closest to the reference point, while the nadir value is the value furthest away.

A number of modelling tools and modelling techniques are employed to resolve the optimisation problems that most decision support systems are designed to answer. Many of the tools try to accommodate the fact that the decision is ultimately the responsibility of the decision maker. Hence, many of the tools have a graphical interactive interface that allows for the capture of the intuition and preferences of the decision maker with regards to parameters that impact on the outcomes of the model. However, the parameters may also be specified in non-graphical format, by use of text files, XML, or other data-carrier formats. The important principle is that the decision maker's inclinations are incorporated into the model, and affect the outcome

4.7 MULTI-OBJECTIVE CRITERIA MODELLING

A basis for dimensioning decision models that would be suitable for this discussion is the expected outcomes resultant from the model. The classic decision optimisation formula is:

$$y = f(x) \qquad x \in Xo$$

The outcome y represents a result of variable choices x belonging to the set space, Xo. Criteria can be introduced into the objective space to frame the possibilities of outcomes, in line with the principle of bounded rationality. This formulation reduces very elegantly under linear computation to a bounded valuation that satisfies the mathematical condition, resolving into a model

$$y = f(x) \in Rn \quad y \in Rm$$

where Rn and Rm are sets of bounded possible variables and outcomes.

However, most decision problems cannot be reduced directly into such basic notations. The reality of decision making is that a number of considerations, machinations and interests need to be accommodated in arriving at a choice. Assigning criteria for outcomes would result in the composition of a unique set of possible outcomes

$$q = y \;\; q \in Q \;\; y \in Rm$$

Outcome y is a member of Rm set of outcomes or output, and the function $Yo = f(Xo)$ is the set of attainable outcomes. However the set of attainable outcomes does not yield the 'best' outcomes. We still need to filter out the optimal set of outcomes for the given decision variables that satisfying our criteria conditions. Therefore, a set of criteria conditions, Qo is described such that Qo is a subset of the Yo space, and outcomes q are achievable by a function $q = F(x)$, and $Qo = F(Xo)$:

$$Qo \subseteq Yo, \;\; q = F(x) \text{ and } Qo = F(Xo) \;\; \text{given } q \in Qo$$

For business and institutional choices, multiple criteria would usually influence the way and manner in which decisions are reached. However, there is usually no systematic method of assessing and reviewing these criteria in the decision making process. Even in the context of Herbert Simon's work relating to the decision making process, a lot of the process still depends on the internal machinations of the individual decision maker – how he/she is able to interpret and internalise the framework posited by Simon. The complexities of the present day organisations and the complexities of the decisions that need to be made means that a subjective, 'per person' basis of decision making, though largely effective, poses grave risks. Again, in the context of the principle of bounded rationality, the decision variables that confront today's decision makers have grown too large to be fully comprehensible to a rationale being.

The criteria that seek to cushion the jagged boundaries of decision variables are themselves complex. Were decisions based on single criteria, the requirements for a support system would seem tenuous. However, modern day decisions are multi-criteria-ed, meaning that there are a number of contending (and sometimes conflicting) decision variables requiring optimisation. Multi-criteria decision problems are more or less the norm, and extensive research is already available that addresses much of the problems in the subject area. To accommodate the variations in criteria setting, and to improve the chances of an acceptable optimal outcome selection, the pareto optimal principle of assigning a range of acceptance bounded by a utopia and nadir point is adopted. Extending the earlier basic formulation, a multi-criteria decision problem could be represented as:

$$Outcome\ q = \sum_{i=1}^{k} \frac{qi - qilo}{qiup - qilo}$$

Where qilo and quip are the nadir (low) and utopia (high) points of the possible outcome set Q.

The objective is therefore to use research and literature to describe a methodology premised on this principle which is feasible for energy generation decision support.

An important feature of decision support systems is the interface presentation (Bai, 2003). Multi-criteria decision would perhaps yield more than one single optimal outcome, which would be ordinarily seen as a conflicting problem (Wierzbicki et al, 2000). However, an interactive approach allows the decision maker to constantly tweak the combination of decision variables supplied, hence improving the understanding of how best the model, and by extension the decision problem should be resolved. DSS interface is therefore a fundamental element of the overall system, and our approach will be a review of interface modelling for multi-criteria decision support as it exists in literature, and the most critical aspects of an interface that is best suited for the research question.

The multi-criteria scenario of the decision system under consideration raises the question of how best to arrive at a satisficing outcome for the modeller. Modelling techniques would normally seek to arrive at an optimal outcome (Korhonen and Wallenius, 1990). Optimality is subjectively defined, depending on what modelling philosophy in literature is being considered, but an interesting take on optimality is that proposed by Makowski, Wessel and Wierzbicki (Wierzbicki et al, 2000) in which the modelling outcome seeks to achieve *Pareto optimality.*

A pareto optimal outcome for a multi-criteria decision scenario is defined as the outcome of an objective for which no better (or more optimal) solution can be achieved for a decision variable without degrading the optimal outcome of some other objective. In notational form, this can be denoted (again) as:

$$Solution\quad s(q,\alpha) = \sum_{i=1}^{k} \alpha i \frac{qi - qilo}{qiup - qilo}, \quad \alpha i \geq 0, \quad \sum_{i=1}^{k} \alpha = 1$$

, where α is a scalarising coefficient

Pareto optimality can be attained, model wise by first defining the objective functions that bound the multi-criteria space, and associating reference point values to the criteria. A large portion of our subsequent discourse will surround techniques and strategies of achieving pareto optimality for the application areas we will subject our emergent model to.

The reference point allocated to a given criteria owes much to the intuitive component of the decision making process. Recall that the overriding objective is to achieve an efficient outcome – be it by way of a maximisation or a minimisation. It therefore follows that as a baseline, the modeller would possess a conceptual appreciation of the domain to which the decision problem belongs. This would serve as a starting point from which the model can be used to simulate outcomes which, theoretically, should improve with every parse.

An earlier intention was to identify the aspects of the energy generation decision problem that could be optimised, and to show how an optimising algorithm can achieve better results. However, a good DSS should not operate on the basis of trying to fit the decision terrain into the model available. Rather, the modelling should follow a graduated process, allowing for the accumulation and synthesis of knowledge along the way; a further deepening of the intuitive pool of decision makers (or, in the sense of DSS, modellers) towards the end of optimising their perceptions of what is best for the particular decision process. The philosophy aligns with the theory that a DSS should primarily function as a learning tool for the modeller, wherein the understanding of a system can be widened and deepened, with a culmination in better quality choice alternatives being posited by the DSS (Nakayama, 1994). There is an alternative school of thought, which suggests the a DSS should focus exclusively on making different choices available to the modeller, with the assumption being that the modeller should be well versed within the context of operations of the current system (Keeney, 1992). This is a somewhat older school, and is better suited for decision types that are generic and repeatable – a form of automation of sorts. DSS for energy generation might in some regards fall under this school, since it could be argued that infrastructure development for energy purposes should adopt a repeatable model, once an efficient mechanism is agreed. However, the dynamics of the energy world is ever-changing, and with the realities of the current energy resource crisis brought about largely due to the booming economic growth in China and relative instability in the oil producing regions of the Middle East and Africa, it means that core resource base of energy generation is always in question, and 'automation' might be inimical to the flexibilities that a learning culture engenders. Our approach will be to find some middle ground between the two ideologies – an automated generic base upon which a more flexible, learning inclined series of processes will be anchored to yield a functional and case specific DSS. Indeed, from literature we find that progressive DSS modelling flows from substantive modelling tools, which are described as generic all-purpose solvers, to preferential modelling tools, which are more specific to the needs and requirements of the immediate environment, and modeller (Wierzbicki et al, 2000).

To revisit Herbert Simon's much vaunted "satisficing theory", which is a word-play with the two words 'satisfy' and 'suffice', decision making in organisations aims at reaching an outcome that is acceptable. The concept leans on the theory of bounded rationality, which states that humans have a limited capacity to assimilate and process all factors that can be considered in reaching some decision or conclusion. Rather than attempt to review and satisfy all possibilities, rational possibilities are highlighted, within the cognitive limitations of the decision maker, and these are targeted at for optimisation. In summary, it can be stated that:

a. Optimisation of decisions, especially in the face of uncertainties, is very difficult and requires support using models
b. Decision models do not replace decision, they only enhance the quality
c. Multi criteria models create conflicts of interest; the conflicts are best resolved by settling for satisficing rather than optimising solutions.

4.8 MODEL APPROACH

As mentioned in chapter 2, DSS for industry application are abstractions of real world problems, and hence are generally more complex to formulate than purely mathematical puzzles. It therefore would be difficult to reduce the problem definition to single criteria form and address with straightforward mathematical formula. Various criteria would emerge from discussion and reflection. To fully represent all such possibilities, a multi-criteria approach would be most suitable. Multi criteria problem resolution using DSS is a subject area with excellent resources, particularly within the research body International Institute for Applied Systems Analysis (IIASA). There are available models and theories of approach that, with modification, are applicable for suggesting a framework that addresses the problems identified within this research. One such utility is the Multi-Criteria Model Analysis (MCMA) program, which supports the use of multi criteria specification as a complex objective for solving optimization problems. Interface design is an important aspect of a DSS as the interface motivates the nature and basis of communication between man and machine (Bai, 2003).

An interface supporting multi-criteria systems should therefore have elements of accommodation for multi-criteria interaction. The Interactive Specification and Analysis of Aspiration based Preferences (ISAAP) is a generic DSS interface that affords the modeler the ability to test different criteria combinations dynamically and reflect on the outcomes of the combinations in real time.

The AMPL mathematical modelling language (short form of "A mathematical programming language"), allows the translation of mathematical model notation into a formalized program expression that can be resolved using an LP or non-linear solver (Fourer et al, 1993). Mathematical programming is a technique for solving problems involving maximisation or minimisation, subject to constraints on resource, capacity, supply, demand, and such other criteria. AMPL is a language for programmatically specifying such optimization problems. It provides an algebraic notation that is very close to the way that you would describe a problem mathematically, so that it is easy to convert from a familiar mathematical description to AMPL.

The selection of AMPL as utility for describing the core model of this study is borne out of the ease of translation of the mathematical expressions defining the problem into an equivalent program expression. To follow the premise of Wierzbicki, the pattern of DSS construction flows from a constructive model design to a preferential model design which is then subject to the intuitive and experiential manipulation of the modeler (Wierzbicki, 1997). In that guise, the constructive model (core model) will be described using AMPL.

Ultimately, the goal will be to describe a generic model incorporating as many energy sources as can be motivated from available resource information, at minimal energy generating cost and with maximum energy output levels; and secondarily to accommodate various combinations and a scenarios of energy source, expenditure level and output targets as suits the particular intentions of decision makers.

4.9 METHODOLOGY

The methodology adopted for evaluating the project problem and prescribing a solution to the problem stated in the previous section adopts as much as is possible the precepts for a scientific research as described by Christian Dawson (Dawson, 2005). For our specific task, the problem domain lies within the field of computer science, but it can be seen from the review of literature that the application domain of decision support systems cuts across many subject and industry areas.

A case study review of energy decision support models and other industry decision support models is done to establish the process and important aspects of a DSS for energy generation.

Information and knowledge gathering is done from review of internet sites and publications on energy generation, decision support systems and on the state of Nigeria energy infrastructure. Of particular use is the Nigeria statistic bureau website (http://www.nigerianstat.gov.ng). Request for information was submitted to the statistics website, and the feedback was used to formulate the data tables that were used as input for the AMPL model. The gathered information is then used to motivate an objective function for energy generation, and to describe the constraints surrounding the objective. The model for the solution of the function is described using AMPL, and the data is formatted in AMPL format. A hypothesis is described using the AMPL model as its basis, and then the AMPL program is run and the outcomes are compared with the null hypothesis. The result is analyzed and compared with prevailing performance information on energy generation and resource utility, and based on the analysis the hypothesis is accepted or rejected.

5 CHAPTER FIVE: CASE STUDY AND EXPERIMENT

5.1 THE NIGERIAN ENERGY SITUATION

The national grid electric energy network is currently serviced by 11 principal generating platforms as follows:

PLANT	REGION/ NUMERIC DESIGNATION	GENERATING SOURCE	ENERGY PRODUCTION (Maximum) MW
Egbin	Lagos/7	Gas powered thermal	1320
Sapele	South-South/3	Gas	1020
Ughelli	South-East/2	Gas	930
Afam	South-South/3	Gas	710
Ijora	Lagos/7	Gas	60
Oji	South-East/2	Gas	30
Jebba	North-Central/4	Hydro	760
Kainji	North-Central/4	Hydro	570
Shiroro	North-Central/4	Hydro	600
Lagos Barge (AES)	Lagos/7	Gas	170
Abuja IPP	Abuja/8	Gas	30[3]
			6200

Table 5-1: Electric energy generating capacity in Nigeria (2006)
Source: Nigeria Statistics Bureau website

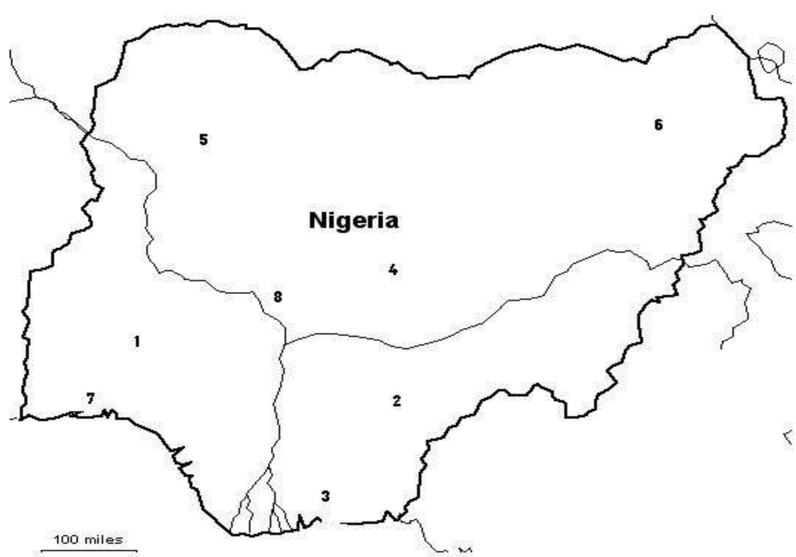

Figure 5-1: Map of Nigeria

[3] Output figure for the power station subject to debate, as various references list output ranging from 30MW to 450MW. Current estimate accepted as valid owing to consistent validity of other information from same source.

Source: Google images

There are eleven (11) electricity generating installations servicing the national energy grid in Nigeria, with a combined energy outlay of 6200MW. However, the stations do not produce at maximum output on account of infrastructure failure, unsustainable management practices, and in some cases, economic sabotage.

The combined output from the stations still fall short of the effective demand estimated at over 15000MW. Some of this shortfall is met by informal electricity generation using backup generating systems running on diesel or petrol fuel. It is estimated that a total of 1000MW is generated via this means. The still very large shortfall in energy demand/supply is lost to unproductive downtime.

The pattern of energy consumption is such that a very large percentage of the demand is concentrated within the Lagos Region, with a current requirement that is estimated at being larger than the entire national capability. This pattern of consumption owes a lot to the industrial, commercial, and financial mix of industries within the region. It is a fact that economic and industrial activity in Nigeria is largely concentrated within the region.

An effective model for energy generation should see generating stations as close as is feasible to the point of usage (or in this case, distribution). This would then form the building block for an integrated grid connection between the different generating systems located in different regions.

The energy strategy document for Nigeria states the requirement to diversify energy sources away from the primary sources of gas and hydro-power (Nigerian Energy Policy, 2003). There is already a proposal for the establishment of nuclear power stations in Lagos (Region 7) and Ondo (Region 1), and also a study of the possibility of reactivating energy generating capacity using coal and coking oil as source.

Furthermore, studies into the potential for wind energy generation shows wind speed aggregates that should sustain reasonable and commercially feasible energy outputs in the North-Central and North-Eastern regions of the country.

Aside from enhancing national grid capacity, there is also research into the potential for small hydro-power (SHP) energy generation. In total, about 270 potential sites have been identified, and whilst the mobilisation and allocation of capital for exploiting this resource will not be covered in this study, a systematic review of the processes required to translate this potential into reality could form the basis of subsequent research.

Following is a schedule of ongoing (and soon to commence) electric energy projects. As a hypothetical case, the study includes energy generation using nuclear as primary fuel source. While this is outside the schedule of actually deliverable energy content, the study projects that the plants will come on-stream in the near future, as it is a bedrock of energy resource diversification embedded in the country's energy policy document.

PLANT	REGION/ NUMERIC DESIGNATION	GENERATING SOURCE	CAPITAL COST (million $)	ENERGY PRODUCTION (MW)
Omotosho	South-West/1	Thermal (Gas)	170	335
Papalanto	South-West/1	Thermal (Gas)	170	335
Ibom	South-South/3	Thermal (Gas)	100	70/240
Mambilla	North-West/6	Hydro	3500	2600
Alaoji	South-East/2	Thermal (Gas)	148	300
Geregu	North-Central/4	Thermal (Gas)	195	414
Ondo Nuclear[a]	South-West/1	Nuclear	1400	1000
Lagos Nuclear[a]	Lagos/7	Nuclear	1400	1000
Omoku	South-South/3	Thermal (Gas)	100	100
Egbema	South-East/2	Thermal (Gas)	N/A	175

Eyaen	South-South/3	Thermal (Gas)	N/A	250
Calabar	South-South/3	Thermal (Gas)	N/A	250
Gbara Ugbie	South-South/3	Gas	N/A	125
TOTAL			7183[c]	6954[b]

Table 5-2: Ongoing Energy infrastructure development in Nigeria
Source:
[a] All values for nuclear power are estimates (Source: IAEA, 2005)
[b] The value reduces to 4954MW without the nuclear energy.
[c] Total figure excludes investment for four projects. Actual investment amounts for these unavailable.

The time-lines for the completion and commissioning of some of the new generating stations have already been missed, and projections as to cost of completion have also been over-run. These issues are critical to plans for future project undertakings, but the reasons for budget and time over-runs will not be investigated in this study. Suffice to say that the occurrence of such is symptomatic of existing shortcomings in the planning, and probably decision making that defines project scope, cost and time-lines.

The energy diversity that should be achieved should capture energy from as many sources as possible into the grid. Energy diversity varies from country to country, depending on resource availability, local cost of resource, technology sophistication, and constitutional and legislative regulation (Energy information administration, 2007). A review of the energy mix for the USA using 2006 data reveals the following distribution:

SOURCE	**PERCENTAGE (%)**
Coal	49
Gas	20
Nuclear	20
Hydro	7
Other Renewable	2
Other	2

Table 5-3: Percentage Distribution of Energy sources in USA
Source: Energy Information Administration, US Department of Energy

Whilst the dynamics of the energy market for USA, a well developed energy market, are different from those for Nigeria, it still offers a template for the distribution of energy sources, motivated as it is by the cost of production, long term availability of resource, and efficiency of production process.

An interesting point to note from the distribution of energy sources for the USA is the fact that coal accounts for a very high percentage of electric energy generation. This underscores the fact that availability of energy resource in its raw form can motivate the extent of its utility, irrespective of the higher efficiencies attainable using other sources. The United States has the world's largest coal reserves (over 27 % of world total) and therefore the high rate of utility of the resource is logical, despite its higher carbon content and lower energy density when compared with gas (Fisher, 2003). This philosophy in approach shows the variations in considerations that might occur from country to country, when considering the strategic best approach to securing energy sustenance.

Present day resource distribution for the available energy capacity in Nigeria is as follows:

SOURCE	***PERCENTAGE***	***REFERENCE PERCENTAGE***	***UTOPIA PERCENTAGE***	***COST PER KWh ($)***[a] ***(International Estimates)***
Gas	60	40	50	0.105
Hydro	40	30	50	0.042
Coal	-	20	25	0.058
Wind	-	2	10	0.084
Solar	-	3	15	0.168
Nuclear	-	5	15	0.064

Table 5-4: Energy generation mix for Nigeria
[a] Estimates source: Energy Information Administration, US DOE

Unit cost per resource is limited to the actual turbine to electricity conversion costs, and precludes the site specific construction and developmental, and also transmission and distribution costs that forms the bulk of investment. We estimate that unit cost per resource constitutes about 30% of total energy infrastructure cost.

5.2 ANALYSIS AND PROBLEM DIMENSIONING

Current generation pattern shows absolute reliance on gas and hydro power as main sources. However, generation patterns studied over the course of this research shows a high degree of obstruction and failures in gas supply to the generating plants on account of political volatility in the South-south region of Nigeria. In addition, hydro power generation is affected by the seasonal variations in rainfall and river water levels. Low rainfall periods coincide with reduced river levels and therefore reduced reservoir holding for powering electricity turbines. This fact, while of incidence, is of no primary concern to the study. What it underlines is a requirement for greater diversity in energy resource for electricity generation, to at least mitigate the impact of a disruption to supplies from one source.

The relatively high commercial costs for unit generation of electricity notwithstanding, the very abundant availability of oil and gas locally makes it a primary choice as a resource for energy generation. Coal, in its lignite form, is also an option, and was an energy generating resource of great importance until the discovery of huge oil and gas resources in Nigeria in the late 1950s. The potential for its revival as an alternative resource persists, as coal reserves still exist in the south-east and north-central regions of Nigeria, with reserves quantification in the regions of 639 million metric tons (Nigerian Ministry of Solid Minerals Development (MSMD), 2006).

In order to motivate the appropriate division of capital resources to energy development projects and undertakings, a revisit of the underlying objectives of the energy question in Nigeria is required.

5.3 DEVELOPING A NIGERIAN MODEL

With the available information, the requirement to increase energy generation output would rest on two planks:

- Improving and sustaining output from existing infrastructure
- Building new infrastructure.

Long term strategic planning normally covers a period not less than 10 years. It could of course be greater than 10 years, but projecting too far into the future weakens the reliability of whatever variables that are being used.

The objective is to attain an immediate energy output of at least 10000MW. The growth expectation is to yield an incremental value of at least 5000MW per year for 10 years. The energy mix objective is to reflect a distribution as detailed in table 5.4.

Demands on a per region basis are expected to follow the current pattern of demand concentration within the Lagos region. However, there was no available data on the growth projections and consumption patterns on a region by region basis. Furthermore, no good data could be gotten on the transfer pattern of energy from generating plants in one region to consumers in other regions. There therefore would be no strong basis for motivating the locating of energy infrastructure at specific regional locations. However, closeness to energy resource can be used as a basis, hence high wind availability in the north-central and north-eastern region, and higher solar energy levels in the north-west would motivate the locating of future plants in these regions.

Infrastructure development cycle varies from energy source to energy source. A gas driven thermal turbine system yielding up to 1000MW can be constructed and made operational in 18 months barring any construction delays. A nuclear power plant is a longer term development undertaking, requiring upwards of 7 years to bring online. Infrastructure costs are higher for nuclear systems than fossil based systems, but fuelling costs are more manageable and not subject to market volatility. Both nuclear and gas power plants have high potential for environmental degradation, which as a factor should count against their acceptability. This is not a disadvantage with hydro powered systems, which are more environmentally friendly, but also have some ecological impact which could include loss of agricultural land. Hydro power is also seasonal, and might better serve to shore up energy generation during peak demand rather than as the primary energy source. The earning coefficient of the power plants, and the multiple utilities to which it could be put (i.e. electricity, heat and desalination functions carried out centrally) (Weber, 2006) is beyond the scope of this study – a basis for motivating fund allocation is the narrow intention.

The objective function is to maximise output of a given period such that new production should increase total production by a factor, or by a constant value:

$\textit{Maximise Output}: \sum_{i=1}^{n} Cxi \quad x \in Xo$, where Xo is the set of possible energy sources (i.e. gas, hydro, nuclear, etc)

Possible criteria for determining how to arrive at the total outputs include:

- The assigned ratio distribution of energy resources.
- A set limit of how much of a particular energy resource should be developed
- Prevailing cost of generating energy using a particular source

5.4 PROBLEM CONSIDERATIONS

The study has so far identified a major area where decision support can help in improving energy efficiency. The study has also determined the energy resources that can potentially help to achieve this. The study has identified the investment that is required (from literature) to achieve good energy generation capacity for the country. The study has stated the ideal energy generation capacity (15,000MW per annum). Logically following, an objective function for the study is defined, and a hypothesis to be tested is stated.

5.4.1 PROBLEM STATEMENT

The available information shows an energy capacity of 6200MW. Further information shows that up to 6954MW could potentially be added to that value. To take an average, this is approximately 875MW per year for the period between 1999 and 2007. This falls short of the target of at least 5000MW energy increase per year required to meet the strategic expectations of the country. Also, resource allocation of an estimated $10 billion over the 8 year period does not yield the maximum output possible at current costs of energy infrastructure development. The intention is:

a. To increase energy production by a factor of at least 5000MW per annum
b. To maximise the energy return from the amount that is invested
c. To abide to some energy source ratio of distribution (see table 5.4 for a suggested ratio pattern)

5.4.2 OBJECTIVE FUNCTION

The objective of the model would be to:

1. Maximise energy output at the recommended mix.
2. Minimise cost per unit output
3. Maximise investment/generating output ratio

Further considerations would include:

1. Minimise environmental impact (carbon, sulphur and other pollutants)
2. Maximise long term sustainability

5.4.3 HYPOTHESES

The following hypotheses are postulated for the experiment carried out using the AMPL model:

Null Hypothesis (H_0): The AMPL modelled DSS for energy generation yields an infeasible and inefficient energy generation outcomes compared to historical practices for improving energy generation.

Alternative Hypothesis (H_1): The outcomes of the AMPL model are not inefficient.

5.5 INSTRUMENTATION

The criteria and objective functions are defined as objectives and constraints in the AMPL model file *"energy.mod"*. The energy resource types are described as members of the resource set, and the annual energy increase amount (5000 MW) is parameter limit of the objective function.

Data from tables …., are used to describe the data set in the file *"energy.dat"*. The ratio distribution for energy is captured, as a reference point, while optima and nadir ratio values are intuitively assigned. The values can be changed subject to the modeller's intentions or expectations.

From AMPL program was set up on a regular Pentium IV computer with 512MB RAM and 4.2GHz clock speed.

5.6 THREATS TO RESULT VALIDITY

The following threats to the validity of the experiment are listed as follows:

1. Use of fixed unit price of energy per resource: The unit price of energy generated per resource is subject to market volatility. For instance, the price of oil has increased

astronomically over the past year, and this could have an influence in the efficiency of investment compared with energy returns. In addition, the unit cost is only one function in overall cost of any type of resource, so a better mechanism for costing would include the fixed costs for the different resources.

2. Selection of parameters affecting decisions. The primary criteria were cost of investment and availability of resource but the multi-criteria of environmental suitability, long term sustainability, and other criteria would better motivate the model.

6 CHAPTER SIX: EXPERIMENT ANALYSIS AND CONCLUSIONS

6.1 RESULTS

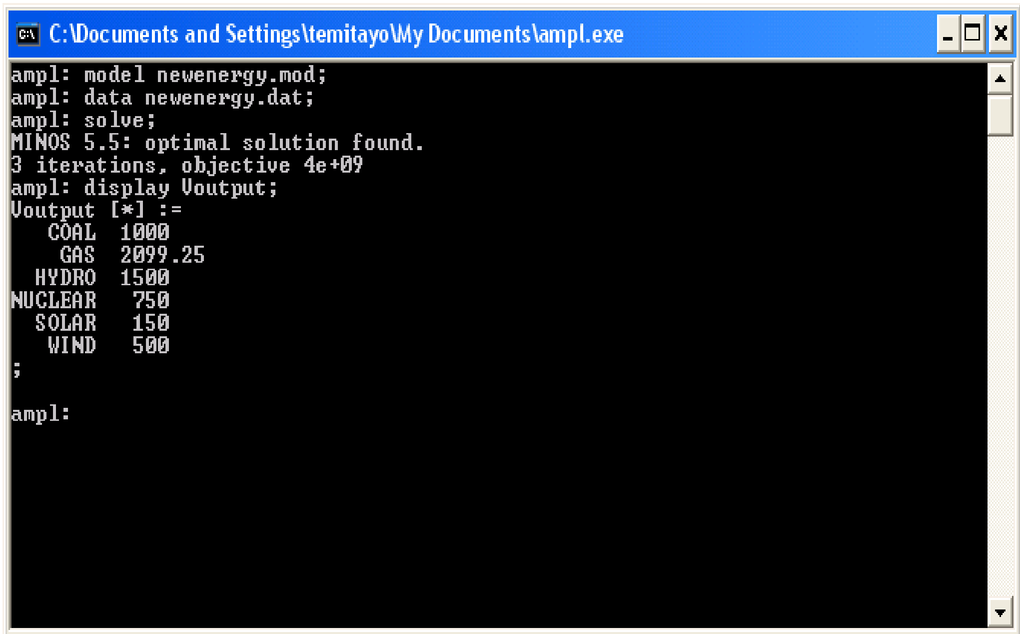

Figure 6-1: Screenshot of program output

Following are the results of one run experiment:

ENERGY RESOURCE	**REFERENCE (MW)**	**POTENTIAL (MW)**
Gas	2000	2099.25
Hydro	1500	1500
Coal	1000	1000
Nuclear	250	750
Wind	100	500
Solar	150	150
Total	**5000**	**5999.25**

Table 6-1: Results of Experiment

6.2 ANALYSIS

The potential values suggested by the model are better or at least equal to the reference point values intuitively assigned by the reference ratio distribution. This satisfies the condition for pareto optimality. The values gotten are also feasible and within the investment amount available for energy generation. Since the amount of energy that is created for the investment amount of $4 billion is at least as much as the reference energy amount of 5000MW, then the null hypothesis is rejected. A model developed using AMPL does not compute infeasible energy generation figures for selection by decision makers.

From the results of the experiment, it is seen that an optimised solution can be derived for the energy generation question using the AMPL model approach as tool for decision support.

However, the multi-criteria component of the model will be better appreciated by interchanging between objective functions and criteria. The first objective of maximising energy output at a given cost can be interchanged with the objective to minimise the ecological impact for the given investment outlay. For such a scenario, the model's primary objective would change to focusing on the environmental impact of the different energy resources instead of the cost of energy production.

A third alternative from the multi-criteria options in 5.4.1 could be to build the model around the objective of long term sustainability of the energy resource. In this third scenario, the objective would be to optimise energy generation with resources that have longer term availability and renewability potential as opposed to optimising primarily for reasons of cost. The changes to the model would require changes to the structure of the input data, as follows:

ENERGY RESOURCE	ENVIRONMENT-FRIENDLY RANKING	AVAILABILITY RANKING	PERECENT - ENVIRONMENT	PERCENT - AVAILABILTY
Gas	4	1	15	30
Hydro	3	2	18	20
Coal	5	4	10	15
Nuclear	6	6	5	5
Wind	2	5	20	10
Solar	1	3	30	18

Table 6-2: Ranking Alternative Objective for the DSS

6.2.1 RANKING ANALYSIS

The environmental impact of various energy resources has been extensively discussed and reviewed (Janssen, 2003) and the environmental ranking is a result of a review of literature on the subject. Solar energy is totally compliant environmentally; it is silent, it requires no fuel, it is natural occurring and it does not carry pollution overhead. However, it is still about the most expensive energy resource to harness. Wind and Hydro energy are both natural occurring, but both require extensive land and water resources (respectively) to implement, with some ecological impact. Wind energy also is criticised for high fatality consequence it has on avian wildlife. Both resources however carry negligible environmental pollution overheads, and do not account for the bludgeoning green house effect experienced worldwide. Gas and coal have relatively high carbon overhead and hence are major contributors to increasing environmental carbon content and green house escalation. Nuclear energy is silent and efficient in controlled environment, but the resultant wastes have a harmful radioactive lifespan running into thousands of years.

The availability ranking is based on the natural occurring abundance of the various energy resources within Nigeria. The country has abundant reserves of oil and gas, and sizeable reserves of coal (MSMD, 2006). The country has substantial hydro resources, and within its boundaries is located the confluence point of two major African rivers – the Niger and the Benue. There is therefore a huge reservoir of untapped hydro-electric power, probably second only in potential in Africa to the Rift Valley and Congo basin energy potential of East and Central Africa. There exists also year long sunlight in the northern Sahel region of the country, and relatively stable wind conditions in especially the central region and, to a lesser extent, the coastal region of the country. Nuclear availability potential is ranked lowest on account of the relative infancy of the industry in the country, and the non-availability of the high technology that is needed to harness that energy option.

6.2.2 RESULT OF ALTERNATIVE RUN

ENERGY RESOURCE	REFERENCE (MW)	ENVIRONMENT (MW)	AVAILABILITY (MW)
Gas	2000	652.32	1304.63
Hydro	1500	1956.95	2391.82
Coal	1000	787.28	1180.92
Nuclear	250	356.74	356.74
Wind	100	1087.20	489.24
Solar	150	815.40	543.60
Total	**5000**	**5655.89**	**6266.95**

Table 6-3: Output of alternative DSS run

The results show still efficient outcomes for the amounts invested in energy supply with an emphasis that is slightly different from when investment is optimized at fixed ratios for the energy resource, as with our primary analysis. The total figures that are suggested by the model for the environment run and availability run both have higher energy yields than the reference totals which were sourced from the Nigerian energy commission. As has been stated before, the approach to adopt in running the AMPL model, and the emphasis of a given resource over another is primarily the responsibility of the decision maker, but the decision support model should offer optimal results for whatever model configuration the decision maker might consider.

6.3 FURTHER RESEARCH

There is obvious value in the use of DSS for motivating business decisions especially where there is high amount of investment involved. The choice of modelling strategy, and modelling utility that is selected should help to reduce the level of technical requirements that is needed to use the DSS system. The AMPL approach requires practice and mastery of the use of AMPL and the various solvers that can work with it. The interface for AMPL is command line driven, although there are now GUI based variants of the utility. More user-friendly and user-centric models that have allow interactive dialog with modeller/analyst to achieve the same functionality would improve the solution.

The selection of the criteria, and the switch within a decision process from criteria to objective would enhance the multi-criteria capabilities of the model. Further work might also explore alternative tools like MCMA for preferential modelling, as what as been done within this study may be viewed as a substantive model.

The modelling effort is limited to the question of energy generation, but a comprehensive energy model would have to deal with transmission and distribution to fully serve the decision making purpose. This area also has a lot of possibility for further research.

6.3 CONCLUDING REMARKS

Decision support systems are assuming a bigger and more critical role in business decision making and resource management.

From the examples in section 2, a DSS approach to solving problems must begin with an in-depth analysis of the problem domain, as was done in designing the German energy model (Schmitz and Schwefel, 1977). As such, the decision making is premised on the synthesis of data and information; such synthesis being achieved using an optimising or satisficing model. The AMPL tool, because of it easy to grasp and very amenable to the parameters and variables of the energy decision model, offers a quick-to-learn and deploy tool for achieving the optimisation goals. Overall, this study has presented a template of how to use DSS in energy infrastructure development in an emerging economy; such a template could be further extended using different tools and technology resources to create models for support in other inefficient decision areas of emerging nations such as Nigeria.

In summary, the study has shown how an efficient and diversified energy generation capacity can be attained by using the optimisation utility, A Mathematical Programming Language (AMPL), to build an energy model that accommodates the different criteria and constraints that affect decision making when planning to invest in energy capacity expansion.

In addition, the study tests the model under the scenarios of availability, environmental consideration and resource sustainability to see how well the model recommendations compare with the default state of affairs as regards energy generation in Nigeria. The results from the test show that the model generates values that are better that the default state and would serve as a good decision support resource.

APPENDIX A: AMPL MODEL SCRIPT

```
# ================================================
# NIGERIAN ENERGY: Energy Infrastructure Model
# ================================================
    # Source:  "Decision Support for Multi-Criteria Energy
    # Generation Problem" by Temitayo Arikenbi
# --------------------------------------
# SETS
# --------------------------------------
set plant;                          # Distinct energy plants (old and proposed) generating electric energy

set newplant within plant; # Proposed new plants to be built to extend infrastructure

set explant within plant;  # Existing plants to be maintained, optimised or scaled down

# set region;                       # Regional delineation for administrative purpose

set output;                         # Productive unit of energy generated

set resource;                       # Energy source for the different plants

# set investment;                   # Investment blocks and sources allocated to energy infrastructure

# --------------------------------------
# PARAMETERS
# --------------------------------------
param enerprod {j in resource,  o in output} >= 10;        # minimum qualification of 10MW capacity

param annualmin;                                               # minimum annual
increase in energy output

param ratio {j in resource};                                   # reference amount
of energy per resource

param upp_lim {j in resource};                                 # nadir ratio value

param cost {j in resource};

param mwconverter;                                             # to convert MW to
MW hours

param totalresource > 0;                                       # total annual
investment amount

# --------------------------------------
# VARIABLES
# --------------------------------------
var Voutput {j in resource} >= ratio[j] * annualmin, <= upp_lim[j] * annualmin;

# --------------------------------------
# OBJECTIVE
# --------------------------------------
maximize Investment  : sum {j in resource} Voutput[j] *  cost[j] * mwconverter;

# --------------------------------------
# Constraints
# --------------------------------------
subject to invlimit:
      sum {j in resource} Voutput[j] *  cost[j] * mwconverter <= totalresource;

#subject to tlimit:
#     Production >= annualmin;                  # minimum total output requirement is met
```

APPENDIX B: AMPL DATA SCRIPT

```
# data for energy.mod

data;

set resource := GAS HYDRO COAL NUCLEAR SOLAR WIND ;

# set region := SOUTH_WEST SOUTH_EAST SOUTH_SOUTH NORTH_CENTRAL NORTH_WEST NORTH_EAST LAGOS ABUJA ;

param: cost        ratio       upp_lim:=

GAS 105            0.4         0.5

HYDRO              42          0.3         0.5

COAL               58          0.2         0.25

NUCLEAR 64         0.05        0.15

SOLAR              168         0.03        0.15

WIND               84          0.02        0.1 ;


param annualmin := 5000 ;


param mwconverter := 8760 ;                 # Product of 24(hours in a day) and 365(days in a year)

param totalresource := 4000000000 ;   # Annual investment amount of 40 billion naira (local currency) for current year
```

REFERENCES

Bai, G., (2003), Feedback Principles for Studies of Social Activities, *4th International Conference on SocioCybernetics,* Corfu.

Dawson, C., (2005), *Projects in Computing and Information Systems: A Student's Guide*, Pearson Press.

DoE (ed.), (2007), *Energy Information Administration Annual Report,* Department of Energy Washington DC US.

Dreyfus, H. and Dreyfus, S., (1986), *Mind over Machine: The Role of Human Intuition and Expertise in the Era of Computers*, Free Press, NY.

ECN (ed.), (2003), *The Nigerian Energy Policy*, Energy Commission of Nigeria Publication Abuja NG

FAO/IIASA (ed.), (1993), Agro-Ecological Assessment for National Planning: The Example of Kenya, *FAO Soils Bulletin 67*, Rome.

Fischer, G., Granat, J. and Makowski, M., (1998), AEZWIN: An Interactive Multiple-criteria Analysis Tool for Land Resources Appraisal, *IR-98-051 International Institute for Applied Systems Analysis*, Austria.

Fisher, J., (2003), Energy Density of Coal, *The Physics Factbook*, available online from http://hypertextbook.com/facts/2003/JuliyaFisher.shtml

Fourer, R., Gay, D. and Kernighan, B., (1993), *AMPL, A Modelling Language for Mathematical Programming,* The Scientific Press, CA.

Ginzberg, M., and Stohr, E., (1982), Decision Support Systems: Issues and Perspectives, *NYU Information Systems Working Paper Series*, vol. 82 no. 12, NYU Press.

Gondzio, J., (1997), Presolve Analysis of Linear Programs Prior to Applying an Interior Point Method, *INFORMS Journal on Computing,* vol. 9 no. 1 pp. 73 – 91.

Huang, M., (1999), Lithuania's Nuclear Dilemma, *Central Europe Review Journal,* vol 1 no 9, Aug. 1999

Ibitoye F. and Adenikinju, A., (2007), Future Demand for Electricity in Nigeria, *Applied Energy Journal,* vol 84 iss 5, pp 492 – 504

IIASA (ed.), (2007), *International Institute for Applied Systems Analysis Annual Report 2006,* IIASA Press Austria.

Ikeme, J. and Ebonhor, J., (2005), Nigeria's Electric Power Sector Reforms: What Should Form the Key Objectives?, *Energy Policy* vol. 33 pp. 1213 – 1221.

Janssen, R., (2003), *Renewable Energy into the Mainstream*, IEA Press.

Keeney, R., (1992), *Value-Focused Thinking: A Path to Creative Decision Making,* Harvard Press MA.

Korhonen, P. and Wallenius, J., (1990), A Multiple Objective Linear Programming Decision Support System, *Decision Support Systems*, vol. 6, pp. 243 – 251.

Kraemer, K. and King, L. (1988), Computer Based Systems for Cooperative Work and Group Decision Making, *ACM Computing Surveys*, vol. 20 no. 2, June 1988.

Lahdelma, R., Makkonen S. and Salminen, P., (2006), Multivariate Guassian Criteria in SMAA, *European Journal of Operations Research,* vol. 120, pp 957 – 970.

Lewandowski, A., Rogowski, T. and Kreqlewski, T., (1985), A Trajectory Oriented Extension of DIDAS and its Applications, *Plural Rationality and Interactive Decision Processes*, vol. 248.

Lewandowski, A. and Wierzbicki, A., (1989), Aspiration Based Decision Support Systems, *vol. 331 Lecture Notes in Economics and Mathematical Systems,* Springer-Verlag, Berlin.

Makowski, M., (2000), Modelling Paradigms Applied to the Analysis of European Air Quality, *European Journal of Operations Research,* vol. 122 no. 2.

Markandya, A., Pedroso, S., and Streimikiene, D., (2004), Energy Efficiency in Transition Economies: Is There Convergence Towards the EU Average?, *FEEM Working Paper* no. 89 pp. 121 - 145.

MSMD (ed.), (2006), Nigeria: An Exciting New Mining Destination*, MSMD Mining Journal Special Edition* London

Nigerian Statistics Bureau (ed.), (2007), Nigerian Energy Statistical Information, available online from http://www.nigerianstat.gov.ng

Nakayama, H., (1994), Aspiration Level Approach to Interactive Multi-Objective Programming and its Applications, *Working Paper 94-112 International Institute for Applied Systems Analysis*, IIASA.

Pomerol, J. and Adam, F., (2004), Practical Decision Making – From the Legacy of Hurbert Simon to Decision Support Systems, *Decision Support in an Uncertain and Complex World: The IFIP TC8/WG8.3 International Conference 2004*

Sambo, A.S., Iloeje, O.C., Ojosu, J.O., Olayande, J.S. and Yusuf, A.O., (2006), Nigeria's Experience on the Application of the IAEA's Energy Models (MAED and WASP) for Energy Planning, *IAEA Workshop, Korea Atomic Energy Research Institute, April 2006.*

Schmitz, K. and Schwefel, H., (1977), An Integrated Energy Simulation Model of the Federal Republic of Germany as a Decision Aid for Analyzing and Planning the Energy System, *Proceedings of the 9th conference on Winter simulation*, vol. 1 pp. 202 – 211.

Simon, H.A., (1957), *Models of Man*, Wiley Publishers, NY.

Simon, H.A., (1977), *The New Science of Management Decision*, 3rd ed. Prentice-Hall, Englewood Cliffs NJ.

Tahirov, T., (2005), Energy Reforms in Transition Countries: What Are the Main Problems of Domestic Energy Pricing?, *University of Dundee Press*

Turban, E., Aronson, J., Liang, T. and Sharda, R., (2007), *Decision Support and Business Intelligence Systems*, 8th Edition, Prentice-Hall, NJ.

Weber, C., (2005), *Uncertainty in the Electric Power Industry: Methods and Models for Decision Support*, Springer Publishing, NY.

Wessels, J. and Wierzbicki, A., (1993), User-Oriented Methodology and Techniques for Decision Analysis and Support, *vol. 397 Lectures in Economics and Mathematical Systems,* Springer-Verlag, Berlin.

Wierzbicki, A., (1997), On the Role of Intuition in Decision Making and Some Ways of Multi-criteria Aid of Intuition, *Journal of Multi-Criteria Decision Analysis*, vol. 6 pp. 65 – 76.

Wierzbicki, A., Makowski, M. and Wessels, J., (2000), *Model-Based Decision Support Methodology With Environmental Applications*, Kluwer Academic Publishers Holland.