ADDRESSING THE INHERENT LIMITATIONS OF TRADITIONAL MODELLING FRAMEWORK FOR SUSTAINABLE ENERGY DEVELOPMENT IN A DEVELOPING ECONOMY

Titus Kehinde Olaniyi PhD
Reader in Engineering
College of Engineering
Afe Babalola University
Ado-Ekiti, Nigeria
tkolaniyi@abuad.edu.ng; tkolaniyi@yahoo.co.uk

ABSTRACT
This article addresses the literatures in respect of the inherent limitations of traditional modelling techniques for sustainable energy planning in a Developing Economy (DE). DE are undergoing socio-economic changes in their energy settings - socio-economic policies such liberalisation, financial sourcing and climate change implication of energy projects. This article describes a critical review of the inherent dynamics of Sustainable Energy Development (SED) and reveals the limitations of traditional planning tools such as optimisation, econometric and general simulation models. It argues that traditional approaches are inadequate for SED in the DE due to its inherent weakness in guiding future policy decisions. Optimisation based models may be suited for well-defined solutions, however, the macro-energy scene at a decision support level in most DE do not lend itself to simplified modelling technique that are rooted on past algorithms. Econometric models has seen applications across many economies, sadly, they fail to consider the technological nature of energy supply (production) and demand (consumption) in a rapidly changing DE. Further, they fail to demonstrate the path taken and erroneously assumed conditions of equilibrium for energy planning and policy formulation. This article bridge the gaps in literatures by showcasing the inherent weaknesses of traditional planning approaches and the urgent need to seek an alternative paradigm shift for sustainable energy planning and policy formulation in the DE.

Keywords: Energy, Developing Economy, Frameworks, Optimization, Modelling.

1. INTRODUCTION

Developing Economies (DE) are undergoing complex socio-economic and technological changes in their energy settings. These include energy market liberalisation, sourcing for scare financial resources to undertake complex energy projects, identification of reputable technical partners to deliver energy projects and incorporation of climate change implication on energy projects. In an attempt to reconcile the above dynamics, this article describes the findings of literatures on the subject of the inherent limitations of the traditional planning approaches that have hitherto applied in the developed nations but fails to address the complex dynamics of energy planning and policy formulation in DE. It describes the various applications of modelling as a Decision Support System (DSS) for sustainable energy planning with special focus DE. The paper addresses the methodological approaches, planning tools, framework, and techniques as reported in the literatures of energy planning and policy formulation. The next section of this paper reviews the traditional DSS planning paradigm and stipulates their inherent limitations as the case may be.

2. REVIEW OF TRADITIONAL DECISION SUPPORT SYSTEMS AS A PLANNING PARADIGM

Mintzberg (1973) stated that managerial roles involve Interpersonal, Informational and Decisional roles. Although early information systems mainly support informational roles; however, modern computerised systems can support all the three managerial roles. Turban *et al* (2002, pp. 436) described two phases of manager's decisional roles where Phase I focuses on problems identification and Phase II concerns with opportunities.

Manual attempts at the complex managerial roles are difficult to attain. This is due to factors such as information overload, large number of alternatives, continuous change in business environment, and the need to make quick and urgent decisions. Quality of decision made by energy planners will depend on the information adequacy, availability, options and appropriateness of the modelling effort (Sauter, 1997).

Little (1970) defined DSS as a *"model-based set of procedures for processing data and judgements to assist a manager in his decision-making"*. Gorry and Scott-Morton (1971) define DSS as *"interactive computer-based systems, which help decision makers utilise data and models to solve unstructured problems"*. According to Keen and Scott-Morton (1978), DSS *"couples the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions"*. Alter (1980) argued that DSS should involve active decision by line and staff management for the purpose present and future time horizon. Moore and Chang (1980) defined DSS as an *"extendable systems geared toward future planning and used at uneven and spontaneous intervals with the capability of supporting ad-hoc data analysis and decision modelling"*.

Bonczek *et al* (1980) defined DSS as a *"computer-based interacting component systems consisting of a language, knowledge and problem-processing systems"*. The language system provides communication between the user and other DSS components. The knowledge system is the storehouse of the problem domain. The problem-processing system is a link between the language and knowledge components. Gorry and Scott-Morton (1971) proposed DSS framework based on the combined work of Simon (1977) and Anthony (1965) and stated that decision-making process is along a continuum of highly structured (*programmed*) to highly unstructured (*non-programmed*). Pinson *et al* (1997) discussed application of distributed DSS that integrates distributed decision-making and artificial intelligence in strategic planning. Chuang and Yadav (1997) proposed a conceptually and adaptive DSS as an integrated system.

Barr and Sharda (1997) focus on incorporating longitudinal designs to assess effectiveness of decision quality typically associated with DSS were due primarily to *'development'* or *'reliance'* effects. Reliance effect suggested *'let the computer do it'* while development effect suggests that the DSS assists the decision makers in making informed decisions. Rizzoli and Young (1997) proposed an Environmental Decision Support Systems (EDSS) for modelling categories of users but stated that desirable features are difficult to implement. Brans *et al* (1998) presented a complex and hyper-complex socio-economic structure by combining the principles of system dynamics in controlling system behaviour. Palma-dos-Reis and Zahedi (1999) investigated the feasibility of personalised intelligent financial DSS in terms of users' behaviour in choice making.

3. TRADITIONAL ENERGY MODELLING AND PLANNING APPROACHES

Huang *et al*. (1995) presented literature findings on Decision Analysis (DA) in energy and environmental modelling as a modelling technique under uncertain energy planning and policy scenarios. Eierman (1995) described DSS theory as a model of constructs and relationships that includes users' socio-economic and technological characteristics. Kant (2000) argued that the factors that affect the characteristics include heterogeneity of the users group and their direct dependence. Kleinpeter (1995) stated that depending on the variable of interest, energy models are of three types; namely *'energy demand'*, '*energy supply*' and '*integrated model*'. This paper favours the application of integrated approach that considers energy demand and supply perspectives. Models used in policy analysis are of two categories (Figure 1) - *optimisation* and *simulation* models (Sterman, 1991). Simulation based models can be further divided into three i.e. *General Simulation*, *Econometric* and *System Dynamics Modelling*. The following gives a brief overview of these modelling approaches as identified in literatures.
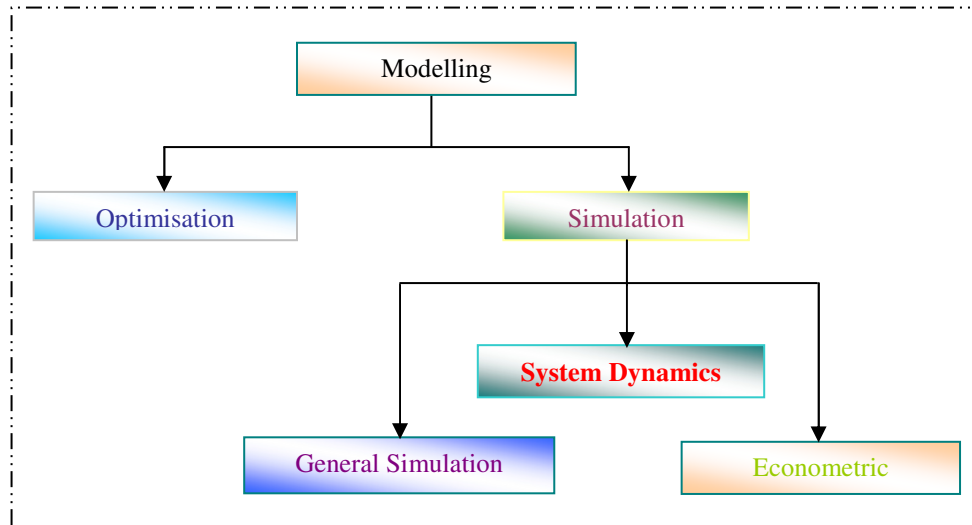
Figure 1 Generic Problem Structuring Modelling (Source: Adapted from Stermans, 1991)

3.1 Optimisation Modelling Approaches in Energy Planning

Optimisations models (Islam, 1997; Matson and Carasso 1999; Suganthi and Samuel 2000) find the optimum (best) way of meeting some clearly defined and specific objectives. It requires accurate definitions of the objectives and the existence of a reliable data bank. Precise definition of objective function requires clearer understanding of the dynamics variable of interest and thus the application of optimisation modelling in the developed nations. Energy demand for each activity in end-use models is the product of activity level (energy service) and energy *intensity (defined here as the energy use per unit of energy service).* Technology switching (old to new) can reduce energy intensity. Substituting technology with improved energy efficiency can occur without affecting the level of energy services delivered as desirable for SED in DE.

Reducing the usage (hours) of a given end-use device of a given power consumption (kW) can result in reduced energy demand (kWh). Wastage reduction and unnecessary usage (*improved maintenance and better control devices*) is an encouraged efficiency enhancement in sustainable energy debate. If the reduction comes from the consumer taking less advantage of the end-use, then the resulting savings is a reduction in the level of energy services this is presently contrary to the argument for SED in DE. A typical example is reducing lighting levels or curtailment of power supplies (*very typical in many DE i.e. Nigeria, Ghana, Zimbabwe, Jamaica etc*).

Malik and Satsangi (1997) discuss how India government attempt estimation of consumer expenditures on energy related products met with difficulties. Das and Banerjee (1995) developed a mathematical model using Lagrange multiplier technique to derive an optimum solution. The authors stated that excess energy supply does not encourage energy efficiency and that technology improvement is responsible for increased demand. However, with increasing energy requirements technology efficiency increases. Islam (1997) developed a multi-level optimisation (MLO) model to study energy issues (i.e. self-sufficiency, conservation, sustainability, etc.) pertinent to Australia's economy and argued that reduced energy usage and technology development of renewable energy as important strategies for sustainable development. Matson and Carasso (1999) stated the choices made amongst energy supply options using models of cost/benefit analysis in a competitive energy market. The model assumed economic rationality and choose the options that maximise net present value. Near terms values are express in quantifiable monetary terms however, non-quantifiable terms are not considered. However, such practice can yield misleading conclusions in economics and policy studies (Zarnikau *et al*, 1996).

Pokharel and Chandrashekar (1998) work attempt to correct this deficiency using a multi-objective programming method for rural energy policy analysis. June Wu and Rosen (1999) described an equilibrium models (Waterloo Energy Modelling Systems - WATEMS) as decision-making aid with specific focus on modelling and optimising cogeneration-based direct energy systems. The authors concluded that cogeneration-based direct energy systems could have significant economic and environmental advantages over conventional independent systems in certain situations.

Andy S. Kydes and Susan H. Shaw in Bunn and Larsen (1997, pp. 9-30) described the application of National Energy Modelling System (NEMS) for energy, economic, climate change and the security forecasting and its consequences on alternative energy policies. Claudia Kemfert and W. Kuchshinrichs in Bunn and Larsen (1997, pp. 47-66) described the application of Micro-economic Information System (MIS) as a bottom-up input-output macroeconomic hybrid-based (optimisation/simulation) energy analysis tool for German economy. The limitations of the developed model was the usage of employment figures for macroeconomic analysis, hence, changes in other macroeconomic effects (i.e. changes in foreign trade) are ignored in the model. Bunn and Larsen (1997, pp. 117-139) also described the work of Y. Arikan, C. Guven and G. Kumaroglu in a General Equilibrium Framework applied to the Turkish economy in explaining the interactions between energy, economy, and the environment.

3.2 General Simulation and Econometric Models in Energy Planning
Simulation is a method whereby phenomenon or systems with similarities are represented using a less-complex model (Kleinpeter, 1995). Decision makers can adopt simulation as an approach for solving technical and economic problems. Simulation models tend to move from rigid mathematical formulation without neglecting logical evaluation. Modelling of concepts in simulation is not about extrapolation of trend, but representation of all possible and probable future events available to the decision maker - *it is possible to detach the present from the past*. Simulation methods consist of determining a set of probable results as a combination of severally defined parameters and permits sensitivity analysis by including the predominant variables that are difficult to include in optimisation models. It further allows the formulation of certain assumptions using exogenous variables that are not permissible in other modelling paradigms. Georgopoulou *et al* (1997) described a methodology for a Multi-Criteria Decision aid Approach (MCDA - ELECTRE III) for energy planning problems using renewable energy option in an Island of Greece. The authors presented a sequence of procedures (*identification of actors; selection of criteria, formulation of alternative strategies; application of specific method; analysis of results and actors reactions*) and claimed that incorporation of large numbers of different and often conflicting values into criteria set makes it difficult in assessing strategic options.

Hobbs and Horn (1997) described a model for confidence building as a multi-method Multi Criteria Decision Making (MCDM) approach to demand-side energy planning using British Columbia (BC), Canada as a case analysis. The authors claimed that MCDM could cause people to feel manipulated by a 'black-box' methodology and hence suggested the application of two or more methods in addition to reconciliation in building confidence and understanding. Sadoun (1998) presented a computer-based simulation model that analyse the energy interactions between built-up sites under alternative climatic conditions. Manzini and Martinez (1999) proposed a methodology for evaluating energy technologies and environmental impact assessment and argued that the methodology is capable of data analysis of differing end-use technologies. The approach however lacks impact assessment of energy use/technology on the environment. Roughgarden and Schneider (1999) addressed the controversy surrounding climate-change policy analysis due to uncertainties and suggested a policy impact assessment.

Econometrics is the logical integration of economics, mathematics, and statistics to provide quantitative values of economics relations and theories verification (Koutsoyiannis, 1973). Measurement of economic relations in its originality involved statistical analysis of economic data in a widely practised three stages of specification, estimation and forecasting (Sterman, 1991). Econometric models use regression of economic relations through statistical analysis of economic data, which has been widely applied to energy demand projections. Econometric models projections are base on economic parameters (i.e. price, income etc) and their causal effect to energy demand.

Its advantages include less data requirements than optimisation and general simulation models. Stern (1995) described the contribution of the mining sector to sustainability in DE using an econometric model to ascertain that future generations opportunities equal to or greater than those of the present generation. Malik and Satsangi (1997) described a three level integrated econometric computer-based model to addresses the need to introduce new technologies and economic options of various cooking fuels into the planning paradigm of DE. The model share one of the inherent drawbacks of econometric models in that it requires the need to increase the population sample to enhance the statistical validity of the extrapolated data that are often non-existence in many DE. Hammond (1998) revisited a bottom-up econometric approach as alternative energy strategies for United Kingdom.

The author assessed the potential for energy saving in physical terms, using available technical fixes and found that the "bottom-up" projections of energy consumption departed from the historic correlation "top-down" approach that purely utilise economic growth as the deciding variable. However, the study was deficient in its understanding of the macro-economic factors influencing energy use and the energy conservation measures. Cohen and Labys (1998) conducted a critical policy review using econometric modelling of atmospheric CO_2 with energy use and concluded that the development of new energy resources should be support economic activity as long as energy efficiency growth is less than GDP growth rate.

4. DEFICIENCIES OF TRADITIONAL MODELS AND THE NEED FOR ALTERNATIVE PARADIGM

Optimisation models are best suited for optimising from among well-defined solutions. The macro-energy scene at a decision support level in most DE is far from a set of simplified conditions. End-use optimisation-based models hold the mix of energy services and activities constant across different scenarios but not over time. Optimisation models require strictly formulated logical, mathematical presentation; hence, considerations are for the objective (quantitative) elements at the expense of the subjective (qualitative) elements. There is a great misinterpretation in estimating consumer expenditure using optimisation-based model due to variations (seasonal and regional) in the quantity of fuel used and the inability to quantify fuel consumptions. Hence, different energy surveys used in DE often yields divergent results (Malik and Satsangi 1997). Economic discounting models favour conventional energy technologies and oppose renewable energy technologies - as the initial costs that show up in the full analysis (Matson and Carasso 1999). The major cost of conventional energy technology is the future fuel cost incurred throughout the system life span. Given the discounted nature of the costs, it tends to show as a relatively minor cost in present value analysis. These drawbacks call for alternative energy planning and policy formulation for SED in the DE.

General simulation is a methodological approach that identifies weak points of systems; however, its adoption is not always successful in resolving conflicts or coalitions. In contrast to economic rationality model where choices are deduced by net present value, new modelling approaches should offers the same opportunities to both now and future in its energy planning and policy formulation. General simulation has the following advantages over optimisation-based model in energy planning and policy formation in the DE:

- Greater flexibility of the different energy scenarios
- Greater adaptation or validity, especially with respect to uncertain future projection or decision-making given the dynamics of energy planning and policy formation in the DE
- Possible dissociation of present socio-economic and technological abuse of energy use from the desired future

Amongst the merits of econometric models is that it be might useful in projecting the base-line energy-service growth when conducting energy efficiency projections. It can equally be applied when technological structure of energy demand and end-use efficiency remains constant, and the projected growth in energy consumption is identical to the growth in energy services - referred to as a "frozen- efficiency" scenario. DE energy market is undergoing important changes in the technological structure of energy demand, consumer behaviour, market liberalisation, privatisation, political stability etc. Hence, there are increasing possibilities that the relationship between energy, income and prices will vary significantly in the DE.

Hence, this article argues that the application of frozen-efficiency scenario would not suffice as a tool for addressing SED in the DE. Although econometric models are widely applied across many applications, however, they do not take into consideration the inherently complex-dynamics of technological nature of energy supply (production) and demand (consumption) as witnessed in a rapidly changing DE. Econometric models do not show the path taken and associated feedback implications of such equilibrium (Smith and Ackere, 2002). The major weakness of econometric models in its application to sustainable energy planning in the DE stems from the assumptions of the underlying economic theory on which they are based (Sterman, 1991). These include the assumptions concerning rational human behaviour, information availability for informed decision and market equilibrium that hardly exist in the DE.

Econometric model contains inherent statistical limitations as the regression procedures postulate unbiased estimates only under certain conditions known as '*maintained hypotheses'*. Another significant drawback of econometric models is reliance on numerical data for formulation sustainable energy policy. Econometric models narrowly focuses on hard and objective data which direct the modeller to focus on less tangible factors – ignoring potentially observable quantities inclusive of soft variables that have not been measured in the past and ones for which no data exist. Applications of econometric models as a planning approach for SED and policy formulation can meet with difficulties due to its inability to provide policy guidance to scenarios not previously witnessed. Model validation is another limitation of econometric model, as determination of validity of an energy equation for complex policy analysis will depend on the degree to which it fits the data - *statistical significance*. However, statistical significance would only indicates how well the energy planning equation fits the observed data, it does not indicate whether a relationship is a correct or true characterisation of the inherently complex and energy dynamics as usually the case in the DE.

Econometric models are of the inherent fundamental assumptions that the relationship between income, price, and demand, which existed in the past, will continue to hold in future. Energy planning experiences from the developed world indicates that such assumption is erroneous in its entirety. Simply described, the fundamental structural composition of energy demand in econometric models are not scrutinised, hence the model usefulness in terms of its predictive capabilities breaks down if the structural composition changes. The inherent rigidity of econometric and other traditional models make it impossible to demonstrate a shared understanding of the impact of varying energy policies on key performance indicators and its associated feedback. Econometric models do not take into consideration the complex and dynamic nature of energy systems structure within its cause and effects paradigm and hence its limitation to DE. DE is undergoing developmental phases different to those previously observed in the developed nations. Hence, there is a need for a paradigm shift in its energy planning and policy formulation. In summary, traditional modelling techniques such as econometric, optimisation and general simulation are limited in their application to dynamically complex energy issues in DE due to the following and hence the need for a new modelling approach to energy planning and policy formulation for SED in a DE:

- Projections are based on experience, current laws, and future policies
- Does not formulate a plan to achieve a desired goal
- Demand variable are exogenously determined
- Future predictions are based on past assumptions
- Lack of insight of the real players in the energy systems
- Does not address the inherent dynamics and complexities of energy systems in DE
- Does not give adequate explanation of the causalities in the energy systems
- Does not provide support to facilitate understanding of the energy problems and the associated dynamic implications
- Does not show the patterns of energy system behaviour in the DE over its lifetime
- Most tools are relevant to stable and developed economies (e.g. OECD nations).

5. CONCLUSIONS OF LITERATURE REVIEW OF ENERGY MODELLING FRAMEWORK

Review of literatures in this article reveals many facets of the methodological approaches employed in addressing the issues of energy planning. The dynamic complexity of SED in the DE is often rooted in the ill-defined structure of the energy issues during the decision-making process, which prevents the application of simplified algorithm (optimisation) for solving the issues of SED in the DE. In circumstances where solutions were been proposed (general simulation and econometric) it was obtained in cumbersome stages. Since, the local communities that make up the DE are passing through different phases of economic growth in their development life cycle; its optimal energy strategy should entail continuous refinement as opposed to a static state-planning paradigm (optimisation, simulation and econometric model). Future work would include the development of a systemic tool that could adequately address the inherent dynamics of complex energy planning and policy formulation as currently witnessed in the DE given the current exodus from central planning to market-based energy resource allocation commonly seen as energy industry liberalisation and privatisation efforts. Energy planning systems should be capable of understanding the emerging complexities and change that underlie the dynamics of sustainable energy planning and policy formulation in the DE. The role of computer-based Decision Support Systems (DSS) would be paramount in the planning and policy formulation of SED in the DE.

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ABOUT THE AUTHOR

Dr Titus Kehinde Olaniyi is a Reader in Engineering at Afe Babalola University Ado-Ekiti (ABUAD), Nigeria. He is a Decision Scientist and a Fellow of The Higher Education Academy, UK. Dr Olaniyi is a Senior Member of the American Institute of Aeronautics and Astronautics and a Chartered Information Technology Professional of British Computer Society (UK). He has taught information systems, aerospace, energy, strategic management and quality/reliability engineering etc. He is the Editor-in-Chief of the International Journal of Aerospace Research and Development; and the International Journal of Sustainable Energy Development. He adopts System Thinking/System Dynamics as sustainable decision support paradigm for planning and policy formulation.