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An Alternative Decision Support Systems Paradigm for Sustainable Energy Planning in the Developing Economy: A Case for System Thinking / System Dynamics Methodology

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ABSTRACT

This article proposes an alternative Decision Support Systems (DSS) framework using a System Thinking (ST) and System Dynamics (SD) approach for sustainable energy planning in a Developing Economy (DE). Many DE have undergone dramatic changes in socio-economic policies such liberalisation, finance sourcing and the incorporation of externalities such as the environmental implications of energy projects. The underlying dynamics of Sustainable Energy Development (SED) in the DE reveals their inherent limitations of traditional planning tools such as optimisation, econometric and general simulation models in guiding future policy decisions. The unsuitability of traditional tools is rooted in the socio-economic, political and technological differences, as compared to those of the developed nations. DES methodology facilitates the design of policy rules that govern complex decisions by demonstrating how past policies created the current crises. It enables the modelling of complex energy issues, and enhances understanding of the dominant system characteristics that causes systems' instability. This article fills an important gap in the literature by demonstrating the needs for a new modelling framework that permits focusing on the holistic structure identifiable within energy systems as prevalent in the DE.

1. Introduction

Developing Economies (DE) needs to improve productivity and the living standards of their populations. It is a strategic commodity for the promotion of economic growth via industrialisation and exportation of manufactured goods (Nijkamp and Volwahsen 1990). Energy is utilised for warmth in winter, cooling in summer and cooking all year round. It is an essential input to agricultural produce, transportation, commerce, industry, domestic sector etc. However, energy usage is not for its own sake but as a means to many ends in the provision of appropriate and adequate food, shelter and in the production of other goods and services. Further DE is 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 complexities in energy provisions, this article built on earlier work of Olaniyi *et al* (2008) by proposing Dynamic Energy Systems (DES) an alternative Decision Support Systems (DSS) for Sustainable Energy Development (SED) in the DE. The next section reviews the limitations of traditional planning paradigms of energy planning methodologies with specific focus to the DE.

2.0 Limitations of Traditional Models and the Need for Alternative Paradigm

Optimisation models (Islam, 1997; Matson and Carasso 1999; Suganthi and Samuel 2000) are best suited for optimising from among well-defined solutions. However, the macro-energy scene at a decision support level in most DE is not as simplified. Optimisation models require strictly formulated logical, mathematical presentation of both objectives (quantitative) as well as subjective (qualitative) elements many of which are absent in the DE. The inherent misinterpretation in estimating consumer expenditures in the DE results in different energy surveys yielding divergent results (Malik and Satsangi 1997). Given the future major cost of conventional energy technology, economic discounting models favour conventional energy technologies and oppose renewable energy technologies. These drawbacks call for shift in the planning and policy paradigm formulated for SED in the DE.

The generic advantages of general simulation over optimisation-based model for energy planning and policy formulation in the DE are as discussed in Olaniyi *et al* (2008). General simulation is a methodological approach identifies systems weak points. However, its adoption is not always successful in resolving the prevalent conflicts or coalitions of the dynamic and complex energy systems in the DE. 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.

Econometric models might be useful in projecting the base-line energy-service growth and could work when technological structure of energy demand and end-use efficiency remains constant (assuming '*frozen efficiency*' scenario). However, DE energy market is undergoing important changes in the socio-economic and technological structures, which reveals increasing possibilities that the relationship between energy, income and prices will vary significantly. It is the position of this article that the application of frozen-efficiency scenario would not suffice as a tool for addressing SED in the DE. Econometric models 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; and do not show the path taken and associated feedback implications. The major weakness of econometric models in its application to sustainable energy planning in the DE stems from the assumptions of the underlying economic rationale theory on which they are based (Sterman, 1991). 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.

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. However, 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. Application of SD in energy policy goes beyond the single focus of providing insight into pre-selected policy issues. Dyner and Bunn in Bunn and Larsen (1997) argued that application of traditional approaches of optimisation and econometrics are no longer gaining their historical relevance in the new era of energy market liberalisation. 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. ST/SD modelling approach would appropriately fill the gap as a new modelling paradigm for SED in the DE.

3.0 System Thinking and System Dynamics Modelling in Energy Planning

System Thinking (ST)/System Dynamics (SD is an emerging technique for energy planning and policy formulation. Forrester (1961) described SD as a set of simulation tools in a book titled *Industrial Dynamics*. SD could be use as structural model of human systems to gain better understanding of systems behaviour (Pidd, 1996, pp. 181). Control engineers have deployed SD tool to analyse the stability of mechanical and electrical control systems. Senge (1990) defines ST as:

> *"Conceptual framework, a body of knowledge and tools with the primary focus of making the full patterns of a system clearer, and to guide in shaping the future outcome of the system more effectively" (Senge 1990).*

The above definition calls for the need of energy planners in the DE to consider the application of ST/SD in getting a clearer understanding of the inherent dynamics and complex feedback of energy planning that refuses to yield to traditional models as described in Olaniyi *et al* (2008) to better shaped the future of energy scenarios in DE. ST is the interconnectedness of framework, knowledge, and tools. Maani and Cavana (2000) described ST as consisting of paradigm, language, and methodology. The paradigm consists of dynamics, operational and closed-loop thinking. Richmond (1997) stated that the paradigm consist of dynamics, operational and closed-loop thinking. Anderson and Johnson (1997, pp. 20-21) argued that ST language is characterised by ruling, emphasis, translation, and display. ST approach requires a shift in the way of thinking by focusing on causes as opposed to isolated events given the interacting parts in an organisation (Kirkwood, 1998). It is the position of this article that energy planning and policy formulation paradigm in the DE needs to steer away from isolated events of energy failures to holistic thinking that takes a step further to understand the underlying causes of such inherently complex events as observed in the DE.

Although applications of SD emerged between the late 1950's and early 1960's as *industrial dynamic;* however, interest in its methodological approach became famous during the 1960's and 1970's with emphasis on general management problems (i.e. production instabilities, employment dynamics, corporate growth etc). Forrester (1968, 1971) later showed the use of SD in understanding environmental and socio-economic problems. Renewed interest in the application of SD to business and strategic problems started in mid 1980's (Smith and van Ackere, 2002) with specific reference to managerial issues. Numerous literatures (Forrester, 1968; Forrester; 1968a; Forrester, 1973; Naill, 1977; Richardson and Pugh III, 1981; Goodman, 1989; Senge, 1990; Senge and Sterman, 1991; Roberts *et al*, 1996; Morecroft and Sterman, 1994; Coyle, 1996; Sterman, 2000) describing SD modelling approaches have also played key roles. The contributions of static methodologies such as optimisation and econometric modelling approach to clearly defined problems have been notable (Adegbulugbe and Oladosu, 1994; Khella, 1996; Islam, 1997; Adenikinju, 1998, Fagbenle *et al* 1998; Dincer and Rosen, 1999). However, SD contrasts with traditional methods, which rely on detailed models with the main object of providing tactical advice about energy supply and demand. SD viewed human systems by stressing the importance of certain structural features i.e. such as dynamics, feedback, non-linearity etc (Wolstenholme, 1990).

Forrester (1961) defined SD as:

> *"… the investigation of the information-feedback characteristics of [managed] systems and the use of models for the design of improved organisational form and guiding policy".*

The above definition described the relevance of SD methodology in addressing the issue of sustainable energy planning in the DE. It enables understanding of the complex information-feedback characteristics of SED that could act as a guide to decision makers in planning and policy formulation. Coyle (1979) defined SD as:

> *"… a method of analysing problems in which **time** is an important factor, and which involve the study of how the system can be **defended against**, or made to **benefit** from, the **shocks** which fall upon it from **outside world**".*

Applications of SD to issues of energy planning have been numerous (Ford, 1983; Ford and Bull 1989; Bunn and Dyner, 1996). SD has become a favourite modelling approach in the energy sector in both developing and developed economies. Issues such as energy and economy, regulatory policies (Ford, 1983), conservation (Ford and Bull 1989), climate change (Fiddaman, 1996), strategic competitive behaviour and the impact of deregulation and privatisation of the energy sector (Bunn and Larsen 1997) has been addressed using SD methodological approach. The history of SD models in energy analysis and planning dated back to the early 1970s at Massachusetts Institute of Technology (MIT). The research conducted at MIT was primarily concerned with world dynamics, including factors such as economic and population growth, depletion of natural resources and climate change. Other research (Naill, 1977) followed to examine the behaviour of energy market (COAL2). Development to COAL2 model led to FOSSIL2 used as a tool to support US energy planning at various stages since 1977 and most importantly the National Energy Strategy in 1991.

Ford (Ford 1983; Ford and Bull 1989; Ford *et al,* 1989; Ford, 1995) made valuable contributions using SD as a tool to address policies such as investment requirement and uncertainties in the United States electricity industry. Geraghty and Lyneis (1985) conducted a study of the effect of external agents on utility performance in the US economy using SD. Moxness (1990) presented an intuitive model on inter-fuel substitution in European electricity production. The model focuses on fossil fuels (oil, gas and coal) in a manner that overcomes the unsuitable fuel substitution representation yielded by the traditional constant-elasticity-demand models. In the UK, privatisation issues in the electricity industry, reserve margin, market share and plant retirement uses SD methodology (Bunn & Larsen 1992; Bunn *et al.* 1993). Application of SD to the electricity sector in Argentina was pursued from the beginning of the 1980s (Rego, 1989).

In Colombia, the study energy efficiency penetration and electricity substitution by gas in the residential and industrial sectors adopts SD concepts (Dyner *et al.* 1995). Bunn and Larsen (1997) developed a generic framework using SD for strategic modelling of market liberalisation initiatives while maintaining integrated approach to energy planning in Colombia. Meadows *et al* (1972) published an ambitious study entitled '*The Limit to Growth*' and was later updated and revised in 1992 under a new titled called '*Beyond the Limits*' (Meadows *et al.* 1992). The study consists of large-scale SD simulation model that simulate likely future outcome of the world economy. The study utilised the prominent features of SD in the use of feedback loops to explain underlying system behaviour. Frances P. Wood and Jay C. Geinzer (Bunn and Larsen 1997, pp. 31-46) developed an SD model known as '*Integrated Dynamic Energy Analysis Simulation*' (IDEAS) model for the United States (US) economy. IDEAS are large-scale climate change model for reducing greenhouse gas emissions. IDEAS primarily focuses on energy conservation has a history of providing policy support for long-term investigations of energy supply-demand balance.

John Morecroft and Brian Marsh (Bunn and Larsen 1997, pp. 167-203) described the development of SD model used as a *"management flight simulator"* to facilitate strategic thinking with a major oil companies - Royal Dutch / Shell. It illustrates the micro-world of the oil producer used for exploring oil market dynamics by identifying the feedback within and between the different sectors of the oil market. David C. Lane (Bunn and Larsen 1997, pp. 205-240) demonstrated how SD modelling process helps managers to resolve conflict and generate insight by producing a model describing the diary of oil market. Andrew Ford (Bunn and Larsen 1997, pp. 241-257) constructed a model titled *'The Changing Role of Simulation Models: A Case of the Pacific Northwest Electricity System'.* The model describes the use of SD for better understanding of conservation measures in the electric system in the Pacific Northwest region of USA. Issac Dyner and Derek Bunn (Bunn and Larsen 1997, pp. 259- 271) proposed SD technique that focuses on managing a large but rather less focused model for developing Columbia economy in pursuing market liberalisation initiatives, at the same time, maintaining a commitment to integrated energy planning. Smith and van Ackere (2002) use SD to model each of the explicit causal links and track the resulting system behaviour over time.

James M. Lyneis (Bunn and Larsen 1997, pp. 273-301) described a generic feedback model for developing strategies for America's electric utilities in preparing for a competitive environment to understand the implications of future finances in structural market changes and argued that reduction of utility's cost is an essential part of any long-term strategy. Derek W. Bunn, Erik R. Larsen and Kiriakos

Vlahos (Bunn and Larsen 1997, pp. 303-325) formulated a complementary SD modelling approach for analysing effects of privatisation on electricity investment in the United Kingdom (UK) focusing on industry restructuring, corporate and regulatory behaviour. Ford *et al* (1989) commented on the difficulty of applying SD models in the electric utility industry in the US relating the needs of managers coming from engineering background demanding for detailed model for confidence building and model - *as the managers concerns has always been more operational rather than strategic.* Gevorgian and Kaiser (1998) conducted a fuel distribution and consumption using SD as a simulation model for the Republic of Armenia. The authors used SD to describe the extreme importance of energy and fuel situation in Armenia given the blockade due to geopolitical situation resulting in five times decline in energy production; hence, creating a deteriorating economic condition. Rodrigues and Bowers (1996) use SD to offer general conclusions about the dynamics of energy market behaviour.

4.0 Applications of Modelling to Sustainable Energy Policy Systems

Decision makers around the world have begun to realise that there is a need to de-couple the very strong relationship that exists between energy consumption and economic growth (Reid and Goldemberg, 1998). Many economies are now taking steps (or at least showing willingness) to open their energy market to more competitive environment via privatisation and liberalisation. Abdalla (1994) examined various short and long-term energy policies measures that sometimes imply lower overall growth rates to promote SED in the DE. The short-term measures are energy specific policies that encourage the prudent use of energy while the longer-term policy involved broader development policies that have implication on energy development and usage patterns. Bunn and Dyner (1996) describe the application two different energy policy contexts that constitute an important energy policy issues in the 1990s. The first was global concern for sustainability and the financing of new energy conservation capacity and the second was the rapid restructuring and privatisation of public utilities into competitive markets, which posed conflicting policy and modelling objectives (i.e. planning versus liberalised market forces).

Malik and Satsangi (1997) identified national, state, district, block, and village model as the five levels of energy planning models. However the authors stresses the need for more concentration on the district level (middle-point) as a preferred level that permits suitable coordination linkages that addresses sustainable energy technologies issues under the resource constraints. Islam (1997) discuses set of policy instruments determined by the government and the associated strategies given variations of taxes-subsidies and argued that the net government revenue should be positive. Sutanto and Lachs (1998) argued that the cost of providing a reliable and secure electricity supply to all consumers increased substantially given and hence called for the use of Battery Energy Storage Systems (BESS) as matured technology reduces vulnerability; and inverters that provides ideal energy storage interface between direct and alternating current. Bohringer (1998) shows the use of complementary format in a hybrid economy for production possibilities representing energy sectors by bottom-up activity analysis. Skutsch, (1998) commented that the gap between gender policies as adopted by government and donors is partly due to difficulties in translating policy into achievable objectives.

Matson and Carasson (1999) conducted a policy study of economic, social-political and environmental consequence of using Renewable Energy Technologies (RETs) as Conventional Energy Technologies (CET's). The authors reflected on the right of the future generations to the same opportunity of access to a healthy ecological future and the finite endowment of the Earth's resources as that of the present generation. Green (1999) investigated the policy difficulties in transferring non-indigenous renewable energy technologies to rural areas of industrialising countries focusing on the cultural and organisational interactions of the stakeholders in transfer process. The author argued that there has been lack of attentions to these interactions are as a result of neglect to consult with the end users of the systems by the project implementer due to lack of appropriate institutional support mechanisms and financial resources. Shiferaw and Holden (2000) highlighted land degradation that poses threat to food production in many DE and stated that '*command-and-control*' policies, have been tried (*with limited success*) to encourage adoption of erosion-control practices but high transactions costs and negative distributional impacts on the welfare of the poor limits its efficacy. Podobnik (1999) conducted an analysis that adopts a long-wave perspective to global shift away from primary reliance on coal towards over-reliance on petroleum and examined state and private investment patterns of energy technologies, as well as the growing pressure of environmental regulations and concluded that a shift in favour of sustainable energy regime.

Galeotti and Lanza (1999) stated that the climate change debate has drawn attention to the problem of Green House Gases (GHG) emissions. Bauer and Quintanilla (2000) argued that deregulation policy and financial constraints are impinging on commitment to reduce GHG emissions in the development of the Mexican energy system. Wiser (2000) stated that although green power markets viewed by some as a means to create a private market for renewable energy (driven by customer demand for green products), however, profitable, sizable, credible markets for the green products would evolve naturally without sympathetic public policies. Suganthi and Samuel (2000) conducted an exergy based supply side energy management for SED where sustainability is a major consideration for urban and rural development. The authors argued that people have been exploiting the natural resources with no consideration to the effects in both short term (environment) and long term (resource depletion). The urban areas depends largely on commercial energy sources while the rural areas utilised non-commercial energy sources such as firewood, agriculture wastes etc. The authors called for renewable energy as an option (gap) between the rural and urban areas. Hence, the policy makers will either concentrate on renewable energy resources or have them as substitutes for commercial energy resources. Alternatively, the authors requested for a dual approach in which renewable energy will contribute to meet a portion of the demand and the conventional commercial energy resources will features with caution wherever necessary!

5.0 Conclusions of Literature Review of Energy Modelling Framework

This article reviews the limitations of traditional energy modelling approaches employed in addressing energy planning in the DE. The dynamic complexity of SED in the DE is often rooted in the ill-defined structure of energy issues during the decision-making process, which prevents the application of simple algorithm for solving complex issues. A systemic tool is required for DE in their exodus away from central planning to market-based energy resource allocation commonly seen as industry liberalisation and privatisation. The role of computer-based DSS is paramount in the planning and policy formulation of SED in the DE. This article argues that such tools should employ a holistic approach under the umbrella of ST/SD. Systemic of *'wholeness'* and *'interconnectedness'* in energy planning and policy formulation in the DE calls for rethinking energy planning. Appropriative tools 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 proposed future work will utilise a Dynamic Energy System (DES) as a methodological approach using ST/SD as a planning paradigm for SED in the DE.

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