Vol. 3, Nos. 1 & 2, 2010, pp. 45 -53
ISSN 2006-1781

APPLICATIONS OF SYSTEM THINKING AND SYSTEM DYNAMICS METHODOLOGY TO SUSTAINABLE ENERGY PLANNING

Olaniyi Titus Kehinde PhD
London South Bank University
United Kingdom
Email: tkolaniyi@yahoo.co.uk

Received 12nd November, 2009

ABSTRACT

This article reviews the applications of System Thinking / System Dynamics (ST/SD) methodology to Sustainable Energy Planning (SEP) with specific focus in Developing Economy (DE). DE has been undergoing tremendous changes in order to keep up with balancing demand and supply of energy services in an attempt to deregulate the energy market. Traditional methodologies such as optimisation, econometric and general simulation techniques that has address the issues of energy planning elsewhere fails to address the inherent complexities, non-linearity, delays and feedback as witnessed in the DE. 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. ST/SD is an emerging technique for energy policy formulation and can demonstrates how models of the structure of a human system and policies could help in understanding the operation and behaviour of complex systems. ST/SD employ a holistic approach suitable for the DE that are passing through different phases of economic growth in their development life cycle whose optimal energy strategy should entail continuous refinement as opposed to a static state-planning paradigm. This article bridges the gaps in literatures by showcasing the divergent applications of ST/SD with specific focus on the DE.

Keywords and Phrases: Developing Economy, Sustainable Energy Planning, System Thinking / System Dynamics

I. PLANNING SUSTAINABLE ENERGY DEVELOPMENT IN THE DEVELOPING ECONOMY

Energy is needed in Developing Economies (DE) to improve productivity and the living standards of their populations. It is a strategic commodity used in the promotion of economic growth via industrialisation and exportation of manufactured goods. 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 is not used for its own sake but as a means to many ends in the provision of appropriate and adequate food and shelter and in the production of other goods and services.

The provision of energy services through the combustion of fossil fuels and biomass contributes adversely to environmental degradation of land, air and water. The world as a whole and the DE in particular has reached a stage at which energy demand growths are resulting in the rapid depletion of finite fossil energy resources. Naturally occurring Green House Gases (GHG) such as carbon dioxide, methane, oxides of nitrogen and ozone concentration in the atmosphere had significantly increased in recent times, mainly by anthropogenic activities.

Environmental degradation such as air pollution, acid rain contributes adversely to the global climate change. There is an urgent need on a global scale to stabilise the GHG concentrations in the atmosphere at a level that would prevent dangerous interference with the naturally adjusted climate change system.

The precise future changes in population; technological progression, accessible natural resources, climatic changes and economic growth of DE are difficult to predict. The pace of socio-economic and technology development to solving energy problems in the DE raises questions that urgently needed to be addressed. How can the energy planner understand the detailed complexities associated with SED? How can the path of SED be defined? The complex causal-relationship between continued dependence on finite energy resources, penetration of renewable energy resources, socio-economic and technological development and the accompanied climate change issues will need to be thoroughly analysed in the DE for SED to evolve.

The paradigm of energy planning in DE is shifting from orthodox government-protected planning systems to a more liberalised and integrated global economy. However, there is a clear evidence of increased energy usage, mobilisation, urbanisation, and foreign dependence. Global energy development requires an immediate attention as the level (stock) of pollution in the atmosphere approaches a limit at which the environment can sustain without detrimental effect. Given the dynamic complexities of SED noted above, there is a need for systemic tools and techniques that facilitate strategic SED with minimum impact on the environment.

II. SYSTEM THINKING AND SYSTEM DYNAMICS METHODOLOGY

System Thinking (ST)/System Dynamics (SD is an emerging technique for energy planning and policy formulation. Jay Forrester (the prime developer of SD) defines it as a set of simulation tools [1] and demonstrated how models of the structure of a human system and the policies used to control it could help in understanding the operation and behaviour of system as discussed in [2]. SD paradigms are similar to those adopted by control engineers in the analyses of stability of mechanical and electrical control systems. As contained in [3], ST was defined 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".*

ST is the interconnectedness of framework, knowledge, and tools. It was described in [4] that ST consists of *paradigm, language, and methodology*. The paradigm consists of dynamics, operational and closed-loop thinking. It was stated in [5] that the paradigm consists of *dynamics, operational and closed-loop thinking* while [6] emphasised that ST language is characterised by ruling, emphasis, translation, and display. ST approach requires a shift in the way of thinking as it focuses on *causes* as opposed to *isolated events* as organisation is made up of interacting parts [7].

III. EMERGENT OF SYSTEM THINKING AND SYSTEM DYNAMICS METHODOLOGY

SD emerged in the late 1950's as *industrial dynamic;* however, interest in its methodological approach became famous during the 1960's and 1970's in solving management problems such as instabilities in production, employment, and corporate growth etc. Application of SD was later extended to understanding environmental and socio-economic problems [1, 8, and 9]. Renewed interest in the application of SD to business and strategic problems started in mid 1980's [10] with specific reference to managerial issues. Numerous literatures [11, 12, 13, 14, and 15] describing SD modelling approaches have also played a key role in understanding complex problems.

The contribution of static methodologies such as optimisation and econometric modelling approach to clearly defined problems has been notable [16, 17 and 18]. 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. dynamics, delays, feedback, non-linearity etc [19].

> SD was defined in [1] 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 characteristic of sustainable development*. The understanding generated could act as a guide to decision makers and their advisers in policy formulation. The definition of SD in [14] as follows makes it relevance to the complex dynamics of energy planning in the DE:

> *"… 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".***

IV. APPLICATIONS OF SYSTEM THINKING AND SYSTEM DYNAMICS TO ENERGY PLANNING

SD has previously been applied to energy planning issues [20, 21 and 22]. SD has become a favourite modelling approach in the energy sector in both developing and OECD economies. Issues such as energy and economy, regulatory policies [20], conservation [21], climate change [23], strategic competitive behaviour and the impact of deregulation and privatisation of the energy sector [24] has been addressed using SD methodological approach. The history of SD models in energy analysis and planning can be trace 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 [11] followed to examine the behaviour of energy market

(COAL2). Development to COAL2 model led to FOSSIL2 that supports US energy planning at various stages since 1977 and most importantly the National Energy Strategy in 1991.

Ford [20, 21, 25 and 26] made valuable contributions using SD as a tool to address policies such as investment requirement and uncertainty issues in the United States electricity industry. [27] conducted a study of the effect of external agents on utility performance in the US economy using SD and [28] 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, SD has been used to explore a diversity of issues relating to privatisation of the electricity industry, reserve margin, market share and plant retirements [29 and 30].

Application of SD to the electricity sector in Argentina was pursued from the beginning of the 1980s [31]. In Colombia, SD tool was used to study energy efficiency penetration and electricity substitution by gas in the residential and industrial sectors [32]. Generic framework was developed in [33] using SD for strategic modelling of market liberalisation initiatives while maintaining integrated approach to energy planning in Colombia. Ambitious study was conducted in [34] entitled 'The Limit to Growth' and was later updated and revised in 1992 under a new titled called Beyond the Limits [35]. The study consists of large-scale system dynamics (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 in [33] developed an SD model known as Integrated Dynamic Energy Analysis Simulation (IDEAS) Model for the economy of United States. IDEAS are large-scale climate change model for reducing greenhouse gas emissions and have a history of providing policy support for long-term investigations of energy supply-demand balance primarily focusing on energy conservation. John Morecroft and Brian Marsh in [33] described the development of SD model as a "management flight simulator" to facilitate strategic thinking with major oil companies - Royal Dutch / Shell that illustrates the micro-world of oil producers in exploring market dynamics and identify the feedback within the different sectors. David C. Lane in [33] demonstrated how SD modelling process was used with managers to resolve conflict and generate insight. Andrew Ford in [33] constructed a model that uses of SD to improve understanding of conservation measures within the electric system in the Pacific Northwest region of USA.

Issac Dyner and Derek Bunn in [33] proposed SD technique for managing developing Columbia economy in pursuing market liberalisation initiatives, at the same time, maintaining a commitment to integrated energy planning. The authors argued that energy research in the utilities sectors has been dominated by two different themes – central planning and market-based resource allocation. James M. Lyneis in [33] described a generic feedback model in preparing for a competitive environment within the America's electric utilities. The author claimed that reduction of utility's cost is an essential part of any long-term strategy; such reduction should put into consideration the needed investment in productivity, such as new technologies, training, and process reengineering. Derek W. Bunn, Erik R. Larsen and Kiriakos Vlahos in [33] formulated a complementary SD model for analysing the effects of privatisation on electricity investment in the UK with special reference to industry restructuring, corporate and regulatory behaviour.

The difficulty of applying SD models in the electric utility industry in the US which relates to the needs of managers coming from engineering background with considerable details in the models in order to have confidence in their validity was documented in [25]. A fuel distribution and consumption using SD model for the Republic of Armenia was describe in [34]. The article described the extreme criticality of energy and fuel situation in Armenia. In particular, transport routes for energy supplies have been blockaded due to geopolitical situation; industrial production of energy supplies has declined five times faster than has electricity production, hence creating a deteriorating economic condition.

SD seeks to model each of the causal links explicitly, and track the resulting system behaviour over time [10]. Although, SD can offer general conclusions about the dynamics of energy market behaviour; however, it might not be obvious how such advice might be incorporated into a daily plan [35]. Application of SD in energy policy goes beyond the single focus of providing insight into pre-selected policy issues. Dyner and Bunn in [33] argued that application of traditional approaches of optimisation and econometrics are losing some of their relevance in the new era of energy market liberalisation. SD modelling approach is well placed to fill the new modelling requirements.

V. CONCLUSIONS OF LITERATURE REVIEW OF ENERGY MODELLING FRAMEWORK

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. Review of literature in this paper reveals many facets of applications of ST/SD as a methodological approach for energy planning and policy formulation. It argues that such tools employ a holistic approach suitable for the DE that are passing through different phases of economic growth in their development life cycle whose optimal energy strategy should entail continuous refinement as opposed to a static state-planning paradigm. The systemic characteristics of *wholeness* and *interconnectedness* in the DE call for rethinking of the planning approach. A systems approach as adopted in reviewed in this paper entails collection of parts that interact with one another to function as a whole – *sustainable energy development*.

REFERENCES

[1] Forrester, J. W. (1961). Industrial Dynamics. *MIT Press,* Cambridge, Mass.

[2] Pidds, M. (1996). Tools for Thinking: Modelling in Management Science. *John Wiley & Sons Limited, pp 181*

[3] Senge, P. M. (1990). The Fifth Discipline: The Art & Practice of the Learning Organisation. *Century Business,* London.

[4] Maani, K. E. and Cavana, R. Y. (2000). Systems Thinking and Modelling: Understanding Change and Complexity. *Pearson Education* New Zealand Limited.

[5] Richmond, B. (March, 1997). The 'Thinking' in Systems Thinking; How Can We Make It Easier to Master? *The Systems Thinker.* Vol. 8. No. 2.

[6] Anderson, V. and Johnson, L. (1997). Systems Thinking Basics. *Pegasus Communications*, *Cambridge, MA, USA, pp. 20-21*

[7] Kirkwood, C. W. (1998) System Dynamics Methods: A Quick Introduction.

[8] Forrester, J. W. (1968). Urban Dynamics. *MIT Press*, *Cambridge, Mass.*

[9] Forrester, J. W. (1971). World Dynamics. MIT Press, Cambridge.

[10] Smith, P. C. and van Ackere, A. (2002). A Note on the Integration of System Dynamics and Economic Models. *Journal of Economic Dynamics & Control.* Vol 26, pp 1-10.

[11] Naill, R. (1977). Managing the Energy Transition. *Ballinger,* Cambridge, MA. USA

[12] Goodman, M. R. (1989). Study Notes in System Dynamics. *Productivity Press. Portland*, Oregon.

[13] Mocroft, J.D.W. and Sterman, J.D. (1994). Modelling for Learning Organisations. *Productivity Press,* Portland, USA.

[14] Coyle, R.G. (1996). System Dynamics Modelling: A Practical Approach. *Charpman & Hall, London.*

[15] Sterman, J. D. (2000). Business Dynamics: Systems Thinking and Modelling for a Complex World. *McGraw,* Tokyo.

[16] Adegbulugbe and Oladosu (1994). Energy Use and CO_2 Emissions in the West and Central African Region. *Energy Policy Vol. 22 No 6 pp. 499-508.*

[17] Islam, S. M. N. (1997). Sustainable Economic Developments in the Australian Energy Sector: Findings of Australian Energy Planning System Optimisation Model (AERSOM). *Renewable and Sustainable Energy Reviews, Vol. l., No. 3, pp. 229-238.*

[18] Dincer, I. and Rosen, M. A. (1999). Energy, Environment and Sustainable Development. *Applied Energy. 64, pp. 427-440.*

[19] Wolstenholme, E. F. (1990). System Enquiry: A System Dynamics Modelling Approach. *John Wiley & Sons Ltd,* Chichester.

[20] Ford, A. (1983). Using Simulation for Policy Evaluation in the Electric Utility Industry. *Simulation, Vol 43, pp. 85-92.*

[21] Ford, A. and Bull, M. (1989). Using System Dynamics for Conservation Policy Analysis in the Pacific Northwest. *System Dynamics Review* Vol. 6, pp. 1 - 16.

[22] Bunn and Dyner (1996). Bunn, D. and Dyner, I. (1996). Systems Simulation to Support Integrated Energy Analysis and Liberalised Planning. *International Transactions in Operational Research. Vol. 3, No. 2, pp. 105-115.*

[23] Fiddaman, T. (1996). A System Dynamics Perspective on an Influential Climate-Economy Model. *MIT Sloan School of Management.* Cambridge, MA.

[24] Bunn, D, W. and Larsen, E. R. (Eds). (1997). Systems Modelling for Energy Policy. *John Wiley & Sons Ltd.*

[25] Ford, A., Bull, M. and Naill, R. (1989). Bonneville' Conservation Policy Analysis Models. *Energy Policy Vol. 15.*

[26] Ford, A. (1995). Short Lead-Time Technologies as a Defence Against Demand Uncertainty, in J. Plummer, E. Oatman and P. Gupta (eds) Strategic Management and Planning for Electric Utilities, *Prentice Hall, Englewood Cliffs,* NJ.

[27] Geraghty. D.M. and Lyneis, J. (1985). Feedback Loops: The Effect of Extemal Agents on Utility Performance in J. Plummer, E. Oatman and P. Gupta (eds) Strategic Management and Planning for Electric Utilities, *Prentice Hall, Englewood Cliffs*, *NJ.*

[28] Moxness, E. (1990). Interfuel Substitution in OECD European Electricity Production". *System Dynamics Review* 6, 44-65.

[29] Bunn, D. W. and Larsen, E. R. (1992). Sensitivity Reserve Margin to factors influencing Investment Behaviour in the Electricity Market of England and Wales. *Energy Policy Vol. 29. pp. 420- 429.*

[30] Bunn, D.W., Larsen, E. and Vlahos, K. (1993). Complementary Modelling Approaches for Analysing Several Effects of Privatisation on Electricity Investment. *Journal of Operational Research Vol. 44, No. 1 0, pp. 957-971.*

[31] Rego, J. (1989). Schedule Delays and New Financing for the Argentine Electricity Sector Growth. System Dynamics Conference, Stuttgart, Germany. In: Computer-Based Management of Complex Systems (P. Milling and E.Zahn, eds), Springer-Verlag, Berlin.

[32] Dyner, I., Smith , R. and Pena, G. (1995). System Dynamics Modelling for Energy Efficiency Analysis and Management. *Journal of Operational Research Vol. 46. No. 10, pp. 1163-1173.*

[33] Bunn, D, W. and Larsen, E. R. (Eds). (1997). Systems Modelling for Energy Policy. *John Wiley & Sons Ltd.*

[34] Gevorgian, V. and Kaiser, M. (1998). Fuel Distribution and Consumption Simulation in the Republic of Armenia. *Simulation. 71:3, pp 154-167.*

[35] Rodrigues, A. and Bowers, J. (1996). The Role of System Dynamics in Project Management. *International Journal of Project Management.* Vol. 14, No. 4, pp. 213-220.