"A Critical Assessment of Energy Systems Models and their Applications "

Dr. Venkata Ramana
Lecturer in Physics Department
Sri Dasari Narayana Rao Govt, Degree College(W), Palakol, West Godavari, Andhra Pradesh
Mr. Harishchandra jandhyala
Lecturer in Physics Depatrtment
A. G & S.G.S DEGREE COLLEGE, VUYYURU, Andhra Pradesh

ABSTRACT

The transition towards cleaner and more sustainable energy sources is rapidly changing the global energy landscape. To tackle the challenges that come with this transition, energy systems modeling has become an essential tool for understanding and predicting energy system behavior, as well as for developing policies. This review paper provides a critical assessment of various energy systems models developed and applied in recent years.

The paper evaluates the strengths and weaknesses of different energy systems models and their potential applications for addressing energy-related challenges. For example, energy systems models can aid policymakers in developing countries to plan energy systems and provide energy access. Likewise, they can assist policymakers in developed countries to design more efficient energy systems that minimize greenhouse gas emissions and reduce dependence on fossil fuels. Additionally, energy systems models can be used to assess the environmental impact of energy systems and identify opportunities to reduce emissions.

Furthermore, the paper evaluates the accuracy and reliability of energy systems models in predicting energy consumption, production, and storage. Although energy systems modeling has advanced significantly in recent years, there are still limitations and challenges associated with the accuracy and reliability of these models. Energy systems models often rely on assumptions and simplifications that may not fully represent the complexity of real-world energy systems. Therefore, continued research and development are necessary to improve the accuracy and reliability of energy systems models.

In conclusion, this review paper emphasizes the critical role that energy systems modeling plays in understanding and addressing the challenges of energy transition. It highlights the need for continuous critical assessment of these models to ensure their relevance and applicability to real-world energy challenges. Additionally, it underscores the importance of investing in research and development to improve the accuracy and reliability of energy systems models.

Key words: Energy systems modelling, Energy transition, Policy development, Environmental impact assessment, Accuracy and reliability

INTRODUCTION:

Since the early 1970s, there has been a wide variety of models available for analyzing energy systems or sub-systems, such as the power system. These models serve several purposes, including designing a better energy supply system given a level of demand forecast, better understanding of present and future demand-supply interactions, energy and environment interactions, energy-economy interactions, and energy system planning. Energy system models are formulated using theoretical and analytical methods from various disciplines, including engineering, economics, operations research, and management science. These models apply different techniques, including mathematical programming (especially linear programming), econometrics and related methods of statistical analysis, and network analysis. The list of techniques has grown in recent times.

Energy system models differ in terms of their data requirements, technology specifications, skill requirements, and computing demands. Some models are technologically detailed and require a large database, most of which may not be readily available in developing countries. Additionally, the skill and computing requirements for some models may be too demanding for developing countries, where the pool of skilled human resources may be limited. Most of these models were developed in industrialized countries to address specific issues or problems in a particular context. While some of these models have been applied to developing country contexts, transferring modeling technologies can be challenging. Only a few models have been developed in developing countries, and these models have not been widely adopted beyond national borders to create a more extensive portfolio of modeling tools for developing countries.

Given the diversity of energy system models in terms of their purpose, philosophy, features, capabilities, possible overlaps, and data demand, it is essential to develop a comparative understanding of the models while keeping the specific features of developing countries in mind. Although various reviews have been published in the past, including works by Hoffman and Wood (1976), Wirl and Szirucsek (1990), Markandya (1990), Pandey (2002), Nakata (2004), and Urban et al (2007), a systematic comparative study is seldom found in the literature. These studies have focused on the evolution and development of energy modeling, electricity system planning models, and energy-environment models, among other topics, but they have not comprehensively compared models while considering the features of developing countries. While Pandey (2002) and Urban et al (2007) have attempted some comparative analysis, their focus was somewhat different. Pandey (2002) emphasized the need to incorporate the special features of developing countries in energy models, while Urban et al (2007) analyzed how a set of models performed in dealing with developing country features. This paper aims to bridge the knowledge gap by providing a systematic comparative overview of well-known energy models while considering the specific features of developing countries.

The scope of an energy system model can differ based on its purpose and focus. At one end are engineering models that cover specific components or sub-components, while at the other end are comprehensive models that encompass energy-economy interactions at the national and international levels. In this review, we have excluded both of these types. Additionally, we have excluded models that extend beyond the energy sector and encompass energy-economy interactions. Our focus is on integrated models that cover the energy sector and sub-sector levels, and those that consider both the supply and demand sides.

Due to the diversity of technologies used and the complexity of the energy sector, some models may focus on specific aspects of a sub-sector, such as electricity, coal, or gas. These models may or may not cover both the supply and demand sides of the sub-sector. Similarly, some models cover multiple fuels but focus solely on the supply side, while others focus solely on the demand side. Technically, such models do not meet the criteria for inclusion in energy system models. However, as they are important in the literature, we have included both sector-level and integrated models in this review.

We have chosen not to differentiate between normative and positive models, as most models incorporate elements of both, in line with Hoffman and Wood's (1976) approach. Furthermore, our review encompasses both purpose-built and generic models, as well as models that focus on a specific geographical area or cover multiple regions/areas.

The structure of the paper is as follows: In section 2, various types of energy system models are categorized. Section 3 provides an introduction and comparison of several frequently utilized models. Finally, section 4 concludes the paper by identifying the policy implications of model selection for developing countries.

Evolution of energy system models

Evolution

The energy accounting approach, which utilizes an energy balance to provide a straightforward representation of an energy system, is a commonly used framework in energy system analysis. According to Hoffman and Wood's (1976) description, this method was initially developed in the US during the 1950s, and it remains a popular and comprehensive approach to this day. Models like LEAP or MEDEE/MAED are based on this accounting framework.

In the early 1970s, a network-based description of the energy system was developed as a natural extension of the energy balance framework. This approach has been extensively used since then. The Reference Energy System (RES) is a detailed representation of all the activities involved in energy production, conversion, and utilization, taking into account the technological characteristics of the system. By incorporating both existing and future technologies, this approach enables analysis of the economic, resource, and environmental impacts of alternative development paths. Hoffman and Wood (1976) introduced this approach, which has set a new tradition in energy system modelling.

Despite the potential for complexity as more technologies and resources are added, the RES approach offers the advantage of being able to develop optimization or simulation models to tackle complex problems. The key benefit of this approach is the ability to apply optimization techniques to analyze alternative system configurations using different technologies and energy sources, based on a given set of end-user demands. Linear programming models were utilized from the early stage of RES development. One notable application of this was the BESOM model, which was developed to facilitate efficient resource allocation in the US. The initial version of the model was implemented at the national level to provide a snapshot analysis of a future point in time. Subsequent versions expanded the capabilities of the model, including macroeconomic linkages via an input-output table. Dynamic or multi-period models have also emerged, and the well-known MARKAL energy system model is actually a derivative of the BESOM model.

Hudson and Jorgenson (1974) were the pioneers of linking an inter-industry energy model with an econometric macroeconomic growth model in the US. The input-output coefficients of the inter-industry model are determined endogenously, and the macro-model enables consistent estimates of both demand and output.

Most of the aforementioned initiatives focused on national-level modeling. However, the development of large-scale global modeling began with Jay Forrester's World Dynamics and its application in the Limits to Growth report by Meadows et al (1972). Although the report's doomsday prediction ignited a debate about resource dependence and sustainability, it had limited representation of the energy sector and limited support. Nevertheless, this report initiated a new trend of global modeling. Notable collective efforts at the global level include the Workshop on Alternative Energy Sources (WAES, 1977), the US Energy Information Administration (EIA, 1978), and the International Institute for Applied System Analysis (IIASA) [in Haefele et al (1981)].

During the period between 1973 and 1985, there was significant progress in understanding the interaction and interdependence between energy and the economy. Researchers debated and investigated this relationship extensively. Hogan and Manne (1979) developed a simple aggregated conceptual framework to explain the relationship between energy demand and the elasticity of substitution between capital and energy. Berndt and Wood (1979) also contributed to this area by suggesting that money and energy may be complementary in the short run but substitutable in the long run. In contrast, Hudson-Jorgenson (1974) conducted a disaggregated study using the general-equilibrium framework to analyze the effects of oil price increases on the economy.

The disagreement of top-down and bottom-up modellers over this period's major progress is the other. Bottom-up models focused on the technical aspects of the energy industry whereas the traditional top-down approach highlighted an aggregated perspective and the influence of pricing and markets. The gap persists today despite efforts at reconciliation.

The 1970s' high oil prices highlighted the need for coordinated advancements in the energy systems and sparked a number of modelling initiatives for tactical planning. In 1978, IAEA created WASP for the planning of the electrical industry. Over the past three decades, this model has seen widespread use and modification to include different functions. Models for electricity frequently use optimisation as their fundamental methodology. According to Hobbs (1995), the following are the main components of their structure:

A decision-making objective function includes the following elements:

a) an objective function where cost minimization is frequently taken into account, although financial and environmental goals can also be employed;

b) a collection of decision variables that the modeller seeks to determine through the model; and

c) a set of constraints that ensure the feasible range of the choice variables.

At this time, the idea of integrated planning gained popularity, and efforts to integrate modelling—either by connecting several modules or by creating a standalone model—increased.

We have already mentioned the trends in the US at the national level. Two popular models, MEDEE and EFOM, were among a group of alternate models created in France. India used an input-output model to guide its planning, which also took energy into account. An integrated model for energy system analysis is reported by Parikh (1981). This model, which was something of a hybrid, combined a description of the energy sector's end-uses with a macroeconomic component. In the middle of the 1980s, the emphasis turned to energy-environment interactions. Deregulation of the energy industry also began at this period. In-depth environmental considerations were integrated into the energy models at this point, which also marked the beginning of long-term modelling. TEEESE (Teri Energy Economy Environment Simulation Evaluation) was introduced afterwards.

The 1990s saw a shift in emphasis towards concerns relating to climate change and linkages between energy and the environment. The majority of energy system models made an effort to include environmental concerns. This was an

extension that made sense for energy models:
The network-based models could similarly identify the environmental burdens using environmental pollution coefficients and analyse the economic impacts by considering costs of mitigation; energy models with macro linkage could analyse the allocation issues taking into account the overall economic impact; accounting models could include the environmental effects related to energy production, conversion, and use by incorporating appropriate environmental coefficients;

The work for regional and global models considerably grew during this time, and several new models were created. These include the Asian-Pacific Model (AIM), the Second Generation Model (SGM), the RAINS-Asia model, the Global 2100 model, the DICE and POLES models, etc.
Existing models were upgraded and expanded at the same time to add new features.
The MARKAL model's use across the globe increased dramatically. Similar to this, the UNFCCC reporting LEAP format established the de facto standard for usage in national communications. Modelers began to think beyond the typical 20 to 30 years and began to take 100 or 200 years into consideration because the climate change issue requires an understanding of very long durations (100 years or more). However, there is significant uncertainty and danger associated with such extensions, and the validity.
Categorisation
Models of the energy system can be categorised based on a variety of different factors. Hoffman and Wood (1976) employed modelling techniques to classify and identify models. The methods listed below:
A approach based on linear programming is employed because it provides "a natural link between process and economic analysis" and offers intriguing and practical economic interpretations through dual problems.
9 - Input-output technique, which is popular because it may reflect sectoral interdependence but has limitations due to fixed technology assumptions, zero price elasticity, and lengthy data availability delays.
- The econometric approach, which can represent and support economic ideas and laws.
Process modelling, system dynamics, and game theory are among examples.

Model comparison

The analysis of the energy system involves the systematic use of a number of models that can be found in the literature. In this part, we compare model capabilities with the intention of determining how well-suited they are to emerging nations. We take into account the following substitute models for energy systems:
- models based on bottom-up optimisation (such as EFOM, MARKAL, etc.); - models based on bottom-up accounting (such as LEAP)
- Top-down, statistical models (such as DTI energy model)
- Hybrid models (such POLES and WEM), as well as 10 models of the power system (such as WASP, EGEAS)

Policy issues related to energy system models for developing countries

As a result of the nonmonetized transactions and reliance on traditional energy sources in developing countries, our analysis in the preceding sections has shown that: a) there are unresolved conceptual issues; and b) the majority of the existing energy system models are unable to accurately capture the unique characteristics of energy systems in developing countries.

Economic theories have been supported by econometric models, which have frequently tried to assess effects at the aggregate level by detecting statistically significant associations.
Over the past 30 years, these studies have changed by going through the trans-log wave and, more recently, the co-integration revolution. Although these techniques have been used in developing nations, they have not fully addressed challenges such as the rural-urban split, traditional energy, unofficial economies, technological diversity, and inequality. Furthermore, the transition to new energies and structural changes have received less attention. Although the end-use models are in theory better suited to capture the characteristics of developing countries, the reality is not always very positive. No model really captures the informal activities, but the spatial disparity

Conclusion
We give a comparison of current energy system models in this work along with an determining whether or not they are appropriate for developing countries. We have examined a number of models that encompass energy systems for this purpose, excluding models of the energy economy. We have taken into account models from a variety of modelling traditions, including using diverse strategies including optimisation, accounting, econometric, and hybrid procedures, top-down and bottom-up. A set of predetermined criteria that addressed the requirements of developing countries were used to conduct the review.

According to the review, accounting models are less likely to suffer from this issue than econometric and optimisation models, which both fail to effectively account for the features of developing countries. These models are less useful because of the quantity of data they require, the theoretical foundations they are built upon, and the fact that they are unable to account for particular characteristics of developing countries such the informal economy and non-monetary transactions. The end-use models of the accounting type are more applicable for developing nations due to their flexible data requirements and emphasis on scenarios rather than ideal answers. The same issues plague global models as well, as developing nations are not given enough attention in these models, and the modelling methodology is not adjusted for developing nations.

poor analysis and policy recommendations result from poor portrayal of the characteristics of developing countries. The dynamics of economic expansion and its energy consequences are not well understood, which leads to erroneous representations of the energy problems, energy-environment interactions, and climatic effects. A better representation of the characteristics of emerging countries in the models is urgently required to advance our understanding. However, modelling the energy system is a substantial problem.

References

- Bhatia, R., 1987, Energy demand analysis in developing countries: A review, The Energy Journal, Vol. 8, Special LDC Issue, pp. 1-32.
- Bhattacharyya, S. C., 1996, Applied general equilibrium models for energy studies: A survey, Energy Economics, 18(3), pp. 145-164, 1996
- Bhattacharyya, S. C., 2006, Renewable energies and the poor: Niche or nexus? Energy Policy, 34(6), pp. 659-63.
- Bhattacharyya, S.C., 1995, Internalising externalities of energy use through price mechanism: A developing country perspective, Energy & Environment, 6(3), pp. 211-221, 1995.
- Brendt, E. R. and D. O. Wood., 1979, Engineering and econometric interpretations of energy-capital complimentarity, American Economic Reivew, 69(3), pp. 342-352.

- E. A. Hudson, and D. W. Jorgenson, 1974, US Energy Policy and Economic Growth: 1975-2000, Bell J. of Economics, 5, pp. 461-514.
- EIA, 1978, An evaluation of Future World Oil Prices, EIA Analysis Memo EIA010121/4, Energy Information Administration, Washington, D.C.
- Finon, D., 1974, Optimisation model for the French Energy Sector, Energy Policy, 2(2), pp. 136-51.
- Haefele, W. et al 1981, Energy in a finite world, International Institute for Applied System Analysis, Austria.
- Heaps, C., 2002, Integrated energy-environment modelling and LEAP, SEI Boston and Tellus Institute, Boston (see http://www.energycommunity.org/default.asp?action=42).
- Hobbs, B. F., 1995, Optimisation methods for electric utility resource planning, European Journal of Operational Research, 83, pp. 1-20.
- Hoffman, K. and D. O. Wood, 1976, Energy system modelling and forecasting, Ann. Rev. En, Vol. 1, pp. 423-453.
- Hoffman, K. and D. W. Jorgenson, 1977, Economic and technological models for evaluation of energy policy, Bell Journal of Economics, 8, pp. 444-66. Hogan, W. W. and A. S. Manne, 1979, Energy-Economy interactions: the fable of the elephant and the rabbit, Advances in Economics of energy and resources, Vol. 1, pp. 7- 26.
- Loulou, R., U. Remne, A. Kanudia, A. Lehtila and G. Goldstein, 2005, Documentation for the TIMES model, Part 1,. ETSAP, (see http://www.etsap.org/Docs/TIMESDocIntro.pdf).
- Markandya, A., 1990, Environmental costs and power system planning, Utilities Policy, October, pp. 13-27.
- Meadows, D. H, Meadows, D. L., J. Randers and W. W. Behrens III, 1972, The Limits to Growth, Universe Books, New York.
- Munasinghe, M. and P. Meier, 1988, Integrated national energy planning and management: Methodology and application to Sri Lanka, World Bank Technical Paper Number 86, World Bank, Washington D.C.
- Munasinghe, M. and P. Meier, 1993, Energy Policy Analysis and Modelling, Cambridge University Press, Cambridge
- Nakata, T., 2004, Energy-economic models and the environment, Progress in Energy and Combustion Science, 30, pp. 417-78.
- Pachauri, R.K. and L. Srivastava, Integrated Energy Planning in India: A Modelling Approach, in The Energy Journal, vol. 9, No. 4, October 1988.
- Sadeghi, M. and H. M. Hosseini, 2008, Integrated energy planning for transport sector – a case study of Iran with techno-economic approach, Energy Policy, 36(2), pp. 850-66.
- Seebregts, A. J., G. A. Goldstein and K. Smekens, 2001, Energy/environmental modelling with MARKAL family of models, in Operations Research Proceedings 2001— Selected Papers of the International Conference on Operations Research (OR2001).
- Urban, F., Benders, R. M. J. and Moll H. C., 2007, Modelling energy systems for developing countries, Energy Policy, 35(6), pp. 3473-3482. Vaillantcourt, K. M. Labriet, R. Loulou, and Jean-Philippe Waaub, 2008, The role of nuclear energy in the long-term energy scenarios: an analysis with the World TIMES model, Energy Policy, 36(7), pp. 2296-2307.
- WAES, 1977, Workshop on Alternative Energy Sources, Global Prospects 1975-2000, New York, McGrawhill.
- Wirl, F. and E. Szirucsek, 1990, Energy modelling – a survey of related topics, OPEC Review, Autumn, pp. 361-78