Energy modeling applications for analysis of policy options-an overview

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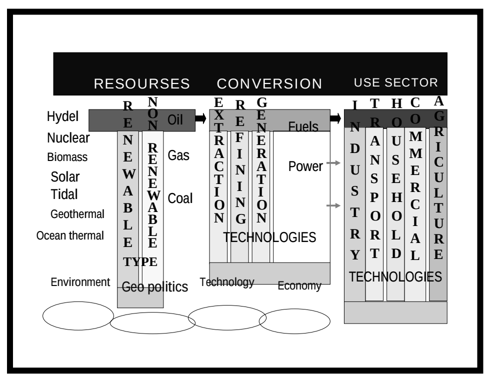
Abstract:- The paper reviews the complex relationships of the elements of a national energy system and the integrated energy planning approach that can be inevitably implemented through computer based modeling tools. General format of an IEP model and its main modules have been described and typical examples of energy models developed and used in different countries have been quoted to show the world-wide application of energy models for policy planning. Energy modeling tools and representative E3-models, that offer capacity building opportunities to the developing nations, have been described.

Key-Words: Integrated Energy Planning, Modeling, energy models

1 Introduction

Energy in the recent past has evolved as a strategic commodity and being the life-line of the industrialized economies, it has become a focus of interest in the geo-politics of the globe. Traditionally a sub-sector based disintegrated approach remained instrumental in the energy policy planning but the major incidences of the oil price shocks in the 1970s changed the scenario altogether. Energy security issues became a vital consideration in the national security policies and a system based integrated approach replaced the traditional practices. Numerous energy models of different kinds were developed at institutional and national levels in the developed world and used for analysis of the long term strategic options. A comprehensive review of the methodological advances in energy modeling between 1970 and 1990 has been presented by [1].

Due to inherent complexities of a national energy system, necessary elements of which are shown in Fig.1, the energy models required expensive institutional setups and main frame computer systems.



The modeling practices, therefore, remained limited to rich developed nations for quite some time, however with the recent enhancements in the capabilities of the personal computers and the dissemination of knowledge through web, the developing nations have also entered the energy modeling-based research and planning; see [2] & [3]. In fact in the context of growing concerns of energy security, IEP approach is being advocated as the only choice even for the developing economies of the third world [4]. The start of a postgraduate degree course in a new discipline *Energy Planning Engineering* at COPPE/HFRJ Brazil is an indication of the growing interest in the field; details can be seen at www.ppe.ufrj.br. The following sections present an overview of the conceptual framework of the main modules of a generalized integrated energy planning model and show typical examples of the energy models developed in various parts of the world.

2 Conceptual framework of an IEP model and its main modules

An IEP model is essentially a software system, consisting of a number of interconnected main modules- each containing an array of sub-modules, which combines representative data sets and parametric relationships of the economic, social, technological and physical sub-systems into a unified analytical environment. Depending upon the type of model e.g. econometric or optimizing and the scope of intended applications, different modeling methodologies are employed in the design of individual models; however the conceptual framework of their main modules is quite similar. Fig.2 shows a generalized format of an IEP model.

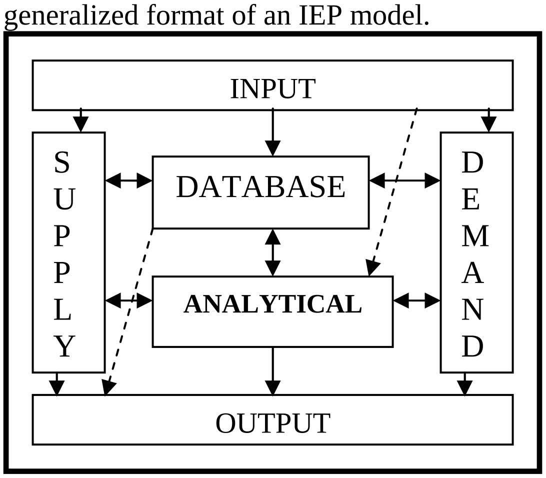


Fig. 2

2.1 The supply module

The supply module identifies the energy input sources of a national energy system, including the supply potential of renewable and non-renewable sources, and analyses the quantum of indigenous and import based resources in the scenario contexts set through short and long term policy perspectives. Supply side technologies with the potential of individual resources, assessed in the context of energy security strategies are modeled in the sub-modules contained within the main module. The supply module generates interactive data linkages with the analytical and the database modules. Fig. 3 exhibits the thematic scope of the supply module.

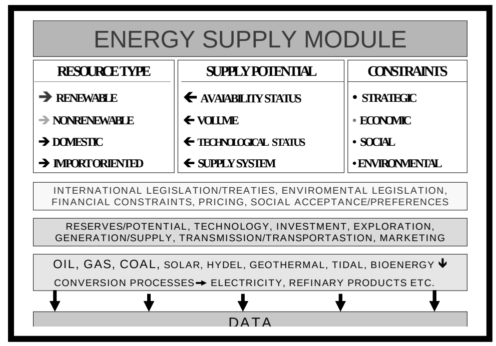


Fig.3

2.2 The demand module

The demand module identifies the energy consuming sectors of a national economy and analyses the energy consumption patterns of the individual applications within the sectors. Technological options available and the impacts of socio-economic and environmental constraints are also taken into account. Bottom-up approach is usually used and the module forms interactive relationships with the database and analytical modules. Macroeconomic linkages of the energy use and sector-wide development targets of the national economy are embedded in this module. Inferences can be drawn and demand projections for the future are shared by this module with other modules in the scenario-based policy perspectives. Fig. 4 shows the thematic scope of the demand module. The database module is the heart of the IEP model, which provides backup support and interactively communicates with other modules. Sub-modules within the database module maintain inter-and-intra module data transfer linkages in a complex but reliable statistical environment. Data sets generated

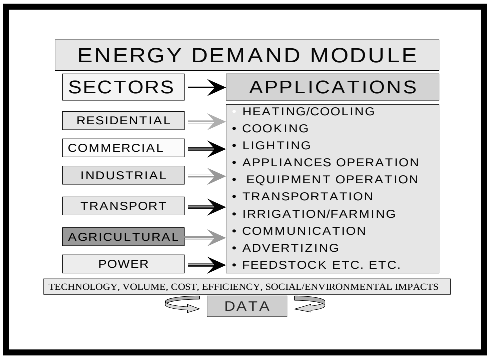


Fig. 4

and required by the supply module, the demand module and the analytical module are managed within the sub-modules of the database module; maintaining interactive linkages with the input and the output modules. Popular database management systems are generally employed by most of the energy models so that requisite data handling and customized report generation may be facilitated.

2.3 The analytical module

The analytical module is the brain of an IEP model. In fact it is a true representative of the model type and is essentially equipped with the necessary computational tools, logics and the mathematical and statistical parametric relationships. Depending upon the particular model type it may consist of variables, arrays, mathematical relations, heuristics and algorithms etc. It has two-way communication links with the database module and necessary interactions with the demand and supply modules. Scenario inputs based on socio-economic, technological and environmental constraints, in conjunction with the data sets generated by various modules, are processed by the analytical module to generate outputs representing the alternate decision options.

2.4 The input/output modules

The input and output modules are highly model-type dependent and these are designed according to the specific requirements of the users. The input module is usually provided with constraints and scenario data in a user friendly input format and the output module furnishes customized outputs. Some of the models generate report formats to be directly used in the documentation of the Governments or the planning agencies, while others generate outputs which are subjected to further processing by the researchers and decision makers in the light of their experiences, judgments and other factors that can not be addressed through the modeling process alone. In fact the energy models are used as decision tools with the help of which a decision maker can analyze different scenarios and alternatives.

3 Examples of IEP model applications:

The following section presents examples of some representative models, with institutional links and references to pertinent studies, developed in various parts of the world. The purpose of the selected listing is merely to show the world-wide application of the IEP models and the number of models listed here represents only a small fraction of the actual models available.

3.1 Examples of country-specific applications

i) **Asian-pacific Integrated Model / end-use, abbreviated as AIM/end-use** was developed by National Institute for Environmental Studies, Japan and it has been used for many useful studies like CO2 emissions forecast described by [5]. Further details can be seen at URL: www.nies.go.jp/social/aim

ii) **Canadian Integrated Modeling System, abbreviated as CIMS** was developed by Energy and Materials Research Group (EMRG), School of Resource and Environmental Management (REM), Simon Fraser University, Canada. A typical study by use of CIMS is reported by [6]. Further details can be accessed through URL: www. erg. sfu. Ca / EMRGweb.

iii) **Energy Flow Optimization Model – Combined Heat and Power**, **abbreviated as EFOM–CHP** was developed by Systems Analysis Department, Risø National Laboratory, Denmark. Economic features of the model have been described by [7]. Further details can be had through URL: www.risoe.dk/sys/esy/models/efom_chp.htm

iv) **Model for Energy Supply Systems Analysis and their General Environmental impact, abbreviated as MESSAGE** was developed under the **Environmentally Compatible Energy Strategies (ECS) Project, IIASA, Laxenburg, Austria.** A stochastic version of the model was described by [8].

v) **Model for the Optimization of Dynamic Energy Systems with Time-dependent components and boundary conditions, abbreviated as MODEST** was developed by Linköping Institute of Technology, Sweden. [9] describes the applications of the model at utility and national levels.

vi) **National Energy Modeling System, abbreviated as NEMS** was developed for the Department of Energy (DOE), USA. An overview of the modeling system was presented by [10].

vii) **Program package for Emission Reductions Strategies in Energy Use and Supply**, **referred as PERSEUS family** was developed by the Institute for Industrial Production (IPP), University of Karlsruhe, Karlsruhe, Germany. The capabilities and applications of the model have been reported by [16].

viii) **TERI Energy Economic Simulation and Evaluation, abbreviated as TEESE** was developed by the Tata Energy Research Institute (TERI) in Dehli, India. The modeling approach has been described in detail by [11].

ix) **PRogram for Optimization and Dimensioning of Energy conversion Systems, abbreviated as PRODESign** was developed by **Energy Research Centre of the Netherlands (ECN), The Netherlands.** [12] shows the capabilities of the model for the analysis of the energy conversion systems.

3.2 Examples of energy modeling tools

Some energy modeling software tools have also been developed, which are not energy models, but can be used as tools for the energy system models. Through international development support programs to developing nations, these tools have been successfully used for the energy planning needs. Some selected examples are given below:

i. RESGEN (Reference Energy System GENerator)

Based on the concepts of Reference Energy System (RES) and matrix algebraic relationships, a flexible software package, called RESGEN was developed. With the help of international development support programs like USAID, RESGEN has been successfully used by the energy planning agencies of many developing countries for their specific planning needs. Some of these countries are Indonesia, Thailand, Sri Lanka, Haiti, the Dominican Republic, Uruguay, Pakistan and Morroco. [2].

ii. ENERPLAN

A highly flexible and user friendly software package, called ENERPLAN was developed by the Tokyo Energy Analysis Group for UNDP in 1984-5. The package can be used for generating macroeconomic and energy sector models and it has been successfully employed for specific studies in many countries, including Thailand, India and China.

iii. ENERGY TOOLBOX:

The Energy Toolbox is an advanced microcomputer base software package, which was developed in 1990 in the UK [3]. It includes a number of established energy modeling tools like Reference Energy Systems, Linear Programming, energy balance tables, and econometric demand analysis, integrated through a common database.

iv. WWW-WATEMS-GDL

The WWW-WATEMS-GDL is a web-based energy modeling system designed for easy construction and updating of energy planning models of mathematical programming type and make them available to other researchers through internet. The system has been developed at the Department of Management Sciences, City University of Hong Kong. The system capabilities have been described by [13].

3.3 Examples of E3-model applications

Energy-Economy-Environment models, generally called E3-models provide a flexible modeling environment which can be adopted for generating the energy system models of any country or region with pertinent data inputs. E3 models have been developed through multinational institutional initiatives and have been successfully used for:

- Strategic planning of future energy supply options;
- Analysis of least-cost strategies for achieving energy and emission policy targets;
- Economic evaluation of environmental and energy policies and measures;
- Examination of the collective potential of key technologies and resources;
- Evaluation of different R&D strategies for energy technologies.

Planners and researchers from developed as well as developing nations across the glob are using these for specific analytical studies. Training and capacity building support is provided to developing nations by the developers of these models. [14] shows a typical application in Indonesia.

A review of three representative models, that have been successfully employed by the nations across the world i-e ENPEP, MARKAL, LEAP are described below:

i) **ENergy and Power Evaluation Program, abbreviated as ENPEP** was developed by systems analysis section of the U.S. Department of Energy's Argonne National Laboratory, which provides energy planning tools, training and support to the developing nations. ENPEP is a tool that lets researchers and planners compare alternatives quickly to determine the most cost-effective and environmentally safe solutions for their country's energy needs. *Argonne's ENPEP software has been used in more than 95 nations for energy planning.* More than 530 researchers from 68 countries, ranging from Algeria to Zaire, have been trained at Argonne since the program began in 1978. Because energy planning is evolutionary, researchers learn to use the software so they can continue to revise and plan as needed instead of relying on outside consultants for assistance. [15].

ii) **MARKet ALlocation model abbreviated as MARKAL** was developed in a cooperative multinational project over a period of almost two decades by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency. MARKAL is a generic model tailored by the input data to represent the evolution over a period of usually 40 to 50 years of a specific energy system at the national, regional, state or province, or community level. The number of users of the MARKAL family of models has multiplied to 77 institutions in 37 countries, many with developing economies, promising to continue and broaden these accomplishments. [16] & [17]. Further details can be seen by following the link: www. ecn. nl/ unit _bs/etsap/markal

iii) **Long Range Energy Alternatives Planning System, abbreviated as LEAP** was developed by Stockholm Environment Institute-Boston USA. This is a tool for strategic integrated energy analysis and has been successfully used for:

- Environment Scenario Studies:
- Energy Outlooks (forecasting)
- Integrated Resource Planning.
- Greenhouse gas mitigation analysis.
- Energy balances and environmental inventories.

LEAP has been used to develop local, national and regional energy strategies, conduct greenhouse gas mitigation assessments, and train professionals in sustainable energy analysis by over 1700 researchers and planners in nearly 140 countries, including most of the developing countries. Further details of the tool and its applications can be found through the link: www.forums.seib.org/leap. A typical study is shown by [18].

4 Conclusions

Analysis of the energy policy options in the context of conflicting sub-sector objectives, peculiar constraints of the geo-politics, socio-economic and technological limitations and environmental implications has made integrated planning approach inevitable. The fast growing computational capabilities of the personal computers and the web based communication tools has made it possible to develop and use energy system models as decision tools. The developed nations have already adopted and almost optimized the modeling practice for energy policy planning and the developing nations have also stepped in the field.

In the context of growing concerns of energy security, regional and global initiatives, the complexities of the national energy systems have reached a level, where traditional approaches in energy planning have lost their significance and model based IEP approach has become inevitable even for the developing nations. IEP modeling, however, is neither an easy task nor a cheap option and requires a strong and sustainable institutional backup for initiating a successful modeling practice. Comprehensive modeling environments provided by the modeling tools developed through multinational initiatives, e.g. the E3 models described above, offer accessibility and training support to the developing nations for capacity building and these opportunities must be availed.

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