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MODELS AS DECISION SUPPORT TOOLS FOR ENERGY PLANNING IN DEVELOPING COUNTRIES

A. Voss, A. Adegbulugbe*, F. Dayo*, A. Reuter, Y. Saboohi
Institut für Kernenergetik und Energiesysteme,
University of Stuttgart

S. Rath-Nagel, F. Rebstock
GOPA mbH, Bad Homburg

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1. Introduction

Energy planning is a complex and data intensive task requiring the expertise of the decision maker and the modeler and an adequate planning tool. Many energy models have been developed during the past 20 years and some have been applied for analyses of the energy system of industrialized countries. In recent times some of these models have been adopted and applied to the situation of developing countries, and some few have been developed by organizations in developing countries itself.

* CERD, University of Ife, Nigeria

Table 2: Energy Supply Models

No.	Name of Model	Time	Space	Modelling Technique	Application	Computer Requirements	Rural-Urban Dichotomy	Analytical Representation of Non-commercial Fuels	Potential of Renewable Energy	Regional Imbalance	Management of Exhaustible Resources	Interaction between Energy and Economy	Foreign Exchange Requirements
1	EFOM	medium term long term	country region, country groupings	Optimization (linear program) or Simulation	- Thailand - Swaziland	Implementations IBM 3033 ICL 2980	not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	not explicitly addressed	can be addressed	not applicable	can be addressed
2	Energy Planning System Model (Bogazici)	medium term (15 years horiz.) (3 year steps)	country region	Optimization (linear program) Decisions after each step	- Turkey		not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	not explicitly addressed	can be addressed	not applicable	can be addressed (cost inputs are specified in local and foreign part)
3	Energy Technology Assessment Model (Stanford)	long term	country region	Optimization (non-linear programming)	- Mexico		not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	not explicitly addressed	can be addressed	not applicable	not explicitly addressed
4	KAU and INTERATOM Models	medium term long term	country (with subdivided regions)		- OPEC countries - Indonesia	memory > 500 kB progr. language FORTRAN	not explicitly addressed	not explicitly addressed	can be addressed	can be addressed (each region may have exports or imports)	can be addressed	not applicable	can be addressed
5	Less Developed Countries Energy System Network (BNL)	short term (3 years) long term	country region	Accounting (network flow)	- Egypt - Thailand		not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	not explicitly addressed	can be addressed	not applicable	not explicitly addressed
6	MARKAL	medium term long term	country region	Optimization (linear programming)	- Brazil - Guandong Province (China) - Indonesia - Morocco	progr. language OMNI Implementations different main frame	not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	can be addressed	can be addressed	not applicable	can be addressed
7	MESSAGE II	medium term long term	country region, country grouping	Optimization (linear progr.) non-lin. opt., multiple objective function	- China - World regions	Implementations different main frame and micros	not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	can be addressed	can be addressed	not applicable	can be addressed
8	NEXINE	medium term long term	country	Optimization (static, constraints in linear form objective fct. in non-linear form)	- Ecuador - China	Implementations micro and main frame computers	not explicitly addressed	not explicitly addressed	can be addressed in network representation of supply system	not explicitaly covered	can be addressed	not applicable	can be addressed (cost inputs are specified in local and foreign part)
9	WASP	medium term long term	country	Sector Model, Optimization (dynamic programm. and probabilistic simulation	applied in more than 40 countries (including developing countries)	memory > 640 kB operating syst. any progr. language FORTRAN Implementations IBM - AT, PC ver. main fr.	not explicitly addressed	not explicitly addressed	can principally be addressed	not explicitaly addressed	can be addressed	not applicable	can be addressed by splitting the input cost in local and foreign
10	Development of an Electric Network (CICRE)	short term (1 year intervals)	country region	Sector Model, Optimization (static)	- CSSR		not explicitly addressed	not explicitly addressed	not addressed	not addressed	not addressed	not applicable	not explicitly addressed

Table 3: Energy Demand Models

No.	Name of Model	Time	Space	Modelling Technique	Application	Computer Requirements	Rural Urban Dichotomy	Analytical Representation of Non-commercial Fuels	Potential of Renewable Energy	Regional Imbalance	Management of Exhaustible Resources	Interaction between Energy and Economy	Foreign Exchange Requirements
1	Argentine Energy Model	long term	country region	Generalized Equilibrium (simultaneous non-linear equ. defining price and quantity under market equil.)	- Portugal - Republic of Korea - Argentina	memory > 1.3 MB progr. language FORTRAN Implementations IBM 0333	not addressed	not addressed	can be addressed (through representation in system network)	not addressed	not applicable	not applicable	can be addressed, (one of outputs is fuel importation)
2	EDE	medium term long term	country with possible disaggregation into regions	Simulation with simple structure (input data are socio-economic development)	- Algeria	progr. language FORTRAN Implementations IBM CD Cyber 175	not addressed	can be addressed (demand for non-commercial energy in household is considered)	not addressed	not addressed	not applicable	not applicable	not addressed
3	Energy Requirement Model - Rural Area (IDEE)	short term medium term	country region	Statistical (productive and household sector are divided into homogeneous groups)	Simplified example applied	memory > 650 kB operating syst. MS - DOS progr. language FORTRAN Implementations WANG PC Micro-Computer	addressed (contribution on non-comm. and comm. energy requirements is considered)	addressed (supply of non-comm. energy is estimated. Energy requirement in rural area is determined)	addressed (the availability and contribution of renewable resources to energy requirem. is considered)	not addressed	not applicable	not applicable	not addressed
4	Long term energy demand forecasting for EC (Thailand)	medium term long term	country	Accounting techn. (determine final energy in each economic sector)	- Thailand	progr. language SUPERLAC pack. Implementations Micro-Computer Apple II	not addressed	addressed (demand for non-comm. energy in household and agriculture is considered)	can be addressed (penetration rate of solar, wind and bagasse is considered)	not addressed	not applicable	not applicable	not addressed
5	MAED	long term	country region	Accounting techn. (demand for useful and final energy is calculated on the basis of socio-economic devel. scenarios)	- Jordan - Turkey - Algeria - Malaysia	progr. language FORTRAN Implementations Micro-Computer or main-frame	not addressed	can be addressed (it is considered under the heading "non-comm. fuels")	can be addressed (contribution of solar energy)	not addressed	not applicable	not applicable	not addressed
6	MEDEE - S	medium term long term	country region	Accounting techn. (demand for energy in each sector of economy is determined on the basis of economic development)	- Ecuador - Mexico - Venezuela - Colombia	progr. language FORTRAN Implementations Micro-computer or main-frame	not addressed	can be addressed (traditional fuels are considered under the heading "biomass")	can be addressed	not addressed	not applicable	not applicable	not addressed
7	Minimum Standard Model (World Bank)	short term medium term long term	country	Econometric and Accounting techn. (energy demand is determined by price and income elasticities)	- India - Brazil - Chile - Portugal - Kenya - Pakistan		not addressed	can be addressed (demand for non-comm. energy is explicitly considered)	not addressed	not addressed	not applicable	not applicable	not addressed
8	OAK RIDGE Model	long term	country	Econometric (Macro-economic variables are estimated using simultaneous system of Keynesian model)	- Liberia		not addressed	addressed (demand for traditional fuel is estimated)	not addressed	not addressed	not applicable	not applicable	can be addressed (the export and import level of fuels are determined)
9	Mexico National Energy Model (Mexico University)	long term	country region	Statistical (energy demand is estimated by statistical analysis of devel. of pop., GNP and energy consumption)	- Mexico		not addressed	not addressed	can be addressed	not addressed	not applicable	not applicable	not addressed

Table 4: Energy-Economy Models

No.	Name of Model	Time	Space	Modelling Technique	Application	Computer Requirements	Rural Urban Dichotomy	Analytical Representation of Non-commercial Fuels	Potential of Renewable Energy	Regional Imbalance	Management of Exhaustible Resources	Interaction between Energy and Economy	Foreign Exchange Requirements
1	Intertemp. Mathemat. Model of National Economy with I/O technique	medium term long term	country	Input/Output (whole economy is divided into 6 sectors: oil, coal, elec., agriculture, industry, transportation)			not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	can be addressed (effect of conservation policy on exhaustible resources)	addressed (the I/O model is used for analysis of the interaction between energy and economy)	not addressed
2	Computable General Equilibrium Model for Mexico		country	comp. general equ. (10 classes of identical consumers are considered; Cobb-Douglas funct., consumption by Keynesian function)	- Mexico		not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	not addressed	addressed (the model focuses on energy pricing, government investment & trading policy)	not addressed
3	Energy Economy Simulation for Oil-Importing DC (Blitzer)		country	Simulation (outputs are determined by Cobb-Douglas funct., consumption by Keynesian function)	- Jordan		not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	not addressed	addressed (the model considers the feedback between energy and economy	can be addressed (F.E. needs for importation of fuels can be calculated)
4	Blitzer-Eckhaus Mexico Model	long term	country	Multi-Period LP	- Mexico		not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	can be addressed (optimal supply of oil and gas can be inferred)	addressed (it is energy-economy model; adjustment of economy to exogenous changes is checked)	can be addressed (by specifying foreign and domestic components on input data)
5	TEESE	medium term	country	Input/Output + LP (I/O represents the economy; LP represents the energy system)	- India		not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	can be addressed (LP model of energy system is used for optimization of resources)	addressed (I/O is coupled with LP; effect of energy demand & supply on economy and subst. between fuels addressed)	can be addressed (by specifying foreign and domestic components on input data)
6	Energy-Economy Simulation for Oil-Importing DC	long term	country	Simulation (energy is disaggregated into coal, oil hydro, nucl.; the economy is not disaggregated)	-India		not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	not addressed	addressed	can be addressed (foreign exch. requir. for importation of oil can be calculated)
7	ESPM	user specified horizon	country region	Accounting (the energy flows and related costs are tracked) Impact Model	- Egypt - Indonesia - Peru - Portugal - Republic of Korea	progr. language FORTRAN Implementations IBM 360/370, CDC	not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	not addressed	addressed (the impact of energy on industrial sector is partially considered)	partly addressed (domestic and foreign components of the requirements are specified)

Table 5: Integrated Energy Models

No.	Name of Model	Time	Space	Modelling Technique	Application	Computer Requirements	Rural - Urban Dichotomy	Analytical Representation of Non-commercial Fuels	Potential of Renewable Energy	Regional Imbalance	Management of Exhaustible Resources	Interaction between Energy and Economy	Foreign Exchange Requirements
1	ENERPLAN	short term medium term long term	country region	set of integr. simul. models: - energy balance - statistics - simulation mod. - traditional sector resource model	- Thailand - Costa Rica	memory > 256 kB progr. language BASIC Implementations IBM - PC NEC	addressed in traditional sector model	resource supply/ demand balance model for wood, animal dung, agric. residues	not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed
2	ENVEST	short term medium term	country region	set of interlinked simul. and optimization models: (step by step "bottom-up" approach)	- Morocco - Costa Rica	memory > 256 kB operating syst. MS - DOS progr. language BASIC Implementations IBM - PC NEC	not explicitly addressed	not explicitly addressed	not explicitly addressed	not explicitly addressed	can be addressed	not explicitly addressed	not explicitly addressed
3	IDEA	short term medium term long term	country region	set of interlinked simul. and optimization models: - subsectoral - energy sector - macro-economic analysis	- Sri Lanka - Indonesia - Haiti - Dominican Republic	memory > 320 kB operating syst. MS - DOS Implementations IBM - PC	addressed in fuel wood demand model	not available	can be addressed in network supply system model	not explicitly addressed	can be addressed	interaction between energy demand and macro-economic module realized	addressed by split between domestic and foreign comp. of fuel and technology
4	LEAP	medium term long term	country region	set of interlinked simul. models: - macro-economic - demand - supply (transf.) - resource model	- Kenya	memory > 256 kB operating syst. MS - DOS Implementations IBM - PC	addressed in the model (also treated in food/energy and fuelwood/ commercial wood usage)	resource progr. forecasts land use wood availability, wood stock: food and wood balance of supply and demand	addressed in demand and supply (transformation) program	addressed in resource program, which is on a regional interlinked basis	can be addressed	not explicitly addressed	can be addressed
5	MESAP	short term medium term long term	country region	integr. set of simul., account. and optimization models: demand, supply (opt.), energy balance, statistics, investment calc.	- Nigeria - Iran	memory > 1000 kB operating syst. VMS, UNIX progr. language FORTRAN Implementations DEC - MICROVAX PCS - CADMUS	addressed in household model (HHOD)	household energy demand is funct. of: househ. type (MESSAGE) income, energy, prices, opport. costs for non-comm. fuels, behaviour	can be addressed in supply system model (MESSAGE)	not explicitly addressed	can be addressed in supply system model (MESSAGE)	not explicitly addressed	can be addressed in supply system model (MESSAGE)
6	ENPEP	short term medium term long term	country region	integr. set of models: macro, demand, balance of demand and supply, load forecast, impact	ENPEP is yet in a developing stage	memory > 640 kB operating syst. MS - DOS progr. language FORTRAN Implementations IBM - PC, AT DEC, MICRO-VAX	still open (ENPEP is in a developing stage)	still open (ENPEP is in a developing stage)	still open (ENPEP is in a developing stage)	still open (ENPEP is in a developing stage)	still open ENPEP is in developing stage)	addressed in impact model	still open (ENPEP is in a developing stage)

- rural-urban dichotomy,
- analytical representation of non-commercial fuels,
- potential of renewable energy,
- regional imbalance,
- management of exhaustible resources,
- interaction between energy and economy, and
- foreign exchange requirements.

The DC-specific criteria, which deserved our particular attention, are commented below.

a) The Rural-Urban Dichotomy

The urban sector depends in most cases strongly on the consumption of the so-called commercial fuels, while the rural population depends, in some cases, almost entirely on traditional forms of energy (non-commercial fuels). The latter leads to severe problems such as deforestation, erosion, loss of soil fertility and traditional farmland.

There are two reasons why the non-commercial fuel should be treated differently from the commercial ones. First they are by and large untraded and fall outside the normal cash transactions aside from areas near the urban centers. There especially firewood is traded. Secondly, for commercial fuels the suppliers and consumers are distinct entities while the consumers and suppliers of non-commercial fuels are the same. There exists a difficult quantification problem for the non-commercial fuels.

In most of the models that treat non-commercial fuels, only fuelwood is considered in details because it is the largest form consumed and the inclusion of animal dung, crop residue, twigs and leaves will greatly complicate an already complex structure. Some models miss the point by not recognising this rural-urban dichotomy present in most developing countries. As an example the LEAP model includes a good representation of the rural-urban differences.

b) Analytical Representation of Non-Commercial Fuels

Under this criteria, we examine how the models represent analytically the supply and demand of non-commercial fuels. Among the models, two approaches are used to analytically handle the supply of non-commercial fuels.

The first method is the network approach. It is applied by most supply optimization models. The principle is that the "optimal" supply structure for non-commercial energy can be found if the necessary technology and cost data are available which represent the flow of energy from the resource extraction to the end-use device, given a level of useful or final energy demand.

The second method, implemented for instance in ENERPLAN, approaches the supply of fuelwood from a resource balance equation. The total available forestry resource stock at a given time is equated to the available stock at a previous time step, plus incremental addition due to afforestation and natural growth of the foresting resource in that period, less the consumption and deforestation due to other causes in the same period.

c) Potential of Renewable Energy

Many developing countries are endowed with a large resource base of renewable energy sources. These sources include resources such as hydropower, solar energy, wind, tidal, geothermal, biomass, etc.

The potential of renewable energy sources for satisfying energy demand can principally be analyzed by all energy supply models reviewed in this study. The representation of renewable sources in energy supply models such as MESSAGE, requires, however, very detailed information about resources and conversion technologies, which is generally not available. In addition, the amount and availability of renewable sources depend largely on climatic conditions, which may add another dimension of uncertainty to the use of such supply models.

d) Regional Imbalance

Most developing countries are characterised by a heterogenous spatial development. The economic and social infrastructure are distributed unevenly. While some regions are heavily industrialised, others have subsistence economy. Differences in economic development of various parts of a country often result in different regional levels of energy demand. As a result, energy is also distributed unevenly in the regions. Lack of energy supply systems in underdeveloped regions has often lead to lack of investment in those areas.

Many of the energy supply models reviewed represent the technical dimension of the energy system only. Homogenuity throughout the country or region is assumed implicitly. An application of these models for a larger developing country requires often modifications in order to add the regional dimension.

e) Management of Exhaustible Resources

Management of exhaustible resources is an important issue in most developing countries and has considerable direct or indirect impact on the economic development. Optimal utilization of resources and development of a proper resource pricing policy will either contribute to the increase of foreign exchange revenues (from the export of these resources) or to the decrease of energy imports, and consequently helps to reduce foreign exchange requirement.

The developing countries can be classified into two major groups: net oil exporting countries and net oil importers. The management of exhaustible resources in net oil importing countries can be achieved through development of an optimal energy supply system. The main characteristic of oil exporting developing countries is that they export a large share of the production of exhaustible resources, with such export playing an important role in the economic development of these countries.

Therefore, development of prices, determination of the level of export and domestic requirements are the most important issues.

The energy supply system models, which have been reviewed, use optimization techniques which are normally based on minimization of objective functions subject to certain constraints. In these models, the export revenues from energy are negative contributions to the objective function. In the case of a large oil exporting developing country this modelling feature would lead to false conclusions for the domestic market. It would, therefore, be necessary to analyse the utilization of exhaustible resources for the domestic and for the export market separately.

f) Interaction between Energy and Economy

Understanding the relationship between the energy sector and the rest of the economy is important in two respects. First, the energy sector is linked with almost all the sectors of the economy, hence economic activities will have a large influence on the energy demand. Secondly, an energy planning exercise is not a goal in itself bur rather a means of achieving national development objectives. For developing countries in particular, the interaction between the energy sector and the economy assumes a bigger dimension since the singular objective of these countries is that of achieving balanced development within the shortest feasible period.

There are three different techniques used in the energy-economy models reviewed: The first method is Linear Programming with an Input-Output table. This is the technique adopted for instance by the TEESE model, which was structured and developed around the Brookhaven Energy Economy Assessment Model (BEEAM).

The second major method is somewhat different from the first approach because there is no optimization but rather simulation of the economy under the assumptions of various alternative policies. This was the approach used by the Blitzer model of the energy-economy in Jordan. This type of model is basically built around variables such as GNP, investment and savings.

The third methodology is applied by the so-called Computable General Equilibrium Models (CGEM). The CGEM are based on the original Walrasian equilibrium in which prices are adjusted to make excess demand equal to zero, such that consumers maximize their utility functions while the producers maximize profits.

g) Foreign Exchange Requirements

The developing countries are usually characterised by underdeveloped industrial infrastructures. Expansion of any sector of the economy will require importation of technology from industrialized countries.

The energy sector is a large scale system. Development of this sector requires the construction of large extraction and conversion technologies, which are usually, to different extents, not within the technological capabilities of most developing countries. Therefore, a large sum of foreign exchange will have to be allocated for the importation of the necessary extraction, conversion and transmission facilities.

In addition, net energy importing developing countries have to spend foreign exchange for importation of fuels, which is needed by the energy system. Foreign exchange expenditures on importation of fuels and technologies are important issues. In most developing countries, the availability of foreign exchange is a major problem and may limit the development of the energy sector. A flexible tool for planning the energy system must have the capability of being used to analyse the effect of foreign exchange shortages on the structure of the energy system.

The objective function of reviewed energy supply system models, like EFOM or MARKAL, is usually minimization of total cost. This total cost is the sum of domestic costs and the foreign exchange expenditure for operating and developing the energy sector. For analysis of the foreign exchange requirement, it will be necessary to specify the domestic and foreign components of the total cost in the objective function explicitly.

4. Conclusions and Recommendations

From the model review the following conclusions can be drawn.

On the problem of data, it is clear that the lack of reliable and consistent data in most developing countries limits the usefulness of some of the more comprehensive and detailed models. Apart from the problem of data, those models which utilize econometric techniques have an additional complication due to the structural change and political/economic disequilibrium ever present in developing countries. Yet, despite these problems, if models are to serve as a useful aid for decision making, there may be no choice but to dedicate more efforts to data collection on a more frequent basis. In the interim," educated guesses" or cross-country comparison may be used, albeit with a great deal of caution in estimating some input parameters.

On the major problem of the inadequate analytical representation of the rural energy system, some models simply miss the point by not recognising the rural-urban dichotomy present in most developing countries. Those, that do recognise this structure, deal with the rural energy system inadequately. The source of this problem is twofold: First, the lack of data which was explained earlier; secondly, it must be recognised that the rural energy system is complex, and far from completely understood. The complexities arise from reasons such as

- the difficult distinction between supply and demand for traditional fuels in the rural energy system
- the transactions for fuels which are generally outside the traditional monetary systems
- the different purposes for which traditional fuels are used, thereby further complicating the estimation process.

The use of traditional energy sources, especially wood, has a major impact on the ecological system and may cause serious environmental problems, which consequently will affect other sectors. The treatment of this issue requires a thorough consideration of intertemporal allocation of natural resources.

On the problem of imbalances between demand and supply of energy in various regions, which is mainly due to heterogenous socio-economic development, no model has addressed this issue explicitly, although this problem exists in most developing countries, and its solution requires expansion of transportation and transmission networks and consequently has a major impact on the investment and siting policies. A step forward in the process of treating this problem is to include the territorial dimension alongside the technical dimension in the energy supply models.

In addition to these major issues, the potential contribution of technologies tapping renewable energy resources like mini-hydro, biogas, etc., which are usually decentralized, are not adequately covered by the supply models. While one might argue that they could be included in energy supply system models in principle, once the relevant technical and economic parameters are available, other criteria have to be defined to distinguish them from the more conventional large-scale centralized energy supply systems. Renewable energy resources with the regeneration function characteristics are not reflected explicitly in the existing energy supply models.

In view of the above observations, it becomes obvious that there is a need for more efforts in the direction of data collection and institutionalization of these efforts in the developing countries. In addition, more research efforts are needed to understand the rural and the regional aspects of energy systems in developing countries. Perhaps, when the state of knowledge improves and data become more readily available, improved methods and approaches will emerge for the analysis of developing countries' energy system.