NATIONAL ENERGY PLANNING IN SRI LANKA
Part 1 - Development of Computer Models

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Abstract : This paper describes the formulation and use of a set of micro-computer based models for Energy Planning and Policy Analysis in Sri Lanka. It describes the three-tier hierarchical modeling framework. The overall Energy sector analysis is carried out by using RESGEN, a physical Energy Balance model and Energy Network and EFAM, its financial counterpart, which provides information on corresponding economic and financial flows. The three principal Energy sub-sectors, electricity, oil and biomass, are analysed by means of appropriate sub-models. ENMAC is a multi-sector simulation model at the top level of the hierarchy which captures the chief interactions between the Energy sector and other important sectors of the macro-economy.

THE BACKGROUND

The Energy Planning and Policy Analysis Task Force (EPPAN) of the Ministry of Power and Energy, Sri Lanka was formed in 1982. This Task Force, and its working group on Energy Modeling have been largely responsible for the Integrated National Energy Planning (INEP) exercise conducted during 1983-1985. The objective of INEP was to formulate a long-term National Energy Strategy for Sri Lanka. Micro-computer models were developed by EPPAN staff for detailed investigation of the National Energy situation and policy options.

The micro-computer models described in this paper were developed by the working group of the EPPAN with the assistance of an overseas consultant. The project was funded by the Asian Development Bank (ADB).

THE MODEL FORMULATION

The key design feature of the modeling system is its hierarchical structure. Instead of developing a large, comprehensive model, a series of smaller models have been developed. Each model is capable of being run on its own, but also could be linked to each other. Different models were developed for different levels of detail, resulting in the hierarchical system depicted in figure 1.

At the Energy supply sub-sector level, two models have been developed. The first is a Linear Programming (LP) model for the Petroleum Refinery. This model determines crude type and throughput to meet the petroleum product demand at minimum foreign exchange cost, subject to existing refinery configuration. The second sub-sector model is for the fuelwood sector.

At the next level are the Energy Sector Models. The first is an Energy Balance Model (RESGEN) that is designed for construction and analysis of National Energy Balance Tables. The model has the flexibility to configure the Energy Balance in many different formats (such as OECD, World Bank or UN format) with foreign currency transactions for imports, exports and bunkers. The Energy Financial Analysis Model (EFAM) keeps track of Energy demand, prices and investment. Finally, at the top of the hierarchy, stands the Energy Economic Model that provides the macro-economic linkages.

RESGEN, based on the Reference Energy System (RES) Framework, provides a complete progression, in network form, from Energy demand through distribution, transmission and conversion to supply. The pictorial format for RES is a network diagram which indicates Energy flows and the associated conversion efficiencies of the technology employed in various stages of the Energy system. For each Energy resource a complete RES specifies the technologies employed in extraction, refining, conversion, transmission, distribution and utilization in an end-use device. RESGEN is fully interactive, with data entry programmes that free the user from concern about format. It is particularly suited to scenario analysis. Scenarios can be structured and their impact evaluated with great ease and speed.

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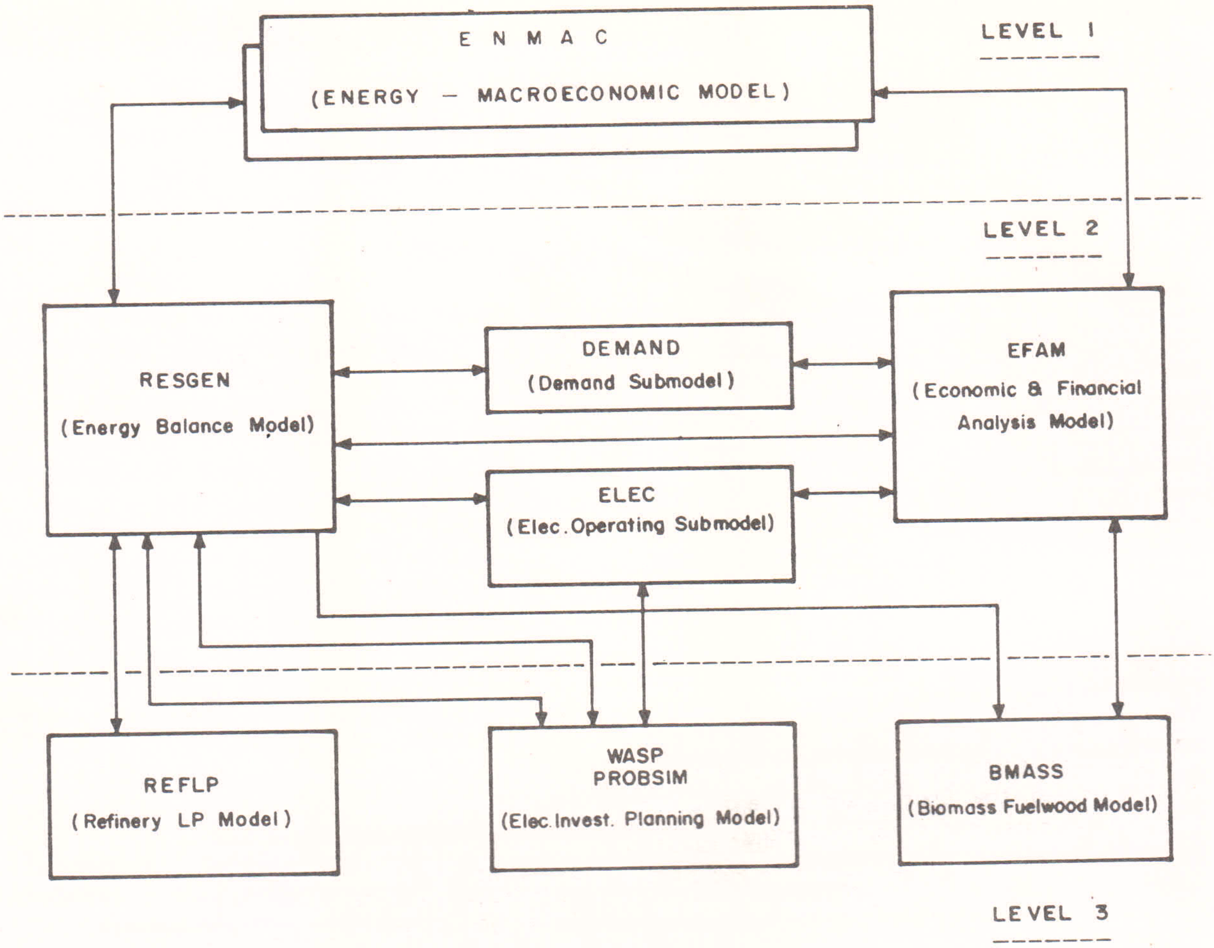

Figure 1 - The hierarchical modeling system

The computational sequence and the flow of information at the sector and macro levels are done at different stages. GDP growth rates, exchange rate and world oil prices are given in separate data files in RESGEN analysis. This information provides the basis for RESGEN to carry out Energy Demand Projections. RESGEN then provides an analysis of the Energy Balance, and the projects that are necessary to meet the estimated demands. Such project specific information is necessary to estimate the aggregate investment requirements, construction outlays and debt service for the sector. This information is in turn passed back to the macro-model together with the Energy related transactions on current account oil imports and exports, bunkers and Energy investment related capital goods imports. It then returns to Macro Model to superimpose the Energy sector transactions on those of non-Energy sectors to produce an overall picture of the resource gap and financing requirements. In this way consistency is attained between the overall macroeconomy, Energy Sector and the external balance of payments.

RESGEN

RESGEN uses three types of files. Every RESGEN structure requires a 'network' file, which is the basis for every application. Any analytical problem that can be formulated as a network can be translated in to RESGEN structure. The process of breaking down a network into a series of individual steps in our network has been illustrated in figure 2. For example, in the simple network of figure 2, the three steps in the network would require three data tables in the network file.

Summary Tables (Energy Balance and Foreign Exchange Transaction Tables) can be generated in RESGEN by moving information from the out-

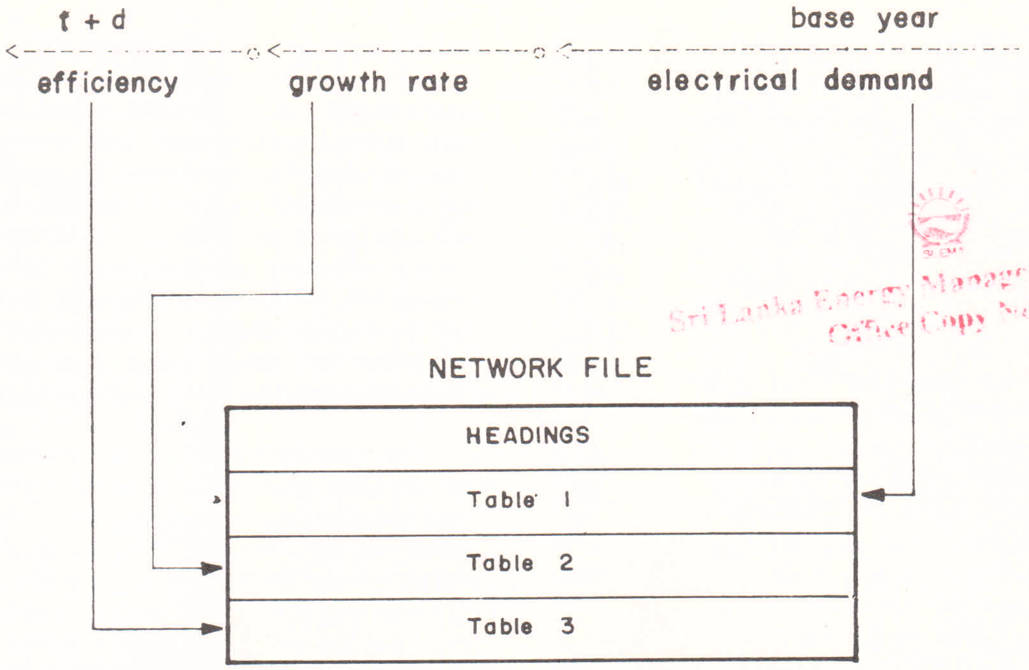

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Figure 2a- The NETWORK FILE that forms the input to RESGEN

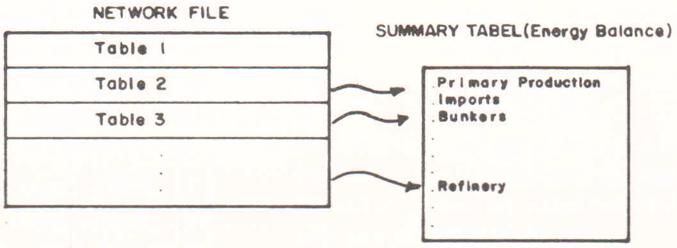

Figure 2b- The transfer capability of NETWORK FILE

put of each computation step to a particular row of a Summary Table. At each step in the calculation, the values can be transferred up to two different rows.

RESGEN provides for a number of generic matrix operations including addition, subtraction and multiplication. These could be used for all network calculations. However, many of the manipulations necessary for an accurate representation of the electric sector are performed by special purpose operators, such as optimal dispatch algorithm. These will be described later.

Calculation Process

The Network starts with base year demand of 33 sectors defined in annex I. These sectors were selected not because they are the most appropriate but for the availability of data. It was also planned to launch some activities to collect the necessary data to link Energy demand with macro economic parameters in future analyses. Next the i-elasticity operator is used to represent constant annual growth rates after adjusting the demand for income elasticity. RESGEN automatically compounds the growth rates over the proper interval, depending on the scenario year.

Income elasticity operator makes an adjustment of the type,

$$d_j(t) = d_j(0)\cdot(1+g)^{\alpha_j}$$

where g is the GDP growth rate and α is the elasticity defined by

$$\alpha_j = \frac{\log[g(\mathrm{SECTOR}_j)]}{\log[g(\mathrm{CEB})]}$$

The objective is to adjust the Ceylon Electricity Board (CEB) sectorial projections in a consistent way for GDP growth rates that are different to CEB's GDP assumption.

For some Energy demand sectors, functional equations using growth rates are not appropriate. This is because Energy demand increases in the manner of step functions with new capacity. This demand is included by using a special operator that adjusts the network Energy flow accurately to a plant capacity expansion plan that is contained in an external file. This file contains a list of projects and their impacts. The Energy impact may be negative to represent a conservation or fuel substitution project.

Next step is to implement price elasticity operator to adjust demand according to following model.

$$X_n(t) = X_{n-1}(t)\cdot\left\{\lambda_t/\lambda_o\right\}^{\beta}$$

where β is the price elasticity of demand and λ_t is the price at time t.

However, since,

$$\lambda_t = \lambda_o\,(1+g_\lambda)^t$$

where g_λ is the rate of price escalation, the above equation can be rewritten as:

$$X_j(t) = X_j(0)\cdot(1+g_\lambda)^{\beta t}$$

The escalation factor g_λ is taken from an external file.

If the model is being run for a conservation scenario, the demand is adjusted for conservation goals given in the network table after the price adjustment. At this point, all the Energy demand is known except for electricity generation and the sectorial demand is aggregated according to the fuel sources. The next step is to calculate the actual electricity generation and petroleum products requirement, taking into account the transmission and distribution losses of electricity and the transportation losses of petroleum products, anticipated during the scenario period.

Electric Sector Optimal Load Dispatch Model

The next step in the simulation exercise is to calculate Electric Sector fuel consumption for the projected electricity demand and a capacity expansion plan given in a separate file in accordance with CEB's generation expansion model (WASP) run. The annual load duration curve is linearized into three blocks; peak, intermediate and base. The shape of this curve is entered in a separate file (LOAD.DAT) and applied to the total annual Energy demand from the demand projection to produce the Energy and power requirements for each vertical load curve block for the scenario year. The algorithm used in RESGEN to dispatch plants is based on minimizing total fuel costs.

The computation of fuel requirements by dispatching power plants into a linearized load duration curve (see figure 3) is complicated and detailed, but technically more credible. In any event, a plant-by-plant approach is necessary for Energy sector investment and debt service calculations. For this, the special operator ELECTRIC has been developed, which invokes the optimal dispatch algorithm described in detail below.

Once the fuel requirement for electricity generation is known, the total fuel requirement by source is calculated by using an aggregate operator.

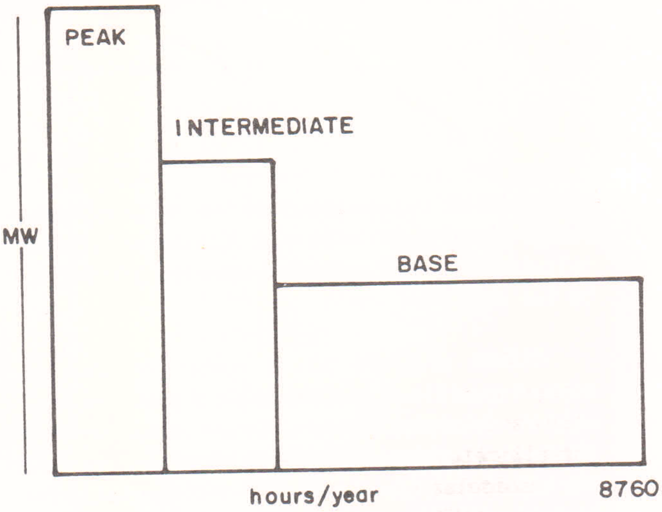

Figure 3 - Linearised load-duration curve

In a strictly thermal system, dispatching available plants into this curve is fairly straight-forward, since dispatch by strict merit order (i.e. in order of marginal costs) provides the optimum dispatch. In such a case, it could be readily shown that optimality requires,

$$X_p \geqq X_i \geqq X_b \geqq 0$$

Where X is the dispatch of plant into the peak, intermediate and base block. In other words, this means that a plant that is dispatched in the base period block must be dispatched to at least the same level in the intermediate block and a plant dispatched into the intermediate block must be dispatched to at least the same level in the peak block. This is true also when considering the availability rates, because the peak period availability is almost always higher than off-peak as scheduled maintenance is presumably conducted in the off-peak periods.

Thus, if X(Inst) is the installed capacity, and AV_j is the availability rate in the j-th load curve block, and X_j the dispatch into the j-th block :

$$X_j < X(\text{Inst}).AV_j$$

In a mixed thermal-hydro system, optimal dispatch is a much more complicated matter because of the presence of Energy limits on hydro plants. For each hydro plant, the condition,

$$\sum X_j \cdot h_j < E(\max)$$

where E(max) is the annual Energy limit, X_j the dispatch in the j-th load curve block, and h_j the hours in the j-th block, must always be met. An iterative procedure has been designed to provide a reasonable, and in almost all cases, an optimal dispatch pattern to minimize total fuel costs.

One begins with a strict base load dispatching of hydro plants, with all plants in their strict merit order. Thus hydro plants are dispatched first and fossil plants last.

In such base load dispatching, the dispatch level of the hydro plants can be taken to be given by:

$$X_p = X_i = X_b = \frac{E(\max)}{8760}$$

Next step is to check whether peak load is met by this strategy and if not, increase the peak period hydro dispatch until the peak load is exactly met. With these increases in peak hydro dispatch, a solution is feasible. This solution, whilst feasible, may be far from optimal. Next step is to check whether the total Energy for hydro in the solution is less than the upper limit. If so, by increasing the peak period hydro, one pushes out part (or all) of the most inefficient thermal plants, and adding what is taken away from the base period (since more peak means less base for hydro plant) by any hydro Energy slack, or, more commonly, by the next most efficient thermal plant. The objective of the algorithm is thus to displace relatively expensive plants from the peak period by increasing the dispatch of relatively efficient thermal plants in the base period. It takes 5 to 10 iterations to obtain the optimal solution and the sequence of tables at the end of each iteration could be monitored. Finally, it should be noted that the total fuel cost should decline monotonically at each step of the iteration. If not, the merit order, or the sequence of plants used, is not consistent with the actual marginal costs.

Next step is to start a side chain to the main network to project charcoal exports and local demand in the scenario year, using base year charcoal demand and anticipated growth rates. Then the wood requirements for charcoal production are calculated. Using the addition operator, this demand is linked to the main network. At this point of the model run, the domestic resource requirements by fuel source are projected.

At this point, the total petroleum products requirement is known and this information is fed into the Refinery Model, which determines the crude throughput, yield pattern of finished products and other vital information on refinery operation at a minimum foreign exchange cost to the country. These calculations are made subject to existing refinery configuration, product specifications and matching the demands projected by RESGEN upto this point. Once the Refinery LP Model run is completed, information is stored in an external file called REFINE.DAT to be accessed by RESGEN. It then becomes possible to continue the RESGEN analysis. The refinery input output information is read from REFINE.DAT for calculations as well as to be written into Summary Tables.

Again, a new chain is started from the main network to calculate bunker requirements after adjusting for world oil prices, similar to i-elasticity. The price operator is used to calculate the value of bunkers using external file containing the bunker prices. This result is put into the second summary table that represents the Energy related foreign exchange transactions. The next step is to calculate the Imports/Exports requirement for the petroleum sector. For all the petroleum sources, the following calculation is done.

Imports/Exports = Refinery production - Local Demand - Bunkers

If the value is positive for a fuel source it goes to the Imports row of the Energy balance, otherwise automatically moves to the Exports row. Again using the price operator, the value of imports and exports are calculated for the second summary table. This completes the analysis for the two summary tables.

THE ENERGY FINANCE ASSESSMENT MODEL (EFAM)

EFAM is for the analysis of Energy pricing, finance and investment. It provides a year-by-year simulation of the

(i) Income Statement
(ii) Balance Sheet
(iii) Sources of funds
(iv) Uses of funds

for the institutions of the Energy Sector and their related transactions with the banking and non-Energy sector of the domestic economy, financial institutions and Energy markets overseas. The model keeps track of both domestic and foreign currency flows, and is particularly suited to the analysis of pricing and tariff issues.

The fundamental concept underlying the model is its correspondence of a money flow to every Energy flow. Thus, each link in RESGEN that captures a particular Energy flow (or conversion) also represents, in most cases, a sale and purchase among different institutions. The starting point for application of the model, therefore, is an analysis of the institutional structure among whom such transactions occur. Figure 4 illustrates this structure.

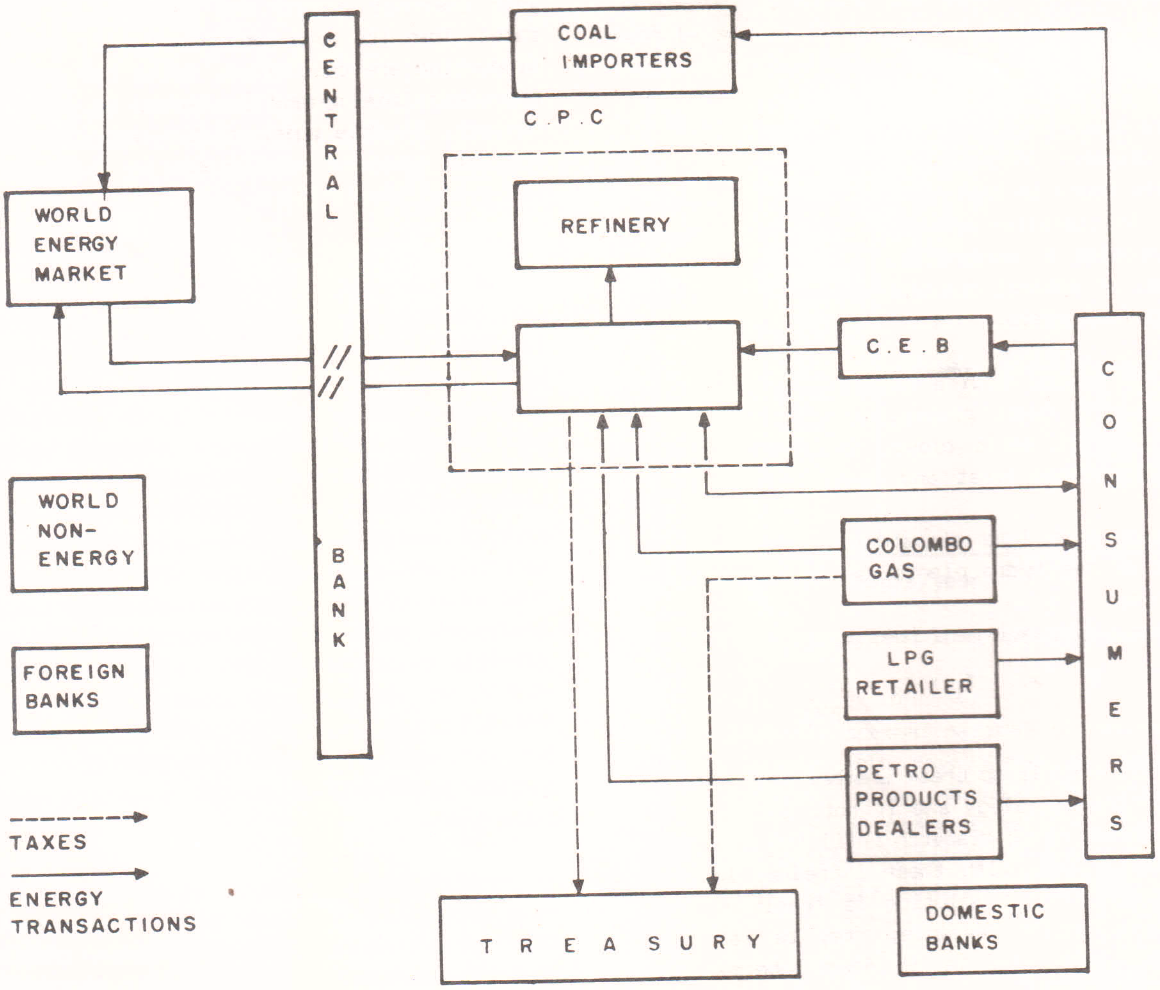

Figure 4 - Institutional structure for Sri Lanka

EFAM distinguishes between 'primary' and 'secondary' institutions. Primary institutions are those whose finances are determined entirely by their activity in the Energy sector, such as refinery, electric utility and LPG distributors. The financial accounts of these can therefore be simulated by an analysis of Energy transactions. Secondary institutions are those whose participation in the Energy sector represent only a part of their overall business. Such institutions include banks, the Government Treasury etc. For these institutions one cannot simulate financial statements based solely on Energy sector related transactions. However, because of their importance to the Energy sector, enumeration of their Energy sector transactions is still important.

Because EFAM is dependent on RESGEN for its inputs, it cannot be run independently. The software is therefore designed as an add-on to the RESGEN software. As RESGEN does the Energy network calculation, information is transferred to a set of files, which could be read directly by EFAM.

THE ENERGY MACRO-ECONOMIC ACCOUNTING FRAMEWORK (ENMAC)

The macro-economic accounting framework was designed to meet three primary criteria. First, the framework was to provide consistency between RESGEN and EFAM models and the overall macroeconomy. Secondly, the framework had to serve as a means for evaluating the first order macro-economic impacts of Energy policies. Finally, the framework was to recognize the institutional realities and the policy making process, which emphasizes the collaboration of the institutions involved at working committee level.

The overall approach

The overall approach is illustrated in figure 5. The base line for the model is the macro-economic projection of the Ministry of Finance and Planning (MFP), which covers the immediate five-year planning horizon. The estimates of GDP are passed down to the Energy models where they are used as a basis for Energy demand projections.

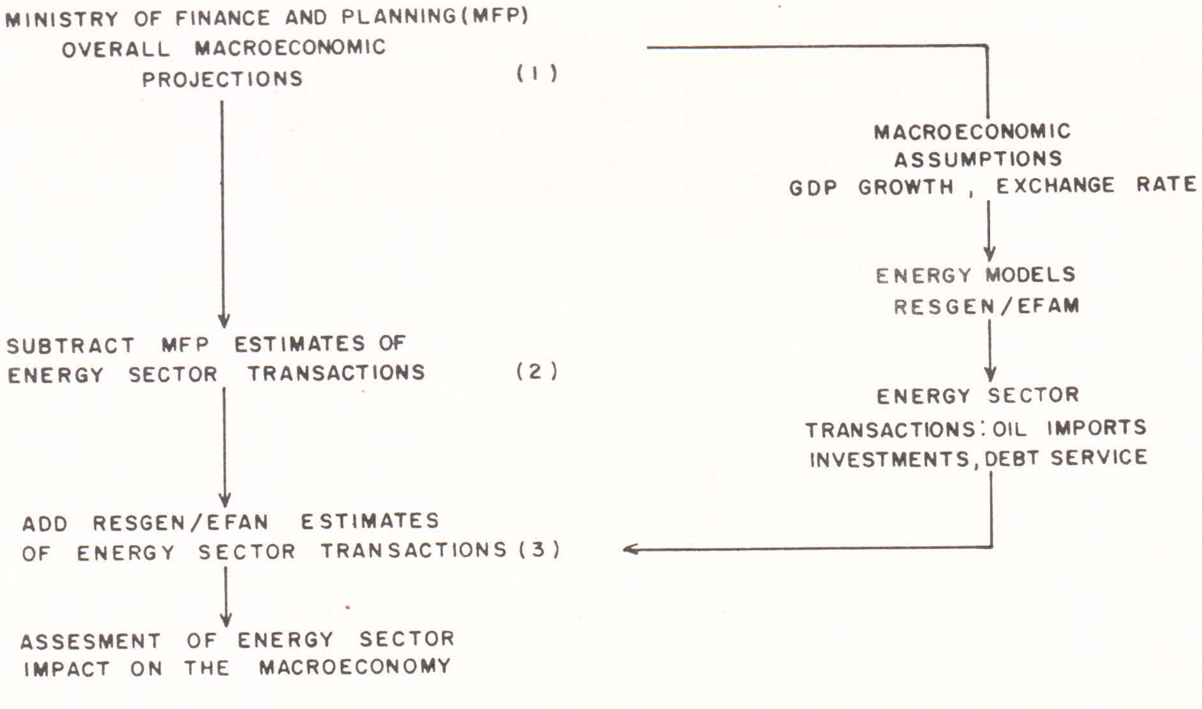

Figure 5 - The analytical approach

However, the MFP projections must first be desegregated into Energy and non-Energy transactions: this involves subtracting the MFP estimates of Energy imports, Energy investments etc. This is because RESGEN provides a more detailed basis for these transactions, which are added back at a later stage. The main source for historical data, and the base line, is the Annual Review of the Economy published by the Central Bank of Sri Lanka.

Components of the Model

The accounting framework consists of a series of tables organised into three LOTUS 1-2-3 worksheets. The following four tables are contained in the first worksheet :

(i) Table 1 contains the scenario, entered by the user, for the exchange rate and the world oil price.

(ii) Table 2 provides the projection of non-Energy exports

(iii) Table 3 has non-Energy imports using the desegregation scheme of the MFP.

(iv) Table 4 provides the sectorial decomposition of GDP, again using the MFP desegregation scheme.

The next four tables are contained in the second worksheet.

(v) Table 5 provides an analysis of the total resources and their utilization. Each row of this table is taken from some other table or, in the case of Energy related resources, passed to the macro-economic accounting framework from RESGEN.

(vi) Table 6 contains the savings and investment rates expressed as percentages of GDP taken from the MFP public investment Report. Consumption is calculated as a residual, and shows slight differences to the MFP projection because RESGEN provides somewhat different estimates of the Energy sector transactions than those by the MFP report.

(vii) Table 7 contains the estimates of the growth in private transfers and non-factor services, specified as percentage rates over the base year.

(viii) Table 8 provides a summary of the composition of Investment and savings.

The last set of tables are included in the third worksheet, which produces the balance of payments.

(ix) Table 9 determines the breakdown of the financing of the external resource gap. The base year entries come from the Central Bank Report.

(x) Table 10 sets the terms for the external debt. The base year outstanding debt is available from the Central Bank Annual Report. However, the terms for both existing and new debt must be adjusted by the user on a trial and error basis in such a way as to provide reasonable results.

Unfortunately, the Central Bank makes no detailed projection of future debt services, whilst the MFP projections provided are impossible to replicate. Therefore, the results of this table have been arrived at by trial and error, rather than by a detailed, loan-by-loan estimate. This was needed for the purposes of assessing the incremental impact of Energy sector policies.

(xi) Table 11 is the centerpiece of the model, where the external resource gap is calculated. All the entries in the top half of the table are transferred from other tables, and summed to produce the year-by-year estimates of the external resource gap. Transactions that do not affect the debt position are then subtracted. These include official transfers and direct investments. For these categories, the user must specify the growth rates. The balance must be financed, or accommodated by change in reserves. User sets the anticipated changes in reserves, and calculate the required borrowings.

(xii) Table 12 provides year-by-year projections of the external debt and of external assets. The equation for each debt category are based on the simple identity

d(t) = d(t-1) + new debt(from "borrowings" in Table 11) - amortization (from Table 13)

(xiii) Tables 14 and 15 provide a presentation of the Balance of Payments.

CONCLUSIONS

The approach taken in scenario analysis is by making a distinction between events within the control of Sri Lankan decision-makers, and those that are not. For example conservation and loss reduction efforts, world oil price and hydro conditions. Among the many types of policy analysis undertaken over the past years with this modeling system is a scenario analysis to test the robustness of the conservation program goals and construction of a series of scenarios that reflects different market conditions, and then examine the degree to which alternative policy options are sensitive to the oil price. The loss reduction programme of the CEB and the impact due to different hydro conditions were also considered. However, detailed discussion of the results of the analysis is beyond the scope of this paper and it is hoped to present such information in a future publication.

ACKNOWLEDGMENTS

I wish to mention that, without the initiative taken and the leadership given by the Energy Planning and Policy Analysis (EPPAN) Task Force of the Ministry of Power and Energy, the work described in this paper would not have taken place. In particular, I would like to gratefully acknowledge the guidance given by Prof Mohan Munasinghe, under whom I had the privilege of working for more than three years. A special word of thanks go out to the Asian Development Bank for providing the funds necessary, making this project a reality.

REFERENCES

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[2] EFAM VERSION 3.1 USER MANUAL
International Development and Energy Associate Inc(IDEA) of USA

[3] An Energy Macro-economic Accounting Framework
Peter M Meier

Annex 1

Sectors

1. Electricity, domestic
2. Electricity, Small and medium industry
3. Electricity, Large industries
4. Electricity, Commercial
5. Electricity, Street lighting
6. Electricity, Local authority
7. Electricity, Hotel
8. LPG
9. Gasolene
10. Naphtha
11. Auto diesel
12. Kerosene
13. Avtur
14. Diesel
15. Diesel, transportation
16. Diesel, cement
17. Fuel oil
18. Residual
19. Residual, fertilizer
20. Asphalt
21. Coal, railways
22. Coal, others
23. Coal, cement
24. Baggasse
25. Wood, industry
26. Wood, domestic
27. Charcoal, industry
28. Charcoal, domestic
29. Solar
30. Biogas
31. Wind
32. Mini-hydro
33. Industrial LPG