Development of Analytic Methodologies to Incorporate Renewable Energy in Domestic Energy and Economic Planning

ASIA-PACIFIC ECONOMIC COOPERATION

Expert Group on New and Renewable
Energy Technologies

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ABBREVIATIONS AND ACRONYMS

ANL	Argonne National Laboratory
ALGAS	Asia Least Cost Greenhouse Gas Abatement Strategy
APEC	Asia-Pacific Economic Cooperation
BNL	Brookhaven National Laboratory
BOE	barrel of oil equivalent
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
DSM	demand-side management
EGAT	Electricity Generating Authority of Thailand
ENPEP	Energy and Power Evaluation Program
GHG	greenhouse gas
GJ	gigajoules
GW	gigawatt
KBOE	thousand barrel of oil equivalent
kg	kilogram
kW	kilowatt
kWh	kilowatt-hour
LEAP	Long-Range Energy Alternatives Planning System
LNG	liquified natural gas
LPG	liquified petroleum gas
MARKAL	Market Allocation Program
MTCE	million ton of coal equivalent
MUSS	MARKAL Users' Support System
MW	megawatt
NGL	natural gasoline
NOx	nitrogen oxide
NREL	National Renewable Energy Laboratory
O&M	operating and maintenance
PJ	petajoules
PRC	People's Republic of China
PV	photovoltaics
RES	Reference Energy System
RETs	renewable energy technologies
scf	standard cubic feet
SO_2	sulfur dioxide
TCE	ton of coal equivalent
T&D	transmission and distribution
TWh	terawat-hour
USCSP	US Country Study Program on Climate Change

EXECUTIVE SUMMARY

BACKGROUND

Though advantages of using renewable energy are acknowledged, its use in developing economies has not progressed as rapidly as expected. Renewable energy options are not widely adopted in the energy and economic planning of APEC member economies and the role of renewable energy in the total economy energy supply is expected to decline in the future.

This project was funded by the APEC Energy Working Group under the recommendation of the Expert Group on New and Renewable Energy Technologies. The objective of this project is to identify, assess, and improve analytic methodologies to incorporate renewable energy options in an economy's energy and economic planning.

It was suspected that existing energy models were not adequate tools for evaluating the penetration of renewable energy technologies in an economy. Thus it was thought that the models could not show the currently cost-effective renewable energy technology options to policy makers. This would make renewable energy technologies not receive a fair evaluation in the economy's fuel mix when it came to energy planning. The Energy Working Group funded this study with the hope that the development of improved models to assess the potential of renewable energy technology would contribute to the provision of distributed energy services at both economy and regional levels. The APEC member economies can use the recommendations developed through this study to assist in objectively evaluating the role of renewable energy in domestic and regional economic development plans.

This study expects to contribute to three main areas. First, this study examines three principal economy-level energy models with special emphasis on the characterization of renewable energy options. This comparison should help senior policy officials and modelers in selecting economy-level energy models for use in their own energy planning. Second, this study reveals detailed information on assumptions and methodologies utilized by the selected economies, which could benefit other APEC member economies who are currently developing, or plan to develop, their own economy-level energy models. Finally, this study discusses important factors and attributes of renewable energy resources that modelers should take into consideration when developing their economy-level energy models so as to have a fair evaluation of all energy supply options including renewable energy options.

The overall conclusion of this study was that the existing economy-level models like ENPEP and MARKAL have high capabilities for capturing most of the important factors and attributes of renewable energy and can present a reasonable picture of renewable energy potential in an economy, if the necessary information is made available and the models are utilized to their full potential.

The economy-level models such as ENPEP, MARKAL and, to some extent, LEAP can serve the purposes for which models are normally used by energy policy analysts. Those are to show impacts of various energy supply and demand scenarios on resource consumption, technology choices, environmental implications, and policy decisions.

It is also important to recognize that the inadequacies of the existing economy-level energy models in characterizing renewable energy technologies were only a minor impediment to showing the potential penetration of renewable energy resources into an economy's resource mix. The other factors responsible for low penetration of renewable energy in an economy are lack of necessary information (both for resource characterization and technology definition) and lack of policies which support the many aspects of renewable energy technology development and implementation.

Whereas past use of renewable energy was based on very simple technologies, the future use of renewable energy will be based on sophisticated technologies which can require significant expertise to design and implement. Therefore, in order to fully capture the benefits of the new technologies, increased effort must be spent on all aspects of renewable energy development.

REVIEW OF THE ENERGY MODELS

Three energy models were reviewed in the project—the Energy and Power Evaluation Program (ENPEP), the Market Allocation Program (MARKAL), and the Long-Range Energy Alternatives Planning System (LEAP). These three models were selected because they are widely used in many APEC member economies as well as non-APEC member economies worldwide, for their own domestic economic planning and at the international level of energy analysis. In addition, they represent three different types of energy models. Each model takes a different overall approach to the analysis of energy and environmental systems, which will provide a broad understanding of how various energy models handle existing and potentially new renewable energy technologies in an economy. Some principal characteristics of the three models are summarized in Table E.1.

Table E.1: Comparisons of the Principal Characteristics of ENPEP, MARKAL, and LEAP

ENPEP	MARKAL	LEAP
Model Nature • BALANCE is a system of simultaneous non-linear equations and inequalities, based on an approach of generalized equilibrium model. • The equilibrium modeling approach for BALANCE is based on the concept that the energy sector consists of autonomous energy producers and consumers that carry out production and consumption activities, each optimizing individual objectives. • A demand-driven model	• MARKAL is a dynamic linear programming model. • MARKAL is an optimization model of the entire energy sector. The main function of the model is to optimize a linear objective function under a set of linear constraints. The problem is to determine the optimum activity levels of processes satisfying the constraints at the minimum costs. • A demand-driven model	• LEAP is an accounting model framework. • LEAP is structured as a series of integrated programs that can be used, for example, to develop current energy balances, projections of supply and demand trends, and calculate the consequent environmental emissions. • A demand-driven model
Model Operation • The BALANCE module works with an energy sector network that consists of nodes and links. Each node type corresponds to a different submodel in BALANCE and is associated with specific equations that relate the prices and energy flows on the input and output links of the node.	• MARKAL operates on data using matrix forms, in the forms of sets, scalars, parameters, and tables. These components are supplied by users to represent an energy system that will show all possible routes from each source of primary energy through various transformation steps to each end-use demand sector.	• LEAP forecasts energy demand by multiplying the activity levels by the energy intensities. Based on the energy demand forecast, energy supply and conversion processes will be simulated to assess the adequacy of primary resources to meet the set of energy demands and export targets.

Table E.1: (Continued)

ENPEP	MARKAL	LEAP
Renewable Energy • The model treats renewable energy differently from non-renewable energy. The production cost of renewable energy resources is simulated using a step function while that of depletable resources is simulated using a quadratic function. The step function allows any physical limits on the annual production of the resource. It could also represent a different source of production for the resource, and sources are ordered in terms of increasing costs.	• The model does not handle the estimation of renewable energy differently from non-renewable energy. There are no special functions designed to handle renewable energy estimates. The plausible solutions for renewable energy technologies depend on the constraints added in the model to control the availability and the utilization of each renewable energy technology. The model also provides several parameters that could be applied to specify the existence of renewable energy technologies.	• Both renewable and non-renewable energy are entered into the model in the same way. The difference is that an estimation of renewable energy requires the data on maximum annual supply of the renewable resource whereas an estimation of non-renewable energy requires the data on quantities of resource addition and depletion. For biomass resource, it is optional to use the LEAP Biomass program to assess the current and future status of biomass resources under different scenarios.
• To introduce renewable energy in BALANCE, first, the renewable energy node must be included in the energy network. The node will have an output link into RET directly, or into an allocation node to distribute resources into various types of RETs. The outputs from RETs are then allocated into end-use demand. • Any type of renewable energy technology can be included.	• To introduce renewable energy into MARKAL, first, the type of renewable energy must be identified in the Set of renewable energy carrier. RETs are then specified in the Set of technologies they belong to, for example, demand technologies, conversion technologies, or process technologies. • Any type of renewable energy technology can be included.	• Renewable energy can be entered into LEAP as a direct fuel in an end-use by specifying its percentage shares among other fuels in the same end-use. Renewable energy that is required to be processed must be entered in the Transformation program by setting up a module to represent its RETs. The information on the renewable energy resources consumed is required in both cases. • Any type of renewable energy technology can be

		included.

Table E.1: (Continued)

ENPEP	MARKAL	LEAP
<u>Solutions</u> • A solution from BALANCE is based on simulating the behavior of energy consumers and producers through a market-sharing algorithm. An equilibrium model represented by the designed energy network is solved by finding a set of prices and quantities that satisfy all relevant equations and inequalities.	• MARKAL creates the solutions by minimizing the present value of total energy system costs throughout the planning horizon subject to specified constraints such as availability of primary energy resources, availability of certain technologies and upper bounds on pollution emissions.	• The solution from LEAP is deterministic since LEAP is an accounting model.
<u>Major Advantages</u> • The model allows not only price but also non-price factors to determine resource consumption in the economy. • Since the solution is based on a market-sharing algorithm, the model allows for the simulation of market operation with multiple decision-makers which has an advantage over least cost optimization approaches that are suitable for simulating a single decision maker. • BALANCE can be linked with other sub-modules of ENPEP or other ANL models for detailed analysis.	• MARKAL performs least-cost competition of fuels, which is particularly worthwhile in dispatching electric power plants where one wants to see the effects of fuel competition over the planning periods. • A marginal cost calculation is available, which makes it easy to compare each supply option and technology directly within the model. • MARKAL can be used with a macroeconomic model to allow interplay between the energy system and the economy, or with a partial equilibrium model where demand levels are endogenously determined.	• LEAP is a simple model that does not require a long-period training. The program is designed to be user-friendly with a detailed manual and on-line help. • LEAP has a function to display results in any desired unit, and in various formats. All reports can be represented in absolute values, growth rates, and percent shares. • LEAP is useful in cases where the analysts wish to determine an energy and environment impacts of proposed governmental policies where the initial technology projection has been predetermined.

Table E.1: (Continued)

ENPEP	MARKAL	LEAP
Major Limitations • BALANCE is data intensive compared to the other two models reviewed, thus requiring a significant effort for data collection. • The model is complicated and not user friendly. Extensive training and experience are required in order to work successfully with the model. • BALANCE does its calculations on a year-by-year basis. Therefore, it does not make current energy use decisions in conjunction with a projection of what will happen in the future.	• MARKAL picks the solution that provides the lowest costs. The lowest cost fuel will take the entire market and the competitors with only slightly greater costs will be excluded. Non-price factors can only be addressed to a limited degree. • MARKAL calculates an energy balance on the basis of multiple year planning periods, which poses problems for renewable energy modeling in terms of resource characterization and technology implementation since renewable energy technologies can have very short construction times.	• The model does not take account of economic factors in determining energy supply and fuel choices. Shares among fuel usage and fuel substitution among end uses must be determined exogenously. • Due to the nature of the model, the model cannot analyze fuel competitiveness between renewable energy and fossil fuels. • Future energy systems are synthesized largely according to the judgement of the modeler of what preferred future technologies should be

ECONOMY MODEL ANALYSIS

Four APEC member economies—Thailand, Indonesia, the Philippines, and the People's Republic of China—were selected as case studies. They were selected based on the criteria that they are APEC member economies, they have participated in economy-wide-level energy system modeling, they provide examples of different energy models, they provide examples of various renewable energy resources to be included in the models, and they make available reports and data sets utilized in actual economy-level modeling projects. Thailand was used as a case study for ENPEP, Indonesia and the Philippines were used as case studies for MARKAL, and the People's Republic of China (PRC) was utilized as a case study for LEAP.

The uses of the economy-level energy models—ENPEP, MARKAL, and LEAP—in the four economies—Thailand, Indonesia, the Philippines, and the PRC—are compared in Table E.2.

Table E.2: Comparison of the Models Used in Thailand, Indonesia, the Philippines, and the PRC

	Thailand	Indonesia	Philippines	PRC
Model	ENPEP	MARKAL	MARKAL	LEAP
Study Periods	1994-2030 (annually)	1991-2021 (5 year interval)	1990-2020 (5 year interval)	1990-2020 (10 year interval)
Technology	• Conversion • Refinery • Multiple Input Process	• Process • Conversion • Demand	• Process • Conversion • Demand	• Transformation Module
End-Use Sector	• Transport • Industrial • Commercial • Residential • Agriculture	• Transport • Industrial[1/] • Household[2/]	• Transport • Industrial • Commercial • Residential • Agriculture • Non-energy uses	• Transport • Industrial • Building • Services • Residential • Agriculture
Renewable Energy	• Hydro • Biomass	• Hydro • Geothermal • Biomass	• Hydro • Geothermal • Agricultural waste • Fuel wood • Animal dung	• Hydro • Geothermal • Wind • Solar • Biomass
Renewable Energy Technology	• Hydropower • Biomass stove • Biomass cogeneration • Biomass for steam demand	• Hydropower • Geothermal power • Biomass steam electric • Biomass burners • Biomass boilers • Biomass stove	• Hydropower • Hydro pumped storage • Geothermal electric • Biomass steam electric • Charcoal conversion • Biogas digester • Biomass burner • Fuel wood cooking • Charcoal cooking • Agricultural waste cooking	• Hydropower • Geothermal power • Wind for power • Solar for power • Biomass steam electric • Biogas digester • Charcoal conversion

			• Charcoal ironing • Biogas cooking	

Table E.2: (Continued)

	Thailand	Indonesia	Philippines	PRC
Projection Methodology	• Econometrics • Forecast from other sources • Assumed growth rates	• Assumed growth rates • MACRO program	• Official forecasts	• Using LEAP projection • Interpolation
Determinants of Renewable Energy Penetration	• Availability of supply • Costs of resources • Costs of technologies • Non-cost factors (combined effects) • Price sensitivity • Lag parameter • Assumed penetration rates • Based on official plans	• Availability of supply • Cost of resources • Costs of technologies • Maximum capacity of RETs • Minimum capacity of RETs • Maximum annual growth rate on demand for RETs	• Availability of supply • Costs of resources • Maximum capacity of RETs • Minimum capacity of RETs	• Predetermined outside the model

Notes: 1/ Industrial sector included manufacturing, non-energy mining, and agriculture.
2/ Household sector included commerce and services.

ASSESSMENT OF THE CAPABILITIES OF ECONOMY-LEVEL ENERGY MODELS

It appears that energy models have been developed in several different levels of technology complexity and modeling scope. For comparison, this study divides the models in three categories—technology-level, sector-level, and economy-level energy planning. These three levels of models have different objectives. The technology-level model is used to select individual components of a single system. The sector-level model, such as an electric utility model, is adopted to define the least-cost fuel mix for electricity generation to meet an economy's future electricity demand. In comparison, the economy-level energy model is utilized to facilitate the decision to provide the economy energy supplies to satisfy the future energy demand at the least cost by taking into consideration issues such as energy security, energy diversification, and environmental related problems.

Due to the difference in the model objectives, information required and factors influencing the decisions in the planning process are different among these three level of models. There is a lack of set rules on what factors or resource attributes are required in an economy-level energy model to make it an ideal model for an economy's energy planning. Therefore, this study reviews technology-level and sector-level models (which are more detailed models) so as to provide performance benchmarks and an overall framework for establishing realistic expectations for the performance of renewable energy technologies in economy-level models.

This study also includes a discussion of the capabilities of the existing economy-level energy models—ENPEP, MARKAL, and LEAP—in capturing the key renewable energy factors and attributes. The comparison of the capabilities of the three models is summarized in Table E.3.

Table E.3: Comparison of the Capabilities of BALANCE, MARKAL, and LEAP

	BALANCE	MARKAL	LEAP
System Design	No	No	No
Capability and Availability			
Peak capability	Yes	Yes	No
Seasonal and hourly profiles	No	Yes/No[1/]	No
Intermittence	No	No	No
Forced outage	Yes[2/]	Yes[2/]	Yes[2/]
Maintenance requirement	Yes	Yes	Yes
Multiplicity of units	Yes/No[3/]	Yes/No[3/]	Yes/No[3/]
Location			
Central stations	No	No	No
Distributed utility	No	No	No
Modularity			
Incremental size	No	No	No
Short-lead time	No	No	No
Risk Diversity	Yes/No[4/]	Yes	Yes/No[4/]
Cost Factors	Yes	Yes	No
Non-Cost Factors	Yes/No[5/]	Yes/No[5/]	No
Off-Grid v.s. Grid-Connected Power Generation	Yes	Yes	No
Renewables Energy Technologies			
Renewables for electricity generation			
Grid-connected—dispatchable	Yes	Yes	Yes
Grid-connected—nondispatchable	Yes	Yes	No
Off-grid connected	Yes	Yes	Yes
Renewables for thermal energy	Yes	Yes	Yes
Renewable transport fuel	Yes	Yes	Yes
End-use renewable	Yes	Yes	Yes

Notes: [1/] MARKAL can capture seasonal profile but not hourly profile.
[2/] Forced outage can only be treated deterministically.
[3/] The models can handle multiplicity of units of renewable energy resources but

cannot show the resultant impacts on system reliability.

[4/] Risk diversity and uncertainty factor can be captured in limited circumstance by using scenario analysis

[5/] Non-cost factors can only be captured in limited circumstances.

CONCLUSIONS OF THE STUDY

The main conclusions of the study are summarized below.

- Each energy model reviewed in this study has advantages and disadvantages that users have to trade off. The existing energy models are designed to be used for long-term energy planning. With the fact that these models were originally designed and applied in developed economies where renewable energy accounted for only a small portion of the overall energy use, renewable energy systems are not the central focus of any of the three models. However, each model provides special features that facilitate the inclusion of renewable energy technologies.

- Renewable energy was earlier recognized as an important resource in the energy sector of the four economies being reviewed. In the past, the shares of renewable energy in the total primary energy of each economy varied between 25 percent to 42 percent. Based on their own forecasts, renewable energy supplies were expected to increase in the future. However, the share of renewable energy in terms of total energy supply in each economy was expected to decline over time—to be between 8 percent to 14 percent of total primary energy. This decrease in market share for renewable energy occurred, in large part, because traditional biomass fuels were replaced by high quality commercial fuels. Thus, a challenge for energy models is to demonstrate how traditional fuels, such as biomass, can cost effectively be converted into high quality fuels such as gas and electricity.

- The economies forecast that the future use of renewable energy in traditional applications such as biomass consumption in the residential sector (for example, cooking and heating) would decrease. The renewable energy technologies that had the highest potential to penetrate into the economies were those for power generation such as hydropower, wind, and solar energy.

- The principal renewable energy resources included in all models were biomass and hydropower. Geothermal resources were included in the Philippines, Indonesia, and the PRC. Wind and solar were included in the PRC in the base case scenario, and in the Philippines in the mitigation scenarios. In both the PRC and the Philippines models, wind and solar were used for power generation only.

- The renewable energy technologies included in all economies were simple technologies. Their uses included power generation, cooking and ironing in the residential sector, and heat and steam production in the industrial sector. Other renewable energy technologies such as solar water heating, solar thermal power generation, or renewable-based transport fuels were not considered in any model reviewed. There was no use of renewable energy technologies in the commercial, services, transport, or agricultural sectors.

- Each economy was faced with the same problems, though in varying degrees, when modeling renewable energy. First of all, renewable energy was expected to have a declining-trend contribution in the economy's energy mix as industrialization gave rise to the demand for higher quality energy resources. Therefore, because of time and budget constraints in doing research, the economies did not look in detail at renewable energy for their economy energy models.

- The limitation in modeling renewable energy was also influenced by the fact that necessary information to model renewable energy, such as resource data, technology characterization, technology performance, and costs, was not available to most economies. In all cases, the business-as-usual scenario follows the government's energy plans. If there are no government plans to implement renewable energy projects, a modeler will not volunteer to include them in his/her model. In the mitigation scenario, although the modeler is not precluded from suggesting renewable energy technology options, if the economy has not already completed detailed resource assessments and economy specific renewable energy technology cost estimates, the modeler as part of his/her work could not be expected to develop the needed information.

- Energy models could be classified into three categories—technology-level (such as HOMER, Hybrid 2, and ViPOR), sector-level (such as, MABS, MIDAS, and PROVIEW), and economy-level energy models (such as ENPEP, MARKAL, and LEAP). These three levels of models have different objectives. The technology-level model is used to select individual components of a single system. The sector-level model, such as an electric utility model, is adopted to define the least-cost fuel mix for electricity generation to meet an economy's future electricity demand. In comparison, the economy-level model is utilized to simulate the decisions needed to define the necessary energy supplies to satisfy the future economy-wide energy demand at the least cost by taking into consideration other issues such as energy security or environmental related problems. Information required and factors influencing the decisions in the planning process are thus different among these three model levels.

- The economy-level model could not be utilized to conduct an energy system design like the technology-level model. Neither could the economy-level model capture all attributes of renewable energy (such as capability, availability, location, modularity, and risk diversity) that were significant in the comparison of renewable energy resources with conventional supply-side and demand-side options for utility's integrated resource planning. This is not surprising. Given the broad scope and objectives of economy-level energy models, it is not realistic to expect such models to incorporate the technical detail of technology-level or even sector-level models. In addition, some of the renewable energy attributes are more important for the sector-level models but less critical for the economy-level models.

Therefore, those attributes could be ignored for the economy-level model without any significant impact on overall model results.

- There are some limitations in modeling renewable energy in the existing energy models. These limitations are due to special characteristics of renewable energy that are different from fossil fuels. Since the focus of the existing energy models is on modeling characteristics of fossil fuels in detail, they leave out the detailed features of renewable energy. It is also due to the fact that factors involved with the use of renewable energy are more difficult to assess and quantify which makes modeling renewable energy in the existing models difficult.

- However, it is fair to say that the existing economy-level models likes ENPEP and MARKAL have high capabilities for capturing most of the important factors and attributes of renewable energy and could present a reasonable picture of renewable energy potential in an economy, if the necessary information is made available and the models are utilized to their full potentials.

RECOMMENDATIONS FROM THE STUDY

From the review of the economy-level models, and the examination and running of the four economies' models with original data sets, it was learned that modeling-related factors are responsible only partly for the low penetration of renewable energy technologies in an economy. The other factors contributing to the same problem are non-modeling factors. These non-modeling factors could be classified into four groups—resource factors, technological factors, economic factors, and institutional factors. It is difficult to say which factor is the most important. One factor could be relatively more important for a given economy than the other factors. However, lack of any one of these factors would significantly obstruct the penetration of renewable energy in the economy.

This study provides recommendations concerning options that could be taken to increase the use and future penetration of renewable energy technologies. The recommendations are separated into recommendations for future modeling and recommendations associated with the non-modeling related factors including resource factors, technological factors, economic factors, and institutional factors.

Recommendations for Future Modeling

Recommendation (1): Because of the details required to estimate total resource availability (or capacity), specialized resource assessment models should be used in conjunction with the economy-level energy models. Specific resource assessment models should be used to pre-estimate the total resource availability (or capacity) over the study periods. This information will then be entered into the economy-level energy model for evaluation of fuel competition.

Recommendation (2): The technology-level renewable energy models that can design the electric system should be utilized. The results of the system design should then be transferred to the economy-level energy model for further analysis. The regional models should be used to evaluate resources to be utilized at each specific site. A good example of this level of modeling is a recent APEC study, which examined the potential for renewable energy retrofit options to existing diesel mini-grids[3].

Recommendation (3): When designing the modeling energy networks, end-use demand should be broken into detailed applications, instead of being estimated only in an aggregated manner by demand sector. By having disaggregated end-use demand, it will allow for better definition of renewable energy technology options and better capture of potential renewable energy technology uses in the economy energy model.

Recommendations Associated with Resource Factors

Recommendation (4): None of the modeling efforts reviewed cited comprehensive renewable energy resource assessments. Therefore, addressing the issues identified in the APEC report cited above is a good first step in developing better modeling capabilities. In addition, the level or detail of resource assessment required needs to be better matched to the level of modeling anticipated. It should not be expected that an initial wind assessment at the economy level would require the same level of detail as a site specific planning study.

Recommendations Associated with Technological Factors

Recommendation (5): The lack of information has consistently been identified as a priority constraint that slows the adoption of cost-effective renewable energy technologies. APEC could promote information dissemination by highlighting recent technology advances, successful applications, and new information sources at its biannual meetings. This would enable APEC representatives to question presenters on applications to their economy and to provide feedback to developers on current technology needs. Although much information is available over the Internet, there is often a lack of matching the information to real problems.

Recommendation (6): There is a real need to develop cost information on renewable energy technologies which takes into consideration economy specific factors such as local content and local labor rates. The US Department of Energy has made a good start by putting together a summary of costs for renewable energy technologies for power generation.[1] However, the other types of renewable energy technologies need to

[1] Office of Utility Technologies and Electric Power Research Institute (EPRI). *Renewable Energy Technology Characterizations*. Washington, D.C.: U.S. Department of Energy and EPRI, TR-109496, [Internet, WWW], ADDRESS: http://www.eren.doe.gov/utilities/techchar.html, December 1997.

be covered. If centralized databases are developed, they should include adjustments for local factors. This would affect the evaluation of technologies such as solar thermal (both for hot water heating and power generation), that have the potential for high local content, much more than technologies such as photovoltaic electricity generation (although cost advantages could still be seen with this technology based on local production).

Recommendations Associated with Economic Factors

Recommendation (7): Case studies need to be developed on an economy specific basis for each of the basic sources of renewable energy, identifying which are the most cost effective for a given economy. These case studies could then be used by economy-level modelers in generalizing the potential of renewable energy technologies across their economies.

Recommendations Associated with Institutional Factors

Recommendation (8): To understand the impact of these factors on APEC member economies, a survey of the status and needs associated with institutional factors in APEC member economies should be undertaken. This survey could also identify priority actions which should be undertaken to foster the development of cost effective renewable energy technologies

5.3 CONCLUDING REMARKS

Recent major international studies indicate significant growth-potential for renewable energy, particularly in scenarios where environmental constraints are imposed, for example on CO_2 emissions. A study by the International Energy Agency[2] indicated 7.5 percent to 8.5 percent annual growths in the commercial use of energy from "new" renewables to 2010. The World Energy Council[3] forecast the growth of renewable energy to reach from 18 percent to 21 percent of world needs by 2020 in the Business-As-Usual scenario, and from 18 percent to 30 percent in the ecologically driven scenario. The United Nations Solar Energy Group on Environment and Development[4] forecast that 30 percent of world energy needs would be met by renewable energy by 2025, and 45 percent by 2050. In addition, the Group Chief

[2] International Energy Agency. *World Energy Outlook*. 1995 Edition.

[3] World Energy Council. *Renewable Energy Resources: Opportunities and Constraints 1990-2020*. 1993.

[4] Johansson et al. *Renewable Energy: Sources for Fuels and Electricity*. United Nations Solar Energy Group on Environment and Development, Island Press, 1993.

Executive of BP[5] and a Managing Director of the Royal Dutch/Shell Group[6] commented that renewable energy could be providing up to half of the world's total energy needs within 50 years time.

In contrast to the aforementioned forecasts of high renewable energy utilization, all four economies reviewed expected only a small increase in renewable energy consumption in their economies. This led to a declining share of renewable energy in their total energy supplies. This has pointed to the fact that the economies may not fully realize the potential use of renewable energy in their economies, and thus there is a real need for the APEC member economies to examine, in more detail, the future potential for increasing the use of renewable energy technologies.

Capital costs of renewable energy technologies are high, and in many applications still could not be competitive with conventional fuels. However, those costs have been reduced by half over the last decade and are expected to be halved again over the next ten years[7]. Renewable energy could likely become more competitive with conventional fuels in the future and could play an increasingly important role in an economy's energy mix. Therefore, energy planners should make a special effort to understand and incorporate renewable energy technologies in their long-term energy planning.

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[5] Sir John Browne, Group Chief Executive of BP Amoco. "Energy and Environment: Making Rational Choices", Presentation to Natural Environment Research Council, UK, June 21, 1999, [Internet, WWW], ADDRESS: http://www.bpamoco.com/_nav/pressoffice/indexs.htm

[6] Jeroen van der Veer, Managing Director of the Royal Dutch/Shell Group. "Sustainable Solutions Support Sustainable Business", Presentation at the World Sustainable Energy Fair (SUSTAIN 99), Amsterdam, The Netherlands, May 26, 1999, [Internet, WWW], ADDRESS: http://media.shell.com/library/speech/0,1525,3893,00.html

[7] International Energy Agency. *Key Issues in Developing Renewables*, Paris, France, 1997.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Renewable energy can offer several benefits to an economy. It helps an economy increase the diversity of energy supplies, and thus lowers the dependency on fossil fuels and improves the security of energy supplies for the economy. It helps an economy make use of indigenous resources to provide cost-effective energy supplies for the economy and avoid the higher costs of imported energy. It contributes to the reduction of global and local atmospheric emissions. Finally, it can increase domestic employment since the construction of renewable energy facilities are generally of modest scales and modular in nature for which local labor can be used.

Though advantages of using renewable energy are acknowledged, its use in developing economies has not progressed as rapidly as expected. Renewable energy options are not widely adopted in APEC member economies' energy and economic planning and the role of renewable energy in the total economy energy supply is expected to be declined in the future.

This project was funded by the APEC Energy Working Group[1] under the recommendation of the Expert Group on New and Renewable Energy Technologies. The APEC Expert Group on New and Renewable Energy Technologies (formerly, the Expert Group on Technology Cooperation) was established by the APEC Energy Working Group. The central goal of the Expert Group is to promote and facilitate the expanded use of cost effective new and renewable energy technologies in the Asia Pacific region. Recently, the APEC Energy Working Group funded three studies on renewable energy with the purpose of promoting a better understanding of renewable energy opportunities and problems in APEC member economies. These studies are *Asia-Pacific Economic Cooperation High Value End-Use Applications Analysis,*[2] *Overview of the Quality and Completeness of Resource Assessment Data for the APEC Region,*[3] and *Analysis of Renewable Energy Retrofit Options to Existing Diesel Mini-Grids.*[4]

A concern of the Expert Group has been with the relative role of renewable energy technologies from the perspective of total energy supplies in the APEC member economies at present and their expected roles in the future. As seen in recent economy energy level analyses, such as the U.S. Country Study Program (USCSP) on Climate Change[5] and the Asian Least Cost Greenhouse Gas Abatement Strategies[6] (ALGAS) projects, renewable energy was expected to provide a reduced share of the economies' future energy supply. In addition, renewable energy received only minor recognition as a potential GHG mitigation option.

The objective of this project is to identify, assess, and improve analytic methodologies to incorporate renewable energy options in the economy's energy and economic planning. It was suspected that existing energy models were not adequate tools for evaluating the penetration of renewable energy technologies in an economy. Thus the models could not show the currently cost-effective renewable energy technology options to policy makers. This would make renewable energy technologies not receive a fair evaluation in the economy's fuel mix when it came to energy planning. The Energy Working Group funded this study with the hope that the development of improved models to assess the potential of renewable energy technology will lead to the identification of cost effective renewable energy opportunities. The APEC member economies can use the recommendations developed through this study to assist in objectively evaluating the role of renewable energy in domestic and regional economic development plans.

In summary, this study expects to contribute to three main areas. First, this study examines three principal economy-level energy models with special emphasis on the characterization of renewable energy options. This comparison should help senior policy officials and modelers in selecting economy-level energy models for use in their own energy planning. Second, this study reveals detailed information on assumptions and methodologies utilized by the selected economies, which could benefit other APEC member economies who are currently developing, or plan to develop, their own economy-level energy models. Finally, this study discusses important factors and attributes of renewable energy resources that modelers should take into consideration when developing their economy-level energy models so as to have a fair evaluation of all energy supply options including renewable energy options.

1.2 PROJECT APPROACH

The project is composed of three main tasks:

Task 1: Identify and assess existing analytical energy models regarding the inclusion of renewable energy technologies.

The models reviewed in this study are the Energy and Power Evaluation Program (ENPEP), the Market Allocation Program (MARKAL), and the Long-Range Energy Alternatives Planning System (LEAP). These models were selected because each has been widely used in many APEC member economies, as well as non-APEC member economies worldwide, for their own domestic economic planning and at the international level of energy analysis. In addition, they represent three different types of energy models. Each model takes a different overall approach to the analysis of energy and environmental systems, which provides a broad understanding of how various energy models handle existing and potentially new renewable energy technologies in an economy.

Task 2: Identify and assess the uses of the existing energy models in the APEC member economies.

The economies selected as case studies in the project are Thailand, Indonesia, the Philippines and the People's Republic of China. These four economies were selected based on the criteria that they are APEC member economies, they have participated in economy-level energy system modeling, they provide examples of different energy models, they provide examples of various renewable energy resources to be included in the models, and they make available reports and data sets utilized in actual economy-level modeling projects. Thailand is used as a case study for ENPEP, Indonesia and the Philippines are used as case studies for MARKAL, and the People's Republic of China is used as a case study for LEAP.

When this study began, the stated preference was to review the energy models that were constructed for work in the USCSP and/or ALGAS since these programs were directly related to domestic energy planning which was concerned with the use of fossil fuel and renewable energy to reduce GHG emissions. The problem in following this preference was that the work in both programs had been delayed, the economies' reports were not available, and the data sets used in the models could only be obtained from the economies themselves. There was no central point of contact to obtain the work and the data sets from these two programs. Therefore, due to the unavailability of the reports and data sets within the time constraints of this study, the energy models for Indonesia and the People's Republic of China were not from the USCSP or ALGAS projects, but the models were developed as part of the economies' own domestic energy planning projects.

Task 3: Identify and assess the feasibility of augmenting the existing models to improve the representation of renewable energy technologies.

The study divides energy models in three categories—technology-level, sector-level, and economy-level energy models—and examines the principal factors affecting the decision processes of these three levels of energy models. The more detailed models like the technology-level and sector-level models are reviewed so as to provide performance benchmarks and an overall framework for establishing realistic expectations for the performance of renewable energy technologies in economy-level models. The capabilities of the existing economy-level models are accessed to see if they can capture those principal factors in evaluation the economy's fuel mix. The result from this task will help identify the feasibility of augmenting existing economy-level models to improve the representation of renewable energy technologies.

1.3 OUTLINE OF THE REPORT

The report contains 5 chapters. ***Chapter 1*** is an introduction which reviews the project background and approach. ***Chapter 2*** reviews the three energy models selected for the analysis—ENPEP, MARKAL, and LEAP. The reviewed information for each model includes, for example, the background of the model, model structures and operation, data requirements, solutions provided from the model, model features for renewable energy, and advantages and limitations of the model. The three models are also compared to illustrate their similarities and differences among each other. ***Chapter 3*** reviews the framework of the energy models used in the selected economies—Thailand, Indonesia, the Philippines, and the People's Republic of

China—to examine the methodologies and assumptions that each economy used in their existing analyses that project energy supply, demand and prices, and the penetration of renewable energy technologies. An overview of the energy sector is also covered in Chapter 3. All information regarding the economies' energy models was drawn from the economies' reports and/or data sets. This study has attempted to present the information in as a consistent manner as possible for all four economies, based on the level of detail of the reports. ***Chapter 4*** concentrates on assessing the capabilities of existing economy-level energy models to incorporate renewable energy technologies. In addition, this chapter briefly discusses the principal factors and attributes of renewable energy technologies associated with the different levels of energy models. Conclusions that have been learned from the examination and running of the four economies' models are presented in ***Chapter 5*** along with recommendations concerning options which could be taken to increase the use and future penetration of renewable energy technologies in APEC member economies.

END NOTES

[1] For more detail on the APEC Energy Working Group, see http://www.dpie.gov.au/resources/apec-ewg.

[2] Sustainable Energy Solutions, Preferred Energy Incorporated, Yayasan Bina Usaha Lingkungan, and US Export Council for Renewable Energy. *Asia-Pacific Economic Cooperation High Value End-Use Applications Analysis.* APEC Expert Group on New and Renewable Energy Technologies, APEC #97-RE-01.7, December 1997.

[3] David S. Renne' and Stephen Pilasky. *Overview of the Quality and Completeness of Resource Assessment Data for the APEC Region.* APEC Expert Group on New and Renewable Energy Technologies, APEC # 98-RE-01.1, February 1998.

[4] Sustainable Energy Solutions, National Renewable Energy Laboratory, and Strategic Power Utilities Group. *Analysis of Renewable Energy Retrofit Options to Existing Diesel Mini-Grids.* APEC Expert Group on New and Renewable Energy Technologies, APEC #98-RE-01.6, October 1998.

[5] For more detail on the U.S. Country Study Program, see http://www.gcrio.org./CSP/webpage.html.

[6] For more detail on the ALGAS project, see http://store.adb.org.

CHAPTER 2

REVIEW OF THE ENERGY MODELS

This section reviews three energy models that the selected economies employed in domestic energy planning—the Energy and Power Evaluation Program (ENPEP), the Market Allocation Program (MARKAL), and the Long-Range Energy Alternatives Planning System (LEAP).

2.1 ENERGY AND POWER EVALUATION PROGRAM (ENPEP)

Background

ENPEP[1] was developed by Argonne National Laboratory (ANL), with support from the U.S. Department of Energy, International Atomic Energy Agency, the World Bank, and the Hungarian Electric Board. The ENPEP model is composed of 9 sub-modules:

- ***MACRO.*** The MACRO module is used to format macroeconomic growth projections for use in developing energy demand projections.
- ***DEMAND.*** The DEMAND module is used to project useful energy or fuel demand based upon the macroeconomic growth rates generated by the MACRO module, and to generate a set of energy demand growth rates for use by the BALANCE module.
- ***PLANTDATA.*** The PLANTDATA module serves as a library of basic information about thermal and hydroelectric generating facilities for both the ELECTRIC and BALANCE modules. It was created to reduce redundancy and provide a convenient way to enter the required large quantity of data.
- ***BALANCE.*** The BALANCE module is used to project an energy supply and demand balance for any study period up to 75 years.
- ***LDC.*** The LDC module is used to transform data and perform calculations necessary to prepare input data on electricity generation requirements for the ELECTRIC module.
- ***MAED (Model for the Analysis of Energy Demand).*** MAED is a simulation model that can be used for long-term energy and electricity demand forecast.
- ***ELECTRIC.*** The ELECTRIC Module is a microcomputer version of WASP-III (the Wien Automatic System Planning Package). It calculates an electrical generating system expansion plan that meets demand at the minimum cost, subject to system requirements (for example, reliability).
- ***ICARUS (Investigation of Cost and Reliability in Utility Systems).*** The ICARUS module is a detailed dispatch model that can be used to assess the reliability and economic performance of alternative expansion patterns of electric utility generating systems.
- ***IMPACTS.*** The IMPACTS module is used to estimate environmental residuals and resource requirements for the energy supply system (electric and nonelectric) that are determined by the BALANCE and ELECTRIC modules.

Each sub-module has automated connections to other ENPEP modules, but it also has stand-alone capability.

BALANCE and IMPACTS are the ENPEP sub-modules reviewed in this project since they were employed by Thailand, one of the economies used as case studies in this project. BALANCE is the sub-module used for estimating domestic energy supply and demand and IMPACTS is used to estimate the consequential pollution emissions for all activities relating to fuel combustion in the fuel supply system.

Model Structures

BALANCE is based on the approach of generalized equilibrium modeling, which is applicable to model the energy systems of economies having different energy-sector characteristics. The equilibrium modeling approach for BALANCE is based on the concept that the energy sector consists of autonomous energy producers and consumers that carry out production and consumption activities, each optimizing individual objectives. BALANCE is a system of simultaneous non-linear equations and inequalities. The model estimates energy consumption and its associated costs, based on the designed energy network. Various nodes make up the energy network. Each node represents energy activities or processes in an economy from energy production (and/or import, export), conversion, transportation, distribution, to energy consumption by end-use sectors. Nodes of the network are linked. The links represent energy, fuel flows, and associated costs among the aforementioned activities. The relationship between the nodes and links specifies the transformation of energy quantities and processes through the various stages of energy production, processing, and use within the energy network.

BALANCE uses this description of the energy sector and demand projection to “balance” energy supply and demand based on an equilibrium approach. That is, it finds a set of prices and quantities that satisfy all equations and inequalities.

Model Operation

The BALANCE module works with an energy sector network that consists of nodes and links. Each node type corresponds to a different sub-model in BALANCE and is associated with specific equations that relate the prices and energy flows on the input and output links of the node. Therefore, the first step in using BALANCE is to draw a picture of the energy supply and demand sectors using node symbols. This picture is then encoded using menus and forms in BALANCE.

There are many nodes in BALANCE. These nodes include two types of resource nodes, three types of processing nodes, a decision allocation node, a stockpile node, a pricing node, and a demand node.

- *Resource Nodes* include *Depletable Resource Nodes* and *Renewable Resource Nodes*. Depletable Resource Nodes simulate depletable resources (such as coal, oil, and gas) that are either imported or domestically produced. Renewable Resource Nodes simulate renewable resources (such as solar and biomass).

- *Processing Nodes* are separated into *Conversion Nodes, Refining Nodes,* and *Multiple-Input-Link Conversion Nodes*. The Conversion Nodes simulate technologies that convert one form of energy to another (such as residential water heaters). The Refining Nodes, also called Multiple-Output-Link Nodes, simulate technologies that produce two or more outputs from one form of input (such as refineries and cogeneration). The Multiple-Input-Link Conversion Nodes simulate technologies that require more than a single form of input fuel to produce one form of output (such as solar water heater with electric backup).

- *Decision Allocation Nodes* simulate market decisions that choose among energy alternatives.

- *Stockpile Nodes* simulate the stockpiling of resources for use in the future.

- *Pricing Nodes* simulate a government tax, subsidy, price ceiling, price floor, or other government pricing policies.

- *Demand Nodes* simulate the final demand for a fuel or a form of useful energy for either domestic or export demand that must be met by the energy system.

Different symbols represent each of the node types in the energy network. Each link of the network is assigned a unique number between 1 and 999, and the number of input and output links for each node of the network is specified in the input data for the node. An equilibrium model represented by the network is solved by finding a set of prices and quantities that satisfy all relevant equations and inequalities. To find the network equilibrium solution, the model makes initial estimates of values of fuel importation and production quantities at the bottom of the network. After the initial estimates are made, the fuel prices of each successive link going up the network are computed from the price equations defined by the various nodes. Next, the solutions to all the quantity equations associated with the network nodes are computed for successive links going down the network. If the initial estimated quantities satisfy all equations in the network, a solution to the model has been found. Otherwise, the quantities at the bottom of the network are automatically adjusted, and all equations are solved again. This iteration process continues until the proper values for the quantities at the bottom of the network have been found.

Dispatch Algorithm for Electricity Generation

There are two ways to work with the electric sector in BALANCE. The first way is to include each type of power plant in the energy network as a conversion process. The plants are dispatched, based on the fraction of total output as specified in the model. For example, the model specifies that coal plants will be dispatched at the ratio of 0.48 of the total output, gas at 0.22 and oil at 0.30. The fractions used in the base year are the actual fractions to total base-year output. These fractions can be changed over time, based on the utility forecast. This is a more aggregate approach that can be used if only very little information is available on the power sector.

Using BALANCE's electric sector sub-module is the second way to work with the electric sector in BALANCE. The electric sector sub-module is self-contained, in that its computational procedures and logic are distinct from other parts of the module. However, the electric sector is embedded in the energy network and receives electricity demand and fuel prices over the simulation periods. Based on this information, the electric sector sub-module makes the following calculations for each year of the simulation periods:

- Develops a discrete approximation of the inverse load duration curve from a fifth-order polynomial approximation of the annual load duration curve,
- Computes peak load from the load duration curve and total electricity demand,
- Computes the derated capacity of each of the available electricity generating units,
- Computes the total variable cost (variable O&M plus fuel costs) for each available unit and orders the units on the basis of variable cost,
- Loads units in order of least variable cost onto the load duration curve (based on derated capacity) to meet electricity demand, peak load, and reserve margin requirements for the system, and
- Computes average total cost of electricity production and the amounts of fuel consumed by each available generating unit.

Special Features

BALANCE has several special features which provide a wide range of capabilities in simulating the behavior of various energy markets. The most important feature that distinguishes the equilibrium approach from other energy modeling techniques is the idea that the solution from BALANCE is based on the use of a market-sharing algorithm, which allows for the simulation of market operation with multiple decision-makers. In simulating the choice of consumers between two fuels, the market-sharing algorithm can simulate the condition where some consumers will prefer one to the other. If cost is the only factor that determines the choice between two fuels, the decision to use natural gas or electricity for cooking, for example, will be split evenly if the costs of natural gas and electricity are equal. As the price of one fuel increases relative to the other, its market share will decrease.

BALANCE also allows fuel allocation to be based on factors other than price. The existence of non-price factors can be taken into account by identifying a value called the *Premium Multiplier* to multiply the price to weigh the importance of non-price factors in the model. For example, even though electricity costs more than kerosene, people generally prefer to use electricity for lighting because it is convenient and produces a higher quality light. In this example, the premium multiplier reduces the relative price of electricity (making it cheaper than actual price) to reflect the preference for it over kerosene. If the premium multiplier is equal to 1, price is the only factor determining fuel consumption (up to capacity limits). However, the premium multiplier can only capture the combined effects of all non-price factors. Individual non-price factors can not be listed in the model.

One can specify *Price Sensitivity* values to indicate the sensitivity of a price factor toward an input selection. The values of the price sensitivity function range from 0 to 15. A high price sensitivity indicates an input selection toward the least-cost source. A value of 15 indicates that 100 percent of the quantity is allocated to the least-cost source. A lower price sensitivity value indicates a lesser importance of relative prices. A value of 0 implies that there is no price sensitivity guiding the input selection.

The sensitivity of the changes in market shares on price changes can be specified in the model using *Lag Parameter*. A lower value for the lag parameter indicates a relatively slow response of shares to prices. For example, if lag parameter is equal to 0.1, the solution will be the allocation of 10 percent from new market shares and 90 percent from old market shares. Values close to 1 indicate a relatively fast response of shares to prices. If the value is set equal to 1, then the solution will be equal to new market shares. If the value is set equal to zero, it implies constant market shares every year.

Special situations that override allocation decisions based strictly on relative fuel prices (such as government regulations, requirements or restrictions on fuel choices) can be modeled using *Priority Links*. In these situations, the decision node can allocate a demand quantity to sources (input links) in a specified order, without regard to the relative prices on the input links. A quantity is allocated to an input link up to the capacity of the source, if a capacity exists.

Renewable Energy in ENPEP

Renewable energy is incorporated in BALANCE as a resource node. Other examples of resource nodes are the production and importation of depletable resources. This renewable resource node is analogous to the depletable resource node, in that it conveys production cost and quantity information. Due to the difference in their nature, however, BALANCE simulates the production cost of renewable energy differently from depletable resources. The production cost of renewable energy resources is simulated using a step function while that of depletable resources is simulated using a quadratic function.

The production cost of a depletable resource is simulated based on the assumption that the marginal cost of producing the next unit of the resource will increase as the resource is used up. Comparatively, the approach for a renewable resource is based on the premise that, if production is at a rate within the bounds of the sustainable yield, the renewable resource would have a constant production cost. The step function represents an annual supply curve. It relates the cost (or price, depending upon the use of the resource node) of producing the resource to the annual production of that resource.

The step function allows any physical limitation on the annual production of the resource. It could also represent a different source of production for the resource, and sources are ordered in terms of increasing costs. For example, in the case of producing firewood, each step of the step function could represent a different section of land used to produce firewood. The sections vary by soil type, growing conditions, accessibility, and other factors that cause the cost of producing wood to vary. The cost variance among sections can be captured by the step function. The amount of the resource for each step would be the annual production capacity of wood for the section to which the step corresponds.

Some resources, such as solar energy, are more appropriately modeled as having only one step because the cost of using more solar energy (on a barrel of oil equivalent output basis) does not necessarily increase as more is used. In this case, the steps in production cost curve specified in the field will be 1.

The form of the step function for a renewable resource node is:

$P_t = C_i$ if $Q_t \leq L_i$

where :

P_t = cost (price) of the resource in period t,

C_i = cost of producing each unit of the resource from step i,

Q_t = quantity of the resource produced in period t,

L_i = amount of the resource for step i,

i = 1, 2, 3, 4, 5.

The model allows up to 17 renewable resource records. The required data for a renewable resource node includes:

- production quantities of the resource in the base year (in thousand of BOE),
- annual capacity (in thousand of BOE) to represent the maximum quantity of the resource available in any year,
- quantity (in thousand of BOE) and cost (in $US/BOE) of production for each step in production cost curve (up to 5 steps).

The user will design how far along the production cost curve (of these 5 steps) that the economy is willing to pay to obtain renewable energy. The higher the price an economy will pay, the more quantities of renewable energy will be available. The model also provides an option for updating resource curves. The “Update Resource Curve” field serves as a flag to indicate whether the production in each year should be subtracted from the production cost function. This option allows the modeler to specify that the cost of production tracks the cumulative amount of the resource produced (as with depletable resource nodes) as the model progresses from year to year. In general, this flag should be set at 0 for renewable resources.

Environmental Calculation in ENPEP

The information from BALANCE can be transferred to the IMPACTS module of ENPEP to calculate environmental impacts from the energy supply system. Environmental effects in IMPACTS fall into five different categories: air, land, water, human health and safety, and solid wastes. These environmental burdens are calculated for all activities in the fuel supply system, from the point of resource extraction or import through conversion or processing. The environmental impacts are calculated by means of “impact factors” which are specified in the module as either a function of facility output (such as kWh) or a function of production capacity (such as electrical capacity in MW). The total annual impacts associated with a particular fuel cycle activity are thus computed by multiplying the appropriate impact factors for a particular year and a particular energy source times the use or production capacity of that source.

IMPACTS has two databases containing environmental and resource data. These databases contain typical energy, facility, and control device characteristics. The majority of the data in the databases are based on US data. However, it is easy for users to change the databases to reflect economy-specific conditions. In some cases, time-dependent changes can be made to reflect such measures as phased occupational safety standards or the introduction of control technologies. IMPACTS provides a hierarchical menu, along with on-line abstracts and help screens to guide the user through the branches of the module and to modify the existing environmental and resource data to reflect economy-specific conditions.

IMPACTS can be used by linking it with other ENPEP modules or as a stand-alone module. It can also calculate resource requirements for energy facilities such as construction labor and material requirements by year of construction and annual operating labor requirements over the life of the facility.

Data Requirements

BALANCE requires an extensive set of data for the designed energy network. However, the model is flexible in the degree of detail that is built into the energy network. The energy network can be designed to be a simple one to fit the data availability or to be a complex one for more detailed analysis if data is available.

The data required to execute BALANCE is a completed set of quantities and prices of the energy system in the base year and the projection data of all the forecast years, which can be listed as following:

- Base-year supply/demand balances of the entire energy system, which include, for example,
    - Base-year quantities of all resources consumed (both domestic and imported resources),
    - Base-year allocation of each resource to each device,
    - Base-year quantities of fuel demand or useful energy demand by sector, sub-sector, end-use, and devices,
    - Base-year prices of all resources,
    - Base-year costs, such as, production, capital, O&M costs,
    - Stockpile data, such as, quantity of a resource removed in the base year, quantity of a resource at the end of the base year, fraction of stock to export,
    - Resource reserves, annual resource capacities, additional resource throughout the planning periods.
- Energy processing efficiency, processing capacities, capacity factor, life expectancy of plant in the base year and future,
- Projection of final demand (which can optionally be obtained from ENPEP's DEMAND module),

- Projection of all fuel prices (domestic and imported fuels),
- Projection of all costs,
- Price regulation process, that is, price multiplier, price addition, maximum price, minimum prices, and
- Chemical content of energy, emission factors for estimating pollution emissions in IMPACTS. (This data is available in the database, but it can be modified by a user to reflect economy-specific conditions.)

BALANCE has default units which all inputs in the model must follow. For example:

Energy unit:	thousand BOE
Annual capacity limit:	thousand BOE per year
Capacity investment:	thousand US $
Cost:	US $ per BOE
Emission factor:	kg per GJ for air pollution emissions, gram per cubic meter for water discharge

Solutions from BALANCE

A solution from BALANCE is based on simulating the behavior of energy consumers and producers through a market-sharing algorithm. An equilibrium model represented by the designed energy network is solved by finding a set of prices and quantities that satisfy all relevant equations and inequalities. The model will project the balance of energy supply and demand for the entire energy system, up to a 75 year period. The resulting solution is a set of prices and quantities on all of the links in the network for every year of the analysis periods. The data generated from BALANCE could be passed on to the LDC, ELECTRIC, and IMPACTS sub-modules for subsequent calculations.

Advantages of BALANCE

The first step of working with BALANCE is to design the energy network of the economy. The data is then entered, based on this designed network. By having the network, it creates a full understanding of the entire energy system which makes it easy to manipulate the scenario analysis, to add on more details of the energy technologies, or to modify the existing case for the future study.

The market-sharing algorithm technique allows for the simulation of market operation with multiple decision-makers. It offers an advantage over least-cost optimization approaches that are suitable for simulating a single decision maker.

BALANCE allows not only price, but also non-price factors, such as convenience of use, technology related factors and government policies, to determine resource consumption in the economy. Therefore, energy requirements may be met by selecting fuels from several supply sources simultaneously rather than from a single source, as would be the case if fuel choice were based strictly on least cost. BALANCE thus has advantage over a linear optimization approach by recognizing that the “least cost” source of energy does not, in general, capture the entire market shares.

BALANCE has a flexibility that allows the user to make adjustments in the model, in order to control the results to some degree. This flexibility could be beneficial, in the case where the user wants to include a forecast from other sources with the result from the model. For example, the user can manipulate the model to control fuel mix of power generation to be consistent with the forecast from the utility, and let the model allocate other fuel supplies to meet the end-use demand.

BALANCE can be linked with other sub-modules of ENPEP. For example, a more detailed dispatch analysis can be conducted using ICRUS (Investigation of Cost and Reliability in Utility Systems) and a more detailed analysis of energy demand can be performed using MAED (Model for the Analysis of Energy Demand).

ENPEP can also be linked to other ANL models such as GTMax (Generation and Transmission Maximixation Model) to study complex electric utility's marketing and system operational issues, MCITOS (Multi Criteria Interval Trade-Offs System) to perform a mutli-criteria decision analysis, or APEX (Argonne Production, Expansion, and Exchange Model for Electrical Systems) to address various policy options that affect electric utilities.

BALANCE can project energy demand/supply for up to 75 time periods. Also, model calculation periods and model reporting periods need not be the same. The user can define any time interval to be the basis for model calculations (such as 1 year), but can report the results at other time intervals (such as every five years, or every ten years). This attribute benefits renewable energy characterization since it enables one to capture time-dependent resource and technology factors more accurately.

The direct advantage concerning renewable energy component is that the model allows an estimate of annual supply in the form of a step function. This step function allows the user to model any physical limitation of the annual production of the resource, such as the upper limits on the annual amount of solar energy that can be used due to the amount of solar insulation, an upper limit on annual wood production due to the amount of land available for wood production, or the physical limitation of each source of resource supply.

Another advantage regarding the inclusion of renewable energy in the model is that special features in BALANCE that are used to control allocation of resources such as premium multiplier, price sensitivity, and lag adjustment can be applied to the case of renewable energy and make renewable energy have a fairer share in the allocation process.

Limitations of BALANCE

BALANCE is data intensive compared to the other two models reviewed, thus requiring a significant effort for data collection before working with the model.

The model is complicated, and not user friendly. Extensive training and experience are definitely required in order to work successfully with the model.

BALANCE does its calculations on a year-by-year basis. Therefore, it does not make current energy use decisions in conjunction with a projection of what will happen in the future.

2.2. MARKET ALLOCATION PROGRAM (MARKAL)

Background

MARKAL is an acronym for Market Allocation. MARKAL[2] was developed in 1978 in a joint effort by the Brookhaven National Laboratory (BNL) in the United States and the Kernforschungsanlage-Julich (KFA) in Germany for the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). The primary objective was to assess the long-term role of new technologies in the energy systems of the 17 IEA member countries. Since that time the model has evolved and has been applied to a wide range of energy and environmental issues in many countries other than IEA member countries.

MARKAL was written in GAMS (General Algebraic Modeling System), a computer language specifically designed to facilitate the development of algebraic models (for modeling linear, nonlinear, and mixed integer optimization problems). Database management and scenario comparisons have been traditionally handled through an interface known as MUSS (MARKAL Users' Support System) developed by BNL. Through MUSS, the user can modify the individual MARKAL tables. The interface then translates these tables into a form that can be recognized by GAMS. A new Windows-based system, ANSWER, has just been developed and has rapidly become the interface of choice for both existing and new users.

This report reviews the standard version of MARKAL and its interface, MUSS, since it is the version which has been most used to date for economy-level energy modeling.

Model Structures

MARKAL is a dynamic linear-programming (LP) model of a generalized energy system. It is demand-driven for which feasible solutions are obtained only if all specified end-use demands for energy are satisfied for every time period. The end-use energy demand for each demand sector and for each time period are exogeneously forecast.

MARKAL is an LP model, therefore its main function is to optimize a linear objective function under a set of linear constraints. The problem is to determine the optimum activity levels of processes that satisfy the constraints at a minimum cost. Examples of constraints in the model include availability of primary energy resources, production/use balances, electricity/heat peaking, availability of certain technologies, and upper bounds on pollution emissions.

A typical objective function in MARKAL can be shown as:

n

$$\text{Minimize } X_0 = \sum_{j=1} c_j X_j$$

Subject to

$$\sum_{j=1}^{n} a_{ij} X_j \geq b_i, \quad i = 1,2, .., m$$

$$0 \leq X_j \leq u_j, \quad j = 1, 2, ..., n$$

where c_j, a_{ij} and uj are known parameters. The index (*i*) represents a particular resource (total of m resources) and index (j) represents a particular process (total of n processes). The constraint requires that the total demand for a resource does not exceed its supply (b_i). Each X_j variable represents the activity of process j converting some resources into some others at unit cost c_j. The constraints on X_j indicate that X_j is bounded between 0 to u_j.

Model Operation: MARKAL

The elements of MARKAL simulate the flow of energy in various forms (energy carriers) from the sources of supply (import, export, mining, and stockpiling) through transformation systems (resource, process, conversion, and demand technologies) to the demand devices which satisfy the end-use demands.

The elements of an energy system in MARKAL are grouped as:

- *Energy Carriers*: the component that encompasses all the energy forms in the energy system,
- *End-Use Demands*: the component that comprises the demands for end-use energy services in the economy,
- *Demand Technologies*: all devices that consume energy carriers to meet energy demands,
- *Conversion Technologies*: all load-dependent plants that generate electricity or district heat or both,
- *Process Technologies*: all load-independent processes that convert one energy carrier to another,
- *Resource Technologies*: the means by which energy enters or leaves the energy system, other than end-use consumption,
- *Emissions*: the component that encompasses the environmental impacts of the energy system.

By convention, each group has a 'Name Code' that users are encouraged to follow. For example, components of the End-Use Demand group should have 2 alpha numeric characters, in upper case. The first character reflects the End-Use Demand sector. That is, T = Transport, R = Residential, C = Commercial, I = Industrial, A = Agriculture, and N = Non-energy. The second character reflects the End-use Demand sub-sector, such as CO=Commercial/Office. Demand Technologies should have 3 alpha numeric characters, of which the first two characters must match the demand they satisfy, and the third character provides a unique identifier of the technology, for example, CO1= Commercial/Office/Vertical Transport.

MARKAL operates on data in matrix forms. The basic data organization form in MARKAL is in the forms of sets, scalars, parameters, and tables.

Sets. Sets (or classes) are lists of like components (for example, all solid fuels, all central station electric plants) which characterize the nature of the energy system. Each Set has a specific meaning to MARKAL. For example, Set CEN refers to Centralized Electric Plants and Set BAS refers to Base-load Electric Conversion Plants. All fuels and technologies in the model will belong to one or more of the Sets. The individual elements of a Set are defined by the user.

Scalars. Scalars are programming variables without any dimensionality (for example, discount rate).

Parameters. Parameters are one dimensional arrays. MARKAL has two types of Parameters—Data Parameters and Results Parameters. *Data Parameters* specify the economic and technical characteristics of the user defined items of the energy system (for example, residual installed capacity, fixed cost, O&M costs, process efficiency, etc.). The data for the Data Parameters is determined by the user. MARKAL provides some 80 different Data Parameters for describing the characteristics of the energy system and the items within it. The *Results Parameters* are determined by a MARKAL model run. MARKAL provides some 220 different Results Parameters in its reporting of a model run result.

Tables. Tables are two-dimensional structures with each row identifying the nature of the information (for example, investment cost, fuel delivery cost, etc.) and the columns indicating the time period in which the data is to be applied.

These components are supplied by users to represent an energy system in MARKAL, called Reference Energy System (RES). The energy system network will show all possible routes from each source of primary energy through various transformation steps, to each end-use demand sector. These steps include existing technologies in an economy and a wide range of future alternatives.

Model Operation: MUSS

MARKAL and MUSS are independent systems communicating by means of standard MS-DOS exchange files. MUSS is a relational database management system designed specifically to facilitate the MARKAL model use. MUSS oversees all aspects of working with MARKAL. It manages all the input data required by MARKAL, organizes data sets into scenarios to foster sensitivity analyses, integrates seamlessly with the modeling system, and manages the results from model runs.

The calculation process within MUSS can be explained as follows:

1. The user requests that the model be run using a particular set of scenarios/data.
2. MUSS produces the data required by MARKAL in the appropriate format.
3. MUSS exits and starts up the model run.

4. The GAMS optimizer execution trail displays on the screen. When the run has successfully completed, users are left in DOS.
5. The reports associated with each case are left in files in the GMARKAL directory. To access them, the users return to MUSS and import the result files.

Once brought on-line, MUSS supports a wide range of standard and user-defined graphing facilities to facilitate the side-by-side comparison of results between model runs.

Dispatch Algorithm for Electricity Generation

In MARKAL, the power plants will be dispatched on the basis of least total costs (that is, a combination of capital and operating costs). The lowest total cost plant will be dispatched first (up to the maximum capacity factor) before moving to the next least cost plant. Constraints can be added to control the dispatch of a plant.

Special Features

MARKAL is an LP model and thus provides dual solutions of its primal problems. This solution gives shadow prices which could be interpreted as marginal cost or reduced cost of its primal problem. For example, the model calculates a marginal cost of CO_2 reduction at each period. The marginal CO_2 cost at period t is simply the cost of not emitting the last tonne of CO_2 at period t. It thus indicates the “value of carbon rights” or “cost of avoided emissions” or “permit price” associated with reaching a particular emission reduction target.

Another example is that the marginal cost of investment and capacity can be obtained from the model. The investment variable shows the newly installed capacity in each time period, and the capacity variable shows the overall existing capacity. Therefore, marginal cost of the investment variable could be interpreted as the unit cost reduction to be applied to the investment cost which is sufficient to build that technology. Also, the reduced cost of the capacity variable indicates the unit cost reduction to be applied to the overall unit cost which is enough to use that technology.

Since marginal costs of each technology, fuel, and environmental constraints are available, a merit ranking or relativeness of each supply option and technology is determined directly by the model. When examining emission mitigation alternatives, the incremental cost, the cost of reducing emissions, and the ranking of mitigation options are provided as a primary result from the model. In addition, the rankings obtained reflect the relative worth of an individual option to the entire energy system, not just among its immediate competitors. Thus, technology characteristics, fuel costs, up/down steam energy supply and conversion costs, and competition between sectors are all taken into consideration automatically.

Renewable Energy in MARKAL

Any type of renewable energy technology can be included in MARKAL. The model itself does not handle the estimation of renewable energy differently from non-renewable energy. It does, however, make a distinction between limited renewable resources (such as municipal solid waste) and unlimited renewable resources (such as solar energy). The same set of data is required for both renewable and non-renewable energy. There is no special function designed to handle renewable energy estimates. The plausible solutions for renewable energy technologies thus depend on the constraints users add to control the availability and utilization of each renewable energy technology included in the model. The model also provides several parameters that could be applied to specify the existence of renewable energy technologies, for example:

- Table PEAK, designed to specify a fraction of the total capacity of a technology available to supply peak demand for electricity or heat, could be used to specify the availability of renewable energy technologies to supply total demand. An example is to specify that a wind generator has an availability of only 20 percent, or solar central thermal electric has an availability of only 30 percent, of the total capacity to supply peak electric demand for electricity.

- The parameter "Seasonal Capacity Utilization Factor", which is the average use of installed capacity expressed as fraction of time in use, can be used to capture seasonal availability of renewable resources. For example, the solar energy technologies (such as central thermal electric and central photovoltaic) can be included in the model by separating capacity utilization into utilization in winter day, summer day and intermediate day, or in greater detail of day and night for each season.

- The parameter "Annual Availability Factor", which is used to specify total annual availability of a process or conversion technologies, can be used to determine the annual availability of biomass technologies.

- The parameter "BOUND" can be used to put a constraint (lower, fixed, or upper bounds) on capacity, annual production of technology, or investment in new capacity. These constraints can be used, for example, to specify the maximum availability of wind, hydro, or geothermal resources used in the central electric generation.

- The cost parameters, including O&M costs (variable and fixed), investment cost, and delivery cost can be used to compare competitiveness among technologies.

- The parameter "LIFE" can be used to show the number of periods of a technology's productive life.

- User-defined constraints can be built to represent renewable energy policies. For example, the case where there is a policy that 5 percent of all electricity generation must come from "green" technologies.

Renewable energy technologies in MARKAL could be specified as demand technologies (technologies that are used to satisfy a final demand), conversion technologies (technologies that produce electricity or district heat or both), or process technologies (technologies that do not produce electricity or heat or meet a final demand). Renewable energy in the category of "demand technologies" are, for example, solar thermal electric, biomass burner, and wood stoves. The data required for this set is the energy efficiency of the demand device (end-use demand met per unit input energy carrier consumed) and input energy carrier fraction (market allocation of energy carrier for a demand device as proportion of total input). It is the same for both renewable and non-renewable energy technologies. For devices consuming renewable energy carriers, a dummy energy carrier may be used for fossil equivalent energy accounting.

Renewable energy technologies in the category of "conversion technologies" are, for example, solar central thermal electric, wind central electric, geothermal central heating plant, hydroelectric, and biomass combined cycle. The data required is conversion efficiency (units of energy carrier required as input to conversion technology per unit output), the same as non-renewable energy conversion technologies. In the case of cogeneration (such as the use of biomass in industrial cogeneration processes), the amount of energy carrier produced as a by-product of electricity generation must be specified.

Renewable energy technologies in the categories of "process technologies" are, for example, biogas digester, municipal waste landfill gas, and the production of methanol from wood. The data required is energy carrier per unit production (units of energy carrier required as input to a process per unit output), and output energy carrier (amount of energy carrier produced as an output from a process per unit activity). Several inputs can be specified in the process technology table. Therefore, the model can handle the case where several types of biomass are used as inputs in a production process, such as the use of several types of biomass in the production of synthetic gas and methanol.

Environmental Calculation in MARKAL

Environmental calculation can be handled in MARKAL by setting up Set "ENV", Environmental Accounting Functions, for which any environmental indicator of interest can be listed as a member of the Set. One table is required for each environmental indicator. The rows in the table list components of the energy system. The columns contain a numerical coefficient dimensioned to yield a quantity for the environmental emission arising from the system component.

MARKAL allows some specific coefficients to be in the ENV table.

- Environmental coefficients of resource activities, such as, extraction, import, or export.
- Environmental coefficients of technical activities, which are used for environmental indicators related to technology operations, such as pollution emissions.
- Environmental coefficients of technology capacities, which are used for environmental indicators related to the existence of facilities, such as land use. They are also used for some technologies that do not have activities, such as dummy and externally managed technologies.
- Environmental coefficient of technology construction, which is used for environmental indicators related to construction activities and materials.
- Emission per unit of blending activity.
- Cumulative Emission Bound which puts a constraint (lower, fixed, or upper bound) on cumulative emissions over the entire time horizon.

- Maximum emissions, which put an upper bound constraint on emissions in a period.
- Emission tax which associates a cost with each unit emissions.
- Global Warming Potential, which is a user-defined combination of different emissions that yield an index of potential to produce changes in global climate. This coefficient can also be used to account and control similar impacts, such as, acidification equivalents, ozone depletion potential, or other weighed sums of emissions by sector.

Data Requirements

MARKAL requires a moderate set of data. The data used in MARKAL is defined as either required data or valid data. If *required data* is not filled in by users, there are defaults (for example, technical efficiency of the demand technology is equal to 1, and investment cost is equal to 0). *Valid data* is optional. If valid data it is not filled in, the model will ignore that parameter. The following list is some of the required data:

- Technology Data
    - Fuel used and/or produced,
    - Investment costs,
    - Fixed and variable operating costs,
    - Fuel costs,
    - Technical characteristics, such as, conversion efficiency, energy efficiency of demand devices, and capacity and availability factors,
    - Capital stock,
    - Productive life of technology.

- Sources of Primary Energy

Primary energy may include any type of energy supply, for example, oil, gas, coal, biomass, etc. These sources are usually characterized by supply curves that allow the annual potential supply and extraction costs. The information required includes:

    - Resource costs, such as, export, import, and extraction costs,
    - Annual or cumulative limits on availability,
    - Period of resource availability.

- Demand Data

Demand is specified either in terms of energy requirement or of useful energy demand. Demand levels are determined from information such as the square footage of housing heated or vehicle miles traveled. End-use demands are specified exogenously for all time periods.

- Environmental Data

Environmental emissions can be calculated based on the source of a fuel (for example, CO_2 emissions from oil imports) or on the technology used (for example, NO_x emissions from road transport technologies). Environmental constraints may be introduced as a physical cap on pollution emissions.

In MARKAL, users can choose different units for costs, energy flows, final demands, activity levels, and capacities. It is possible within the MARKAL description of the energy system to use a variety of units provided the consistency requirements are met. However, the standard units normally used are the following:

- Energy carriers: petajoules (except nuclear uses metric tons),
- Final demand: petajoules,
- Technology activity: petajoules,
- Conversion technology capacity: gigawatts,
- Process technology capacity: petajoules per annum,
- Demand technology capacity: petajoules per annum,
- Weight unit: metric tons,
- Passenger Transport: billion-passenger-kilometers per annum,
- Freight Transport: billion-tonne-kilometers per annum,
- Emissions: million tonnes contained carbon,
- Emission coefficient: metric tonnes per petajoule,
- Cost: constant units of million $ US.

The only exception is that capacities can be expressed in any units, with the "CAPUNIT" entry providing the conversion factor to petajoules per annum.

There is a data multiplier facility that can be used to change the user's data format to that used in MARKAL. However, the user must provide the conversion factor needed by the multiplier facility.

Solutions from MARKAL

MARKAL creates solutions by minimizing the present value of the total energy system costs throughout the planning horizon subject to specified constraints. As such, it uses perfect foresight whereby all decisions are made with full knowledge of future events (such as, emission targets). Where uncertainty exists in key assumptions about the future (such as, emission levels), probabilities can be assigned and stochastic programming techniques (where the weighted expect value is used) are employed. MARKAL solutions include:

- seasonal activity and capacity level for each conversion technology in each time period,
- annual activity and capacity level for each process and demand technology in each time period,
- the level of additional capacity for each conversion, process, and demand technology developed in each time period,
- activity level for each resource technology in each time period,
- a full range of energy prices, such as electricity price by season and time of day, price of energy provided by renewable technologies,
- a complete breakdown of the costs associated with the building and operating of each of the technologies,
- emission levels for each technology and the total energy system in each time period.

There are 220 different Results Parameters for reporting results of a model run. These Results Parameters are aggregated into 19 standard MARKAL Results Tables, namely,

Table T01	Scenario Indicators
Table T02	Summary
Table T03	Primary Energy Supply
Table T04	Output of Energy by Technology
Table T05	Fuel Consumption by Demand Sector
Table T06	Useful Energy by Demand Device
Table T08	Use of Energy Carriers by Technology
Table T09	Shadow Prices of Energy Carriers
Table REDC	Marginals for Technology, Resource, Demand, and Ratio relation among vectors,
Table T25	Annualized Costs of Technologies and Resources
Table T27	Annual Environmental Indicators
Table ACT	Activity of Each Technology
Table CAP	Capacity of Each Technology
Table DEMAND	Useful Energy (Service) Demand by Sector
Table INV	Investment in Each Technology
Table SUPPLY	Activity of Each Resource Supply Option
Table GDP	M-M Macroeconomic Results
Table MC	M-M Marginal Cost of Demands
Table COSTBEN	Benefit-Cost Ratios

It is Table T01 that contains the results of a total discounted system cost (the MARKAL objective function), total emissions, and security indicator level.

Advantages of MARKAL

MARKAL benefits from a large user community which constantly makes additions to the basic modeling framework. Examples include major model changes such as the linkage with a macroeconomic model, and the addition of new functions such as stochastics and endogenous technology learning. These changes are documented in “info” text files distributed with the model program.

MARKAL can be used in conjunction with a macroeconomic model, such as MACRO, and thus allows interplay between the energy system and the economy, or with a partial equilibrium formulation, such as MICRO or MED, where demand levels are endogenously determined based upon price elasticities.

An inherit advantage of optimization models is that they, by default, perform at least cost competition of fuel. This is particularly worthwhile in dispatching electric power plants where one wants to see the effects of fuel competition over the planning periods.

A marginal cost calculation is available as a standard output, making it easy to compare each supply option and technology directly within the model, as well as to observe the overall effects on the cost of emission reductions for various technology mixes and policies.

MARKAL can track materials, financial flows, employment or any other commodities that can be linearly tied to the activity (or capacity, investment, etc.) of the process.

MUSS provides extensive multi-case comparison graphic facilities to facilitate the task of analyzing the results of runs. The most essential capability is to be able to graph the results of multiple cases (up to 10 cases) side by side using various plot types (such as, line, bar, and cumulative). MUSS can display both primal (such as capacity level) and dual (such as effect on the objective function of one more/less unit of capacity) on a single graph. MUSS can also plot those entries changing between runs, and the differences between runs and periods to facilitate multi-case analyses.

There are two particular useful overview graphing capabilities available in MUSS. The first is the CERI (Constant Emission Reduction Indicator) graph, which shows how the cost of the energy system changes as the emission levels are reduced. The second is the Contribution Reduction graph, which shows how a reduction target is reached, for example, switch from fossil fuel to renewable energy or nuclear, efficiency improvements, or lower demand levels.

MUSS includes a "data multiplier facility" to facilitate changing from the source data units to those used within MARKAL. However, the user must provide the conversion factor needed by the multiplier facility.

MUSS has on-line documentation which can be used for comments associated with a table. It can also record the source of table data or method of calculation. In addition, the system automatically tags modified rows with the date on which they were last changed.

MUSS has a function to print out input assumptions and all the information relating to a technology, demand sector, supply option, or a group of technologies used for the study in a simple documenting format for expert review.

MUSS draws network diagrams, called a Reference Energy System (RES), which provides the user with simplified graphics of the model's system. RES indicates which fuels flow in and out of the various technologies in the system. The RES diagram is drawn according to the data found in the current scenario along with the base-case scenario. The RES can be viewed focusing either on a demand, a technology, or an energy carrier.

MUSS has a function called the "bluebook option", which reorganizes/regroups the input tables so that input assumptions for various technologies or supply options can be examined and compared simultaneously.

MUSS provides an "Enduse Demand Calculation" module to forecast useful energy demand. It calculates future demand by applying basis (for example, in the case of residential space heating, number of households) and saturation values (for example, the percent of households needing heating) given for future periods to the historical technology levels for the first period.

Limitations of MARKAL

Due to the nature of LP, MARKAL always chooses the least cost solution. The energy service with the lowest cost will take the entire market, and the competitors with only slightly greater costs will be excluded. While in reality, factors other than price often affect decisions for fuel choices, these factors can only be addressed in MARKAL to a limited degree by means of technology-based discount rate.

MARKAL will calculate an energy balance based on the year specified, and interpolate linearly between the values found in the period before and the next period following the defined year. For example, if the data is listed for time period 1 (1990) and 3 (2010), the data for period 2 (2000) is interpolated linearly by MARKAL between the values in period 1 and 3. The use of multiple-year planning periods poses problems for renewable energy modeling in terms of resource characterization and technology implementation since renewable energy technologies can have very short construction times. Such modularity related advantages of renewable energy are difficult to show in the multiple year planning context.

MARKAL does not contain a complete environmental database, as do the two other models under review (LEAP and ENPEP).

2.3 LONG-RANGE ENERGY ALTERNATIVES PLANNING SYSTEM (LEAP)

Background

LEAP[3] was developed by the Stockholm Environment Institute-Boston Center at the Tellus Institute, with support from the United Nations Environment Programme and various other organizations.

Model Structures

LEAP is an energy accounting framework. It contains a full energy system which enables consideration of both demand-side and supply-side technologies and accounts for total system impacts.

LEAP is structured as a series of integrated programs. There are four main program groups and five sub-programs:

- Energy Scenarios
    - Demand
    - Transformation
    - Biomass

    - Environment
    - Evaluation
- Aggregation
- Environmental Data Base
- Fuel Chains

The Energy Scenarios programs are the main tools used to perform an integrated energy-environment planning exercise in an area. The programs assist in developing current energy balances, projections of supply and demand trends, and scenarios representing the effects of energy policies, plans, and actions. End-use consumption is calculated by the *Demand program*. Based on this demand estimate, the *Transformation program* simulates the conversion of primary energy resources to final fuel (for example, coal to electricity in power plants) to match supply to demand. Optionally, the *Biomass program* can be used to examine in more detail the adequacy of, and impacts on, biomass resources, based on the need for biomass fuels and the land use changes taking place in an area. The *Environment program* calculates the consequent environmental emissions based on the information contained in the Environmental Data Base. The *Evaluation program* compares the economic (costs and benefits), physical (energy and resource usage), and environmental (emissions) impacts of alternative energy scenarios.

The Aggregation program is a tool used to display multi-area results from analyses carried out in different geographical areas.

The Environmental Data Base can be used either as a stand-alone reference tool, or linked to the rest of LEAP to automatically calculate emissions and other environmental impacts of energy scenarios.

The Fuel Chains program is used to compare the total energy and environmental impacts of alternative fuels and technology choices per unit of energy or energy service delivered. For each end-use fuel and technology option, a “chain” is constructed which traces the energy inputs and environmental impacts for each upstream energy conversion stage.

Model Operation

LEAP is a demand-driven model. It can handle energy demand forecasts. The energy demand forecast is calculated by multiplying the activity levels times the unit energy requirements (or energy intensities). Activity levels can be disaggregated into sector, sub-sector, end-use, and devices. Both the activity levels and unit energy requirements are allowed to vary over time. The default methods for modeling these time variations are interpolation, growth rate, or by using independent variables called “drivers.” The driver method is based upon projecting an activity level or energy intensity as a function of one or more (up to three) driver variables with or without elasticities. Any variable can be used as driver, for example, GDP, rural population, electric prices, rural or urban households. The driver method assumes a standard log-log (constant elasticities) relationship between activities and the driver (independent) variables.

Based on the energy demand forecast, the Transformation program of LEAP will simulate energy supply and conversion processes to assess the adequacy of primary resources to meet the set of energy demands and export targets. The Transformation system has two levels of detail: the module level and the process level. The *module level* represents energy industries or sectors, for example, electricity generation, refining, district heating, and charcoal production. The *process level* describes individual technologies or groups of technologies within a module, for example, coal-fired plants and gas-fired plants of the electricity generation module. There are four different module types:

Simple Modules are used for simple conversion processes, or for processes that are of less interest in the analysis either because they account for a small fraction of overall energy flows, or because they are not the focus of the analysis.

Transmission & Distribution Modules are used to describe the losses occurring in the transportation, transmission, or distribution of fuels.

Detailed Modules are used for any process which produces multiple output fuels, which requires multiple feedstock fuels, or when process capacity limits are considered in the study.

Electricity Modules are special kind of detailed modules with extra features for electricity sector analysis (such as, load curve).

Detailed and Electricity modules can be configured to simulate dispatching, which affect how much each process will be used in meeting the annual output requirements of a module.

LEAP is also capable of iterating transformation calculations in order to resolve systems with looping flows of energy. That is, it calculates flows of energy from downstream processes to upstream processes, in addition to its normal mode of simulating energy flows in the reverse direction.

LEAP explicitly specifies auxiliary input fuels,[4] and separates them from feedstock fuels. Each auxiliary input fuel is linked into the Environmental Data Base. Therefore, it simulates the environmental loading of processes more accurately. Up to five auxiliary fuels can be defined for each process.

The model can include up to 65 fuels. Each fuel is classified into one of the five types:

- Non-renewable (fossil) primary resources
- Renewable Resources
- Biomass Resources
- Secondary Fuel
- Electricity

This classification determines how each fuel should be handled in the system.

The emissions from the baseline scenario can be calculated using the Environment program. The environmental analysis can be performed by linking demand devices in the Demand program, and transformation processes in the Transformation program, to appropriate LEAP's Environmental Data Base demand source and transformation source categories.

Sensitivity analysis could be performed by varying values of the variables in the baseline scenario to evaluate various policy options.

Dispatch Algorithm for Electricity Generation

Two dispatch rules can be selected for power generation. First, power generation can be selected to dispatch according to the merit orders to meet a default load curve. This method does not require load curve data, and is used in the case where the optimum capacity factor of a plant is known. In this method, each electricity plant is dispatched in turn by merit order and run until it meets the total electricity requirements. Peak load will be dispatched first to ensure that peak load plants run. The data required is thus the *optimum* capacity factor, not the *maximum* capacity factor, for peak load plants, to prevent them from running to their full technical capacity factor. The base-year peak system output and the base-year output data must be entered. LEAP will then calculate the base-year load factor and reserve margin. In future years, changes to the system load factor can be entered and that information will be used to report future system peak outputs and reserve margins.

Second, power generation can be selected to dispatch according to the merit orders defined for each plant to meet a user-defined system load curve. This method requires the system load curve data, but does not require the optimum capacity factor. Each plant will be run, if necessary, up to a limit of its maximum capacity factor to meet the system load curve as well as the overall energy requirements on the module. The user-defined load curve method divides each year up into a series of strips representing the cumulative load curve. Each strip is defined by the hours and load curve data entered. Plants are then dispatched in turn in each strip until the peak load of that strip has been met. Each plant is only run up to its maximum capacity factor and, once it has reached that point, will not be available for dispatching in subsequent strips. Thus different plants may be dispatched to meet the requirements of each strip.

Special Features

Fuel Chain Comparisons

The Fuel Chain program of LEAP allows a comparison of the total energy and environmental impacts of specific fuel and technology choices per unit of energy or per unit of energy service delivered of total fuel cycle from resource extraction to end-uses. An example would be to compare two passenger transport fuel chains, one using coal to generate electricity to run an electric car, and the other one using gasoline to run a gasoline car. The Fuel Chain program can be used to create a branching fuel chain with multiple processes in a single stage, for example, to simulate an electricity fuel chain where the electricity is generated from a mix of generating plants, or to simulate a mix of resource extraction facilities such as onshore and offshore oil production. A maximum of 8 stages in each fuel chain, and 8 stages per process, can be created.

In addition to the environmental loading created by the fuel consumed in a device, the data can be defined to estimate pre-operational phase impacts. These are impacts that occur during the manufacture of materials and equipment used in the fuel chain, for example, the impacts from the production of materials in device, device manufacture, and device assembly.

Scenario Comparisons

The benefits and costs of alternative scenarios can be compared using the Evaluation program. This calculation is done using the physical results generated from LEAP and the cost data entered into the various programs of LEAP, which includes:

- Cost of changing the numbers and intensities of demand devices,
- Capital cost, and O&M costs of Transformation devices,
- Cost of resource supplies,
- Cost of environmental externalities,
- Cost of capital, operating, and harvesting and distribution costs of special biomass land-types used for growing wood,
- Cost of cutting wood stocks and the adjustment costs of unmet biomass requirements.

This analysis will show the cost-benefit results for each demand device, transformation process, biomass resource, non-biomass resource, and environmental costs—all summed over the study's lifetime from the base year to the end year. Three statistics are shown for each of these components: costs, benefits, and the net present value. Costs are incurred when a cost in the alternative scenario exceeds its equivalent cost in the reference case. Benefits exist when a monetary cost in the alternative case is less than its equivalent cost in the reference scenario. The net present value for each term is defined as the sum of all discounted costs and benefits over the lifetime of the study.

The emission reduction between two scenarios can also be compared in both physical units and monetary units. For example, it shows in absolute and percentage decrease, relative to the base case over time. It also shows the percentage decrease relative to base year values. The report also calculates the net costs of emission reductions and the levelized costs per unit of emission reduction. The Evaluation program, however, does not provide an analysis of financial viability of the two scenarios.

Renewable Energy in LEAP

Renewable energy can be included in LEAP under the Demand program (if that renewable energy is used as an end-use direct fuel) and under the Transformation program (if that renewable energy is needed to be converted to final fuel), the same as non-renewable energy.

The data requirement for renewable energy under the Demand program includes its share in an end-use demand, end-use device, and its respective energy intensity. To estimate renewable energy under the Transformation program, first, the modules representing renewable energy processes (for example, biogas, solar PV, ethanol production or electricity generation) need to be set up with required information such as input into the process, output from the process, process efficiency, and process shares among different inputs.

The data for renewable energy needs to be entered in both the cases where renewable energy is used as a direct fuel and the case where renewable energy is used as an input in the transformation process. This data is the annual resource limit and import availability. Non-renewable energy is entered in the model in the same way. The difference between the two is that the data required for renewable energy is the maximum annual supply of each renewable resource, whereas the data required for non-renewable energy is the quantities of resource addition and depletion. The annual resource limit of the renewable energy can be used to represent either the physical limit of a resource or the sustainable annual yield of a resource. The cost inputs required for renewable energy (if a cost/benefit analysis will be performed) are identical to those of non-renewable energy, which are capital cost, fixed O&M cost, variable O&M cost, and recovery period.

For biomass resources, it is optional to use the LEAP Biomass program to assess the current and future status of biomass resources under different scenarios of land use changes, and energy supply and consumption patterns. LEAP classifies biomass resources into four groups: wood fuel, dung, crops and crop wastes, and non-energy wood products. Any biomass resource can be included in the analysis under these four categories.

The Biomass program takes the data (base year and projection) of the total area-wide energy requirements of different biomass resources calculated in the LEAP Demand and Transformation programs. This total area-wide energy requirement is allocated to each sub-area by a user-entered allocation fraction. Non-energy wood requirements are projected from data entered directly in the Biomass program. The Biomass program will assess the supplies of each biomass resource in each sub-area. This assessment is based on information such as projected land-use changes in each sub-area, changes in wood stocks and wood yields for each type of land use, annual dung production, and crop and crop waste production. The balance between biomass supplies and biomass requirements in each sub-area is then calculated. The scenarios to investigate alternative assumptions about changing patterns of land use and biomass production can be created.

To fulfill the above analysis, the Biomass program requires three categories of data: Land, Products, and Resources.

<u>Land</u>

Land areas are organized into three-tier structures: sub-areas, zones, and land-types.

- *Sub-areas* identify the names of the geographic sub-areas being used.
- *Zones* identify ecological zones within a sub-area. A convenient set of ecological zones might be high potential, medium potential, and low potential areas.

- *Land-types* classify land-type specifications, for example, grassland, mountain forest, commercial forest, cattle pasture, rice paddy, wheat field, woodlot, etc.

A maximum of thirty names can be specified for sub-areas, ten names for zones, and forty names for land-types. Changes in the land areas of different land-types can be projected by the program. The default method for specifying land area changes is to assume that there is no conversion to that land-type from another land-type. However, the program also provides other options for specifying land area changes. These options include annual conversions to the selected land-type from one or more of the other land-types, an annual exponential growth in the land area of a particular land-type, or a specification that a land-type area will grow in proportion to the values of any specified LEAP driver variables.

Products

The Product menu provides three options to specify supply sources: requirement, transport, and milling.

- The *requirement option* is used to allocate the calculated aggregate (area-wide) biomass resource requirement to the disaggregated sub-areas as specified in the Land data. The non-energy requirements for wood resources (for example, for timber and pulp) entered into the model can also be allocated into each sub-area.
- The *transport option* is used to enter any inter sub-area transportation of biomass resources. By default, LEAP assumes that each sub-area supplies all of its own needs. A modification can be made by indicating that a specified fraction of the sub-area's needs is supplied from another sub-area. LEAP assumes that dung is never transported.
- The *milling option* is only available for non-energy wood products. This option is used to simulate the recovery of wood milling wastes, which substitutes for woodfuels.

Resources

The Resources menu requires data for wood fuel, dung fuel, and crop and crop wastes fuel.

*Wood Fuel***.** Wood fuel supply-demand balance estimation requires three groups of information: assign products to land-types, harvesting, and inventory.

- *Assign Products to Land-Types*. Each land-type is assumed to produce wood to meet the requirements of only one wood product group. Therefore, the types of land that will be used to meet the requirements for each wood product must be indicated. For example, large farm food is used for wood fuel and poles; commercial forest is used for commercial wood.
- *Harvesting*. The required information is the harvest efficiency (defined as the ratio of the wood product to the total wood felled), the fraction of harvest wastes recovered and available for use as wood products, and the wood product group for which recovered wastes can be used. By default, harvesting efficiencies are assumed to be 100 percent. No waste is assumed to be recovered.

- *Inventory*. The required information is the *base-year inventory* (the amount of standing wood per unit of land area), the *base-year yield* (the amount of wood that can be collected in any one year without reducing the standing stock of wood in the following year), the *accessibility of wood resources in the base year* (the maximum fraction of the yields and stocks that can be collected to meet requirements), and the *wood growth pattern*.

The wood growth pattern describes how trees grow and how people manage them through different wood cutting practices. Three alternative wood growth patterns could be selected in the model: unmanaged woodland, managed woodland, and new wood projects.

- *Unmanaged Woodland*. This wood growth pattern assumes that both annual yields and tree stocks may be cut to meet wood requirements.
- *Managed Woodland*. This pattern assumes that trees are sustainably managed so that net stocks never decrease. That is, only the annual yields from the land-types are cut.
- *New Wood Project*. This pattern explicitly specifies cycles of wood stocks and harvest over time. It allows tree stock vintages to be tracked, and thus total stocks can be modeled as a function of the age of trees over the life cycles of a plantation. Thirty differently named wood projects can be defined, each of which can have a cycle length of up to 30 years.

By default, all land-types use a default unmanaged woodland growth pattern, which is a simplified model of a mature forest defined by two assumptions: (1) If stock cutting occurs, yields are assumed to decrease in direct proportion to stocks. Thus, a cleared forest is assumed never to regrow. (2) Stocks are never allowed to grow above their base year values.

For both managed and unmanaged woodlands, the Resources menu requires the data which relates wood yields to wood stocks at all levels of stocks between zero and the maximum stock of the land-types. For new wood projects, the data on stocks and harvest of wood in each planting year is required. This is different from the other two wood growth patterns where the data required is wood yields, for which only some wood may be harvested depending on requirements. Because wood projects are normally commercial wood plantations, their harvests are assumed to be used first, before yields from any other land-types are dispatched to meet wood requirements.

For wood cutting practices, the minimum level of stocks, below which cutting of wood cannot take place, needs to be defined.

Dung Fuels. The data requirement to estimate dung resources is the numbers of different types of animals in each sub-area and annual dung production per head of animals.

Crop and Crop Waste Resources. Each crop and crop waste energy product needs to be assigned to a land-type. The production of each crop and crop waste energy product will then be driven by the land-type area on which it is grown.

Costs

Costs of biomass energy resource supplies include special land-type and wood scarcity response costs.

- *Special Land-type Costs* are costs of biomass resource supplies for a particular land type. These special costs include capital costs, annual operating costs, harvesting costs, and distribution costs.
- *Wood Scarcity Response Costs* are the additional social and environmental costs (over normal supply costs) of each type of response to wood scarcity. For example, user may assign one cost to cutting wood stocks, and another to the costs of unmet wood requirements.

Projection Methodologies

LEAP provides three options for the projection of variables for biomass resource analysis, for example, land areas, non-energy wood requirements, livestock numbers, and crop and crop waste production. Those options are interpolation, growth rate, and driver.

Balance of Biomass Requirements and Supplies

The only supply source for dungs, and crop and crop waste is their annual production, and that production will be balanced with its requirement. The requirement for wood can be met through different sources of supplies. The Biomass program defines that, to meet wood product requirements, the supplies of wood resources in each sub-area are dispatched in the following orders:

1. Waste wood recovered from non-energy wood milling processes,
2. Wood harvested from new wood projects,
3. Any available wood from land clearances,
4. Accessible yields,
5. Any waste wood recovered from harvesting commercial wood resources,
6. Stock cutting.

For the purposes of calculating supply and requirement balances at each sub-area, the requirements for these products are automatically allocated to sub-areas using the following rules:

- Wood requirements are allocated in proportion to base-year wood yields.
- Crop and crop waste requirements are allocated in proportion to base-year crop production.

LEAP assumes that all wood products have the same moisture contents, densities, and energy contents. The same is true for all dung, and crop and crop waste products. However, the user can define, for example, each wood product as different fuel, each of which having different moisture contents, densities, and energy contents.

Environmental Calculation in LEAP

The environmental emissions and impacts associated with demand devices and transformation processes that consume, transform, or produce energy can be estimated using the LEAP Environment program. These estimates are based on emissions coefficients contained in the LEAP Environmental Data Base (EDB).[5] The fuel compositions required for each fuel are sulfur, nitrogen, carbon, ash, and moisture content on a percent weight basis.

In addition to displaying environmental loadings using physical units, the global warming potential (GWP) of GHG can also be displayed. The default data in LEAP is the GWPs for carbon dioxide, methane, and nitrous oxide as recommended by the Intergovernmental Panel on Climate Change, 1994,[6] for three time periods: 20 years, 100 years, and 500 years. GWPs are expressed as tonnes of CO_2 equivalent (that is, a factor of 44/12 greater than tonnes of carbon equivalent).

Environmental Data Base

The LEAP's EDB has extensive data on the energy-related environmental emissions (air emissions, water effluents, and solid wastes) and impacts (direct health and safety) that allows an estimation of the emissions and other environmental impacts of energy consuming and producing activities. The relationships between the quantities used and the consequent pollution emissions are assumed to be linear. Only direct effects that are produced by the sources are incorporated in the EDB. Indirect effects such as health impacts occurring downwind or downstream from pollution emissions are not considered in the database.

The EDB is structured in a two-dimensional matrix: Source categories and Effect categories.

Source categories list the names of technologies which produce environmental effects. Sources are separated into demand categories and transformation categories; each of them is defined by a multi-level hierarchy. Demand categories include demand devices specified by four levels: sectors, sub-sectors, end uses, and devices. Transformation categories are specified into three levels: process type, process, and technology.

Effect categories list the names of environmental effects from the sources. They are categorized by three levels:

- Type of effect, for example, air, water and solid waste emissions, and direct health and safety impacts,
- The effect itself, for example, CO_2, and injuries,
- Different categories of the same effect, for example, biogenic and non-biogenic CO_2.

Emissions coefficients are the unit effects produced by each source. Each cell in the Coefficient Database contains documentation and a reference. The documentation consists of text, equations, and page references, which explain how the coefficient in each cell was derived from the corresponding reference. The document is reported along with the numeric data, so the user will understand any important computations used in developing the data, or caveats on the applicability of the data. The references (up to three references can be identified in each cell) contain summary information about the source of the data. There is also a detailed reference—the Bibliographic Reference Database—that can store information on author, title, publisher, and date.

Emissions coefficients can be defined based on fuel composition, for example, carbon content of the coal. It is defined so that the actual emission of CO_2 from coal-fired electricity generating plants will not simply depend on the quantity of coal consumed by the plant, but will also depend on the carbon content of the coal.

The default effect categories utilized in the EDB are shown in Table 2.1. They are broken into the general classes of air emissions, water effluents, solid wastes, and health and safety.

Table 2.1: Default Effect Categories in the LEAP Environmental Data Base

Air Emissions	Water Effluents	Solid Wastes	Health, Safety
Carbon dioxide	Solids	Mining Waste	Deaths
Non biogenic / Biogenic	Total	Total	Injuries
Carbon monoxide	Suspended	Inert	Work Days Lost
Hydrocarbons	Dissolved	Ash	
Total	Oxygen demand	Total	
Aldehydes	Biochemical	Scrubber sludge	
Benzene	Chemical	Radioactive	
Tar	Sulfates	Low Level (curies)	
Volatile hydrocarbons	Metals	Low Level (Volume)	
Formaldehyde	Total		
Organic acids	Cadmium		
Methane	Chromium		
Hydrogen sulfide	Copper		
Metal	Iron		
Lead	Mercury		
Arsenic	Zinc		
Boron	Salts		
Cadmium	Nitrates		
Chromium	Organic Carbon		
Mercury	Total		
Nickel	Oil and grease		
Zinc	Chlorides		
Nitrogen oxides	Ammonia		
Total	Phosphates		
Nitrous oxide	Cyanide		
Sulfur oxides	Radioactive		
Total	Tritium		
Sulfur dioxide	Activation &		
Toxic hydrocarbons	Fission Products		
Polycyclic organic molecules			
Particulates			
Total			
Size less than 10 microns			
Fugitive coal dust			
Radioactive			
Carbon 14			
Iodine 131			
Noble gases			
Radon			
Tritium			
Ammonia			
Thermal emissions			

Data Requirements

LEAP is very flexible in its data requirement. The model can be run with a minimum of data, or the model can be designed for a detailed energy system if the data is available. The default energy unit is GJ, but data can be entered and results can be displayed in any energy unit by using conversion factors provided in the model. The main data used in the program is listed as the following:

- Cost Data
  - Cost of changing activity levels and cost of changing energy intensities of demand devices (Demand program),
  - Capital cost, annual fixed O&M cost, variable O&M cost of energy conversion equipment (Transformation program),
  - Resources cost including cost of imported fuels, exported fuels, and indigenous resources (Evaluation program),
  - Environmental externalities cost (Environment program).

Costs in the Transformation program are non-fuel costs only. Fuel supply costs are considered only at the point of primary resource supplies and entered into the "Resource Cost" field in the Evaluation program.

- Quantities of resource additions and depletions (for non-renewable energy).

- Export and import targets for each fuel,

- Transformation Data
  - Feedstock fuel,
  - Output fuel,
  - Process shares (if there are many processes in a module),
  - Process distribution losses,
  - Efficiency of conversion process,
  - Process capacity,
  - Maximum capacity factor,
  - Lifetime of the process.

- Electricity and Refinery Data
  - Plant capacity,
  - Base year output,
  - Plant efficiency,
  - Maximum capacity factor.

- Energy demand data in a hierarchical format based on four levels—sector, sub-sector, end-use, and device.

- Biomass Resource Data
  - Wood cutting practices: minimum level of wood stock allowed,

- Harvesting: harvest efficiency, fraction of harvest wastes recovered,
- Special Land-type Cost:[7] capital costs, annual operating costs, harvesting and distribution costs,
- Wood Scarcity Response Costs,[8]
- Numbers of different types of animals in each sub-area,
- Annual dung production per head of animal.

- Non-Biomass Renewable Energy Data
  - Availability of import,
  - Maximum annual supply,
  - Cost: capital cost, fixed O&M cost, and variable O&M cost,
  - Recovery period (for cost-benefit analysis).

- Financial data
  - Inflation rate,
  - Discount rate,
  - Foreign exchange rate (if using any foreign money).

- Driver variables, for example, GDP, electricity prices, population, etc. (if used for the projection).

Solutions from LEAP

The solution from LEAP is deterministic since LEAP is an accounting model. The solutions from LEAP include energy demand and supply balance, the calculation of the consequent environmental emissions, and biomass resources demand and supply balance. LEAP can also compare the overall costs and environmental consequences of different scenarios.

Energy Demand and Supply Calculation

LEAP estimates energy demand and supply over the specified periods of time. The results can be displayed as an aggregate energy balance of primary resource requirements, subdivided into its indigenous production, import, export, and stock changes. The results can show transformation energy supplies by process, and total energy demand by sector, in either physical or monetary units, and in the format of either absolute values, growth rates, or cumulative values. The results can also be displayed in detail. For example, it can show the energy demand for a particular fuel by sector/sub-sector/end-use, the demand in a particular sector/sub-sector/end-use by fuel, total primary resource supplies by year, or resource supplies from indigenous production, imports, or exports.

Biomass Demand and Supply Calculation

The overall results from the Biomass program are reported in two forms: the supplies of biomass in physical units, and the costs and foreign exchange components of biomass supplies. The *supplies report* shows the total wood supplies from various sources (for example, from wood projects, from other land-type yields, and from stocks and other sources such as land-clearances) by sub-area. The report also shows total dung, and crop and crop waste supplies from each sub-area. The *costs report* displays (1) the cost of biomass supplies divided into wood, crop, and dung (using the default resource costs entered on the Evaluation program); (2) special land-type costs which are capital costs, operating costs, and wood harvesting costs; and (3) the cost of responses to wood scarcity (for example, the cost of cutting wood stocks and the adjustment cost of unmet requirements). The Biomass program can also provide a detailed report on demand and supply balances of each biomass. For example, the detailed report on wood resources displays the wood demand and wood supplies (divided into supplies from yields, stock, and land clearance) by land type or by sub-area, or the detailed report on dung balance shows the dung requirement and dung supply by animal types.

Environmental Calculation

The result from the environmental calculation is reported in total quantities of each environmental effect from all demand and transformation sources. It can be displayed in either the total cost of the effect loadings or the physical quantities of each effect (which can be in a physical unit or to show the total GWP of air emissions in tonnes of CO_2 equivalent).

Scenario Comparisons

The overall costs and emission reductions, and costs between two scenarios, can be reported from the model.

Advantages of LEAP

LEAP is a simple model that does not require a long training period. The program is designed to be user-friendly with a detailed manual and on-line help.

LEAP will be useful in cases where the analyst wishes to determine the energy and environmental impacts of proposed governmental policies where the initial technology projection has been predetermined.

LEAP has a feature allowing coordinated planning at more than one spatial level.[9] For example, energy scenarios can be developed at the state or provincial level and then aggregated to the national level, or from the national level to the multinational or global level.

LEAP provides an option for examining the material requirements of an energy scenario.[10] The material analysis feature can also potentially be used to study non-material inputs to energy chains, such as the study of employment impacts of alternative fuel and technology choices.

LEAP has a function to display results in any unit desired, rather than just have the default unit. All reports can be represented in three standard formats: absolute values, annual growth rates and percentage shares. In some reports, the results can also be displayed as cumulative values, for example, cumulative emissions loadings.

LEAP has an extensive environmental database available that covers air emissions, water effluents, solid waste, and health and safety. The database may also contain documentation and references that can be used to document the database of coefficients, sources of data, data computation, etc.

Limitations of LEAP

LEAP is just an accounting framework. Impacts of economic factors on energy supplies and fuel mixes are ignored in the model. Shares among fuel usage and substitutable devices for an end-use must be determined exogenously and not by the model. Future energy systems are systhesized largely according to the judgement of the modeler of what preferred future technologies should be. Although energy prices/costs can be one of up to three driving variables in specifying activity levels (for example, transportation demand) or energy intensities, prices/costs can not be factors in making choices among alternative energy technologies or fuels.

Due to the nature of the model, the model cannot analyze fuel competitiveness between renewable energy and fossil fuels.

The dispatch rule for the electricity module has to be specified. The default method is to dispatch in turn by merit order and run until the total electricity requirements are met. Using this method means that the optimum capacity factors of plants are known, which means an electric utility dispatch model has to be run first. The results from the run can then be entered in LEAP. Another option of dispatching is to enter data describing a load curve. Plants will then be dispatched according to the merit orders defined for each plant. Each plant will be run up to its maximum capacity factor to meet the system load curve as well as the overall energy requirements within the module. This method does not allow for random outages during the year. All plants are assumed to be available at peak load time. Since in reality, only a proportion of plants will be available at any given time due to planned or forced plant maintenance, this method tends to overestimate the reserve margin in the peak load and underestimate it during the lowest load.

2.4 MODEL COMPARISONS

Model Similarities

The three models have the same concept. Initially, each creates a picture of the current energy situation with an estimate of future changes based on the expected plans and growths in the economy. This scenario is referred to as the Base Case or Business-as-Usual. The alternative scenarios are thus created with alternative assumptions about future developments and plans. The alternative scenarios could then be compared with the Base Case to see the impacts on energy systems and the impacts on pollution generation.

All three models are demand-driven models, in that feasible solutions are obtained only if all the specified end-use demands for energy services are satisfied for every time period. Demand is forecast exogeneously for each time period. LEAP and MARKAL have a feature to make a demand forecast. ENPEP has a module called DEMAND that can handle demand projection and feed the input to BALANCE, or the forecast has to be made exogenously and entered into BALANCE. Demand is classified by end-use sector.

Any renewable energy can be included in any of the three models. Each model, though, has different features to handle the renewable energy characteristics.

All three models are designed to be used as a long-term forecasting tool. ENPEP can project energy balances up to 75 time periods. MARKAL can handle any number of periods while MUSS is limited to 9 periods, but any fixed period length can be used. LEAP can handle up to 120 projection periods.

Model Differences

The major difference is in the solution structure of the models. MARKAL is a linear programming model, ENPEP is a system of simultaneous non-linear equations and inequalities, while LEAP is an accounting model framework.

MARKAL selects the options that minimize total system cost, subject to constraints. A solution from BALANCE is based on simulating the behavior of energy consumers and producers through a market-sharing algorithm. The market share is split among alternative choices, and not only based on the least cost source of energy. The solution from LEAP is deterministic.

The use of a market share algorithm such as BALANCE is one thing that distinguishes the equilibrium approach from the other energy modeling techniques. This technique allows for the simulation of market operation with multiple decision-makers. By contrast, least-cost optimization approaches, while suitable for simulating a single decision-maker, cannot address the more complex behavior of multiple decision-makers. For example, in simulating the consumer choice for using natural gas or electricity for cooking (assuming both are readily available), the market-sharing algorithm can simulate the condition where some consumers will prefer one to the other.

BALANCE estimates renewable and depletable resources based on different supply functions. It requires a quadratic supply function for depletable resources and a step supply function for renewable resources. In contrast, MARKAL does not treat renewable and depletable resource supplies differently, and both supplies are based on linear relationships. Constraints can be put in the MARKAL model, however, to control renewable energy supply to be a step function. Both renewable and depletable resources are also treated in the same manner in LEAP.

The equilibrium modeling approach for the BALANCE module is based on the concept that the energy sector consists of autonomous energy producers and consumers that carry out production and consumption activities, each optimizing individual objectives. By contrast, MARKAL (which is an optimization model of the entire energy sector) can take in the interpretation of a central planning authority that has control over all energy flows and prices in the entire energy sector.

BALANCE projects the balance of energy supply and demand. The results can be fed into IMPACTS, another module of ENPEP, to calculate the consequent environmental impacts such as pollution emissions. LEAP works in a similar fashion, where the Demand and Transformation programs results could be linked to the Environment program for environmental analysis. The environmental impact is not treated as a constraint in the projection of energy options in either BALANCE or LEAP. MARKAL works in an opposite manner, where environmental factors can be put as a constraint on the energy options selected by the model. The environmental impacts are thus reported as part of the MARKAL standard model run.

For MARKAL, emission restrictions can be one of the constraints put into the model. The model will then modify the energy system to meet such a restriction. ENPEP handles the case in different manner. The energy balance has to be calculated first in BALANCE and then the data is fed into IMPACTS for calculating the consequent pollution emissions. If the pollution emissions are higher than the requirement, a new scenario has to be made in BALANCE in order to cut down the pollution emissions. IMPACTS must then be re-run for a new calculation of the emissions. The same is true with LEAP.

Demand projection in BALANCE is forecast exogenously and is imported into the model in the form of a growth rate. However, the demand projection can be obtained from DEMAND, another ENPEP sub-module. MUSS provides an End Use Demand Calculation module to forecast final demand for use in MARKAL. Variants of MARKAL also permit demands to be determined endogenously in response to prices. LEAP includes a feature to project demand. The demand projection then drives the calculations of the other LEAP programs.

In BALANCE and MARKAL, cost variables are factors that determine the allocation of fuel. In LEAP, cost variables are only required for cost-benefit analysis, and cannot be factors in making choices among alternative energy technologies or fuels.

The MARKAL data handling system provides facilities for analyzing the results of multiple model runs (up to 10). ENPEP permits the results of a single run to be examined at a time. LEAP can handle the comparison of two runs.

LEAP is publicly available and free of charge. ENPEP is available free of charge for government agencies but not available for commercial use. MARKAL is publicly available at a cost varying between $3,300-$15,000 depending on such factors as number of users, solver selected, and institutional affiliation.[11]

2.5 MODEL UPDATES

The three models being reviewed in this study—ENPEP, MARKAL and LEAP—have been, or are being, updated since the time they were used by the selected economies. This section discusses new developments with the three models. Brief discussions of the ENPEP and MARKAL related models are also included in this section. Although a review of the related models is outside the scope of this study, it was felt that a brief model description was useful for understanding the wide range of energy issue which could be addressed by the two modeling systems.

ENPEP[12]

The new version of ENPEP—ENPEP for Windows—is currently under development. The ENPEP for Windows fully utilizes graphical capabilities of the MS Windows operating system. It is more user-friendly and operates with a point-and-click graphical user interface. With this version, the user can construct an energy network by drawing it directly on the screen, instead of having to use another graphical program (such as Power Point) to draw the network. In addition, all input data for any component of the energy network can be entered, viewed, or edited by simply double-clicking on that component in the network. The same applies for viewing the output results of the model runs. All output results (such as energy flows and prices) can be graphically displayed on the links of the energy network or, for viewing more detailed results for a single component of the network, by double-clicking on that component and selecting the option to view the results.

ENPEP for Windows version uses the PowerSoft PowerBuilder 7.0 programming environment. PowerBuilder is designed excellent package for the construction of large-scale applications. It has a proven track record and impressive market support. PowerBuilder comes with its own internal database (SYBASE) and has good connectivity with other (external) databases. ENPEP for Windows fully utilizes this database-supported environment so that all input data and output results are stored in the database which provides a convenient interface between different ENPEP modules.

A beta test version of the ENPEP for Windows will be first used at the International Atomic Energy Agency (IAEA) and Argonne National Laboratory (ANL) international training course, which will take place at ANL during September 13 to November 5, 1999. The first release of the software is expected after the training course.

In many applications, ENPEP can be used in combination with other models. For example, Valoragua can be used to determine the optimal generating strategy of mixed hydro-thermal electric power systems. WASP-III Plus (Wien Automatic System Planning Package) can be used to analyze long-term electric system expansion, and GTMax (Generation and Transmission Maximixation Model) can be used for the applications such as determining seasonal power and energy offers to customers, and computing the costs associated with environmental legislation. GTMax can also be employed to fine tune hourly resource generation patterns, spot market transactions, energy interchanges, and power wheeling on the transmission system.

ENPEP can be linked to MCITOS (Multi Criteria Interval Trade-Offs System) to perform a mutli-criteria decision analysis. MCITOS is a general-purpose decision support system which can be used to determine the most desirable alternatives in various decision problems, not only those related to electric power systems.

ENPEP can also be linked to APEX (Argonne Production, Expansion, and Exchange Model for Electrical Systems). APEX is a menu-driven programming package that can be used to conduct simulations of production costs, system reliability, spot market network flows, and optimal system capacity expansion.

MARKAL[13]

MARKAL has a Windows 95 interface called ANSWER. ANSWER was developed by the Australian Bureau for Agricultural and Resource Economics (ABARE), and introduced during 1998. With the Windows-based system of ANSWER, the MARKAL model is more readily accessible and usable to the energy policy and systems analyst. ANSWER provides a number of enhancements over MUSS for the analysis and presentation of input assumptions and results. These enhancements include:

- data editing capabilities via 'direct cell editing', similar to a spreadsheet, with data gathering and organization possible using Microsoft EXCEL,
- utilities for scenario management of model data, and for case management of model runs and results,
- screening/filtering options (for example, data for a given classification of technologies, such as central generation facilities, may be examined as a group),
- inputs or results may be simultaneously examined side-by-side, with data while cascading through the RES,
- powerful graphics and report writing capabilities via a link to EXCEL and paste capabilities into WORD for Windows,
- full support for the latest production MARKAL-MACRO GAMS code.

Several new versions of the MARKAL model have been developed to include various methodology advancements. With few exceptions, individual versions are additive, and they can be used in combination with each other where appropriate. In some instances, however, features are mutually exclusive as they represent different modeling techniques that address the same needs.

MARKAL can be used in conjunction with other sub-models that provide endogenous determination of useful energy demands such as MICRO, MACRO, and MARKAL Elastic Demand (MED). The most popular of these is the MACRO model, a long-term neoclassical economic growth model. MARKAL-MACRO is a non-linear optimization model that allows the interplay between the energy system and the economy, permitting demand levels to respond to prices and reporting the first order affects on GDP.

One advanced version of MARKAL has the ability to solve multiple models to facilitate regional assessments. An example is the combination of two (or more) MARKAL models or the combination of multiple economy-specific MARKAL-MED and MARKAL-MACRO models for evaluation of a specific project that requires bilateral agreements between two economies (or partners in each economy), such as Joint Implementation (JI) project. As the second example, MARKAL-MACRO integrates with MERGE, a global trade model. MERGE links a number of ETA-MACRO sub-models to produce a complete global system. The resulting integrated framework retains the full technology capability available in MARKAL while at the same time providing for global trade in energy, and CO_2 permits.

Another methodology advancement in MARKAL is the development of an endogenous representation of technology learning within the model. That is, the model allows reductions in technology costs and increases in penetration rates as experience is gained with the technologies. This feature is explicitly added to better handle the expected gains in competitive advantage for renewable energy as deployment increases and experience is gained.

Another version of MARKAL is an expansion to include material flows to examine the relationship between energy and materials. MARKAL tracks materials from production through disposal using the same flow structure as is applied to energy, along with provisions for accounting for the value of recovered materials.

Uncertainty is addressed in MARKAL by using stochastic programming. In this version of MARKAL, an optimal solution is calculated by minimizing the expected (probability weighted average) discounted cost of the energy system.

TIMES (The Integrated MARKAL-EFOM System) is the newest member of the MARKAL family which was introduced in April 1999. TIMES is also an optimization framework, which produces the least-cost solution subject to emissions or other constraints. The increased flexibility of TIMES allows for the analysis of a number of problems, which previously required undesirable compromises or were beyond the analytical limits of MARKAL.

Other enhancements are planned for MARKAL. These include:

- linkage to the International Resources Group's Compact and Innovative Enterprise Performance Rating and Analysis System (CIEPRAS),
- development of a technology database and the expansion of the coverage of the multi-region version of MACRO/MED,
- inclusion of a watershed module developed at the World Bank, and
- linkage to the Forestry and Agriculture Sector Optimization Model (FASOM).

LEAP 2000[14]

LEAP 2000 is a new version of LEAP which is being developed as a collaborative work between the Stockholm Environment Institute (SEI) and institutions in Southern Africa

(EDRC), West Africa (ENDA-TM), Asia (FAO/RWED), South America (IDEE/FB), and Europe (ETC International). The initiative is being funded by the Netherlands Ministry of Foreign Affairs, Directorate General for Development Cooperation (DGIS), and is being coordinated by SEI's Boston Center.

LEAP 2000 will operate under Windows 95/NT. Its new capabilities are expected to include:

- An intuitive graphical Windows interface with links to spreadsheets and other models (such as air dispersion model—ISC2, impact and evaluation model—EXMOD, specialize renewables model—Hybrid 2, and vehicle externalities model—EXMOBILE),
- Powerful modeling capabilities, for example, user-editable model equations, improved simulation modeling, scenario management features,
- Modeling templates to match a wide range of analyses, for example, GHG mitigation analysis, integrated (and sectoral) energy and environment planning, fuel cycle analysis, transport planning, rural energy and biomass analysis, and
- A new project/option analysis tool for screening and ranking measures.

Regarding renewable energy analysis, LEAP 2000 will enable better simulation of the operation of intermittent renewable technologies (for example, wind and solar). LEAP 2000 will be able to link to specialized renewables models such as Hybrid 2 and others. Thus it would enable better simulation of off-grid electrification options. Scenarios should also be capable of considering the tradeoffs imposed by both traditional and modern uses of biomass resources, by tracking land requirements and comparing them to demands for other land uses.

LEAP 2000 will link with the new Technology and Environmental Database (TED). TED will provide an extensive and accessible database describing the technical characteristics, and costs and environmental impacts of a wide range of energy technologies. It will provide to users information on existing technologies, current best practices and next generation energy technologies. TED will also include information pages that help users find and match appropriate technologies to the local circumstances in their analyses. These pages will highlights factors affecting the availability, appropriateness, and cost-effectiveness of different technologies, and will link to additional sources of information and expertise. TED will be freely accessible to researchers whether or not they are carrying out scenario analyses using LEAP.

The first public beta versions of LEAP 2000 is expected to be available in early-to-mid year 2000. A prototype of the TED database will be available to selected testers during the year 1999.

2.6 CONCLUSION

Renewable energy is incorporated differently in each model. BALANCE has a node for renewable energy (called a renewable energy node) that is separate from non-renewable energy. A renewable energy node is included in the energy network and has a link of output connected either into a processing node of renewable energy technology directly, or into an allocation node to distribute the resource into various processing nodes of renewable energy technologies. The outputs from the renewable energy technology processing node(s) are then allocated into end-use demand. The limitations on the annual energy supply can be set from the renewable energy node, and costs and renewable energy technology characteristics can be specified in the processing node, which could be a conversion process node (for example, solar heat electric), a multiple-input-link conversion node (for example, solar heater with electric back up), or a refining node (for example, biomass cogeneration).

To introduce renewable energy into MARKAL, first, the type of renewable energy must be identified in the "Set" of renewable energy carriers. Renewable energy technologies are then specified in the "Set" of technologies in which they belong. Demand technologies are set if these renewable energy technologies are used to satisfy a final demand; conversion technologies are used if these renewable energy technologies produce electricity, district heat or both; or process technologies are set if these renewable energy technologies do not produce electricity, heat, or meet a final demand.

Renewable energy is treated the same as non-renewable energy in LEAP, and can be entered into the model as an end-use direct fuel in the Demand program or by specifying its percentage share among other fuels in the same end-use. Renewable energy that is required to be processed must be entered in the Transformation program by setting up a module to represent its renewable energy technologies. The information on renewable energy resources, that is, annual resource limit and import availability, is required in both cases. For biomass resources, it is optional to use the Biomass program to assess the current and future status of biomass resources under different land use changes, and energy supply and consumption patterns.

Renewable energy technologies pose unique challenges to economy level energy modeling. The characterization of renewable energy technologies understandably takes a minor role in traditional energy/economic models. This stems from the simple fact that these models were originally designed and applied in developed economies where renewable energy accounted for only a small portion of the overall energy use. This being the case, renewable energy systems are not the central focus of any of the three models reviewed in this study. However, each model does exhibit its own advantages and disadvantages when faced with incorporating renewable energy technologies into the overall economy energy system.

END NOTES

[1] Bruce P. Hamilton, et al. *Energy and Power Evaluation Program Documentation and User's Manual.* Argonne National Laboratory, (ANL/EES-TM-317), Argonne, Illinoise, September 1994.

[2] Leslie Fishbone, et al. *User's Guide for MARKAL (BNL/KFA Version 2.0).* Department of Applied Science, Brookhaven National Laboratory, USA, and Nuclear Research Center, Germany, (BNL 51701), July 1983.

[3] Stockholm Environment Institute-Boston (SEI-B). *LEAP User Guide for Version 95.0.* Tellus Institute, Boston, Massachusetts, July 1995.

[4] Auxiliary input fuels are additional fuels used in the process as final fuels and not being transformed into other fuels. For example, diesel used for diesel generators in coal mining is considered auxiliary input fuel in the coal mining process.

[5] New source and effect categories, and emission coefficients can be added into the EDB.

[6] Intergovernmental Panel on Climate Change. *Radiative Forcing of Climate Change: The 1994 Report of the Scientific Assessment Working Group of IPCC.* Summary for Policymakers, 1994.

[7] Refers to cost of biomass resource supplies for a particular land type.

[8] Refers to social and environmental costs of each type of response to wood scarcity

[9] Using the Aggregation program.

[10] An option in the Transformation program.

[11] Software requirements and pricing information for MARKAL can be found at (http://www.ecn.nl/unit_bs/etsap/markal/faq.html#howl).

[12] For more information on ENPEP and its other related ANL models, contact

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CHAPTER 3

ECONOMY MODEL ANALYSIS

Four economies—Thailand, Indonesia, the Philippines, and the People's Republic of China—were selected as case studies. This section reviews their existing domestic energy models and especially seeks to understand how renewable energy is included in the models. Thailand employed ENPEP, Indonesia and the Philippines employed MARKAL, and the People's Republic of China utilized LEAP. An overview of the energy sector for each economy will first be reviewed to provide background information of the economy.

Due to the wide range of issues and problems associated with characterizing renewable energy potential at the economy level, the modeling of renewable energy should be conducted on a continuing basis. This would enable information on new technologies and resource characterization to be included and existing assumptions to be revised and updated. Therefore, this report provides a high level of detail on modeling components and assumptions for each case study so it may serve as a baseline for additional studies of the incorporation of renewable energy into economy-level models.

In addition, it is hoped that by providing a high level of detail on assumptions and methodologies, this report can benefit other APEC member economies who either are currently developing or plan to develop their own economy-level energy models.

3.1 THAILAND [1]

The case study for the ENPEP model was taken from the study called *Greenhouse Gas Mitigation Options in the Thai Energy Sector*. The study was prepared for the Office of Environmental Policy and Planning, Ministry of Science, Technology and Environment in preparation for Thailand National Strategies on Global Climate Change. The project was funded by the U.S. Country Study Program on Climate Change. All the information in this section was derived from this report.

Energy Sector Overview

Thailand consumed a mix of energy resources. Total primary energy supply in 1994 was 340,628 KBOE. The proportions of resource supplies in 1994 were the following: 43.5 percent of crude oil (148,257 KBOE), 24.7 percent of biomass (84,005 KBOE), 16.4 percent of natural gas (55,789 KBOE), 13.1 percent of coal (44,767 KBOE), 1.2 percent of condensate (4,017 KBOE), 0.8 percent of hydro (2,812 KBOE), and 0.2 percent of natural gasoline (981 KBOE). Most of the energy resources consumed in Thailand were imported.

Crude oil was obtained from both domestic and imported sources and was fed into four refineries in Thailand. Additional inputs to refineries included natural gasoline from domestic gas processing plants and condensate from gas reserves. Coal demand was also met by both domestic and imported resources. Coal was consumed mainly by the power sector, with the remainder consumed by the industrial sector. Natural gas and condensate were extracted from domestic gas reserves. Some portion of natural gas was imported from neighboring economies. The principal use of natural gas was for power generation, with other users including the industrial sector and the transport sector (in the form of CNG for buses). Condensate was mainly exported with some minimum amounts being fed to domestic oil refineries.

The renewable energy resources consumed in Thailand were hydro resources and biomass (paddy husk, bagasse, fuel wood, and charcoal). Hydro resources were used for power generation. Biomass was used in the residential and industrial sectors.

Power sector consumed about 109,495 KBOE of energy in 1994. Natural gas was the principal fuel used for power generation (at 51,605 KBOE), followed by fuel oil (at 30,045 KBOE), coal (at 22,025 KBOE), diesel (at 3,008 KBOE), and hydro resources (at 2,812 KBOE). Total electricity generation in 1994 was 71,212 GWh.

The transport sector is the largest final energy-consuming sector in Thailand. Of the total final energy consumption in 1994 (327,192 KBOE), about 38.1 percent (or 124,708 KBOE) was consumed in the transport sector. The other energy consumers included the industrial sector (31.5 percent or 103,026 KBOE), the residential sector (22.8 percent or 74,670 KBOE), the commercial sector (4.0 percent or 13,199 KBOE), and the agricultural sector (3.5 percent or 11,589 KBOE). Final energy consumption in each end-use sector by type of energy in 1994 is shown in Table 3.1.

Table 3.1: Final Energy Consumption in the Thailand End-Use Sectors in 1994

Unit: KBOE

	Transport	Industrial	Residential	Commercial	Agricultural
Fuel Oil	5,025	20,746	0	418	130
Diesel	64,130	5,521	0	0	10,933
Gasoline	34,115	504	0	0	412
Kerosene	0	397	273	0	6
LPG	1,817	2,563	10,951	0	31
Jet fuel	19,566	0	0	0	0
Coal	0	22,742	0	0	0
Natural Gas	55 [1/]	4,128	0	0	0
Electricity	0	17,948	8,003	12,781	77
Biomass	0	28,477	55,443	0	0
Total	**124,708**	**103,026**	**74,670**	**13,199**	**11,589**

Note: [1/] In form of CNG

Source: Intarapravich, D., 1996

Model Framework: BALANCE

The objective of the study was to identify mitigation options to reduce GHG emissions in the energy sector of Thailand. The GHG of concern in this study was CO_2, which was the principal GHG produced in the energy sector. Scenario analysis was utilized for the study. The Base Case scenario was first designed to examine future CO_2 emissions in the case where the energy system continued in line with the current system and no specific policy was adopted to encourage actions for reducing CO_2 emissions or enhancing carbon sinks.

Three levels of mitigation options were then constructed to examine the various technology and policy options that could help in the reduction of CO_2 emissions on both the demand and supply sides. First, individual options in selected energy end-use sectors were developed to examine the potential CO_2 reductions of each option. The second level involved linking various mitigation options in each sector to investigate their combined impacts on CO_2 reductions. Lastly, the study performed another mitigation scenario called the "National" scenario where various mitigation options in all major CO_2 contributing sectors were implemented concurrently. The National scenario showed the maximum potential CO_2 reductions in the economy.

The study was based on the design of the energy network representing the current situation, as well as projected changes of energy supply and demand in Thailand. The supply side included conventional energy resources (coal, oil, gas, and electricity) and renewable energy supplies (hydro and biomass). The demand side was classified into detailed end-uses in the industrial, residential, commercial, agricultural, and transport sectors.

The network was composed of various nodes and links in the format designed to run the BALANCE module of ENPEP. The network included 15 depletable and import resources, 2 renewable resources, 74 conversion processes, 5 refinery processes, 5 multiple input processes, 52 decision allocation nodes, 11 stockpiles, 17 pricing nodes, and 40 demand processes. This network was designed specifically to provide the level of detail needed to support a comprehensive analysis of GHG reduction opportunities in the Thai energy sector. The level of disaggregation, thus, was different among sectors. Additional details were presented for the high potential GHG reduction sectors and activities. The major components of the network are explained as follows:

Depletable Resource Sectors

Coal Sector. The coal resource nodes were separated into domestic coal and imported coal. Total coal supply was then allocated to coal power plants and the industrial sector. Coal for the industrial sector was allocated to the cogeneration process, which produced steam as well as generated electricity for industrial uses; to coal boilers, which produced steam for industrial uses; to produce heat for industrial uses; and to the cement industry.

Gas Sector. The gas resource nodes were composed of one domestic gas resource node and two imported gas nodes. The products from the domestic gas resource were natural gas and condensate. Natural gas from gas reserves and associated gas from on-shore oil fields were fed into a gas processing plant. Condensate was mainly exported, with some small amount being fed into local oil refineries. Three products were obtained from the gas processing plant: processed gas, LPG, and natural gasoline. The processed natural gas from local gas processing plants and imported gas were allocated to gas-fired plants for power generation, to the industrial sector, and to the transport sector. Industrial consumers of processed gas were divided into three categories, including gas boilers for industrial steam demand, produce heat for industrial uses, and the cement industry. The network was designed to have gas allocations linked to the transport sector in the form of CNG for buses. LPG from the gas processing plant was added to the LPG allocation node for further allocation to users. The natural gasoline was designated for inputs into the oil refinery process.

The network was designed to have two imported gas nodes. One gas node was assigned for gas imports dedicated to power plants. Another gas node was designed to allow additional imported gas for use in the power sector and/or the industrial sector.

Oil Sector. Crude oil nodes included domestic and imported crude oil. The domestic crude was processed and fed into four refineries in Thailand. Additional inputs to refineries included natural gasoline from gas processing plants and condensate from gas reserves. Refinery products included gasoline, jet fuel, LPG, kerosene, fuel oil, and diesel. For all products, import, export, and stockpile nodes were included to enable potential adjustment during domestic supply shortages and surpluses.

Each oil product was allocated to satisfy the final demand. Gasoline was mainly consumed in the transport sector for automobiles (cars and taxies), motorcycles, buses, trucks, and passenger ships. The remainder was intended for use in agricultural tractors for land preparation in crops, livestock and forestry sub-sectors, and for mechanical uses in the industrial sector. Jet fuel was used by airplanes. Consumption of LPG was allocated in the transport sector for automobiles, buses, trucks, and motortricycles, in the residential sector for cooking purposes, in the industrial sector for steam and heat production, and in the agricultural sector for harvesting. Kerosene was utilized mainly in the residential sector for lighting and cooking purposes. The remaining kerosene was utilized in the manufacturing sector for steam and heat production. Fuel oil was allocated to the industrial sector (for steam and heat production), to the power sector, to the transport sector (for freight ships), and to the agricultural sector (for harvesting). Diesel was allocated to the power sector, the transport sector (trains, buses, automobiles, trucks, and ships), the industrial sector (for mechanical engine use and steam production), and the agricultural sector (diesel tractors for land preparation, diesel pumps for irrigation, diesel equipment for harvesting, and diesel boats for fishing).

Electricity Sector

Electricity was disaggregated into base load and peak load, of which each category was disaggregated into existing and new plants. The base load generation was composed of gas-fired plants (thermal, combined cycle, and gas turbine), coal-fired plants (lignite for existing plants and pulverized coal for new plants), and oil-fired plants (thermal). The peak load generation was from diesel and hydropower plants. Grid electricity was also derived from imports.

Electricity generation was transmitted to final demand, which was classified into residential, transport, industrial, commercial, and agricultural sectors. The electricity demand in the residential sector was for cooking, lighting, cooling, and other demands (for example, refrigeration, water heating, television, radio, ironing, etc.). The electricity demand in the transport sector was for electric trains. Electricity demand in the industrial sector was separated into demand for mechanical uses and heat production. An export node and an import node were included in the network for electricity export to, and import from, neighboring economies.

End-Use Sectors

The end-use sectors were composed of 5 sectors: residential, transport, industrial, agricultural, and commercial sectors.

Residential Sector. The residential sector was dassified into four end uses: cooking, lighting, cooling, and other demands. The equipment for food preparation included kerosene, LPG, biomass, and electric stoves. Lighting demand was fulfilled by electric and kerosene lamps. Cooling demand was divided between fans and air conditioners. The other residential demands that only utilized electricity included refrigeration, water heating, television, radio, washing machines, and ironing.

Transport Sector. The demand for transportation was divided into passenger and freight demand. Passenger demand was disaggregated into long-distance and short-distance demand. Long-distance passenger demand was met by planes and trains. Short-distance passenger demand was composed of road and ship demands. Road demand included automobiles (using gasoline, diesel, and LPG), buses (using gasoline, LPG, diesel, and CNG), motorcycles (using gasoline), motortricycles (using LPG) and electric trains. Although there was no use for an electric train at present, this transport mode was included in the network since future use was expected. Freight demand was separated into demand for airplanes, trains, trucks, and ships.

Industrial Sector. The final demand in the industrial sector was separated into heat demand, steam demand, fuel demand for mechanical uses, electricity demand for mechanical uses and heat production, and fuel demand in the cement industry. The cement industry was singled out because energy consumption in this sector was high, and this sector had significant process-related CO_2 emissions. Fuels for heat production were kerosene, fuel oil, coal, natural gas, LPG, and biomass. Fuels for mechanical uses were diesel, kerosene, fuel oil, and gasoline. Fuels used in the cement industry were fuel oil, natural gas, and coal. The industrial steam demand was fulfilled by both boilers (using coal, fuel oil, natural gas, kerosene, LPG, diesel, and biomass), and cogeneration processes (using coal and biomass).

Agricultural Sector. The demand in the agricultural sector was classified as fuel oil, diesel, LPG, gasoline, and electricity demand.

Commercial Sector. The energy demand in the commercial sector was mainly electricity. Fuel oil was consumed in small proportion for the use in hotels to produce hot water.

The agricultural and commercial sectors were not given a great deal of attention because they contributed much fewer GHGs than other sectors.

Pricing Regulation

The network included 17 pricing nodes to capture the existence of pricing regulations in the oil and electricity sectors. Pricing regulations in the oil sector included, for example, the collection of petroleum taxes on every gallon of petroleum products sold in the market and the collection of import tax on all petroleum products imported. Pricing regulation in the electricity sector was specified at different rates among different end-use sectors.

Conversion, Refinery, and Multiple Input Processes

The network included 54 operational conversion processes (for example, different types of boilers, power plants, transport modes, etc.) to calculate the energy inflows and outflows, and the resultant CO_2 emissions. In addition, 20 dummy conversion processes were added into all links of the final energy demand to calculate CO_2 emissions from energy consumption that did not flow into real conversion processes. The dummy conversion process was assigned to biomass consumption to produce heat and steam in the industrial sector for informational purposes. The emissions from the biomass burning process were discounted from GHG emissions in the energy sector.

Refinery processes refer to the processes that produce more than one output. The network was composed of five refinery processes. These included oil and biomass cogenerations that produced both steam and electricity; gas processing plants that produced processed natural gas, natural gasoline, and LPG; crude oil production from reserves that produced crude oil and associated natural gas; and oil refineries that produced various petroleum products (gasoline, jet fuel, LPG, kerosene, fuel oil, and diesel).

Multiple input processes refer to the processes that can take more than one input to produce one output. There were five multiple input processes in the network. These were the input process to refinery, electricity generation from existing and new plants for base load, and electricity generation from existing and new plants for peak load. The inputs to refinery to produce petroleum products were crude oil and natural gasoline. The electricity generation from existing and new plants for base load was from oil-fired, gas-fired, and coal-fired plants. The electricity generation from existing and new plants for peak load was from diesel and hydropower plants.

The network used 1994 as the base year. The BALANCE module projected energy flows associated with the links of the network until the year 2030. Input data in the form of fuel price projections, final demand projections, and costs and technical data concerning energy resources and conversion activities was required to be fed into the model for use in the module process representations to project future balances.

Projection Methodologies

The BALANCE model requires data on final energy demand (useful energy demand or fuel demand) and energy prices throughout the study periods. The required forecast information on the supply side is the information on energy resource availability in the future for both domestic resources and importation. This information needs to be forecast exogeneously and fed into the model. Based on the resource availability, BALANCE will calculate the mix of energy supply, so as to meet the forecast energy demand. The fuel mix of electricity supply in this study, however, followed the power generation plan of the Electricity Generating Authority of Thailand (EGAT).

Energy Demand

The energy demand entered in the model could be in the form of useful energy demand (in useful energy units) or in the form of fuel demand (in physical units). This study transferred the final energy demand in the residential, transport, and industrial sectors (which were the sectors with a high potential for fuel substitution) from physical units to useful energy units to allow for the possibility of energy substitution. The final energy demand in the agricultural and commercial sectors was in physical units.

Transport Sector. Useful energy demand in the transport sector was divided into passenger and freight demand. Passenger demand was further disaggregated into short-distance and long-distance passenger demand. Passenger demand was forecast in passenger-kilometers (pkm), and freight demand was forecast in tonne-kilometers (tkm). Basically, total demand was forecast as the products of number of vehicles, load factor per vehicle, and travel distances. However, where the data was not available, the demand estimates for some transport modes varied slightly from this basic assumption.

Numbers of taxies, motortricycles, and buses were projected as a function of population. Their travel distances were based on the actual data and were assumed to remain the same throughout the study periods.

Numbers of cars and motorcycles for passenger road demand were forecast by assuming an ownership ratio of vehicles per household. The ownership ratio of cars and their travel distances were assumed to increase over time, whereas the ownership ratio of motorcycles and their travel distances were assumed to decrease over time. This was justified by the reason that people who rode motorcycles were in a lower-income class, and they could not afford to buy cars. As the economy grew and per capita income increased, cars would become more affordable. More people would buy cars including the people who previously rode motorcycles. The number of cars per household was thus expected to increase, while that of motorcycles was expected to decline. In addition, in the future, when the road system was improved, many people would drive further to work and would travel more for pleasure. In contrast, people who used to ride their motorcycles routinely to work would only use the motorcycles for short distances, such as, on the weekend or for business around their neighborhood.

Electric trains were assumed to begin operations in the year 2000 with electricity supplied from power plants. The study assumed that electric train passengers were previous car and bus passengers. Total electric train demand was composed of a 10 percent shift from car passenger demand and a 5 percent shift from bus passenger demand.

Passenger rail and air demand was projected by assuming that their growth rates were a function of population's growth rates.

Passenger ship demand was estimated as a product of the number of ships, load factors, and travel distances. The number of ships was estimated as a function of population. The travel distances were estimated from distances traveled per trip, number of trips per day, and traveling speeds.

Freight road (truck) demand and freight ship demand were forecast by first projecting the numbers of trucks and ships; second, assuming the average maximum load for each type of truck and ship; and, third, averaging their travel distances per year. By multiplying these together, freight road and freight ship demands in units of tonne-kilometer were obtained. The numbers of trucks and ships were estimated as a function of GDP per capita from the industrial and agricultural sectors.

Freight rail demand and freight air demand were estimated by assuming that their growths were a function of growth in GDP from the industrial and agricultural sectors.

Industrial Sector. Energy demand in the industrial sector was estimated using an end-use model that detailed energy end-uses in eleven industrial sub-sectors: food and beverage, textiles, wood and furniture, paper, chemicals, non-metal (excluding cement industry), cement industry, basic metal, fabricated metal, mining, and others. Useful energy demand in these industrial sub-sectors was disaggregated into fuel demand to produce heat, steam, and energy for mechanical use; electricity demand to produce heat, and for mechanical use; and fuel demand in the cement industry. Total useful energy demand in each category was the sum of the demand of each industrial sub-sector in that category. Energy demand in each industrial sub-sector was, in turn, the product of the GDP from that sub-sector and the specific energy intensities of each type of energy equipment or device used in each end-use activity.

Commercial Sector. The electricity demand in the commercial sector was forecast by considering the energy needed in different building types, with no distinction between new and existing commercial buildings. The building types were office, retail store, education, hotel, hospital, and others. Energy consumption in different building types depended on floor space and energy intensity. Existing floor space was estimated from total energy consumption by building type and energy intensity of the whole building. Floor space growth was assumed to be a function of GDP growth. The relationship was developed by building type and the closest matching GDP sub-category in the service sector. Total floor space was thus the summation of existing floor space plus floor space growth. Current energy intensities for offices, hotels, and retail stores were derived through simulation analysis. The energy intensities for hospitals were assumed to closely match those for hotels. The energy intensities for education and other buildings were based on audits and estimates by other studies. The demand for fuel oil in the commercial sector was assumed to increase over time, but at declining growth rates.

Residential Sector. The energy demand in the residential sector was estimated in the form of useful energy using a detailed end-use model, and based on household areas (that is, the households residing in the Metropolitan Areas and those in the Provincial Areas), income classes, dwelling types, end-uses, and devices. Factors such as average number of appliances per household in each income class and appliance saturation rates were taken into account in the forecast.

Agricultural Sector. Energy demand in the agricultural sector was not estimated in the form of useful energy demand, but by assuming growth rates in final demand for each fuel including fuel oil, diesel, LPG, gasoline, kerosene, and electricity. LPG and fuel oil consumption was assumed to have zero growth rates in later years. Their uses were expected to be replaced by other fuels.

Resource Supply

Domestic energy reserves were assumed to remain at the level currently estimated by the government with no new energy discoveries expected in the foreseeable future. Energy imports were assumed unlimited, except for the import of natural gas and LNG that had some limitation as projected by EGAT. Petroleum imports were assumed to be available in unlimited amounts. However, imports were only utilized to make up for the supply shortage from the domestic refineries.

Prices

The study assumed stable energy prices during the study periods. The future energy prices assumed in the model were basically adopted from the published forecasts from other sources up to the years that the data was available, and assumed some certain annual growth rate after that. For example, the forecast of gas, coal, and LNG prices up to 2011 followed the fuel prices forecasts from EGAT, and the forecast of imported crude up to 2015 came from the U.S. Department of Energy. The average growth rates of these prices beyond the year 2011 and 2015 were assumed to be in the range of 1 percent to 1.5 percent per annum for coal and crude oil, and 1 percent to 2 percent for gas and LNG. Domestic crude was assumed to increase at the same growth rates as imported crude.

Renewable Energy in the Thailand ENPEP Model

The renewable energy resources included in the network were hydro resources and biomass.

Biomass Resources

Biomass included fuel wood, paddy husk, bagasse, and charcoal. Biomass supply in the economy included domestic biomass plus import and minus export. Biomass was used in the residential sector for cooking, and in the industrial sector in cogeneration processes (to produce steam and electricity) and for steam and heat production (See Figure 3.1).

In 1994 Thailand consumed biomass at 83,920 KBOE for which 55,443 KBOE, or about 66 percent of the total biomass consumption, was consumed in the residential sector and the rest, 28,477 KBOE was used in the industrial sector. Only a small amount of biomass (mainly charcoal) was exported and imported each year. The assumptions regarding biomass resources in the Base Case scenario are listed below.

- Future biomass production continued to increase at the same rate as the historical trend, which was about 1.2 percent per year. Biomass import was assumed to continue at an increasing rate of 0.1 percent per year. Total biomass supply in the economy (domestic production plus import) was thus estimated to be 86,171 KBOE in 1995, 87,116 KBOE in 2000, 95,440 KBOE in 2010, 105,776 KBOE in 2020, and 121,920 KBOE in 2030. Only a small amount of total biomass supply was exported. The rest of the biomass supply would be divided between the uses in the residential and industrial sectors.

- Real price of biomass from domestic source was treated constant at $5.6/BOE.

- In 1994 about 102.41 KBOE of biomass was imported at price $5.6/BOE. Biomass could be imported to fill in the shortage of the domestic supply from demand. The maximum import availability was 120 KBOE/year. The imported price was assumed to increase at 0.1 percent per year.

- The allocation of total biomass supply (domestic production plus import) in the base year was: 66 percent for cooking demand in the residential sector, 3.6 percent as input into cogeneration process, 27.5 percent for steam demand, 2.8 percent for heat demand, and 0.1 percent for export. Besides cogeneration process and steam demand, the shares of biomass supply to other end-use demand were assumed to remain constant through the study periods. It was assumed that biomass cogeneration processes would be used more in the future, and thus more of the steam demand would be met by the stream supply from a biomass cogeneration process (that produced electricity and stream) and less from a conversion process (that produced only stream). Therefore, the allocation of biomass supply in the future was assumed to increase for cogeneration processes and decrease for the conversion processes that produced stream only.

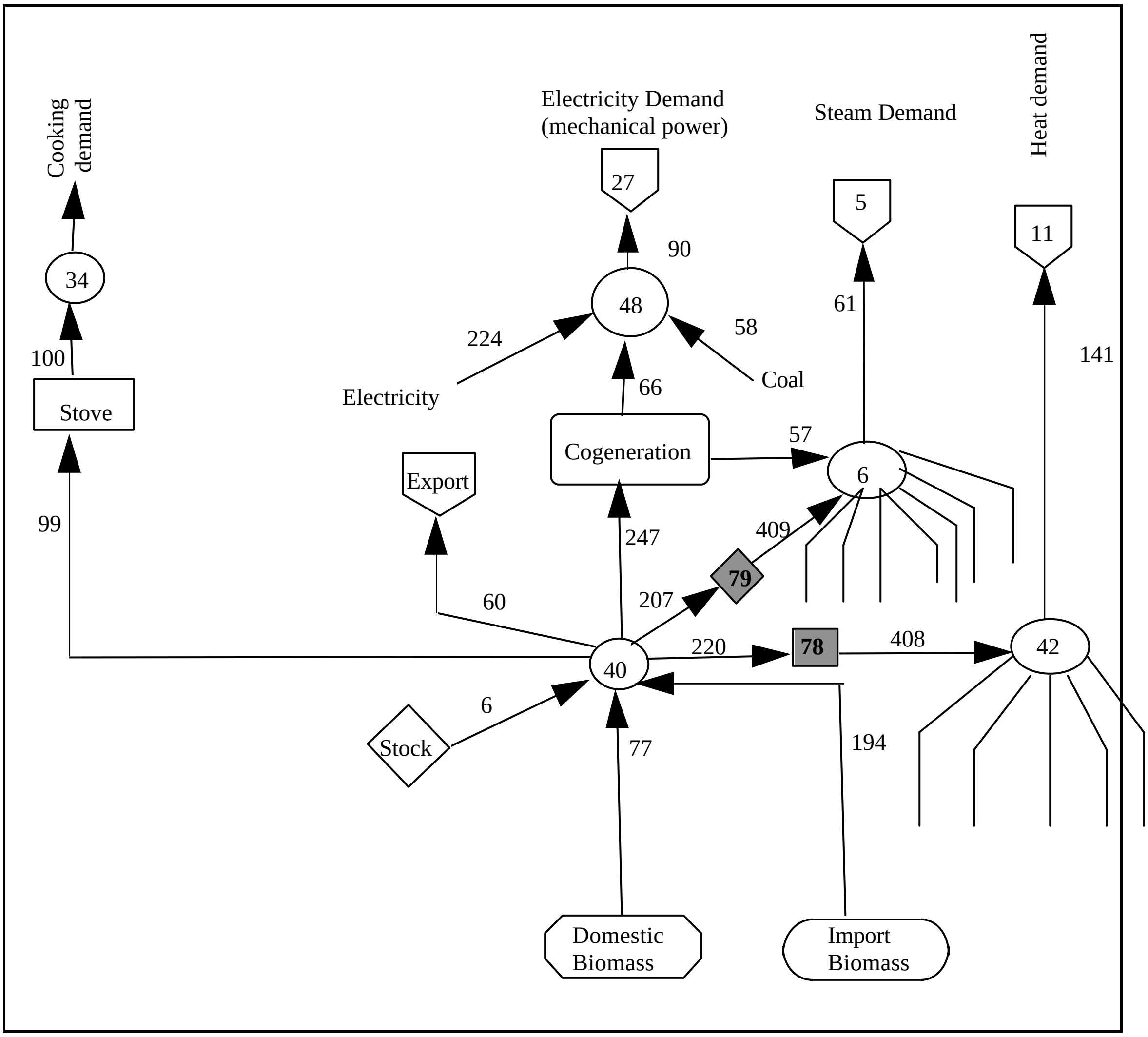

Figure 3.1: Biomass Resources in the Thailand Energy Network

- The conversion process data for biomass stove was:
  - Efficiency (output/input ratio) 0.2
  - O&M cost 0 $/BOE
  - Total capital investment 0.002 thousand $
  - Capacity of a single plant 1 KBOE/year
  - Capacity factor 1
  - Life expectancy 1 year
  - Interest rate fraction 0.1
  - Capacity of all plants unlimited

- The multiple-output-link process data for biomass cogeneration included:
  - Output links to two allocation nodes: electricity demand (mechanical power) and steam demand at the ratio of 0.435 : 0.565
  - O&M cost 2.48 $/BOE input
  - Total capital investment 2424 thousand $
  - Capacity of a single plant 98 KBOE input /year
  - Capacity factor 0.8
  - Life expectancy 30 year

- Interest rate fraction 0.1
- Capacity of all plants 3047.9 KBOE

Capacity of all plants was assumed to expand to 6200.1 KBOE by 2000

- Price sensitivity for heat demand was assumed at 6.4, and that for steam demand cogeneration and electricity demand cogeneration was assumed at 7. The mid-range price sensitivity means that market shares respond to price change to a medium degree (not insensitive and not extremely sensitive).

- Lag parameter for heat demand, cogeneration for steam demand, and cogeneration for electricity demand was specified at 0.05. Lag parameter at 0.05 means the solution for each year is composed of 5 percent of quantities based on new market shares and 95 percent based on old market shares.

- Premium multiplier for cogeneration for electricity demand was assigned to be one. Premium multiplier for heat demand and cogeneration for steam demand was assigned at high number. The premium multiplier equal to one means that the market share is based on fuel price only. If the premium multiplier is greater than one, it means that there are other factors determining market shares besides price factors.

- Proportion of cooking demand satisfied by biomass was determined exogeneously. It was assumed that the proportion of biomass in total cooking demand gradually decreased from about 68 percent in 1994 to the maximum of about 63 percent in 2000, 62 percent in 2010, 57 percent in 2020, and 51 percent in 2030. The quantities consumed were calculated and entered into the model using a feature called capacitated link to control the upper limits on the flow.

Hydro Resources

In 1994, hydropower in Thailand was 4,514 GWh, or 6.3 percent of total generation of 77,212 GWh. Hydro resources were used for power generation to serve peak load demand. The other plants to serve peak load demand were diesel plants. The study separated existing plants with new plants, to allow a retirement of old plants and a higher efficiency of new plants (see Figure 3.2).

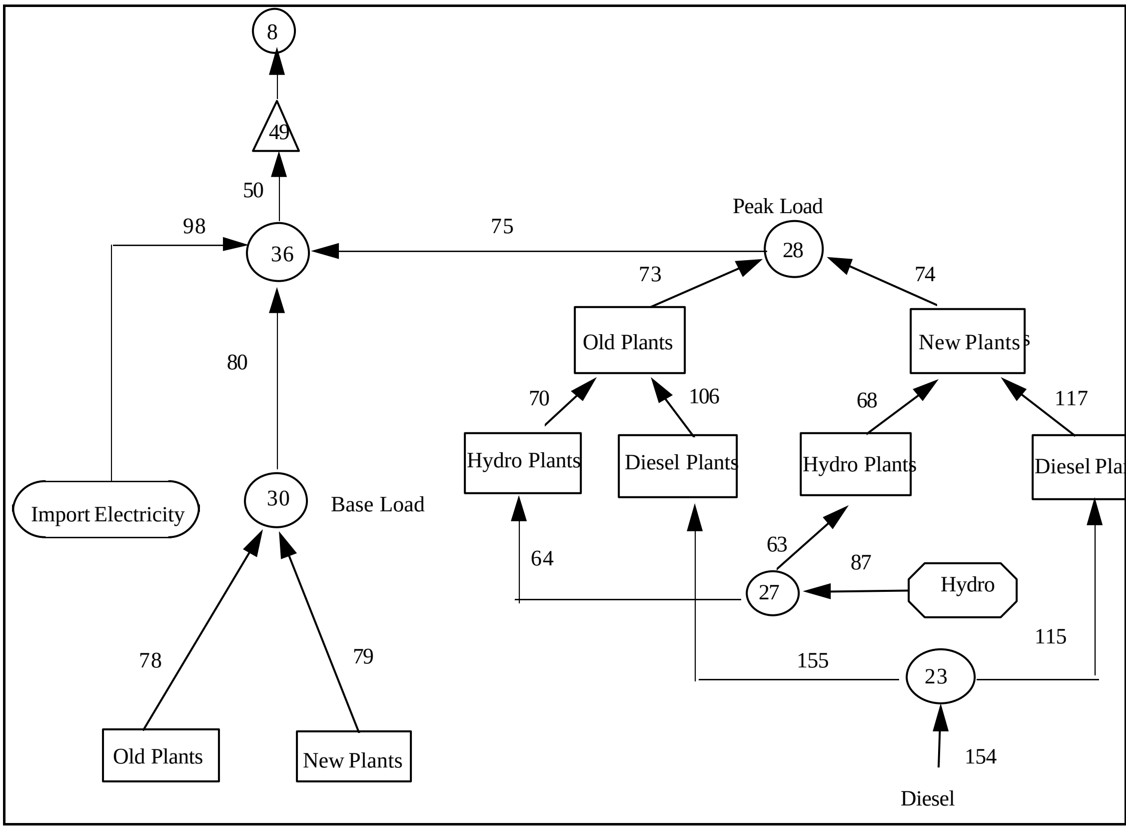

Figure 3.2: Hydro Resources in the Thailand Energy Network

For the power sector, the study followed the EGAT plan on the fuel mix. The additional data required to run the model (for example, capital, fuel, O&M cost) was based on EGAT's data. Additional assumptions required by the model are listed below.

- Assumptions regarding the conversion process for old hydro plants were:
  - Efficiency (output/input ratio) 1
  - O&M cost 107.5 $/BOE
  - Total capital investment 0 thousand $
  - Capacity of a single plant 262 KBOE/year
  - Capacity factor 0.24
  - Life expectancy 50 year
  - Interest rate fraction 0.1
  - Capacity of all plants 3418.6 KBOE/year

- Assumptions regarding the conversion process for new hydro plants, which were pumped storage, were:
  - Efficiency (output/input ratio) 0.75
  - O&M cost 111.7 $/BOE
  - Total capital investment 0 thousand $
  - Capacity of a single plant 150.6 KBOE/year
  - Capacity factor 0.12
  - Life expectancy 25 year
  - Interest rate fraction 0.1
  - Capacity of all plants unlimited

- Total capital investment for both old hydro and new hydro plants was equal to zero, because it was levelized over the life expectancy of the plants and added into O&M cost, which was the format used by EGAT.

- The retirement schedule for the existing plants was based on the economic lifetime of power plants, which were 50 years for hydropower and 25 years for pumped storage hydro. The capacity factor of a hydropower plant was assumed to be 24 percent.

Key Determinants of Renewable Energy Penetration in Thailand

Biomass

The prime determinant of biomass penetration in the end-use sector in Thailand's model was its cost (cost of obtaining biomass plus other costs to bring energy to meet final demand, such as, cost of device, O&M cost, etc.) relative to the costs of its fuel competitors. The cost of energy from biomass was cheaper than other fuels. Therefore, if cost of energy was the only factor determining energy consumption, biomass would be the sole option selected to meet final demand in all applications where it competed with other fuels. However, in Thailand's model, the penetration of biomass in the end-use sectors was limited by the annual availability of supply. The study used an ad hoc assumption on future biomass supply. It was assumed that future biomass supply would increase at the historical trend. The growth rate of future biomass supply (domestic production plus import) was thus low (varying between 1 percent to 1.5 percent per annum).

All biomass available in the market would be totally consumed. The allocation of total biomass available each year among end-uses (cooking, industrial electricity demand, industrial steam demand, and industrial heat demand) depended on its competition with other fuels, which was determined in BALANCE by the values of price sensitivity, lag parameter, and premium multiplier.

For industrial steam demand, industrial electricity demand and industrial heat demand, the study assumed mid-range price sensitivity and low lag parameter. This means that price (or cost) was an important factor in determining market shares of fuels in those end uses, but the response of a fuel consumption to its price change was medium (not insensitive and not extremely sensitive). In addition, a change in market shares of those end uses responded very slowly to a change in relative prices of fuels. For example, if relative price of biomass to fuel oil was lower, the substitution of biomass for fuel oil would not complete in one year but would occur gradually each year.

The market shares among fuels for industrial electricity demand (biomass for cogeneration, coal for cogeneration, and electricity from utility grid) depended on prices, whereas the market shares among fuels for industrial heat demand (biomass, fuel oil, kerosene, natural gas, LPG, and coal), and the market shares among fuels for industrial steam demand (biomass for cogeneration, biomass for a conversion process, diesel, kerosene, fuel oil, LPG, coal, and natural gas) were assumed to depend on other factors besides prices.

Those factors were not identified individually in the model, but their combined effects were captured by using a premium multiplier to weigh the effects of prices.

The proportion of biomass for cooking in total cooking demand was estimated exogeneously and entered into the model. The penetration rate was assumed to become lower gradually over the study periods.

The results from the study showed that biomass was consumed more in absolute terms, but proportionally less as compared to other competitive fuels, for cooking and heat demand. However, the shares of biomass used in the cogeneration process for steam and electricity increased over time. Table 3.2 shows the quantities of biomass consumption in the industrial and residential sectors in the Base Case scenario. Biomass was forecast to be used more in the industrial sector and less in the residential sector.

Table 3.2: Biomass Consumption in Thailand in the Base Case Scenario (1994-2030)

Unit: KBOE

Sector	1994	1995	2000	2010	2020	2030
Industrial	28,477	29,212	29,395	34,571	47,651	69,526
For Cogeneration	3,024	3,102	4,243	6,235	15,729	33,563
For Steam	23,101	23,697	22,591	25,451	28,672	32,301
For Heat	2,352	2,413	2,561	2,885	3,250	3,662
Residential	55,443	56,874	57,636	60,785	58,040	52,310
Total	**83,920**	**86,086**	**87,031**	**95,356**	**105,691**	**121,566**

In the mitigation scenario, an increase in renewable energy consumption was one of the options to reduce GHG emissions in the industrial sector. It was assumed that an additional 20 percent of future steam demand would be obtained from the cogeneration process which used biomass as a fuel, and that biomass input mainly came from the inefficient, traditional use in which the biomass was burned directly, such as in boiler for steam production. The results from the sensitivity analysis showed that this option could lower fuel consumption by about 12,206 KBOE in 2000 and 51,705 KBOE in 2030 and could reduce CO_2 emissions 7.39 million tonnes in 2000 and 40.35 million tonnes in 2030.

Hydro Resources

Electricity generation was projected to increase from 71,212 GWh in 1994 to 257,436 GWh in 2010, and 620,843 GWh in 2030—or at an average of 8.4 percent per annum during 1994-2010 and 4.5 percent during 2010-2030. In the Base Case scenario, generation from hydro resources was projected to be 8,657 GWh in 2010 and 15,679 GWh in 2030 (see Table 3.3). This projection was based on the estimated fuel mix of EGAT.

Table 3.3: Electricity Generation in Thailand in the Base Case Scenario (1994-2030)

Unit: GWh

	1994	1995	2000	2010	2020	2030
Coal	14,106	15,766	17,714	102,276	161,653	246,628
Fuel Oil	19,579	22,778	21,358	52,803	106,454	150,382
Natural gas	31,536	33,881	79,839	93,045	136,822	206,729
Diesel	1,477	2,111	319	655	791	1,425
Hydro	4,514	4,544	4,782	8,657	10,724	15,679
Total	**71,212**	**79,080**	**124,012**	**257,436**	**416,444**	**620,843**

Hydropower was not included as an option for GHG mitigation options, due to the limitation of hydro resources in Thailand.

3.2 INDONESIA[2]

The case study for the MARKAL model was taken from the Indonesian project called *Environmental Impacts of Energy Strategies for Indonesia*.[3] The project was known as the Indonesian-German MARKAL Project 1993. It aimed to develop proposals for environmentally compatible energy supply strategies for the next 30 years, based on air quality forecasts and risk assessments for ecosystems and human health.

Energy Sector Overview[4]

Indonesia is well endowed with various energy sources including both fossil and renewable energy (see Table 3.4). In 1990, estimates showed crude oil reserves at 10.7 billion barrels, natural gas reserves at 102 trillion cubic feet, and coal reserves at 34.3 billion tonnes.

Table 3.4: Energy Reserves and Utilization in Indonesia in 1990

	Oil (10^9 Barrels)	Gas (10^{12} scf)	Coal (10^9 t)	Hydropower (GW)	Geothermal (GW)
Proven reserves	5.3	64	4.8	75	16
Potential reserves	5.4	38	29.5	-	-
Total reserves	10.7	102	34.3	75	16
Production	0.47[a/]	2.1	0.01	-	-
Installation	-	-	-	2.2	0.17

Note: [a/] exclude condensate

Source: *Environmental Impacts of Energy Strategies for Indonesia*, May 1993.

Indonesia has a large hydropower potential of 75 GW, of which only 3.2 GW was used in 1990. However, most of the reserves are located in thinly populated areas, where the demand is too low to justify large-scale hydropower investment.

Total geothermal potential was estimated in 1990 at 16 GW, for which nearly half of the reserves were located in Jawa and Bali. In 1990, only 0.17 GW of geothermal energy was used. Additional geothermal plants of 0.22 GW are under development.

The consumption of primary energy in 1991[5] was composed of 41 percent oil, 31 percent biomass, 18 percent natural gas, 6 percent coal, and 4 percent hydropower and geothermal.

In 1991, 1,348 PJ of oil was consumed. At present, Indonesia is a net oil exporter. In 1991, Indonesia produced 3,011 PJ of crude oil and condensate and exported about 1,994 PJ in the form of crude oil and refined products. However, domestic oil production has been declining, and the importation of crude oil and refined products has been increasing. In 1991, about 331 PJ of oil was imported. It was expected that after the year 2005, Indonesia would become a net importer of oil.

Production of natural gas in 1991 was about 1,696 PJ. Over 65 percent of the total production was exported in the form of LNG and LPG, and the rest was consumed domestically for power generation, final use for heat and feedstock, and NGL production. Non-energy uses of natural gas included the fertilizer industry and, to a lesser extent, the steel industry. Small quantities of city gas were consumed by household, commercial, and service sectors. A very small amount was needed to fuel CNG cars.

Coal was mainly produced to satisfy domestic demand. In 1991 Indonesia produced 288 PJ of coal, of which 198 PJ was consumed domestically and 90 PJ was exported. The principal domestic use of coal was for power generation. Coal as final energy was mainly used in the cement industry.

Biomass, in the form of fuel wood and bagasse, was the principal renewable energy resources used in Indonesia. In 1991, it accounted for 41 percent of the total final consumption. Households, mainly in rural areas, were the major consumers of biomass. Hydropower and geothermal were the second most important renewable energy sources after biomass, and they are an indispensable source for electricity generation in the future.

Total electricity consumption in 1991 was 51.9 TWh. Of total consumption, about 68.4 percent (or 35.5 TWh) was used in the industrial sector, 31.4 percent (or 16.3 TWh) was used in the household sector, and the remaining 0.2 percent (or 0.1 TWh) was used in the transport sector. The fuel mix for power generation in 1991 was 32 percent from fuel oil, 28 percent from coal, 18 percent from hydro and geothermal, 14 percent from automotive and industrial diesel oil, and 7 percent from gas.

The household sector, which included minor sub-sectors such as government and commerce, was the largest final energy consumer. Of total final consumption, the household sector accounted for 46 percent, the transport sector for 22 percent and the industrial sector for 32 percent.[6] The principal fuel used in the household sector was biomass, which was to satisfy cooking demand in the rural area. Gasoline and diesel oil accounted for more than 85 percent of the energy consumption in the transport sector.

About 56 percent of total final energy consumption was consumed in Jawa in 1991 (1,375 PJ). Final energy consumption in Sumatra was 556 PJ, Kalimantan was 215 PJ, and Other Islands consumed 277 PJ. The shares of each region were not expected to change significantly within the next three decades.

Model Framework: MARKAL

The study developed two environmental scenarios called the “Doing Nothing Case” (DNC) and the “Emission Reduction Case” (ERC). The DNC assumed that hardly any significant measures would be taken to reduce emissions in the future. The ERC assumed that significant steps were taken within the next 10 years to reduce air pollution. The DNC was to demonstrate that Jawa would run into severe environmental problems if no significant efforts were made in the future to reduce air pollution. The ERC was to develop proposals for environmentally compatible energy supply strategies for Indonesia in order to support decision-makers. However, the study only reported the results of the energy supply for the ERC. The reason given was that the optimized energy supply only differed marginally between the two cases, due to the resource constraints in Indonesia. Since Indonesia had abundant coal resources, coal was the most important supply option for both the DNC and the ERC.

MARKAL was used to optimize the future energy supply (minimize the costs for the supply of clean energy in Jawa and regular energy in outside Jawa) under the condition of reduced specific emissions according to the improved standards chosen for the ERC. The MARKAL model supplied the future technology and energy mix with the related costs as well as the development of the total emissions for the transition from the DNC to the ERC. The model also accounted for the amount of CO_2 released.

The Indonesian MARKAL model was developed in great detail. The study separated the economy into four geographical areas—Jawa, Sumatra, Kalimantan, and Other Islands. The main components of the model are summarized as follows:

Fossil Energy Carriers

The fossil energy resources used in the model were coal, oil, gas, and petroleum products. These were separated into 143 different fossil energy carriers. For example, coal was separated into the different types of coal (antracite, sub-bituminous, and lignite), different fields (for example, Banko, Muaratiga, and Ombilin), and different areas (for example, coal from Kalimantan to Jawa, and coal from Sumatra to Jawa). Natural gas in Jawa was separated into the production from existing fields, medium cost fields, and high cost fields. Oil, gas, and petroleum products in each area were also classified as different energy carriers.

Technologies

The model included 268 process technologies. Most of the technologies included in the model were being utilized while others had the potential to be adopted in the future. The study treated each refinery process separately (for example, atmospheric distillation, visbreaker, vacuum distillation unit, etc.). Process technologies also included transportation from one area to another, and pipelines (for example, crude tanker, coal vessel, petroleum product tanker, crude pipeline, natural gas pipeline, and pipeline for petroleum products). Each process technology for each of the four areas was entered in the model separately. For example, the model included four process technologies called “city gas distribution”, of which there was one for Jawa, one for Kalimantan, one for Sumatra, and one for Other Islands. Of total process technologies, 16 were related to renewable energy technologies.

There were 38 conversion technologies, for which 31 were categorized as centralized conversion technologies and 7 were decentralized conversion technologies. Of total conversion technologies, 10 were renewable energy technologies. All conversion technologies were for electricity generation in Jawa. Due to its geographical condition as an island-based economy, the electricity generation for each island was defined in separate grids. Since at the time of this study, MARKAL did not support multiple electricity grids, not all four areas could include electricity generation under conversion technologies. Because most of the energy consumption in Indonesia was in Jawa, the study chose to model electricity for Jawa as conversion technologies. Electricity generation outside Jawa (Kalimantan, Sumatra, and Other Islands) was treated as regular energy without grid connection and included in the model as process technologies.

A total of 173 demand technologies were included in the model, classified as 88 industrial technologies, 40 residential technologies, 41 transport technologies and 4 industrial/transport feedstock and lube technologies. Of the total demand technologies, 14 were renewable energy technologies.

End-Use Sectors

End-use sectors were separated into household, industrial, and transport sectors.

Household Sector. The household sector included commerce and services. Energy input to the household sector came from biomass, kerosene, LPG, natural gas, and electricity to satisfy six end-uses: cooking, lighting, commercial indirect heat, demand for commercial electric drives, demand for electric appliances, and demand for government and public uses. Biomass, electricity, natural gas, LPG, and kerosene were used for cooking. Electricity and kerosene were used for lighting. Kerosene, LPG, natural gas, and diesel were used for commercial indirect heat production, while electricity was utilized for electrical appliances, commercial electric drives, and government and public uses.

Industrial Sector. The industrial sector was composed of three sub-sectors—the manufacturing industry, the non-energy mining industry, and the agricultural sub-sector. Energy resources consumed in the industrial sector were biomass, electricity, natural gas, coal, coke, diesel, fuel oil, LPG, and kerosene. The energy demand in the industrial sector was disaggregated into seven end-uses—indirect heat production (including biomass boilers), direct heat production (including biomass burners), electric drives, fertilizer, basic metal, cement, and non-ferrous metal industries. Fuels for direct and indirect heat production were coal, coke, biomass, diesel, fuel oil, kerosene, LPG, electricity, and natural gas. Fuels used in the fertilizer industry were electricity, fuel oil, diesel, and gas. Fuels used in the basic metal industry were coal, electricity, fuel oil, and gas. Fuels used in the cement industry included coal, electricity, fuel oil, diesel, and gas. Fuels used for non-ferrous industry were coal, electricity, fuel oil, gasoline, and diesel.

Transport Sector. Energy consumed in the transport sector included diesel, gasoline, LPG, fuel oil, CNG, electricity, and kerosene. The end-use demand in the transport sector was classified as the following: small transport and bus (using gasoline, diesel, and LPG), other road transport mix (using gasoline and diesel), cars (using gasoline, LPG, diesel, and CNG), and mixed transport of air, sea, and rail (using coal, electricity, fuel oil, gasoline, kerosene, and diesel).

The study used 1991 (the average of the Fifth Five-Year Development Plan, 1989-1993) as the base year, and the forecast was made until the year 2021 (the average of the Eleventh Five-Year Development Plan, 2019-2023).

Projection Methodologies

The projection of energy demand, resource supply, energy prices, and macroeconomic variables was based on the assumed growth rates. There was no further explanation on how those assumed growth rates were derived.

An additional statement made concerning energy demand was that it was estimated using the DEMI model in the forms of useful energy and final energy. The demand forecast in terms of final energy was made only if either the use of a certain energy resource was prescribed (such as the use of coal by the cement industry) or if a certain energy resource was likely to be the only attractive option (such as the case of electricity). The demand projection was separated into four areas of Indonesia—Jawa, Sumatra, Kalimantan, and Other Islands, and it covered all energy-consuming sectors. There was no explanation on projection methodology for energy demand.

The study mentioned that the macroeconomic parameters (for example, gross domestic products, industrial production, etc.) were projected using the computer program MACRO. Two scenarios were developed—high scenario and low scenario. The high scenario (which assumed 6 percent per annum growth rate of GDP) was utilized as the reference scenario in the study.

Population was forecast by regions and urban/rural areas, by assuming values at the end of the year 2023. The linear interpolation of the population growth rate was then applied to calculate the population number for the study periods—1991-2021.

Renewable Energy in the Indonesia MARKAL Model

The renewable energy resources included in the model were biomass, hydropower, and geothermal. The list of renewable energy technologies in the model is shown in Table 3.5. All tables describing model assumptions and attributes shown in this section were taken from an examination of the model data set, since the information was not available in the written report.

Biomass

Biomass was used to satisfy final demand in the household and industrial sectors. Biomass consumption in the household sector was for cooking, and in the industrial sector was for indirect heat production (using biomass boilers) and direct heat production (using biomass burners). Biomass was also used as a fuel for power generation. Figure 3.3 shows an example of a biomass consumption diagram from the Indonesia MARKAL model.[7] The diagram shown was for Kalimantan. However, the pattern of use was the same for Sumatra, and the Other Islands. A similar diagram was made in the model for Jawa, with the exception that Jawa's biomass boilers and burners, and power plants were disaggregated into existing and new plants.

Table 3.5: Renewable Energy Technologies Included in the Indonesia MARKAL Model

<u>Process Technologies</u>	
Existing Hydro Plants (Kalimantan)	Minihydro, ≤1.5 MW (Kalimantan)
Existing Hydro Plants (Sumatra)	Minihydro, ≤ 1.5 MW (Sumatra)
Existing Hydro Plants (Other Islands)	Minihydro, ≤1.5 MW (Other Islands)
Option A Hydro Plants (Kalimantan)	
Option A Hydro Plants (Sumatra)	Biomass Steam Power Plants (Kalimantan)
Option A Hydro Plants (Other Islands)	Biomass Steam Power Plants (Sumatra)
Option B Hydro Plants (Sumatra)	Biomass Steam Power Plants (Other Islands)
Option B Hydro Plants (Other Islands)	
Geothermal Power Plants (Sumatra)	
Geothermal Power Plants (Other Islands)	
<u>Conversion Technologies</u>	
Centralized Conversion Technologies	***Decentralized Conversion Technologies***
Geothermal Power Plants (Jawa)	Minihydro, ≤1.5 MW (Jawa)
Existing Hydro Power Plants (West Jawa)	Biomass Steam Power Plants (Jawa)
Option A Hydro Power Plants (West Jawa)	New Biomass Steam Power Plants (Jawa)[1/]
Option B Hydro Power Plants (West Jawa)	
Existing Hydro Power Plants (Central/East Jawa)	
Option A Hydro Power Plants (Central/East Jawa)	
Option B Hydro Power Plants (Central/East Jawa)	
<u>Demand Technologies</u>	
Industrial Sector	***Residential Sector***
Indirect Heat, Biomass (Jawa)	Biomass Stove (Jawa)
Indirect Heat, Biomass (Kalimantan)	Biomass Stove (Kalimantan)
Indirect Heat, Biomass (Sumatra)	Biomass Stove (Sumatra)
Indirect Heat, Biomass (Other Islands)	Biomass Stove (Other Islands)
New Indirect Heat, Biomass (Jawa) [1/]	
Direct Heat, Biomass (Jawa)	
Direct Heat, Biomass (Kalimantan)	
Direct Heat, Biomass (Sumatra)	
Direct Heat, Biomass (Other Islands)	
New Direct Heat, Biomass (Jawa) [1/]	

Notes: The information in this table was taken from an examination of the model data set.
[1/]New technology adopted air pollution emission measures for dust, SOx and NOx.

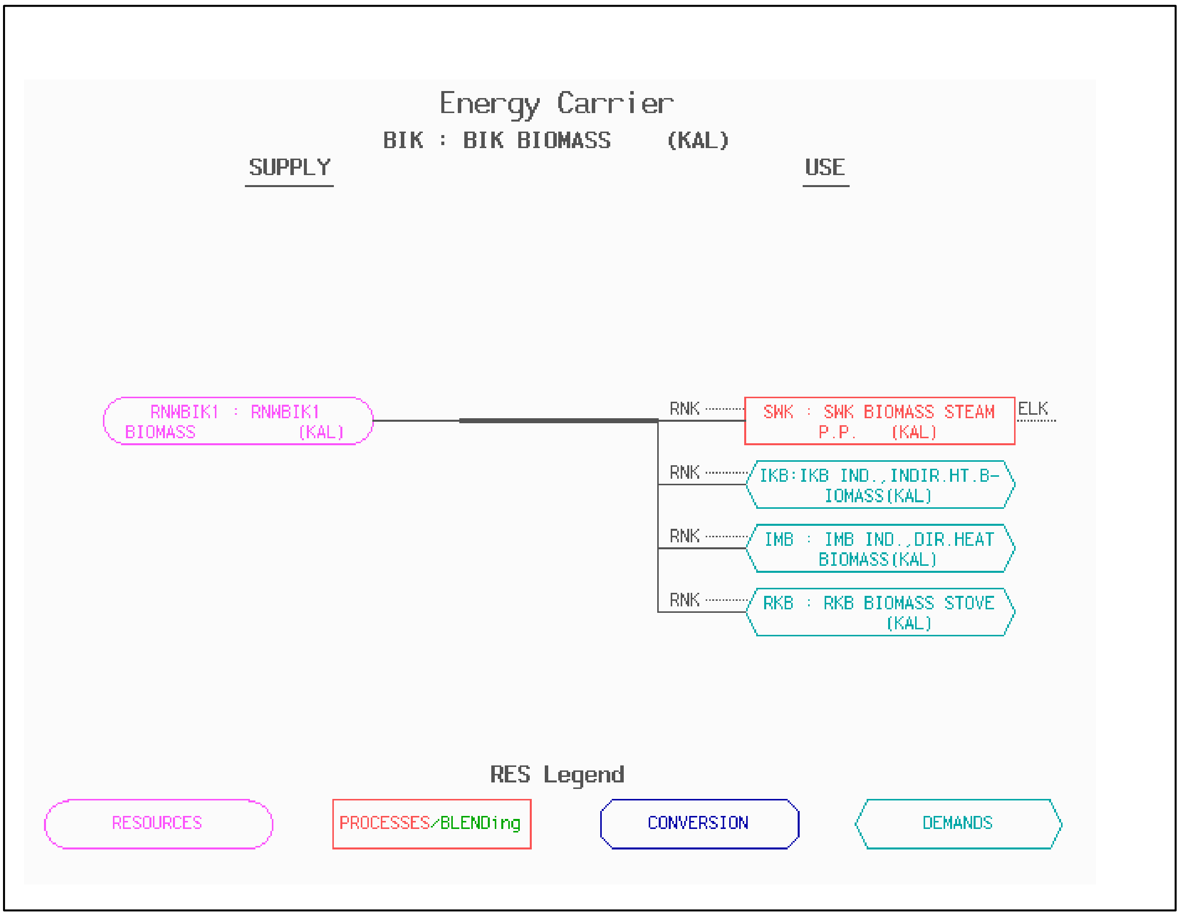

Figure 3.3: Biomass Consumption in the Indonesia MARKAL Model (Kalimantan)

Biomass resources in Kalimantan, Sumatra, and Other Islands were assumed to cost the same at $0.57 million per PJ. In Jawa, biomass was separated into firewood and agricultural waste, both of which cost $0.85 million per PJ. Biomass costs in all areas were assumed to remain constant throughout the study periods. The availability of biomass in Jawa and Sumatra was constrained to some upper limits, but there was no upper limit on the availability of biomass in Kalimantan and Other Islands (see Table 3.6).

Table 3.6: Assumptions for the Maximum Availability of Biomass in Indonesia

Unit: PJ

	1991	1996	2001	2006	2011	2016	2021
Jawa							
-Firewood	600	630	660	700	730	770	810
-Agricultural wastes	100	110	122	135	150	165	180
Sumatra	230	266	309	358	415	482	558

Biomass in the Household Sector. Biomass in the household sector was used for cooking. In all areas, the efficiency of biomass stoves was assumed to be 0.125. The total amount of biomass for cooking in Jawa was assumed not to increase from the base-year quantities, but on most of the outer islands (where biomass was available), the use of wood was assumed to grow further. The study also assumed the quantities of pre-existing installed capacity before the modeling time (see Table 3.7).

Table 3.7: Assumptions for Biomass Consumption in the Household Sector in Indonesia

Unit: PJ

	1991	1996	2001	2006	2011	2016	2021
Residual Installed Capacity[1/]							
Jawa	48.5	13.4					
Kalimantan	4.3	1.2					
Sumatra	16.3	4.7					
Other Islands	13.7	2.7					
Maximum Capacity							
Jawa	72.8	72.8	72.8	72.8	72.8	72.8	72.8
Kalimantan	8.1	9.4	10.9	12.6	14.7	16.9	19.4
Sumatra	32.1	37.8	44.4	50.5	55.8	62.5	70.0
Other Islands	21.9	24.4	27.2	30.3	33.8	37.9	42.4

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Biomass in the Industrial Sector. Biomass consumption in the industrial sector was for heat production by using biomass boilers and burners. For biomass boilers, it was assumed for all areas that the total cost of one unit was $37.5 million per PJ, with an annual fixed O&M cost per unit at $3.9 million per PJ. All costs were assumed constant through 2021. The study further assumed that the annual capacity utilization factor of boilers was 82 percent, and that the lifetime was 25 years. An increase in the use of biomass boilers was expected to be slower in Jawa than in Kalimantan, Sumatra, and the Other Islands (that is, 3 percent maximum annual growth rate in Jawa and 7 percent maximum annual growth rate in the others).

In addition to the above assumptions, which were the same for all areas, the study included different assumptions among different areas regarding the residual installed capacity and the available capacity (see Table 3.8).

Table 3.8: Assumptions for Biomass Boilers in Indonesia

Unit: PJ

	1991	1996	2001	2006	2011	2016	2021
Energy Efficiency[1/]	0.66	0.69	0.71	0.74	0.77	0.80	0.80
Residual Installed Capacity[2/]							
-- Kalimantan	14.474	9.697	4.8487	0	0	0	0
-- Sumatra	17.299	11.59	5.795	0	0	0	0
-- Other Islands	4.554	3.051	1.526	0	0	0	0
Available Capacity[3/]							
-- Jawa	68.158	79.014	91.599	106.19	123.1	142.71	165.44
-- Kalimantan	14.474						
-- Sumatra	19.0						
-- Other Islands	4.554						

Notes: [1/] The same for all areas
[2/] Refers to pre-existing installed capacity from before the modeling time horizon
[3/] The available capacity in Jawa refers to maximum capacity, while that of the other three areas refers to fixed capacity.

For biomass burners, the study assumed that the total cost of one unit was $6.18 million per PJ, with an annual fixed O&M cost of $0.381 million per PJ. Both costs were assumed to be constant through 2021. The technology lifetime was assumed to be 25 years. The maximum annual growth rate was assumed at different rates among different areas, that is, 10 percent for Sumatra and Other Islands, 7 percent for Kalimantan, 10 percent for Jawa for the periods 1991 and 1996, and 5 percent for Jawa in 2001 and onward. Additional assumptions for biomass burners are as shown in Table 3.9.

For Jawa, the study further assumed that new biomass boilers and burners would be used, beginning in the year 2001. The new boilers and burners were assumed to reach a thermal efficiency of 0.8621, which was higher than the existing ones. Both boilers and burners were assumed to use electricity at a rate of 0.04 percent of total input. The new boilers and burners would pose higher costs than the existing ones. The annual fixed O&M cost was $3.9112 million per PJ for a new boiler, and $3.922 million per PJ for a new burner. The annual variable O&M cost was $0.0053 million per PJ for both new boilers and burners. The capital cost was $38.059 million per PJ for a new boiler, and $6.7359 million per PJ for a new burner. All costs were assumed to remain constant throughout the study periods.

Table 3.9: Assumptions for Biomass Burners in Indonesia

Unit: PJ

	1991	1996	2001	2006	2011	2016	2021
Energy Efficiency[1/]	0.66	0.69	0.71	0.74	0.77	0.80	0.80
Residual Installed Capacity[2/]							
-- Jawa	2.0196	1.3531	0.6766	0	0	0	0
-- Kalimantan	0.4844	0.3272	0.1636	0	0	0	0
-- Sumatra	0.4884	0.3272	0.1636	0	0	0	0
-- Other Islands	0.132	0.088	0.044	0	0	0	0
Available Capacity[3/]							
-- Jawa	5.015	8.077	10.308	13.156	16.791	21.430	27.351
-- Kalimantan	0.4844						
-- Sumatra	0.6349						
-- Other Islands	0.132						

Notes: [1/] The same for all areas
[2/] Refers to pre-existing installed capacity from before the modeling time horizon
[3/] The available capacity in Jawa and Sumatra refers to maximum capacity, while that of Kalimantan and Other Islands referred to fixed capacity.

Biomass for Power Generation. Biomass was used for power generation in all four areas. The assumptions were made differently between the three areas (Kalimantan, Sumatra, and Other Islands), and Jawa. For Kalimantan, Sumatra, and Other Islands, the following assumptions were made throughout the study periods:

- Biomass used per unit of electricity was equal to 4.1061,
- Annual capacity utilization was 0.40,
- Annual fixed O&M cost was $27.388 million per GW,
- Annual variable O&M cost was $1.081 million per PJ,
- Capital cost was $4135.50 million per GW, and
- The technology lifetime was 25 years.

The assumptions regarding residual capacity and capacity constraints were, however, different among the three areas as shown in Table 3.10.

Table 3.10: Assumptions for Biomass for Power Generation in Kalimantan, Sumatra, and Other Islands

Unit: PJ

	1991	1996	2001	2006	2011	2016	2021
Residual Installed Capacity[1/]							
-- Kalimantan	0.0371	0.0297	0.0173	0.0049	0	0	0
-- Sumatra	0.1779	0.1778	0.1423	0.083	0.0237	0	0
-- Other Islands	0.0036	0.0029	0.0017	0.0005	0	0	0
Minimum Capacity							
-- Kalimantan		0.0369	0.0367	0.0365	0.0363	0.0361	0.0359
-- Sumatra		0.1778	0.1757	0.1749	0.1740	0.1731	0.1723
-- Other Islands		0.0036	0.0036	0.0036	0.0035	0.0035	0.0035
Maximum Capacity							
-- Kalimantan		0.1684	0.3532	0.3409	0.3392	0.3376	0.3359
-- Sumatra		0.3122	0.4782	0.4189	0.3912	0.3636	0.3359
-- Other Islands		0.1377	0.3376	0.3364	0.3362	0.3361	03359

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

For Jawa, the biomass steam process for power generation was separated into the existing steam process and the new process. The new biomass steam process was in operation in 1996, with higher efficiency. The biomass used per unit of electricity produced for a new biomass process was 3.2151 as compared to 4.1061 in an existing one. However, a new process incurred higher costs than an existing process. The annual fixed O&M cost of a new process was $28.3642 million per GW, and the annual variable O&M cost was $0.7332 million per PJ.[8] In comparison, the annual fixed O&M cost of an existing process was $27.388 million per GW, and the annual variable O&M cost was $0.7185 million per PJ. The capital cost of a new process was $3,660.49 million per GW, as compared to $3,611.9 million per GW of an existing process. All costs remained constant through the year 2021.

The study also assumed that the existing biomass process in Jawa was bound with a fixed capacity in 1991 at 0.0146 GW, and that the residual installed capacity was 0.0131 PJ in 1991, 0.0094 PJ in 1996, 0.0047 PJ in 2001, 0.0005 PJ in 2006, and 0 since 2011. In both new and existing biomass processes in Jawa, the capacity utilization was assumed to be different during daytime and nighttime. Average use of installed capacity during daytime was 0.5309 and nighttime was 0.4918.

There was no explanation on how to derive these numbers.

Hydro Resources

The study distinquished hydropower plants into existing plants, and new plants that would be operational in the year 2001. The new hydro plants were also separated into “option A” plants and “option B” plants—for which the difference was based on the level of investment requirements for the specific site. That is, Option B required more investment than Option A. Figure 3.4 illustrates a diagram of hydropower process in the model. The diagram shows the case of an existing hydro power plant in Sumatra. The hydropower processes in

Kalimantan and Other Islands were included in the model in a similar manner as that in Sumatra. The hydropower processes in Jawa were designed as a conversion technology and not as a process technology.

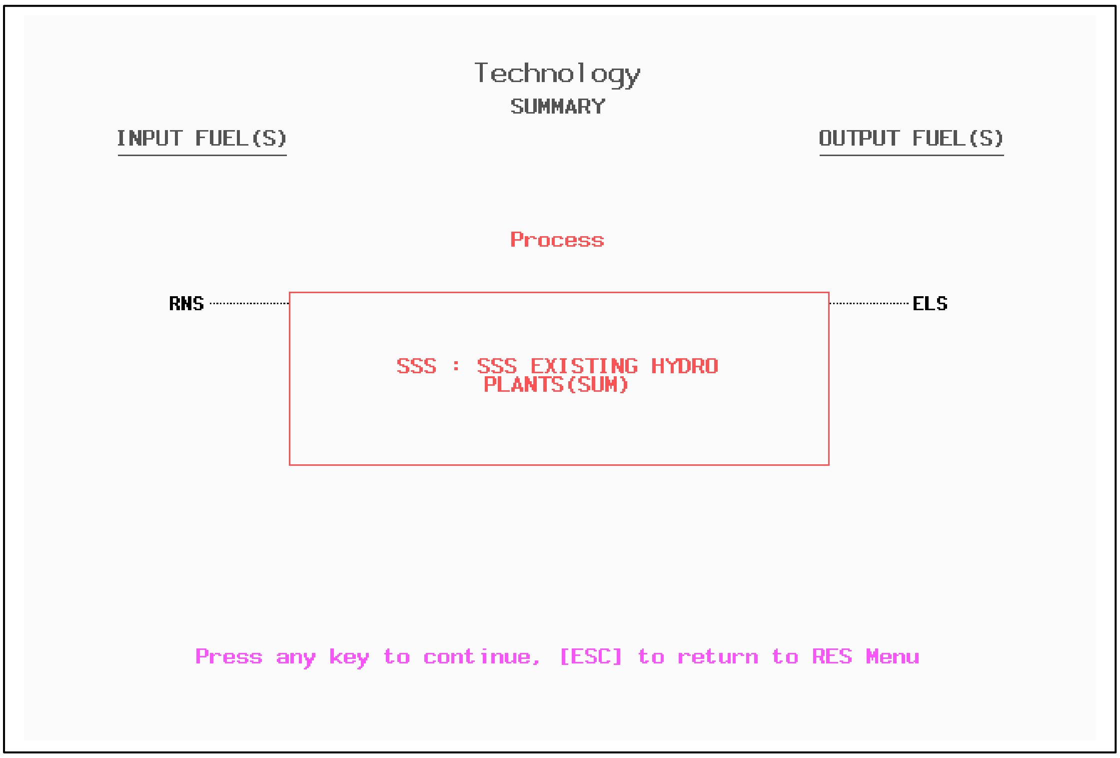

Figure 3.4: Hydropower in the Indonesia MARKAL Model (Sumatra)

Hydropower in Kalimantan, Sumatra, and Other Islands. Both existing plants and new plants in the three areas were assumed to have the same annual variable O&M cost—which was $0.5204 million per PJ, and same fraction of energy input (hydro) per unit of production (electricity)—which was 3.0238. The technology lifetime in all cases was assumed to be 50 years. Annual fixed O&M cost was, however, assumed differently, that is, $20.734 million per GW for Kalimantan, $15.973 million per GW for Sumatra, and $16.231 million per GW for Other Islands. The assumptions that were different among areas and among existing and new plants are as shown in Table 3.11.

Table 3.11: Assumptions for Hydropower in Kalimantan, Sumatra, and Other Islands

	1991	1996	2001	2006	2011	2016	2021
Capacity Utilization Rate							

-Kalimantan							
Existing	0.5175	0.5175	0.7059	0.7059	0.7059	0.7059	0.7059
New—Option A[1/]			0.7059	0.7059	0.7059	0.7059	0.7059
-Sumatra							
Existing	0.7027	0.6449	0.5712	0.5712	0.5712	0.5712	0.5712
New—Option A			0.5712	0.5712	0.5712	0.5712	0.5712
New—Option B			0.5712	0.5712	0.5712	0.5712	0.5712
-Other Islands							
Existing	0.6796	0.6693	0.5727	0.5727	0.5727	0.5727	0.5727
New—Option A			0.5727	0.5727	0.5727	0.5727	0.5727
New—Option B			0.5727	0.5727	0.5727	0.5727	0.5727
Capital Cost ($Million/PJ)							
- Kalimantan							
Existing	4,416	4,416	4,416	4,416	4,416	4,416	4,416
New—Option A[1/]			4,566	4,566	4,566	4,566	4,566
-Sumatra							
Existing	2,881	3,549	3,628	3,628	3,628	3,628	3,628
New—Option A			3,755	3,755	3,755	3,755	3,755
New—Option B			3,905	3,905	3,905	3,905	3,905
-Other Islands							
Existing	2,961	3,934	3,715	3,715	3,715	3,715	3,715
New—Option A			3,799	3,799	3,799	3,799	3,799
New—Option B			3,949	3,949	3,949	3,949	3,949
Residual Installed Capacity (PJ) [2/, 3/]							
-Kalimantan	0.0258						
-Sumatra	0.5874						
-Other Islands	0.1759						
Fixed Capacity Constraint (PJ) [2/]							
-Kalimantan	--	--					
-Sumatra	0.5984	0.9269					
-Other Islands	0.2432	0.3645					
Minimum Capacity Constraint (PJ) [2/]							
-Kalimantan			--	--	--	--	--
-Sumatra			1.4834	1.4834	1.4834	1.4834	1.4834
-Other Islands			0.454	0.454	0.454	0.454	0.454

Table 3.11 (Continued)

	1991	1996	2001	2006	2011	2016	2021
Maximum Capacity Constraint (PJ)							
-Kalimantan							
Existing			0.1098	0.1098	0.1098	0.1098	0.1098

New—Option A[1/]			0.6879	0.6879	0.6879	0.6879	0.6879
-Sumatra							
Existing			2.0156	2.0156	2.0156	2.0156	2.0156
New—Option A			0.6879	0.6879	0.6879	0.6879	0.6879
New—Option B			1.3758	1.3758	1.3758	1.3758	1.3758
-Other Islands							
Existing			0.7588	0.7588	0.7588	0.7588	0.7588
New—Option A			0.6879	0.6879	0.6879	0.6879	0.6879
New—Option B			1.3758	1.3758	1.3758	1.3758	1.3758

Notes: [1/] There was no Option B for Kalimantan.
[2/] Only for existing plants
[3/] Refers to pre-existing installed capacity from before the modeling time horizon

Hydropower in Jawa. The hydro plants in Jawa were separated into the plants in West Jawa, in Central & East Jawa, and mini-hydro (less than 1.5 MW). The separation into West Jawa, and Central & East Jawa was due to the load distribution of the Jawa transmission line. The West part of Jawa (including Jakarta and Bandung) had two-thirds of the total demand. Therefore, the generation in the West Jawa was set to two-thirds of the Jawa system. The hydropower plants in West Jawa and Central & East Jawa were disaggregated into existing plants and new plants (Option A and Option B), which would begin operation in the year 2001. The mini-hydro plants were not separated among different areas of Jawa. Figure 3.5 shows a diagram of the mini-hydro process in Jawa. Mini-hydro, as well as large hydropower, in Jawa were both treated as conversion technologies.

Figure 3.5: Mini-hydropower in the Indonesia MARKAL Model (Jawa)

The study assumed that the use of hydro per unit of electricity generation for all hydropower plants in Jawa during 1991-2021 was 2.6131, and for mini-hydro the use was 2.8938. The lifetime of both hydro and mini-hydro plants was assumed at 50 years. Additional assumptions were made for different plants as shown in Table 3.12.

Table 3.12: Assumptions for Hydropower in Jawa

	1991	1996	2001	2006	2011	2016	2021
Capacity Utilization Rate							
-Mini-Hydro	0.496	0.496	0.496	0.496	0.496	0.496	0.496
Annual Fixed O&M Cost ($Million/GW)							
-West Jawa							
Existing	3.0693	3.0693	3.0693	3.0693	3.0693	3.0693	3.0693
New—Option A			4.9537	4.9537	4.9537	4.9537	4.9537
New—Option B			6.8382	6.8382	6.8382	6.8382	6.8382
-Central & East Jawa							
Existing	8.615	8.615	8.615	8.615	8.615	8.615	8.615
New—Option A			15.047	15.047	15.047	15.047	15.047
New—Option B			16.931	16.931	16.931	16.931	16.931
-Mini-Hydro	19.459	19.459	19.459	19.459	19.459	19.459	19.459
Annual Variable O&M Cost ($Million/PJ)							
-Mini-Hydro	0.057	0.057	0.057	0.057	0.057	0.057	0.057
Capital Cost ($Million/GW)							
-West Jawa							
Existing	2,247	522.84	488.36	488.36	488.36	488.36	488.36
New—Option A			2,497	2,497	2,497	2,497	2,497
New—Option B			2,747	2,747	2,747	2,747	2,747
-Central&East Jawa							
Existing	987.76	1,497.6	2,466.9	2,466.9	2,466.9	2,466.9	2,466.9
New—Option A			2,716.9	2,716.9	2,716.9	2,716.9	2,716.9
New—Option B			2,966.9	2,966.9	2,966.9	2,966.9	2,966.9
Residual Installed Capacity (GW)[1/, 2/]							
-West Jawa	1.4385						
-Central&East Jawa	0.5152						
-Mini-Hydro	0.0082						
Fixed Capacity Constraint (GW)[1/]							
-West Jawa	1.4405	1.9511	2.4693	2.4693	2.4693	2.4693	2.4693
-Central&East Jawa	0.5337	0.6120	0.6185	0.6185	0.6185	0.6185	0.6185
-Mini-Hydro	0.5337	0.6120	0.6185	0.6185	0.6185	0.6185	0.6185

Table 3.12 (Continued)

	1991	1996	2001	2006	2011	2016	2021
Installed Capacity Available in Summer Days (hours) 1/							
-West Jawa	1,684	1,497	1,420	1,420	1,420	1,420	1,420
-Central&East Jawa	1,482	1,430	1,430	1,430	1,430	1,430	1,430
Installed Capacity Available in Summer Nights (hours) 1/							
-West Jawa	2,884	2,262	2,145	2,145	2,145	2,145	2,145
-Central&East Jawa	2,790	2,781	2,779	2,779	2,779	2,779	2,779
Average Use of Installed Capacity in Summer Days							
-West Jawa							
New—Option A			0.7784	0.7784	0.7784	0.7784	0.7784
New—Option B			0.7784	0.7784	0.7784	0.7784	0.7784
-Central&East Jawa							
New—Option A			0.7839	0.7839	0.7839	0.7839	0.7839
New—Option B			0.7839	0.7839	0.7839	0.7839	0.7839
Average Use of Installed Capacity in Summer Nights							
-West Jawa							
New—Option A			0.1418	0.1418	0.1418	0.1418	0.1418
New—Option B			0.1418	0.1418	0.1418	0.1418	0.1418
-Central&East Jawa							
New—Option A			0.2639	0.2639	0.2639	0.2639	0.2639
New—Option B			0.2639	0.2639	0.2639	0.2639	0.2639
Fraction of Capacity to Peak							
-West Jawa							
Existing	0.8474	0.8612	0.8642	0.8642	0.8642	0.8642	0.8642
New—Option A			0.8642	0.8642	0.8642	0.8642	0.8642
New—Option B			0.8642	0.8642	0.8642	0.8642	0.8642
-Central&East Jawa							
Existing	0.5424	0.5549	0.5564	0.5564	0.5564	0.5564	0.5564
New—Option A			0.5564	0.5564	0.5564	0.5564	0.5564
New—Option B			0.5564	0.5564	0.5564	0.5564	0.5564
-Mini-Hydro	0.3384	0.3384	0.3384	0.3384	0.3384	0.3384	0.3384

Notes: 1/ Only for existing plants

2/ Refers to pre-existing installed capacity from before the modeling time horizon

Geothermal

Geothermal energy was used for power generation in Jawa, Sumatra, and Other Islands. Figure 3.6 shows an example of the geothermal process in the Indonesia MARKAL model. This diagram represents the geothermal process in Jawa, where it was treated as a conversion technology. The geothermal process in Kalimantan, Sumatra, and Other Islands were treated as a process technology.

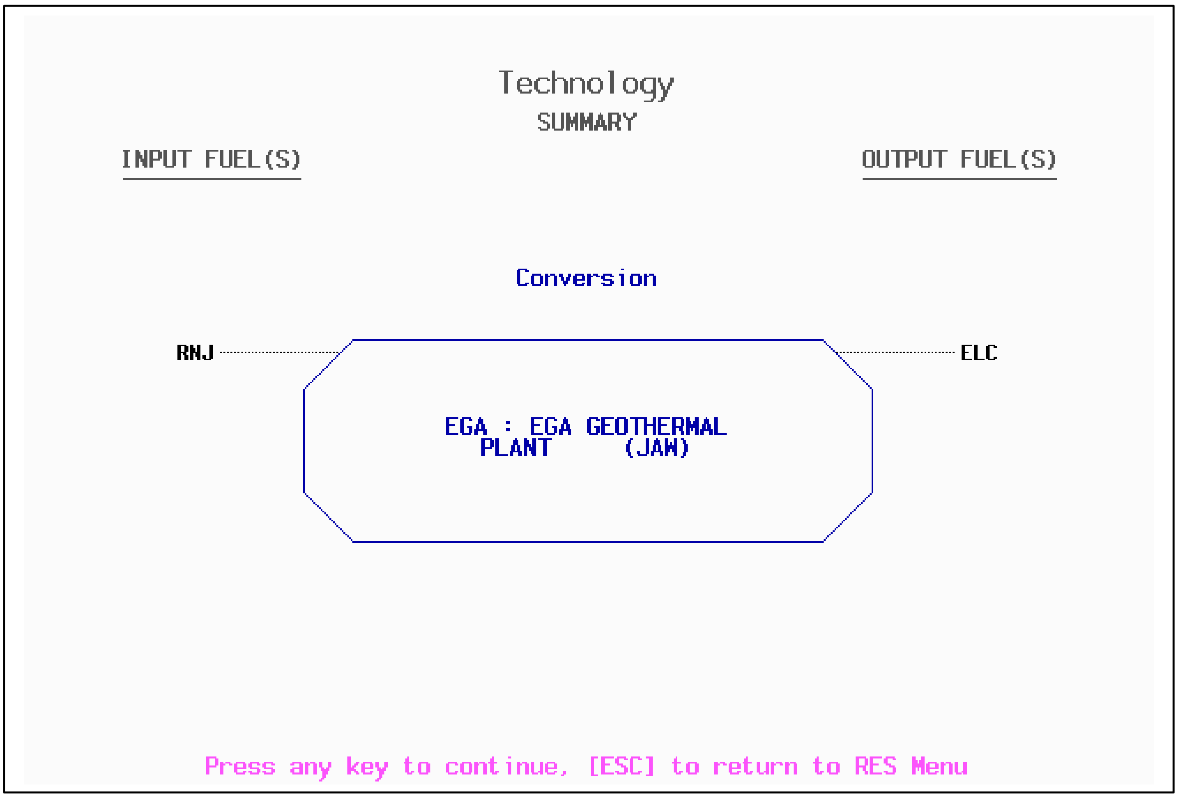

Figure 3.6: Geothermal Process in the Indonesia MARKAL Model (Jawa)

In Sumatra and Other Islands, it was assumed throughout the study periods that geothermal per unit of electricity was equal to 3.3095; capacity utilization was 0.50; annual fixed O&M cost was $38.187 million per GW; annual variable O&M cost was 46.69 million per PJ; capital cost was $2715.7 million per GW; and the technology lifetime was 25 years.

For Jawa, it was assumed that geothermal per unit of electricity was equal to 2.86; capacity utilization was 0.8346; fraction of geothermal energy to supply peak demand was 0.8346; annual fixed O&M cost was $33 million per GW; annual variable O&M cost was 40.3 million per PJ; capital cost was $1582.6 million per GW; and the technology lifetime was 25 years.

Additional assumptions are as shown in Table 3.13.

Table 3.13: Assumptions for Geothermal Power in Indonesia

	1991	1996	2001	2006	2011	2016	2021
Fixed Capacity							
-- Jawa (GW)	0.1473						
-- Other Islands (PJ)	0.0039						
Minimum Capacity							
-- Jawa (GW)		0.3273					
-- Sumatra (PJ)		0.0447	0.0883				
-- Other Islands (PJ)		0.0196	0.020				
Maximum Capacity							
-- Jawa (GW)		1.7409	7.3955	7.3846	7.2791	7.1737	7.0682
-- Sumatra (PJ)		0.8123	3.926	3.926	3.9111	3.8962	3.8813
-- Other Islands (PJ)		1.0801	2.6715	2.6715	2.6650	2.6584	2.6519

Key Determinants of Renewable Energy Penetration in Indonesia

By its nature, MARKAL determines the least-cost solution of the specified objective function. Therefore, cost of the renewable energy technology was the principal determinant of renewable energy penetration in the Indonesia MARKAL model. The other determinants included the availability of a renewable energy supply, the constraints on maximum and minimum capacities of renewable energy technologies, and the constraints on maximum annual growth rate on demand for renewable energy technologies.

The constraints on biomass penetration in the economy included the upper limit on the availability of biomass in Jawa and Sumatra. The total amount of biomass for cooking in Jawa was also assumed not to increase from the base-year quantities. In addition, there were upper limits on the capacity of biomass stoves in all areas.

Biomass used in the industrial sector was constrained by maximum annual growth rate and, for Jawa, also maximum capacity. Similarly, Biomass consumed for power generation in Kalimantan, Sumatra, and Other Islands was constrained to some minimum capacity and limited to some maximum capacity.

The use of hydro resource and geothermal in Indonesia was also constrained to some maximum and minimum capacities. Hydropower in Jawa had additional conditions on the installed capacity available and average use of installed capacity for summer days and nights.

Table 3.14 shows the projected consumption of renewable energy resources—biomass, hydro, and geothermal (High Scenario, Emission Reduction Case). The results showed that biomass consumption grew at a rate of about 1.8 percent per annum, while coal consumption grew at 12.3 percent, and oil and gas consumption both grew at 4.3 percent per annum. Therefore, the shares of biomass in the future primary energy supply declined significantly, from 31 percent in 1991 to 11 percent in 2021. The hydropower and geothermal energy consumption increased at an average rate of 4.5 percent per annum, which lowered its share of total primary energy consumption from 4.3 percent in the base year to 3.4 percent in the year 2021. The study stated that geothermal-based power generation was not economically feasible due to the high steam prices. Therefore, it was assumed that there was no installation of geothermal plants apart from those planned or officially scheduled, and the growth in absolute terms of this supply sector came from hydropower.

Table 3.14: Share and Growth of Primary Energy in Indonesia's Domestic Market

	1991		2021		Average Growth
	10^3 PJ	%	10^3 PJ	%	(% p.a.)
Oil [a/]	1.35	41	4.80	31	4.3
Gas	0.59	18	2.14	13	4.3
Coal	0.20	6	6.52	42	12.3
Biomass	1.00	31	1.71	11	1.8
Hydro and Geothermal	0.14	4.3	0.53	3.4	4.5
Total	**3.28**	**100**	**15.65**	**100**	**5.3**

Note: [a/] Include import of oil and oil products

Table 3.15 shows the projection of biomass consumption in Indonesia. The average growth rate of biomass use in the household sector was projected at 1.17 percent per annum, whereas the use of biomass in small and medium industries was projected to grow at 4.3 percent per annum. The annual average of biomass consumption in households was projected to decline slightly from 362 kg per capita in 1991 to 343 kg per capita in 2021.

Table 3.15: Projection of Biomass Consumption in Indonesia (1991-2021)

Unit: 10^3 PJ

	1991	2001	2011	2021
Household	0.86	1.05	1.14	1.22
Industry	0.14	0.19	0.30	0.49
Total	**1.00**	**1.24**	**1.44**	**1.71**

3.3 THE PHILIPPINES [9]

The other case study of the MARKAL model was taken from the Philippines National Report for the Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) project. The project was funded by the Global Environment Facility (GEF) and executed by the Asian Development Bank (ADB) in collaboration with the United Nations Development Program (UNDP).[10] Work on the project included the development of the 1990 National Inventory of GHG sources and sinks; projection of National GHG Inventories to 2020 under the Business-As-Usual scenario for the energy, forestry, and agricultural sectors; identification of GHG mitigation options and opportunities for the energy, forestry, and agricultural sectors; formulation of Cost of Emission Reduction Initiatives (CERI) curves; and formulation of the national GHG abatement strategies. The results of the ALGAS study would be used for the evaluation and review of policy options included in the Philippines' National Action Plan for global climate change.

Energy Sector Overview

Primary energy consumption in 1990 was composed of liquid energy, renewable energy, and coal. Table 3.16 was taken from the Philippines' ALGAS report to compare the consumption of each fuel. As seen from Table 3.16, the data used for MARKAL baseline was a little bit different from the data reported in the *1996-2025 Philippine Energy Plan* (PEP). Oil was the principal fuel used in the Philippines, accounting for more than half of total primary energy consumption.

Table 3.16: Primary Energy Consumption in the Philippines in 1990

Unit: PJ

Type of Primary Energy	MARKAL Baseline	PEP
Renewables	385.0	222.0
Liquid	489.0	480.0
Coal	52.9	42.5
Gas	0	0
Total	**927.4**	**744.5**

Source: Philippines: Asia Least-Cost Greenhouse Gas Abatement Strategy (1998)

In 1990, the electricity generating capacity in the Philippines consisted of power plants that were 43.3 percent oil, 35.5 percent hydroelectric, 14.8 percent geothermal, and 6.7 percent coal. Natural gas-fired plants were projected to be installed in the future. Solar and wind power were used on a small scale for residential and commercial purposes.

Resource supplies in 1990 included 1,689.4 PJ of crude oil, 109,767.7 PJ of natural gas, 43,449 PJ of geothermal steam, and 200 PJ of biomass.

Model Framework: MARKAL

The MARKAL model was used in the ALGAS project for the development of an energy system-wide baseline, GHG Abatement scenarios, the derivation of cost emission reduction (CERI) curves, and technology assessment. The Base Case and Abatement scenarios were generated in five-year intervals from 1990 to 2020. The Base Case scenario was constructed based on the actual energy data from 1990 to 1995, and it used the projected energy data during 2000 to 2020 from the *1996-2025 Philippine Energy Plan*. In the Base Case scenario, there was no action taken to limit GHG emissions from the energy sector. In addition, it was assumed that there would be no constraints or barriers in adopting the least-cost way of providing energy. This case reflected only the economic and technical factors, not the political considerations or consumer tastes. The Base Case scenario, therefore, overstated the performance of any of the new technologies or understated the barriers to their implementation.

There were 12 GHG Abatement scenarios developed using the MARKAL model. The scenarios could be categorized under fuel switching, supply efficiency, use of new and renewable energy supply, and demand-side management. The uses of wind (50 MW installed by 2010), solar (total capacity addition of 20 MW from year 2000 to 2020), and bioenergy (1000 MW installed by year 2020) were included as options in the Abatement scenarios.

This study reviews only the Base Case scenario since the data set for the Abatement scenarios was unobtainable. The major components of the model in the Base Case scenario are discussed below:

Coal

Coal was used in the power plants, coal burners, and industrial cogeneration.

Oil

Crude oil included indigenous and imported oil. Crude oil was fed into three refineries—Shell, Caltex, and Petron. Outputs from the refineries were heavy distillate, diesel, gasoline, jet fuel, kerosene, LPG, and feedstocks. In addition to being domestically produced, petroleum products were also imported.

Heavy distillate was used in the power sector, commercial sector (for fishing boats and engines), industrial sector (for oil burners), and transport sector (for public and freight ship/boats). Diesel was used in the agricultural sector (for tillers/tractors, diesel-electric pumps, diesel engine pumps, municipal fishing boats, and threshers/shellers/dryers), and power sector (for gas turbines and combined cycles power plants). Gasoline was mainly used in the agricultural sector (for tillers, irrigation pumps, crop sprayers, fishing boats, and threshers/shellers/dryers for post harvesting operations), but it was also used in the transport sector (for passenger cars). Aviation turbo and aviation gas were used for three categories of air transport—public, military, and international flights. Kerosene was used in the commercial sector as well as the urban and rural residential sector for cooking and lighting. LPG was used in the commercial sector and in the urban and rural residential sector for cooking. Gasoline, diesel, heavy distillate, jet fuel, and kerosene were also exported.

Gas

There was no use of gas in 1990—the base year of the study. After 1990, indigenous and imported gas were used in the combined cycles power plants.

Electricity

The technologies used for power generation included coal steam electric, fuel oil steam electric, gas turbine electric, combined cycle, diesel electric, biomass steam electric, hydropower, and geothermal. There was no distinction between base load and peak load or existing plants and new plants.

Electricity was used in the commercial sector (for fluorescent lighting, incandescent lighting, air conditioning, refrigeration, and electric appliances), in the industrial sector (for fluorescent lighting and incandescent lighting), and for hydroelectric pumped storage.

End-Use Sectors

The energy consuming sectors were separated into agricultural, commercial, industrial, residential, transport, and non-energy use.

Agricultural Sector. The end-use demands in the agricultural sector included soil preparation, irrigation, crop maintenance, post harvest operation, and fishing. These demands were satisfied by diesel, gasoline, fuel oil, and kerosene. The end-use devices included: diesel and gasoline tillers/tractors for soil preparation; diesel-electric pumps, diesel engine pumps, and gasoline pumps for irrigation; gasoline sprayers for crop maintenance; gasoline and diesel threshers, shellers and dryers for post harvest operations; and gasoline boats, diesel boats, fuel oil boats, and kerosene lighting for fishing.

Commercial Sector. The commercial sector end-use demands included cooking, lighting, air conditioning, refrigeration, miscellaneous electric appliances, and power and heat. The main energy used in the commercial sector was electricity. Other fuels used were LPG and kerosene for cooking, and diesel and fuel oil for power and heat production.

Industrial Sector. The industrial sector end-use demands were lighting, air conditioning, refrigeration, power and heat, and miscellaneous electric equipment. Fuels used in the industrial sector were electricity, fuel oil, coal, and biomass. Fuel oil, coal, and biomass were used to fuel burners to produce power and heat.

Residential Sector. Energy demand in the residential sector was separated into rural and urban demands. Both rural and urban end-use demands included cooking, lighting, ironing, refrigeration, air conditioning, and miscellaneous electric appliances. Fuels used for cooking demand in the urban areas were electricity, LPG, kerosene, fuel wood, charcoal, and agricultural wastes. In addition to the same cooking fuels used in the urban areas, the rural areas also used biogas for cooking. Fuels used for lighting demand were electricity and kerosene. Fuels used for ironing demand were electricity and charcoal. Fuel used for refrigeration, air conditioning and miscellaneous electric appliances was electricity.

Transport Sector. Energy demand in the transport sector was separated into road demand (cars, trucks, jeepneys, taxies, utility vehicles, motorcycles/tricycles, and buses), rail demand, air demand (public, military, and international flights), and water/sea demand (passenger, freight, and international ships). Fuels used for road demands were diesel and gasoline. Rail fuels were diesel and electricity. Air demand fuels were aviation turbo and aviation gas. Ship fuels were diesel and fuel oil.

Non-Energy Use. The non-energy use referred to the use of energy as feedstocks.

Technologies

The model included 5 process technologies, 11 conversion technologies, and 88 demand technologies. The technologies included in the model are listed in Table 3.17.

Table 3.17: Technologies Included in the Philippines MARKAL Model

Process Technologies

Fuel Wood to Charcoal Conversion
Biogas digesters
Refinery, Shell
Refinery, Caltex (Batangas)
Refinery, Petron (Bataan-BRC)

Conversion Technologies

Centralized Conversion Technologies	***Decentralized Conversion Technologies***	***Storage Conversion Technologies***
Coal Steam Electric	*Biomass Steam Electric*	*Hydroelectric Pumped Storage*
Fuel Oil Steam Electric	Industrial Cogeneration (Coal)	
Gas Turbine Electric (Diesel)		
Combined Cycle Electric		
Diesel Electric		
Hydroelectric		
Geothermal Electric		
Natural Gas Combined Cycle GT		

Demand Technologies

Agricultural Sector	***Residential Sector***	***Transport Sector***
Diesel Tillers/Tractors	Electric Cooking (Urban)	Gasoline Cars (Private)
Gasoline Tillers	LPG Cooking (Urban)	Diesel Cars (Private)
Diesel-Electric Pumps	Kerosene Cooking (Urban)	Gasoline Trucks (Private)
Diesel Engine Pumps	*Fuel Wood Cooking (Urban)*	Diesel Trucks (Private)
Gasoline Pumps	*Charcoal Cooking (Urban)*	Gasoline Jeepneys (Public)
Gasoline Sprayers	*Agricultural Waste Cooking (Urban)*	Diesel Jeepneys (Public)
Gasoline Threshers/ Shellers/Dryers	Fluorescent Lighting (Urban)	Gasoline Motorcycles (Private)
Diesel Threshers/ Shellers/Dryers	Incandescent Lighting (Urban)	Diesel Motorcycles (Private)
Gasoline Boats (Municipal)	Kerosene Lighting (Urban)	Gasoline Utility Vehicles (Private)
Diesel Boats (Municipal)	Electric Ironing (Urban)	Diesel Utility Vehicles (Private)
Gasoline Boats (Commercial)	*Charcoal Ironing (Urban)*	Gasoline Taxies
Diesel Boats (Commercial)	Refrigeration (Urban)	Diesel Taxies
Fuel Oil Boats (Commercial)	Air Conditioning (Urban)	Gasoline Buses (Public)
Kerosene Lighting	Misc. Electric Appliances	Diesel Buses (Public)

(Commercial)	(Urban)	
Table 3.17 (Continued)		
	Residential Sector (Continued)	***Transport Sector (Continued)***
	Electric Cooking (Rural)	Diesel Rails (Passenger)
	LPG Cooking (Rural)	Electric Rails (Passenger)
	Kerosene Cooking (Rural)	Aviation Turbo Air (Public)
	Fuel Wood Cooking (Rural)	Aviation Gas Air (Public)
	Charcoal Cooking (Rural)	Aviation Turbo Air
(Military)		
	Agricultural Waste Cooking (Rural)	Aviation Gas Air (Military)
	Biogas Cooking (Rural)	Aviation Turbo Air (International)
	Fluorescent Lighting (Rural)	Diesel Ships/Boats (Public)
	Incandescent Lighting (Rural)	Fuel Oil Ships/Boats
(Public)		
	Kerosene Lighting (Rural)	Dieesl Ships/Boats (Freight)
	Electric Ironing (Rural)	Fuel Oil Ships/Boats (Freight)
	Charcoal Ironing (Rural)	Diesel Ships/Boats (International)
	Refrigeration (Rural)	Fuel Oil Ships/Boats (International)
	Air Conditioning (Rural)	
	Misc. Electric Appliances (Rural)	
Commercial Sector	***Industrial Sector***	***Non-Energy Use***
LPG Cooking	Fuel Oil Burners	Feedstocks
Kerosene Cooking	Coal Burners	
Fluorescent Lighting	*Biomass Burners*	
Incandescent Lighting	Fluorescent Lighting	
Air Conditioning	Incandescent Lighting	
Refrigeration	Air Conditioning	
Electric Appliances	Refrigeration	
Diesel Engines	Electric Motors	
Fuel Oil Engines		

Note: The information in this table was taken from an examination of the model data set.

Projection Methodologies

There was no explanation on the projection methodologies for exogenous variables used in the study. The study only mentioned that the projections of exogenous variables were derived from the *1996-2025 Philippines Energy Plan.*

Renewable Energy in the Philippines MARKAL Model

Renewable energy resources included in the Base Case scenario were agricultural waste, fuel wood, animal dung/manure, hydro, and geothermal. The model contained 4 renewable conversion technologies (hydroelectric, hydroelectric pumped storage, geothermal electric, and biomass steam electric), 2 process technologies (fuel wood to charcoal conversion and biogas digesters), and 10 demand technologies (biomass burners, urban fuel wood cooking, urban charcoal cooking, urban agriculture waste cooking, urban charcoal ironing, rural fuel wood cooking, rural charcoal cooking, rural agriculture waste cooking, rural biogas cooking, and rural charcoal ironing).

The assumptions regarding renewable energy in the model are described below. All tables describing model assumptions were taken from an examination of the model data set, since the information is not available in the written report.

Agricultural Waste

Agricultural wastes included crop residues and bagasse. Both crop residues and bagasse had the same energy costs. However, their annual availabilities were different. Agricultural waste was used in biomass steam electric conversion processes to produce electricity, and it was also used for cooking in rural and urban areas. The diagram of agricultural waste consumption in the model is shown in Figure 3.7.[11]

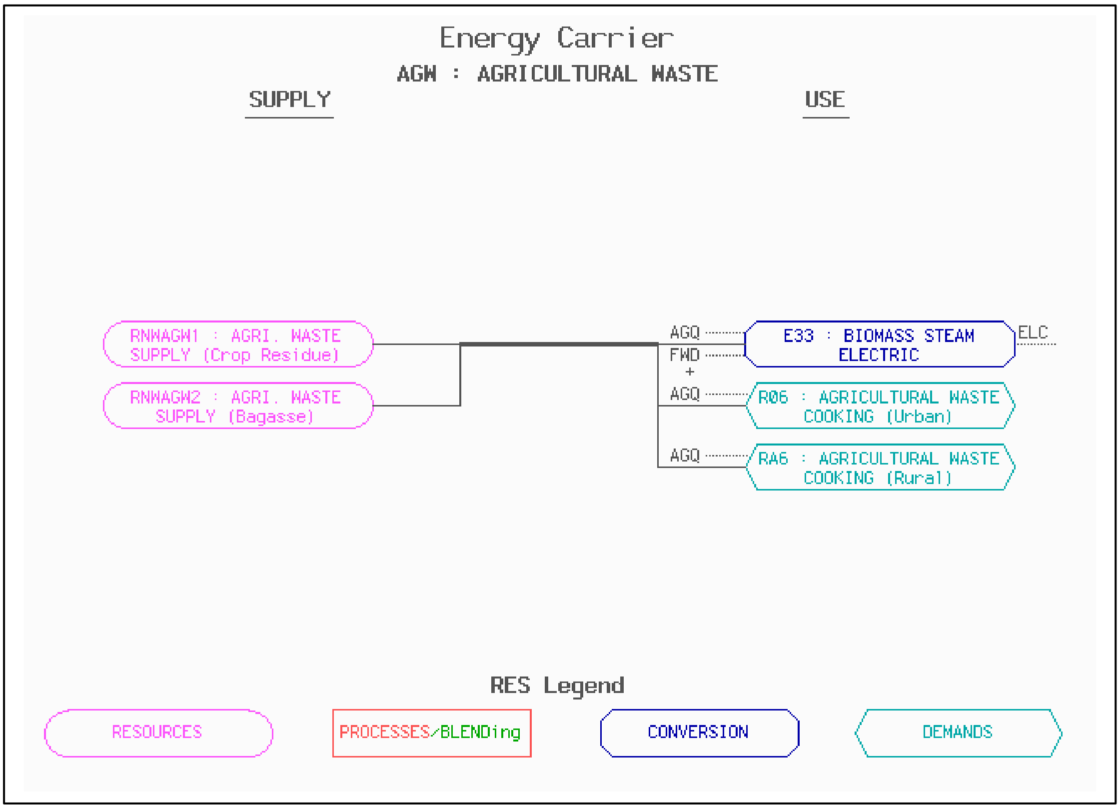

Figure 3.7: Agricultural Waste Consumption in the Philippines MARKAL Model

The assumptions regarding agricultural waste are listed in Table 3.18.

Table 3.18: Assumptions for Agricultural Waste in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Cost (Million $/PJ)							
-- Crop residue	1.50	1.52	1.54	1.56	1.58	1.60	1.62
-- Bagasse	1.50	1.52	1.54	1.56	1.58	1.60	1.62
Fixed Available Supply (PJ)							
-- Crop residue	55.64						
-- Bagasse	26.44						
Maximum Supply (PJ)							
-- Crop residue		155.74	172.5	196.21	223.68	255.51	292.53
-- Bagasse		66.49	77.81	94.69	115.20	140.13	170.50

Fuel Wood

The model contained two categories of fuel wood. The first category was fuel wood from the baseline supply and fuel wood collected from the residential sector and reforestation. The second category was fuel wood from industrial waste. The first category was used for five purposes: (1) to make charcoal for cooking and ironing in urban and rural areas, (2) as input in biomass steam electric conversions to produce electricity, (3) as input in biomass burners, (4) for cooking in urban areas, and (5) for cooking in rural areas (see Figure 3.8). The fuel wood supply from industrial waste was entirely fed into biomass steam electric conversion processes to produce electricity (see Figure 3.9).

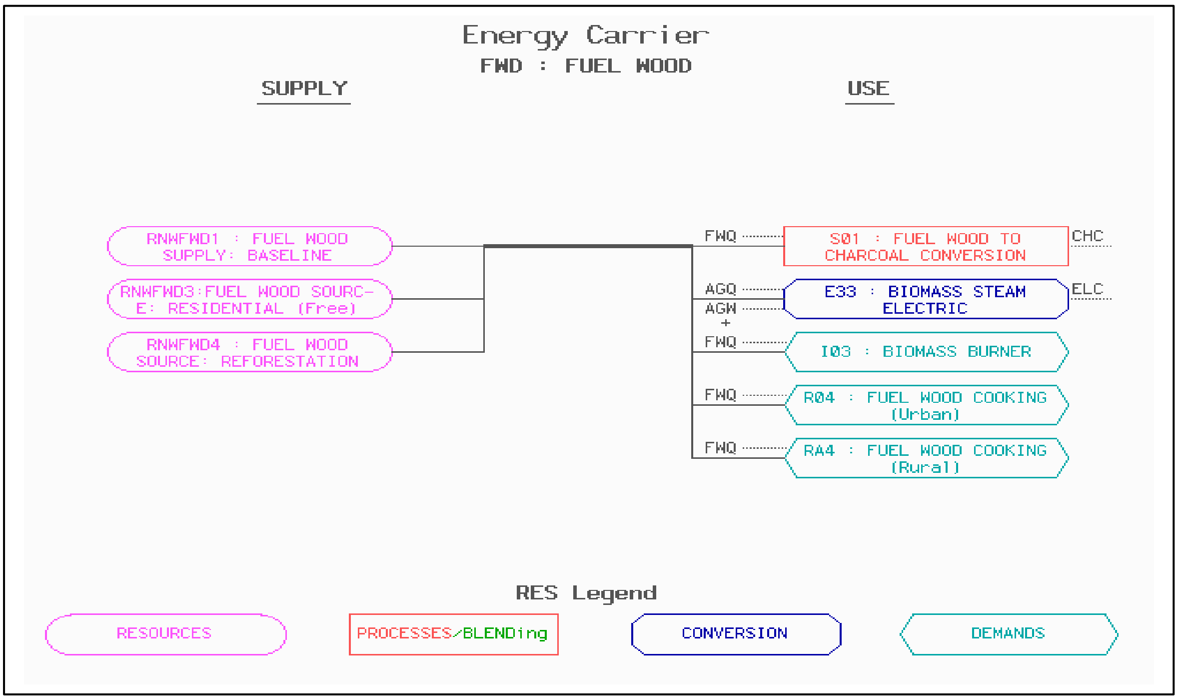

Figure 3.8: Consumption of Fuel Wood in the Philippines MARKAL Model (Fuel Wood from Baseline Supply, the Residential Sector, and Forestation)

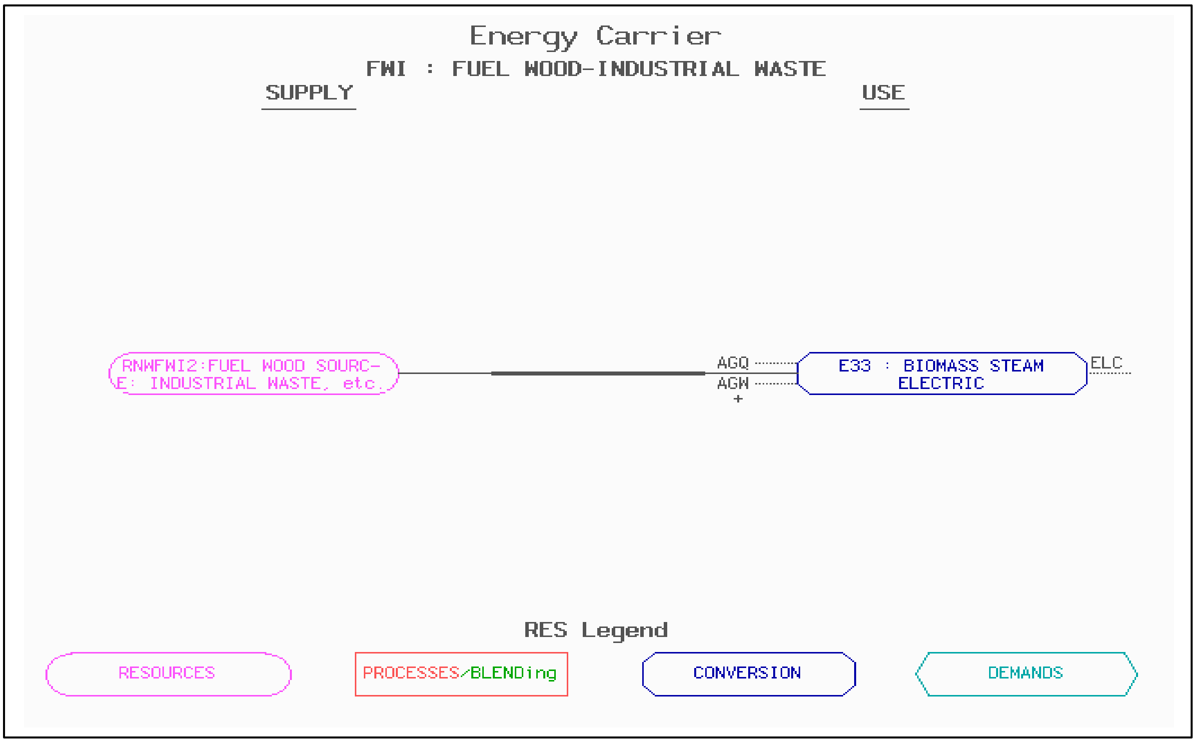

Figure 3.9: Consumption of Fuel Wood in the Philippines MARKAL Model (Fuel Wood from Industrial Waste)

Costs of fuel wood from all sources were assumed to be the same. The baseline supply was assumed to be fixed in 1990 and to have maximum availability during 1995 to 2020. The assumptions on costs and availability of fuel wood supply are shown in Table 3.19.

Table 3.19: Assumptions for Fuel Wood Supply in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Cost (Million $/PJ) -- All sources	2.67	2.703	2.736	2.769	2.802	2.835	2.868
Fixed Available Supply (PJ) -- Baseline	445						
Maximum Supply (PJ) -- Baseline		485.78	533.34	603.58	687.99	789.57	911.73

Animal Dung

Animal dung was fed into biogas digester process to produce biogas for cooking in rural areas (see Figure 3.10).

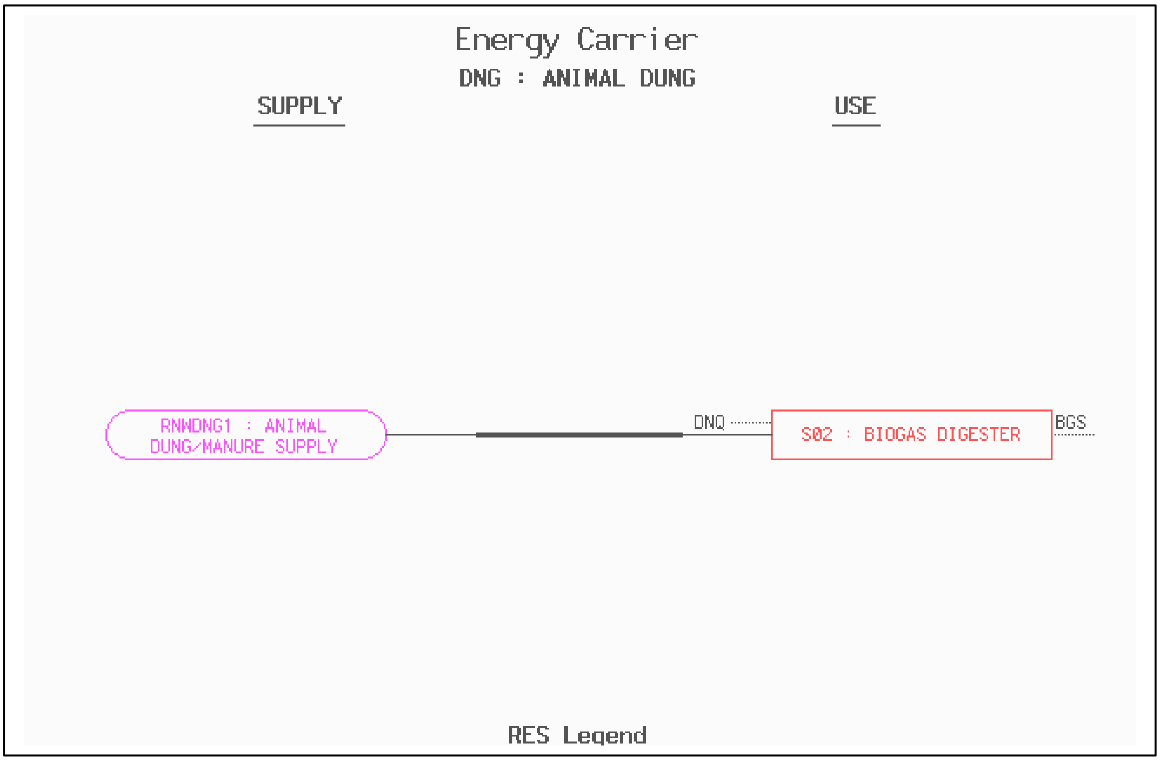

Figure 3.10: Animal Dung Consumption in the Philippines MARKAL Model

Cost of animal dung was assumed to be the same as agricultural wastes. The availability of supply each year was constrained to some specified maximum amounts (see Table 3.20).

Table 3.20: Assumptions for Animal Dung in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Cost (Million $/PJ)	1.50	1.52	1.54	1.56	1.58	1.60	1.62
Maximum Supply (PJ)	65	71.76	74.72	78.47	82.53	86.70	91.12

Hydro Resources

A hydro resource diagram for the Philippines MARKAL model is shown in Figure 3.11.

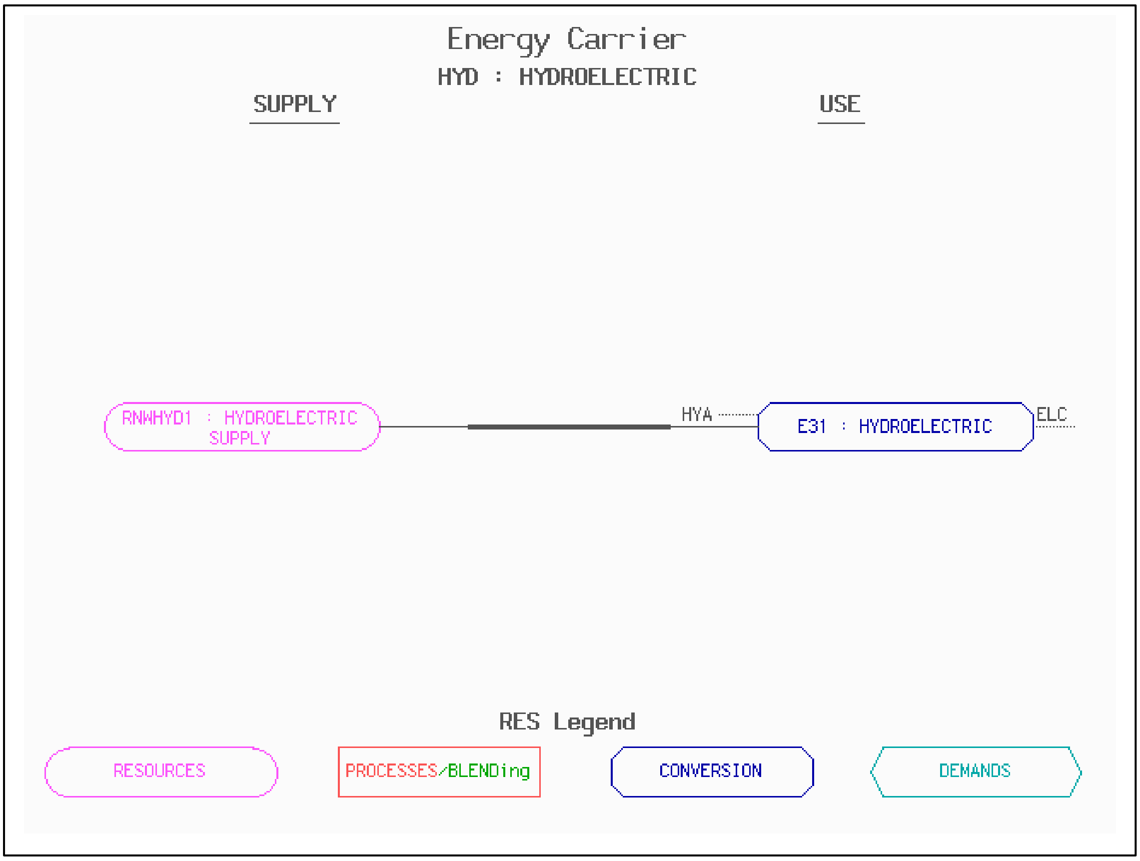

Figure 3.11: Hydro Resource Consumption in the Philippines MARKAL Model

Hydropower plants included regular hydro plants and pumped storage. Regular hydropower was assumed to have an availability of 3,767 hours/year with a scheduled outage of 1,648 hours/year. The pumped storage hydropower was assumed to have the availability at 6,001 hours/year and scheduled outage at 911 hours per year. The use of hydro per unit of electricity produced in both regular hydro and pumped storage was assumed at 3. Lifetime of the regular hydropower plants was assumed at 50 years as compared to 30 years for pumped storage hydro plants. The study assumed that the annual variable O&M cost for pumped storage hydro was fixed at $0.35 million/PJ. There was no assumed annual variable O&M cost for regular hydro. The additional assumptions regarding hydropower are as shown in Table 3.21.

Table 3.21: Assumptions for Hydropower in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Capital Cost ($million/GW)							
--Regular Hydro	3,170	3,274	3,378	3,482	3,586	3,690	3,794
--Pumped Storage	1,056	1,174	1,292	1,410	1,528	1,646	1,764
Annual Fixed O&M Cost ($million/GW)							
--Regular Hydro	17	17	17	17	17	17	17
--Pumped Storage	6.12	6.23	6.34	6.45	6.56	6.67	6.78
Residual Installed Capacity (GW)[1/]							
--Regular Hydro	2.153	2.134	2.115	2.096	2.077	2.058	2.039
--Pumped Storage	0.3						
Fixed Capacity Bound (GW)							
--Regular Hydro		2.33	2.57	4.07			
Lower Capacity Bound (GW)							
--Regular Hydro	2.153						
--Pumped Storage	0.3						
Upper Annual Production Bound (PJ)							
--Regular Hydro	21.82	20.52	23.19	42.69	49.57	59.85	73.99
--Pumped Storage	0.3	0.45	0.60	0.75	0.90	1.05	1.20

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Geothermal Resources

Geothermal resources were used for base load power generation. The diagram of geothermal resources in the Philippines MARKAL model is shown in Figure 3.12. The availability of geothermal was assumed at 7,008 hours/year, and the scheduled outage was at 578 hours/year. The use of geothermal per unit of electricity produced was assumed at 3.012. Capital cost was assumed at $2,103 million/GW, and the annual fixed O&M cost was $7 million/GW. Both costs were assumed to remain constant over time. The geothermal technology was assumed to have the lifetime of 30 years. The additional assumptions are listed in Table 3.22.

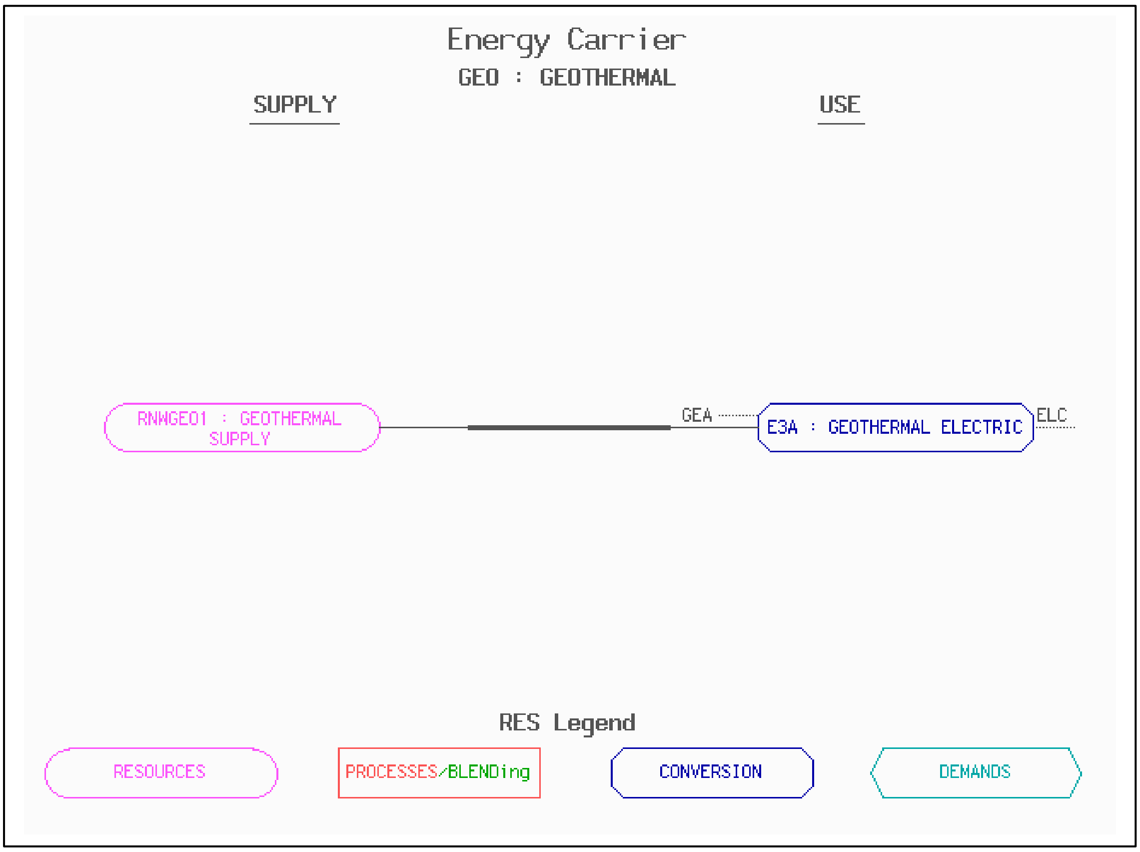

Figure 3.12: Geothermal Resource Consumption in the Philippines MARKAL Model

Table 3.22: Assumptions for Geothermal Resources in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Residual Installed Capacity (GW)[1/]	0.888	0.74	0.592	0.444	0.296	0.148	0
Minimum Capacity (GW)	0.888						
Maximum Capacity (GW)	0.888	1.451	2.014	2.134	2.859	3.489	4.549
Fixed Capacity (GW)		1.194					
Maximum Annual Production (PJ)		30.32	50.81	53.84	72.13	88.02	113.57

Note: [1/]Refers to pre-existing installed capacity from before the modeling time horizon

In addition to the assumptions for renewable energy resources shown above, assumptions were also made for the renewable energy end-use technologies. These technologies included biomass steam electric, charcoal conversion, biogas digesters, biomass burners, biomass for cooking, biogas for cooking, and charcoal ironing.

Biomass Steam Electric

Biomass steam electric was classified in the study as conversion technology process. The biomass used in the process was agricultural waste and fuel wood. The proportion of energy input per unit production was assumed at 3.3. The availability was 2,628 hours per year, with the scheduled outage assumed at 2,024 hours per year. The annual fixed O&M cost was $131 million/GW. The technology lifetime was 30 years. Table 3.23 lists additional assumptions on biomass steam electric.

Table 3.23: Assumptions for Biomass Steam Electric in the Philippines

	1990	1995	2000	2005	2010	2015	2020
Capital Cost ($million/GW)	1743.5	1750.6	1757.6	1764.7	1771.8	1778.8	1785.9
Residual Installed Capacity (GW) [1/]	0.167	0.139	0.111	0.083	0.055	0.027	0
Minimum Capacity (GW)	0.167						
Maximum Annual Production (PJ)					0.158	0.76	0.99

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Charcoal Conversion

Some fuel wood from the baseline supply was used in the charcoal making process. Capital cost was assumed to be constant at $3.21 million/PJ. The technology lifetime was 10 years. Assumptions on the capacities of charcoal conversion are listed in Table 3.24.

Table 3.24: Assumptions for Charcoal Conversion Process in the Philippines

Unit: PJ

	1990	1995	2000	2005	2010	2015	2020
Residual Installed Capacity [1/]	45.037	22.519	0				
Minimum Capacity	45.037	39.407	33.777	28.147	22.517	16.887	11.257
Maximum Capacity		60.38					

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Biogas Digesters

The study assumed that capital cost of a biogas digester was $19.053 million/PJ, and annual variable O&M cost was $0.397 million/PJ. The technology lifetime was 10 years. The capacity was constrained at the lower bound, as shown in Table 3.25.

Table 3.25: Assumptions on Biogas Digester in the Philippines

Unit: PJ

	1990	1995	2000	2005	2010	2015	2020
Residual Installed Capacity [1/]	0.057	0.029	0				
Minimum Capacity	0.057	0.057	0.049	0.041	0.033	0.025	0.017

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Biomass Burners

Biomass burners were fueled by fuel wood. It was assumed that the average efficiency of burners was 0.65. Capital cost was $11.25 million /PJ with an annual fixed O & M cost of $1.125 million/PJ.[12] The technology lifetime was 20 years. The study put a minimum capacity constraint on the use of biomass burners from 1990 to 2020 and a maximum constraint in 1995, as shown in Table 3.26.

Table 3.26: Assumptions on Biomass Burners in the Philippines

Unit: PJ

	1990	1995	2000	2005	2010	2015	2020
Residual Installed Capacity [1/]	53.36	40.02	26.68	13.34	0		
Minimum Capacity	53.36	46.69	40.02	33.35	26.68	20.01	13.34
Maximum Capacity		60.38					

Note: [1/] Refers to pre-existing installed capacity from before the modeling time horizon

Biomass for Cooking

Biomass used for cooking included fuel wood, charcoal, and agricultural waste. The study separated between cooking in urban and rural areas. There was no difference in technical efficiency of the devices or costs of using biomass in rural and urban areas. In addition, both efficiency and costs were assumed to remain constant over the study periods. The difference between biomass cooking in urban and rural areas was based on the assumptions regarding capacity. Biomass for cooking was used more in rural areas than in urban areas. The trend of using biomass for cooking was declining in both areas. The assumptions on biomass for cooking are listed in Table 3.27.

Biogas for Cooking

Biogas was used for cooking only in rural areas. The assumptions on biogas, as compared to biomass, for cooking are shown in Table 3.27.

Table 3.27: Assumptions on Biomass Cooking in Urban and Rural Philippines

	1990	1995	2000	2005	2010	2015	2020
Average Efficiency							

-- Fuel Wood	0.15	0.15	0.15	0.15	0.15	0.15	0.15
-- Charcoal	0.20	0.20	0.20	0.20	0.20	0.20	0.20
-- Agricultural Waste	0.15	0.15	0.15	0.15	0.15	0.15	0.15
-- Biogas	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Capital Cost ($million/PJ)							
-- Fuel Wood							
-- Charcoal	0.265	0.265	0.265	0.265	0.265	0.265	0.265
-- Agricultural Waste	0.662	0.662	0.662	0.662	0.662	0.662	0.662
-- Biogas	0.265	0.265	0.265	0.265	0.265	0.265	0.265
	9.397	9.397	9.397	9.397	9.397	9.397	9.397
Annual Fixed O&M Cost ($million/PJ)							
-- Fuel Wood	0.005	0.005	0.005	0.005	0.005	0.005	0.005
-- Charcoal	0.013	0.013	0.013	0.013	0.013	0.013	0.013
-- Agricultural Waste	0.005	0.005	0.005	0.005	0.005	0.005	0.005
-- Biogas	0.188	0.188	0.188	0.188	0.188	0.188	0.188
Residual Installed Capacity (PJ) [1/]							
-- Fuel Wood							
-- Urban	3.19	0					
-- Rural	14.76	0					
-- Charcoal							
-- Urban	0.79	0					
-- Rural	0.80	0					
-- Agricultural Waste							
-- Urban	0.63	0					
-- Rural	0.85	0					
-- Biogas							
-- Rural	0.03	0					
Minimum Capacity (PJ)							
-- Fuel Wood							
-- Urban	3.19	2.79	2.39	1.99	1.59	1.19	0.79
-- Rural	14.76	12.92	11.08	9.23	7.39	5.55	3.71
-- Charcoal							
-- Urban	0.79	0.69	0.59	0.49	0.39	0.29	0.19
-- Rural	0.80	0.70	0.60	0.50	0.40	0.30	0.20
-- Agricultural Waste							
-- Urban	0.63	0.55	0.47	0.39	0.31	0.23	0.15
-- Rural	0.85	0.74	0.63	0.52	0.41	0.30	0.19

Table 3.27 (Continued)

	1990	1995	2000	2005	2010	2015	2020
Minimum Capacity (PJ) (Continued)							
-- Biogas							

-- Rural	0.03	0.057	0.049	0.041	0.033	0.025	0.017
Maximum Capacity (PJ) -- Biogas -- Rural		0.057	0.192	0.327	0.462	0.597	0.732

Note: 1/ Refers to pre-existing installed capacity from before the modeling time horizon

Charcoal Ironing

Charcoal ironing was used in both urban and rural areas. Efficiency was assumed to be 0.20. Capital cost was assumed at $0.5 million/PJ. Annual fixed O&M was assumed at $0.01 million/PJ. The technology lifetime was 5 years. There was no constraint on capacity for urban charcoal ironing. For rural areas, the constraint was set for minimum capacity (see Table 3.28).

Table 3.28: Assumptions for Charcoal Ironing in Rural Philippines

Unit: PJ

	1990	1995	2000	2005	2010	2015	2020
Residual Installed Capacity 1/	0.15						
Minimum Capacity	0.15	0.13	0.11	0.09	0.07	0.05	0.03

Note: 1/ Refers to pre-existing installed capacity from before the modeling time horizon

Key Determinants of Renewable Energy Penetration in the Philippines

Besides costs, the other factors that control penetration rates of renewable energy in the model included constraints on supply. The uses of agriculture waste, fuel wood, and animal dung were constrained by annual maximum supply. This constraint, therefore, set a limit on the uses of their relevant technologies (such as, biomass steam electric, charcoal making process, and biogas digester). All renewable energy technologies were constrained with the annual maximum and/or minimum capacities available. The use of geothermal resources was also assumed to be bound by maximum annual production.

The results from the study showed that in the Base Case scenario, primary energy supply was forecast to increase from 927 PJ in 1990 to 3,817 PJ in the year 2020. Renewable energy supply, on the other hand, was estimated to increase from 386 PJ to 721 PJ. The shares of renewable energy in the total primary energy supply therefore declined from 41.5 percent in 1990 to 18.9 percent in 2020. The consumption of geothermal, fuel wood, and animal dung declined over time after 1995. The consumption of hydro resources and agricultural waste dropped in 1995, but then it increased afterward. There was no explanation given for variation. The projection of renewable energy supply as compared to total primary energy supply is shown in Table 3.29.

Table 3.29: Projection of Renewable Energy Supply in the Philippines (1990-2020)

Unit: PJ

	1990	1995	2000	2005	2010	2015	2020
Agricultural Waste	82.08	8.63	183.44	290.90	338.88	395.82	463.03

-- Crop residue -- Bagasse	55.64 26.44	8.63 0	172.50 10.94	196.21 94.69	223.68 115.20	255.51 140.13	292.53 170.50
Animal Dung	0.14	0.26	0.22	0.19	0.15	0.11	0.08
Fuel Wood	170.33	201.91	173.07	144.22	115.38	86.53	57.69
Geothermal	67.49	90.74	79.49	68.25	57.0	45.75	34.50
Hydro power	65.46	61.56	69.57	128.07	148.71	166.42	166.11
Total Renewable Energy Supply	**385.5**	**363.1**	**505.8**	**631.6**	**660.1**	**694.5**	**721.4**
Total Primary Energy Supply	**927.4**	**1081.7**	**1323.3**	**1752.6**	**2264.2**	**2980.2**	**3817.3**

3.4 PEOPLE'S REPUBLIC OF CHINA[13]

The case study for the LEAP model was taken from the project *Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China.* It was a joint study of representatives from the Modern Policy Research Center for Environment and Economy under the National Environmental Protection Agency, the Energy Research Institute under the State Planning Commision of China, the Tsinghua University of China, the United Nations Environment Programme (UNEP) Collaborating Centre on Energy and Environment, and other domestic institutes with support from the UNEP.

Energy Sector Overview

PRC accounts for about 10 percent of total global energy use. The production of primary energy in 1990 was about 1,256 MTCE. Coal is the principal energy used in China. The production of coal in 1990 was 1.09 billion tons. Total coal reserve was estimated in 1990 at 966.7 billion tons.

Total crude oil reserves in China were estimated at 78.75 billion tons in 1987 and the total natural gas resources were set at 1,380 billion cubic meters. The exploitation of oil and gas in China remains at a preliminary stage. In 1990, crude oil production in China was 138.31 million tons, and natural gas production was 15.8 billion cubic meters.

China has high potential hydropower resources, estimated at 676 GW. However, the hydropower resources are concentrated in the regions of south-west, north-west and central China. Only 36.05 GW, or about 9.1 percent of total hydropower, was exploited by 1990.

The study divided biomass resources in China into three parts: (1) crop residues used as fuel, (2) various kinds of trees used as firewood, and (3) human wastes, animal wastes, and organic waste used to produce biogas. Production of crop residues in 1990 was estimated at 544 million tons, of which 295 million tons (or about 54 percent of total production) were used as fuel. Various kinds of trees provide 90 million tons of firewood each year.

Besides hydro and biomass, other renewable energy resources included wind, solar, and geothermal. The reserves of wind, solar, and geothermal were estimated in 1990 at 3.8 billion GJ, 21.6 billion GJ, and 10 billion GJ, respectively.

Total energy consumption in China in 1990 was 29.53 billion GJ. Of this total, about 46 percent was coal and 26 percent was biomass. The industrial sector is the largest energy consumer, and the residential sector is the second largest. In 1990, the industrial sector consumed about 47 percent, and the residential sector consumed about 40 percent of total energy consumption. The other sectors accounted for small shares in total energy consumption (that is, in 1990, 3.2 percent for agriculture, 3.0 percent for services, 6.0 percent for transport, and 0.8 percent for building). All biomass was consumed in the rural residential sector, for which it fulfilled about 80 percent of the total energy demand in the rural residential sector in 1990. The composition of energy consumption in China is shown in Table 3.30.

Table 3.30: Composition of Energy Consumption in the PRC in 1990

Unit: Billion GJ

Sector	Coal & Coke	Gas 1/	Crude oil	Oil Products	Heat	Biomass 2/	Electric	Briquette
Residential	2.73	0.11	0	0.12	0.1	7.77	0.17	0.8
Agricultural	0.44	0	0	0.35	0	0	0.15	0
Industrial	9.38	0.73	0.14	1.75	0.51	0	1.40	0
Transport	0.29	0	0	1.45	0	0	0.03	0
Building	0.10	0.04	0.02	0.06	0	0	0.02	0
Services	0.61	0.01	0	0.14	0.01	0	0.10	0
Total	13.55	0.89	0.16	3.87	0.62	7.77	1.87	0.8

Notes: 1/ Includes natural gas, coking gas, and producer gas
2/ Includes biogas, firewood, crop residue, and animal waste

Model Framework: LEAP

The study aimed to explore the economic and environmental impacts of a range of integrated energy policy measures over the 30 year period from 1990 to 2020. It also aimed to examine a range of different environmental indicators, such as emissions of SOx, NOx, CO, CO_2, and particulates.

The model analysis consisted of first developing the Business-As-Usual (BAU) scenario, where the model was designed to represent the energy system of the economy from 1990 to 2020, based on the current official policies of the Chinese government. The Enhanced Environmental scenarios were then developed, incorporating various mitigation options (focusing on mitigation of SO_2 emissions), and developing a package of policies to ensure the implementation of the mitigation options. The Enhanced Environmental scenarios described what could happen in the energy system if mitigation options and the corresponding recommended energy policies were undertaken.

Two alternative Enhanced Environmental scenarios were constructed. Scenario I assumed that the implementation barriers of the recommended energy policies still existed to a certain extent, and thus the behavior of consumers and producers were affected by market imperfections. Scenario II assumed that suggested policies were pursued under a well-established market mechanism. Correspondingly, consumers and producers chose the recommended mitigation options with a full knowledge of the future profile of costs and benefits, and implemented them instantaneously. The final task of the study was to suggest policy options.

LEAP classifies fuels entered into the model into 5 groups. Fuels included in the study are:

- Non-renewable (fossil) Primary Resources: coal, crude oil, natural gas/methane, and nuclear,
- Renewable Resources: hydro, wind, solar, and geothermal,
- Biomass Resources: firewood, crop residual, and animal wastes,
- Secondary Fuels: fine-washed coal, other-washed coal, low-sulfur coal, heat, honeycomb briquette, industrial briquette, coke, coking gas, gasoline, diesel/gas oil, residual /fuel oil, LPG/bottled gas, oil gas, biogas, and producer gas, and
- Electricity: electricity

The main components of the model were the sets of data entered in the Transformation and Demand modules. These components are explained below.

Transformation Module

The transformation module included 13 sub-modules: distribution, electricity generation, biogas digester, thermal heat production, gasification, coke making, oil refining, briquette production, coal mining, coal washing, coal-bed methane recovery, natural gas production, and crude oil production.

Distribution. The distribution module contained the data on process losses, for example, loss of electricity, heat, oil, etc. The primary supplies deducted with process losses gave the quantities available for final consumption.

Electricity Generation. In 1990, the base year of the study, fuels used for power generation included coal, residual/fuel oil, diesel/gas oil, mixed gas (natural gas/methane, coking gas, and oil gas), hydro power, geothermal, and, at a very small amount, wind and solar. Electricity generation from nuclear power was expected to begin in the year 2000. The study assumed that plants ran to full capacity. Electricity was also derived from the cogeneration process, with heat being a co-product. There was no exportation or importation for heat. For electricity, the surplus would be exported and the shortfall of electricity demand in the economy would be imported. Electricity was used for lighting and in electric appliances in the residential sector, in electric motors and electric equipment in the agricultural sector, in all industrial sub-sectors, in both passenger and freight rail transports, in the building sector, and in the service sector.

Biogas Digesters. The feedstock fuel for biogas digesters was animal waste. The output fuel was biogas for use in the rural residential areas.

Thermal Heat Production. The principal input used in thermal heat plants was coal. The other inputs included oil (residual /fuel oil) and gas (natural gas and coking gas). The output from the plants was heat, to be used for space heating in the urban residential sector, in the ferrous metal industry, chemical industry, light industry, other industries, for its own use in the power sector, and for commercial uses in the service sector.

Gasification. The gasification module was separated into two types. Type 1 began operation in 1990 and stopped in the year 2000, when type 2 began. The difference between type 1 and type 2 was due to the feedstock used in the process. Type 1 gasification used raw coal as the principal feedstock (23.8 percent) with the other fuels being residual/fuel oil (19.7 percent) and coke (13.5 percent), whereas type 2 used fine-washed coal as the main feedstock (60 percent) with other fuels being residual/fuel oil (30 percent) and coal (10 percent). In addition, type 2 gasification had higher efficiency—60 percent efficiency as compared to 53 percent efficiency of type 1. The output from gasification was producer gas, to be used in the industrial sector.

Coke Making. The coke making module was separated into existing ovens and new ovens. New ovens would replace the existing ovens in the year 2000. Feedstock fuels for existing ovens were coal and fine-washed coal. For the new ovens, only fine-washed coal would be used. Coke was used as a fuel in the industrial sector, that is, ferrous metal, non-ferrous metal, chemical, light, machinery, and other industries.

Oil Refining. Oil refining took crude oil as feedstock to produce oil products.

Briquette Production. The feedstock for briquette production was coal. The output from the process included industrial briquettes and honeycomb briquettes. Honeycomb briquettes were used in briquette stoves for cooking and space heating in the residential sector. Industrial briquettes were used in the industrial sector, such as in boilers.

Coal Mining, Coal-Bed Methane, and Coal Washing. Coal mining was separated into three types—rural collective mines, local state-owned mines, and ministry-owned mines. Coal was used for cooking and space heating in the residential sector, in the industrial sector such as in boilers, in buildings, and in the service sector. Coal was also used in coke making. Some portion of coal, in addition to coke, was washed in the coal washing process to make fine-washed coal (which had high energy content, that is, 26.4 GJ/ton) and other washed coal (which had low energy content, that is, 8.37 GJ/ton). Fine-washed coal was used as feedstock in the gasification process. Other washed coal was used in the other industry sub-sector of the industrial sector, and in the service sector.

Natural Gas Production. The output was natural gas/methane to be used in the residential, industrial, building, and service sectors.

Crude Production. The output was crude oil to be fed into oil refineries to produce petroleum products.

End-Use Sector

The model comprised of six end-use sectors: residential, agricultural, industrial, transport, buildings and services. Each end-use sector was divided into sub-sectors, end-uses, and devices.

Residential Sector. The residential sector was divided into two sub-sectors—urban and rural households. The urban energy demand was comprised of 5 end-uses—cooking (using coal, honeycomb briquettes, natural gas, coking gas, and LPG), hot water (using natural gas, LPG, and coking gas), space heating (using coal, honeycomb briquettes, coal boiler, and heat), lighting (using electric bulbs), and electric appliances (using electricity). The rural energy demand was disaggregated into 6 end-uses—all biomass uses (including firewood, crop residue, biogas, and animal waste), cooking (using coal, honeycomb briquettes, and LPG cookers), hot water (using LPG), space heating (using coal, briquette stoves, and coal boilers), lighting (using electric bulbs and kerosene lamps), and electric appliances (using electricity).

Agricultural Sector. The demand in the agricultural sector was divided into landing, fishing, and sideline production. The demand for landing included cultivation (using diesel/gas oil tractors), and irrigation and drainage (using diesel motors and electric motors). The demand for fishing had a single end-use category with one device—diesel ships. The demand for sideline production also had a single end-use category with fuels including coal (for boilers), diesel/gas oil (for tractors), electricity (for electric equipment), and residual/fuel oil (for boilers).

Industrial Sector. The industrial sector was disaggregated into 9 sub-sectors—ferrous metal, cement, building materials, chemical, non-ferrous metal, light industry, machinery, supply own use, and other industries. The ferrous metal industry had a single end-use category for which fuels/devices used were coal boilers, coal kilns, coke, residual/fuel oil, electricity, heat, coking gas, and natural gas. The cement industry was divided into dry and half dry, machinery, old dry, horizontal, and other processes, for which each end-use consumed coal and electricity. The building material industry included brick and tiles (using coal and electricity), glass (using coal, residual/fuel oil, and electricity), and others (using coal, residual/fuel oil, natural gas, and electricity). The chemical industry included fertilizer (consuming coal, coke, natural gas, residual/fuel oil, electricity, and heat), and chemical (consuming coal, coke, natural gas, residual/fuel oil, oil products, electricity, and heat).

The sub-sector called "supply own use" included four activities: coal mining (using coal boilers, oil products, and electricity), power generation (using heat, electricity, and oil products), oil and gas exploration (using coal boilers, crude oil, residual/fuel oil, natural gas, electricity, and oil products), and oil refinery (using residual/fuel oil, electricity, and oil products). The non-ferrous metal industry had a single end-use category, which consumed coal, coke, oil, electricity, and natural gas. The light industry had a single end-use category, which consumed coal (for boilers), heat, coke, residual/fuel oil (for boilers), natural gas, electricity, coking gas, and oil products. Both the machinery industry and the other industries also had a single end-use category. Fuels used in the machinery industry were coal, coke, residual/fuel oil, diesel/gas oil, oil products, natural gas, and electricity, whereas fuels utilized in the other industries were crude oil, natural gas, other-washed coal, heat, coke, coking gas, electricity, oil, LPG, producer gas, and oil products.

Transport Sector. The transport sector was separated into passenger transport, freight transport, motorcycle transport, and private car transport. There were four modes of passenger transport: rail (using coal, diesel/gas oil, and electricity), road (using diesel/gas oil, and gasoline), water (using residual/fuel oil), and air (using diesel/gas oil). Freight transport included rail (using coal, diesel/gas oil, and electricity), road (diesel/gas oil and gasoline), water (using diesel/gas oil), air (using diesel/gas oil), and pipeline (using electricity). Motorcycle and private car transport were not disaggregated by end use. The fuel used for motorcycles and private cars was gasoline.

Building Sector. Fuels used in the building sector were coal, crude oil, residual/fuel oil, natural gas, and electricity. There was no disaggregation into sub-sector or end uses.

Service Sector. The service sector was divided into commercial and other services. The commercial sub-sector consumed coal, heat, residual/fuel oil, electricity, and LPG. The other services consumed coal, other-washed coal, natural gas, residual/fuel oil, electricity, coking gas, heat, and oil products.

Projection Methodologies

Energy Demand

Energy demand estimation and projection were carried out using the LEAP model, based on the following factors: driving activities, shares of each end-use in total demand, shares of each device in an end-use, and energy intensities of the device. For example, the demand for firewood in the rural residential sector was estimated by multiplying total residential households times percentage of rural households in total residential households, percentage of rural households that consumed biomass, shares of firewood in total biomass consumption, and energy intensity of a firewood stove. The activity levels and energy intensities for future years can be projected by the model using one of the three different methods—interpolation, growth rate, and driver and elasticity. The study used the interpolation method to forecast most of the activities and energy intensities. The driving activities used in the model are listed in Table 3.31.

Table 3.31: List of Driving Activities for Energy Demand in the PRC End-Use Sector

Sector	Driving Activities
Residential Sector	Numbers of households
Agricultural Sector • Landing • Fishing • Sideline production	 Total landing area Electricity consumption Gross output
Industrial Sector	

• Ferrous metal • Cement • Building materials • Chemical • Non-ferrous • Light industry • Machinery • Supply own use • Other industries	Steel production Cement production Total brick and tile production, total glass boxes, and gross output of other building materials Total demand for fertilizer and total demand for other chemicals Metal production Gross output Gross output Coal production, total power generation and total oil production Gross output
Transport Sector • Passenger • Freight • Motorcycles • Private cars	 Passenger-kilometer Ton-kilometer Number of motorcycles Number of cars
Building Sector	Gross output
Service Sector • Commercial • Other services	 Gross output Gross output

The study mentioned that the forecasting methods used included expert judgement, content analysis (entailing a review and analysis of information content carried through various media with respect to emerging social trends), trend analysis (linear or logarithmic projections of historical trends), end-use forecasting (the product of the number of energy-using devices and the efficiency of those devices, taking into account growth in device stocks over time, the changes in device efficiency and the emergence of new technologies), and the multi-approach combination (two or more methods combined).

Resource Supply

The availability of all energy resources was determined for 1990—with or without additions in the later years. Crude oil reserves were determined in 1990 with no reserve additions, but imports were available. Natural gas and coal reserves were determined, and reserve additions were specified for the years 2000, 2010, and 2020. The importation of natural gas and coal were, however, not allowed. All renewable energy supplies were determined for 1990 with an assumption that imports were not available.

Costs

The information on costs (for example, resources costs, production costs, capital costs, etc.) is optional in LEAP. LEAP allocates energy resources in the end-use sectors and energy inputs into transformation processes based on the pre-determined variables (such as shares of each end-use in total demand, shares of each device in an end-use, energy intensities of the device, plant efficiency, and capacity factor), and it is not based on costs. The information on costs will be required if the comparative costs and benefits among different scenarios are desired.

Renewable Energy in the PRC LEAP Model

The renewable energy resources included in the study were hydro, wind, solar, geothermal, and biomass. Hydro resources, wind, solar, and geothermal were used for power generation. Biomass included animal waste, firewood, and crop residue. Biomass was used as a direct fuel in the rural residential sector, such as for cooking and heating. Animal waste was also used as a feedstock fuel in biogas digester, to produce biogas for cooking in the rural households.

Hydro, Wind, Solar, and Geothermal

The electricity module of LEAP's Transformation program required only basic technical data, for example, plant efficiency, base-year output, total capacity, maximum capacity factor, and plant lifetime. The assumptions regarding the use of hydro, wind, solar,[14] and geothermal for power generation are shown in Table 3.32. The efficiencies of hydro, wind, solar, and geothermal power plants were assumed to be the same. The efficiency was assumed to increase from 31.3 percent in 1990 to 38.4 percent in 2020. Maximum capacity factor of each plant remained constant over time. The power generation from wind and solar in 1990 was relatively small; the data was thus entered in the model as zero.

Table 3.32: Assumptions for Hydro, Wind, Solar, and Geothermal for Power Generation

	1990	2000	2010	2020
Hydro				
Efficiency (%)	31.3	34.1	37.2	38.4
Base-year output (10^6 MWh)	126.4			
Total capacity (MW)	36,040	66,500	100,000	138,000
Maximum capacity factor (%)	45.7	45.7	45.7	45.7
Plant lifetime (years)	40	40	40	40
Wind				
Efficiency (%)	31.3	34.1	37.2	38.4
Base-year output (10^6 MWh)	0			
Total capacity (MW)	10	1,000	4,000	10,000
Maximum capacity factor (%)	22.8	22.8	22.8	22.8
Plant lifetime (years)	50	50	50	50
Solar				
Efficiency (%)	31.3	34.1	37.2	38.4
Base-year output (10^6 MWh)	0			
Total capacity (MW)	0.30	80	1,000	5,000
Maximum capacity factor (%)	28.5	28.5	28.5	28.5

Plant lifetime (years)	50	50	50	50
Geothermal				
Efficiency (%)	31.3	34.1	37.2	38.4
Base-year output (10^6 MWh)	0.10			
Total capacity (MW)	21.0	60	1,000	150
Maximum capacity factor (%)	42.9	42.9	42.9	42.9
Plant lifetime (years)	50	50	50	50

Biomass

The use of biomass in the residential sector is shown in Figure 3.13

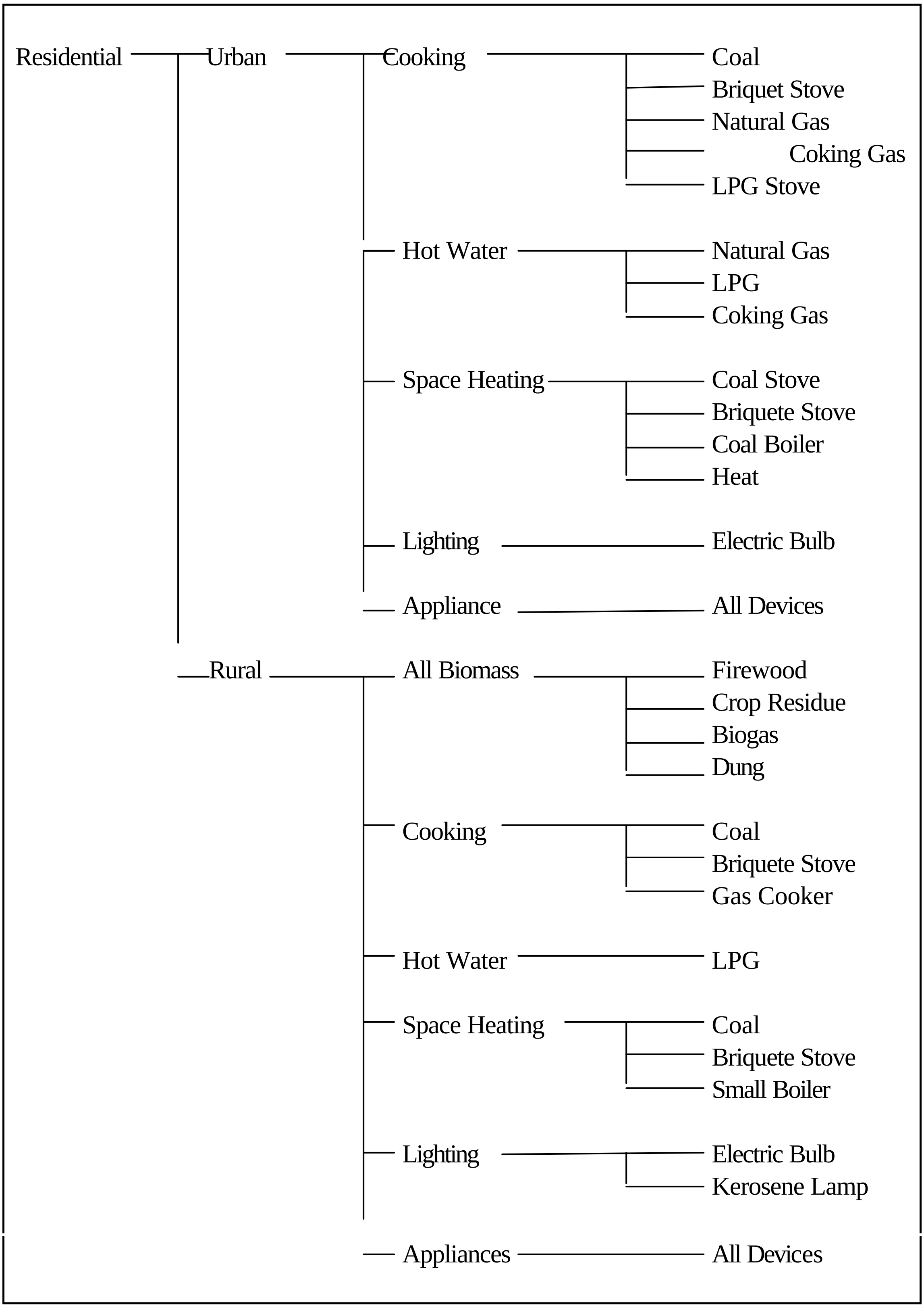

Figure 3.13: Demand Tree for the PRC Energy Consumption in the Residential Sector

Biomass included firewood, crop residues, and animal waste. The availability of each type of biomass was assumed at 1 trillion tons. Biomass was used in the rural residential sector. Animal waste was also used as a feedstock fuel into biogas digester to make biogas available for use in the rural residential. Only domestic biomass supplies were available for consumption. There was no importation of biomass.

In 1990, 80 percent of rural households consumed biomass. The study assumed that the percentage of households consuming biomass would lower to 73 percent in 2000, 70 percent in 2010, and 68 percent in 2020. Of the total biomass consumption in 1990, 48 percent was firewood, 47 percent was crop residues, 3 percent was biogas, and 2 percent was animal waste. These shares were changed during the period 2000 to 2020, in which the share of crop residues decreased from 47 percent during 1990–2010 to 44 percent in 2020, the share of animal waste increased from 2 percent in 1990 to 8 percent in 2020, and the share of biogas was zero since 2010 (see Table 3.33).

Table 3.33: Shares of Biomass in the PRC

Unit: (%)

	1990	2000	2010	2020
Firewood	48	48	48	48
Crop residues	47	47	47	44
Animal Waste	2	3.5	5	8
Biogas	3	1.5	0	0

The assumptions for energy intensity of biomass stoves are listed in Table 3.34.

Table 3.34: Energy Intensity of Biomass Stoves in the PRC LEAP Model (Business-As-Usual Scenario)

Unit: TCE per household

	1990	2000	2010	2020
Firewood	1.75	1.66	1.57	1.48
Crop residues	1.75	1.66	1.57	1.48
Animal Waste	1	1	1	1
Biogas	1	1	1	1

The efficiency of biogas digester was assumed at 50 percent. There was no breakdown into different types of digesters.

Although LEAP contains a detailed Biomass program that can be used for inter-regional allocation of wood and other biomass requirements (as described in Chapter 2), it was not used in this study.

Key Determinants of Renewable Energy Penetration in the PRC

Due to the nature of LEAP, the penetration rate of fuel must be pre-specified outside the model. Variables such as costs and availability among fuels were not used to determine fuel choices. The PRC study determined the penetration rates of fuels exogenously and they were entered in the model for the BAU scenario and the Enhanced Environmental scenario as described below.

Hydro Resources

In the BAU scenario, the penetration of hydro resources in the economy was based on the assumption that 35 percent of hydropower resources would be developed by 2020. Based on this assumption, hydropower capacity would expand from 36 GW in 1990 to 66.5 GW in 2000, 100 GW in 2010, and 138 GW in 2020. The study estimated power generation from hydro in the BAU to be 404,050 GWh in 1990, 781,120 GWh in 2000, 1,076,730 GWh in 2010, and 1,439,450 GWh in 2020. This result revealed the highest penetration rate for hydropower to occur during 1990 to 2000, at an average of 9.3 percent per annum. The penetration rates lowered during 2000 to 2010 and 2010 to 2020, to an average of 3.8 percent per annum, and 3.4 percent per annum, respectively.

In the Enhanced Environmental scenario, one of the mitigation options was to substitute hydropower for traditional coal-fired power. The study defined two scenarios regarding hydropower capacity expansion. Scenario I represented *suitable development prospects* and assumed that the hydropower installed capacity would increase to 80 GW in 2000, 120 GW in 2010, and 160 GW in 2020. Scenario II represented *maximum development prospects* and assumed that hydropower installed capacity would increase to 80 GW in 2000, 130 GW in 2010, and 184 GW in 2020. The power generation from hydropower in Scenario I was estimated to increase at an average of 13.3 percent during 1990 to 2000, 3.8 percent during 2000 to 2010, and 2.9 percent during 2010 to 2020. The power generation from hydropower in Scenario II was estimated to increase at 13.3 percent during 1990 to 2000, 4.9 percent during 2000 to 2010, and 3.7 percent during 2010 to 2020.

The estimated power generation from hydropower in all three cases is shown in Table 3.35.

Table 3.35: Power Generation from Hydro Resources in the PRC (Business-As-Usual and Enhanced Environmental Scenarios)

Unit: (000) GWh

	1990	2000	2010	2020
BAU Scenario	404.05	781.12	1,076.73	1,439.45
Environmental Scenarios				
Scenario I	404.05	939.69	1,292.08	1,668.93
Scenario II	404.05	939.69	1,399.75	1,919.27

Wind, Solar, and Geothermal

The energy input for electricity generation is shown in Table 3.36. Wind, solar, and geothermal resources were predicted to remain a small portion of total power generation. The use of wind was expected to increase over 20 percent per annum during the years 2000 to 2010 and over 10 percent per annum during the years 2010 and 2020. The use of solar energy was expected to double each year during 2000 to 2010, and to increase over 30 percent per annum after the year 2010. However, their shares combined would still be less than one percent of total electricity generation in the PRC. Geothermal was an insignificant source of power, and it did not have high potential for future power generation.

Table 3.36: Energy Input for Electricity Generation in the PRC (1990-2020)

Unit: (000) GWh

	1990	2000	2010	2020
Natural gas/methane	7.67	24.67	42.41	171.18
Diesel/Gas oil	7.14	83.28	127.23	184.88
Residual/Fuel oil	70.90	85.47	131.89	185.04
Crude Oil	7.01	0	0	0
Coal	1,528.89	2,918.63	4,587.79	6,019.59
Other-Washed Coal	24.37	46.42	72.62	97.36
Coking Gas	2.88	9.25	15.90	0
Oil Gas	8.63	27.76	47.71	0
Nuclear	0	51.49	187.06	541.95
Hydro	404.05	781.12	1,076.73	1,439.45
Wind	0	5.86	21.49	52.04
Solar	0	0.59	6.71	32.53
Geothermal	0.32	0.66	1.01	1.47
Total Generation from Renewable Energy	**404.37**	**788.23**	**1,105.94**	**1,525.49**
Total Electricity Generation	**2,061.86**	**4,035.20**	**6,318.57**	**8,725.49**

Biomass

The study assumed a lower penetration of biomass in the economy over time. In the BAU scenario, the growth rate of biomass consumption was assumed to gradually diminish as end-use efficiency improved and coal became more accessible. The shares of biomass in total economy's energy demand were expected to decline from 26.3 percent in 1990 to 19.5 percent in 2000, to 14.9 percent in 2010, and 11.2 percent in 2020. Regarding the rural energy demand, biomass was expected to contribute less over time, from about 82.2 percent in 1990 to 79.3 percent in 2000, 75.6 percent in 2010, and 69.4 percent in 2020. The consumption of firewood, animal waste, and crop residue was expected to decline over time. Only biogas consumption would increase. After the year 2000, animal waste would not be used directly for cooking, but it would only be used as a feedstock to produce biogas. The projection of biomass consumption in the PRC is shown in Table 3.37.

Table 3.37: Projected Biomass Consumption in the PRC in the Business-As-Usual Scenario (1990-2020)

Unit: Billion GJ

	1990	2000	2010	2020
Biogas	0.09	0.17	0.24	0.36
Firewood	3.81	3.79	3.64	3.24
Animal waste	0.14	0.07	0	0
Crop residue	3.73	3.72	3.57	2.97
Total Biomass	**7.77**	**7.75**	**7.45**	**6.57**
Total Energy Demand	**29.53**	**39.75**	**50.08**	**58.63**

In the Enhanced Environmental scenario, two mitigation options relating to biomass were included. One option was to assume, in both scenarios I and II, that by 2010 commercial biomass-saving stoves with 35 percent heating efficiency would replace all past manual biomass-saving stoves with 25 percent heating efficiency. The other mitigation option was to assume that surplus biomass, which was accessible in the future subtracted from biomass consumption in BAU, would replace raw coal. The crop residues available for rural household consumption was estimated to be about 122.5 MTCE. In addition, about 276 MTCE of firewood could be provided by 2020, by implementing a tree-planing program on a large scale. The Enhanced Environmental scenario thus assumed higher shares of households consuming biomass than in the BAU scenario, that is, 80 percent in 2000, 85 percent in 2010, and 90 percent in 2020. Of total biomass consumption, firewood was assumed to account for 50 percent in 2000, 55 percent in 2010, and 60 percent in 2020; and crop residue was expected to take a share of 45 percent in 2000, 40 percent in 2010, and 32 percent in 2020. Due to the higher efficiency of biomass stoves in the Enhanced Environmental scenarios, the energy intensity of firewood and crop residue per household was assumed to be lower than the BAU: 1.577 TCE in 2000, 1.403 TCE in 2010, and 1.23 TCE in 2020.

Table 3.38 shows the projection of biomass consumption in the PRC. The results showed an increase in total biomass consumption in the Enhanced Environmental scenario as compared to BAU scenario. The share of biomass in total energy demand in the Enhanced Environmental scenario was expected to be 20.9 percent in 2000, 17.0 percent in 2010, and 13.1 percent in 2020.

Table 3.38: Projected Biomass Consumption in the PRC in the Enhanced Environmental Scenario (1990-2020)

Unit: Billion GJ

	1990	2000	2010	2020

Biogas	0.09	0.18	0.29	0.48
Firewood	3.81	4.11	4.53	4.45
Animal waste	0.14	0.08	0	0
Crop residue	3.73	3.70	3.30	2.37
Total Biomass	**7.77**	**8.07**	**8.12**	**7.30**
Total Energy Demand	**29.53**	**38.62**	**47.78**	**55.68**

3.5 CONCLUSION

Each economy was faced with the same problems, though in varying degrees, when modeling renewable energy. First of all, renewable energy was expected to have a declining contribution in the economy's energy mix as industrialization gave rise to the demand for higher quality energy resources. Therefore, because of time and budget constraints in doing research, the economies did not look in detail at renewable energy for their economy energy models.

The limitation in modeling renewable energy was also influenced by the fact that necessary information to model renewable energy, such as resource data, technology characterization, technology performance, and costs, was not available to most economies. In all cases, the base case or business-as-usual scenario follows the government's energy plans. If there are no government plans to implement renewable energy projects, a modeler will not volunteer to include them in his/her model. In the mitigation scenario, although the modelers are not precluded from suggesting renewable energy technology options, if the economy has not already completed detailed resource assessments and economy specific renewable energy technology cost estimates, the modeler as part of his/her work could not be expected to develop the needed information.

The review of the four case studies—Thailand, Indonesia, the Philippines, and the PRC—led to the same conclusion that, although renewable energy supplies were expected to increase in the future, the share of renewable energy in terms of total energy supply was expected to decline over time—from between 25 percent to 42 percent in the past to be between 8 percent to 14 percent of total primary energy (see Table 3.39). This decrease in market shares for renewable energy occurred, in large part, because traditional biomass fuels were replaced by high quality commercial fuels. Thus a challenge for energy models is to demonstrate how traditional fuels such as biomass can be cost effectively converted into high quality fuels such as gas or electricity.

Table 3.39: Projection of Renewable Energy Supplies in the Reviewed Economies

	Total Renewable Energy Supply (PJ)	Renewable Energy As Percentage of Total Primary Energy

Thailand	503.5 in 1994 779.2 in 2030	25.5 in 1994 8.4 in 2030
Indonesia	1,140 in 1991 2,240 in 2021	35.3 in 1991 14.4 in 2021
The Philippines	385.5 in 1990 721.4 in 2020	41.5 in 1990 18.9 in 2020
China	9,310 in 1990 12,440 in 2020	25.3 in 1990 15.1 in 2020

In addition, based on the economies' forecast, it appeared that the future use of renewable energy in traditional applications such as biomass consumption in the residential sector (for example, for cooking and heating) would decrease. The renewable energy technologies that had the highest potential to penetrate into the economies were those for power generation, such as hydropower, wind, and solar energy.

Renewable energy was not the central focus of any of the four energy models reviewed in this study. The principal renewable energy resources included in all models were biomass and hydro. Geothermal resources were included in the Philippines, Indonesia, and the PRC. Wind and solar were included in the PRC in the base case scenario and in the Philippines in the mitigation scenarios. In both the PRC and the Philippines models, wind and solar were used for power generation only. The renewable energy technologies included in all economies were simple technologies. Their uses included power generation, cooking and ironing in the residential sector, and heat and steam production in the industrial sector. The renewable energy technologies included in the four models are summarized below:

- Power Sector: Hydro power, geothermal power, biomass steam electric, wind power, and solar power (photovoltaic),
- Residential Sector: Biomass stoves, biogas digesters, and charcoal ironing,
- Industrial Sector: Biomass cogeneration, biomass boilers, and biomass burners.

Other renewable energy technologies such as solar water heating, solar thermal power generation, or renewable-based transportation fuels were not considered in any model reviewed. There was no use of renewable energy technologies in the commercial, services, transport, or agricultural sectors.

The principal determinants of renewable energy penetration into the economies included cost of renewable energy relative to cost of its fuel competitor, the availabilities of resource supplies, the availabilities of renewable energy technologies (that is, the constraints on maximum and minimum capacities of renewable energy technologies), and the constraints on maximum annual demand growth rates for renewable energy technologies. The penetration rate of renewable energy in the PRC (using LEAP) was pre-specified outside the model.

END NOTES

[1] Duangjai Intarapravich. *Greenhouse Gas Mitigation Options in the Thai Energy Sector*. Office of Environmental Policy and Planning, Ministry of Science, Technology and Environment, Bangkok, Thailand, November 1996.

[2] Indonesian Agency for the Assessment and Application of Technology (BPPT), and Research Centre Juelich, Germany (KFA). *Environmental Impacts of Energy Strategies for Indonesia*. Indonesian-German Research Project, May 1993.

[3] Neither the case study from the US. Country Study Program on Climate Change nor from the Asia Least Cost Greenhouse Gas Abatement Strategy (ALGAS) project was available for review.

[4] The information was derived from *Environmental Impacts of Energy Strategies for Indonesia* (Ibid 2), and Agus Cahyono Adi, et.al. "Mitigation of Carbon Dioxide From the Indonesia Energy System", *Applied Energy,* Vol. 56, No.3/4, March/April, 1997.

[5] The year 1991 actually represents an average amount (such as, average production, average consumption) per annum during Repelita (National Development Plan) V which covers the period 1989-1993, and 1991 was the center year.

[6] The final consumption for the industrial sector included feedstocks and non-energy uses (gas, coke, and lubricants).

[7] All diagrams for Indonesia were taken directly from the MARKAL model. The diagrams are not clear when printed in black and white, because they are designed to be viewed only in color.

[8] The unit convention used in this report follows those used in the model. For example, the unit for annual fixed O&M cost for biomass boilers and burners for heat production was million $ per PJ, and the unit for annual fixed O&M cost for biomass steam process for power generation was million $ per GW.

[9] Asian Development Bank, Global Environment Facility and United Nations Development Programme. *Philippines: Asia Least-Cost Greenhouse Gas Abatement Strategy*. Asian Development Bank Publication Stock No. 070698, Manila, Philippines, October 1998.

[10] The international technical expert (ITE) for the project was Alternative Energy Development Inc. (USA) in association with ITEs from the Australian Bureau of Agricultural and Resource Economics (Australia), Asian Institute of Technology (Thailand), ICF, Inc. (USA), Hagler Bailly, Inc. (USA), and Lawrence Berkeley National Laboratory (USA). In the Philippines, the Environmental Management Bureau (EMB) of the Department of Environment and Natural Resources (DENR) was the National Counterpart Agency.

GEOSPHERE Technologies, Inc. of the Philippines was the consulting firm that implements the Philippine ALGAS Project.

[11] All diagrams for the Philippines were taken directly from the MARKAL model. The diagrams are not clear when printed in black and white, because they are designed to be viewed only in color.

[12] The unit convention used in this report follows those used in the model, for example, million $ per GW for annual fix O&M cost for biomass steam electric and million $ per PJ for annual fixed O&M cost for biomass burners.

[13] Modern Policy Research Center for Environment and Economy of NEPA, Energy Research Institute, Tsinghua University and UNEP Collaboration Center on Energy & Environment. *Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China, (Volume I).* Beijing: China Environmental Science Press, November, 1996.

[14] The PRC report used the classification of solar electric without making a distinction between solar thermal electric and solar photovoltaic electric. However, this study assumes that it was solar photovoltaic electric because of the relatively small unit sizes.

CHAPTER 4

ASSESSMENT OF THE CAPABILITIES OF ECONOMY-LEVEL ENERGY MODELS

In reviewing past studies and research on modeling and implementing renewable energy technologies, it appears that energy models have been developed in several different levels of technology complexity and modeling scope. For comparison, this study divides the models in three categories—technology-level, sector-level, and economy-level energy models. These three levels of models have different objectives. The technology-level model is used to select individual components of a single system. For example, selecting the most cost-effective system of wind turbines, PV panels, and battery back up, to make up a hybrid electric system that can generate electricity to satisfy the demand at a specific site, or for a specific application. The sector-level model, such as an electric utility model, is adopted to define the least-cost fuel mix for electricity generation to meet an economy's future electricity demand.

In comparison, the economy-level energy model is utilized to facilitate the decision to provide the economy energy supplies to satisfy the future energy demand at the least cost by taking into consideration issues such as energy security, energy diversification, and environmental related problems. Energy demand in the economy-level model covers demand for all fuels in all economic sectors. In addition, while in the electric utility model, the competition of renewable energy is with conventional fuels and demand-side management options, the use of renewable energy at the economy-level involves the competition of renewable energy among various applications in all end-use sectors.

Due to the difference in the model objectives, information required and factors influencing the decisions in the planning process are different among these models. This chapter discusses the principal factors affecting the three levels of energy planning—technology level, sector level, and economy level. There is a lack of set rules on what factors or resource attributes are required in an economy-level energy model to make it an ideal model for an economy's energy planning. Therefore, this study reviews technology-level and sector-level models (which are more detailed models) so as to provide performance benchmarks and an overall framework for establishing realistic expectations for the performance of renewable energy technologies in economy-level models.

This chapter also includes a discussion of the capabilities of the existing economy-level energy models—ENPEP, MARKAL, and LEAP—in capturing the key renewable energy factors and attributes. Although it was not expected that the economy-level models would contain the same level of detail as the technology-level and sector-level models, knowing how they address the basic issues on which the detailed models are constructed establishes a consistent framework for review and comparison.

4.1 TECHNOLOGY-LEVEL ENERGY MODELS

The technology-level model is less complex in terms of the number of issues involved than sector-level and economy-level energy models since the model is used to satisfy one single objective—an energy system design at a specific site and for a specific application. Unlike the other two models, a compromise does not need to be made among conflicting objectives. The data required to run the model is simply the data at the specific site (for example, resources supply and energy demand at the site where the system will be located) and the specific technology to be used (for example, hybrid system of wind and diesel).

The data required can be very detailed and difficult to obtain, for example, hourly wind data for multiple heights and multiple years for a specific site.

Examples of technology level renewable energy models are found in the work being conducted by the National Renewable Energy Laboratory (NREL) with the computer programs called HOMER, Hybrid2, and ViPOR.

- HOMER, the Hybrid Optimization Model for Electric Renewables,[1] is a design optimization model that determines the configuration, dispatch, and load management strategy that minimizes life-cycle costs for a particular site and application.

- Hybrid 2, the Hybrid Power System Simulation Model,[2] was developed by NREL and the University of Massachusetts. Hybrid2 is a detailed simulation model designed to study a wide variety of hybrid power systems. It allows users to conduct parametric analyses on certain cost parameters, such as fuel cost, discount rate, and inflation rate, to help determine how the value of certain parameters can affect the viability of the project. The users may conduct comparisons between differing hybrid possibilities and power solutions, and determine approximate costs. The hybrid systems may include three types of electrical loads, multiple wind turbines of different types, photovoltaics, multiple diesel generators, battery storage, and four types of power conversion devices.

- ViPOR, the Village Power Optimization Model for Renewables,[3] is used to design the least-cost village electrification system. The model assists rural electrification planners in determining which of the two alternatives—isolated systems or centralized systems—or a combination of the two is the least-cost option to electrify an unelectrified village.

The data required for the technology-level model is site specific resource information and energy demand. For example, the information used for a village power hybrid system design in HOMER includes:

Hourly profiles of the available renewable resources and loads. That could be actual hourly data or hourly profiles for typical days for each season. A season can be any number of consecutive weeks. The stochastic nature of both renewable resources and loads can be captured in the model by adding an hourly noise parameter and a daily noise parameter to the profiles.

Component characterization. Five types of components must be described: wind turbines, photovoltaic arrays, batteries, inverters, and diesel generators. Capital costs and equipment lifetime must be specified for each component. Two different types of wind turbines can be specified with different power curves and derating factors. PV has a fixed cost and a cost per kW. Efficiencies are specified for the inverter and diesel generators. The diesel parameters can be specified separately for small and large diesels to capture the economies of scale in that technology.

Other inputs. Other inputs required are such items as fuel prices and interest rates.

Given the required data, HOMER will produce results that provide the optimal sizes of different components. The PV system, diesel, and the inverter are specified in terms of rated kW. Batteries are specified in terms of kWh. The optimal number of each size of wind turbine is reported. HOMER will also generate all the energy flows for each hour of operation that is modeled, including the output of each of the energy sources, and the rate of (dis)charge and state of charge for the battery.

4.2 SECTOR-LEVEL ENERGY MODELS

A sector model generally examines a single energy sector in detail. For energy, the most widely used sector model is an electric utility model. The purpose of using a sector model like an electric utility model is to define the least-cost generation mix or the least cost next unit to an existing generation system. To meet this purpose, the information on various electric generating technologies, fuel options, and demand-side options are needed. Renewable energy resources provide options for electricity generation in addition to conventional supply-side and demand-side options. Therefore, the developers of electric utility models have attempted to design special model functions to capture the relevant attributes of renewable energy resources for a fair evaluation in selecting renewable resource and other resource options. It is, however, claimed that the capabilities of current utility planning models are inadequate with regard to renewable resources and there is no electric utility model that can capture all relevant renewable energy attributes.[4]

The recent study by NREL on *Modeling Renewable Energy Resources in Integrated Resource Planning*[5] addressed the attributes of renewable energy that were significant in the comparison of renewable energy resources with conventional supply-side and demand-side options for utility's integrated resource planning. This section is drawn from this NREL study in discussing those key attributes.

Capability and Availability

Capability refers to limits on the ability of a renewable energy resource to supply power in a given period under normal conditions. The capability of the resource may vary between time periods because of parameters such as seasonal variations in ambient temperatures that affect the capacity of a thermal unit. Capability includes peak capability, energy capability, seasonal profile, and hourly profile. Renewable energy resources such as hydro, solar and wind options typically have pronounced seasonal profiles. Solar and wind options also have pronounced hourly profiles.

Availability is defined as any reduction in the capability of a resource to generate electric power from what it is under normal conditions. Availability includes intermittence, forced outages, and maintenance requirements. The report referred to "intermittence" as random fluctuations in the energy source, which is distinct from whatever predictable patterns characterize the energy source.[6] For example, wind and solar are intermittent. Hydro capability depends on hydrological conditions. Sometimes it is difficult to differentiate between the resource's capability and the resource's availability. For example, wind and solar have seasonal and hourly profiles, and also have random fluctuations.

Wind and solar resources without storage or backup generation are very different from conventional utility generating resources in several respects, particularly in regard to their time dependence, short-term fluctuation of generation, and multiplicity of generating units.

Time Dependency

Wind and solar are time dependent. Electricity can be generated from them only if the wind blows and the sun shines. The hour-to-hour delivery of power from wind and solar resources is thus difficult to forecast, particularly on the long-term basis. Although timing of power delivery from solar and wind resources is difficult to predict, it needs to be taken into consideration when modeling renewable energy. Since peak load generation costs are much higher than base load generation, the case when maximum output from wind or solar coincides with the hours of peak demand, wind and solar resources could be much more cost effective than conventional fuels. Therefore, the time-dependent nature of these resources must be properly accounted for in the electric utility model to capture their effect on the dispatch of other system generation and on overall production costs. These costs determine the direct value of renewable resource options and other options on the system.

Short-Term Fluctuation

Renewable resources may exhibit considerable short-term fluctuations in power delivery. The short-term fluctuations may have different impacts on the generation system than on the T&D system. The impact of an intermittent resource on the generation system will depend on two issues: (1) the size of fluctuations in resource output relative to the customer load fluctuations that are already accommodated, and (2) the degree of correlation between the resource fluctuations and the load fluctuations. Regarding the first issue, the total amount of renewable resources subject to short-term fluctuation is likely to be small within the planning horizon of a utility. The renewable resource with the largest capacity and energy share is generally hydro, which is not subject to short-term fluctuations. On the second issue, it is likely that these minute-to-minute fluctuations will be largely uncorrelated. Therefore, when aggregated, the impact of short-term fluctuation on the generation system is negligible if the range of fluctuations is small enough relative to the rest of the system so that the rest of the system can absorb the fluctuations.

Short-term fluctuation may have a much greater impact on the T&D systems because the range of fluctuations is not so small relative to the loads on the T&D circuit. Storage capacity to accommodate short-term fluctuation or time-dependent generation that does not match load may be more beneficial on the scale of the T&D systems.

Multiplicity of Generating Units

Wind and solar resources tend to be built as aggregated projects of many small, independent generating sources. In the sense that one large unit has a higher variance of available capacity than several smaller units of the same aggregated capacity, one might conclude that renewable units inherently provide reliability benefits because of their multiple-unit nature. This is given the same forced outage rate, and assumed that outages of individual units are independent of others. However, the practical value of this benefit depends on the aggregate size of the renewable resources relative to the rest of the system. If the aggregate size of the renewable resources is much smaller than the rest of the system, the difference in reliability impact between a single unit and several small units is negligible.

Although it is likely that the routine equipment failure of individual units has little or no dependence on that of the other units, the energy availability of a collection of renewable units at the same site is likely to be dependent. The weather conditions at that site will be the driving factor in determining whether or not any units that are physically available will actually produce any power. Given the interdependence of the energy availability, it is difficult to say whether the multiple-unit nature of a renewable project provides any additional reliability benefits.

Location

Location is an extremely important parameter in energy planning because it determines the effect of using renewable energy on the total cost of future T&D reinforcements, on costs associated with losses, and on the overall reliability of service to a local area. If renewable energy is remote from loads, additional costs must be incurred to integrate that energy into the system and deliver the output of the resource to the load center. If renewable energy is on the customers' premises, distribution as well as transmission reinforcements could be deferred. In addition, if renewable energy is close to customer loads, a smaller portion of the output will be consumed by losses. Renewable energy installed at a substation or on customers' premises can improve local reliability even if they do not defer reinforcements.

Some renewable energy resources (such as wind and solar) can be distributed or dispersed for deployment at numerous locations close to customers and they thus help reduce T&D costs from the central station by reducing line losses, and/or averting transmission network upgrades that would otherwise be required. This concept is known as distributed utility, distributed resources, dispersed system planning, or distributed resource planning.

Although the distributed utility concept is expected to hold great promise for the use of renewable energy technologies, in actuality, all of the important cost elements involved are very complicated and not well understood. In fact, *The Energy Journal* recently dedicated a special issue to address various aspects and issues of distributed utility.[7] After reviewing all the papers, the journal's editors concluded that although distributed utility creates significant opportunities, they may be difficult to evaluate and develop. The competition between T&D expenses and distributed utility development involves difficult problems of lumpiness and flexibility of investments. Overall cost minimization is thus not easy to achieve. Also, considerable details need to be evaluated in particular case studies if distributed utility is to be realistically appraised.[8]

Modularity

Modularity is an advantage that some renewable resources have over many conventional resources. Modularity is defined by the incremental sizes of resources and the lead times required for adding them. This provides advantages to utilities by avoiding the temporary overcapacity that results from adding a large, new conventional resource. Utilities can add only enough modular renewable resources each year to exactly match load growth requirements, which should help reduce the utility's costs, and make the costs of renewable resources more competitive with conventional resources. Short lead times for constructing renewable facilities provide several advantages to utilities because of the uncertainty in future demand levels and fuel prices. Utilities can delay making decisions on adding resources until additional information about uncertain factors is known.

Risk Diversity

Adding renewable energy into a portfolio of conventional fuels provides diversity benefits to utilities. The key concept underlying diversification in electric resource planning includes two dimensions of independence—cost and availability. A resource contributes to cost diversity if the cost of power from that resource is independent of the cost of other resources that represent a large portion of the utility's costs. A resource contributes to availability diversity if its availability is independent of conditions that could limit the output of large blocks of other resources. The costs of renewable energy are independent of conventional fuel costs. Using renewable energy can result in a system that is less sensitive to the uncertainty associated with specific fuel costs. The renewable energy supply is not subject to the supply of conventional fuels, so the renewable project provides availability diversity to the system.

The benefits of diversity depend on the magnitude of the risks. If future prices are stable, diversity provides little additional benefits to utilities. If fuel price or availability becomes more of a concern, the potential diversity benefits from renewable technologies will become more valuable and more important for inclusion in the analysis.

Although the focus of diversity typically is on fuel risk, a portfolio may also be technologically diverse if it contains a mix of technologies. Technology diversity encompasses any non-fuel risk that could be correlated between generating units. Environmental benefits could also be cited as an advantage of diversifying the resource portfolio. Environmental benefits could be considered through the inclusion of monetized environmental externalities as a complement to the financial risk issues captured by portfolio diversity analysis.

The report also mentioned other attributes which, although important, do not pose significant modeling problems in evaluating renewable energy. These attributes include dispatchability and costs. The reason is that dispatchability of renewable resources can be evaluated within the degrees of dispatchability afforded by conventional generation options. Regarding costs of renewable energy, they are covered by the same cost components as conventional resources. The key issue in modeling renewable energy is to ensure that all relevant cost components for renewable energy are taken into account and estimated on a consistent basis as costs of conventional energy that will be compared with.

The same study by NREL reviewed eleven utility planning models to examine their capabilities in addressing the above attributes. Those models were Delta, DYNAMICS, Electric Generation Expansion Analysis System (EGEAS) and IRP Workstation, Elfin, IRP-Manager, Integrated System for Analysis of Acquisition (ISAAC), Multi-Attribute Bidding System (MABS), Multi-objective Integrated Decision Analysis Model (MIDAS), PROMOD IV, PROSCREEN II / PROVIEW, and UPLAN III. The study found that none of these models was capable in addressing all relevant renewable energy attributes. Every model reviewed can address the "capability" attribute. MABS was the model that could capture most of the aforementioned attributes including capability, location, modularity, and risk diversity. ISSAC and MIDAS can address capability, modularity, and risk diversity. PROSCREEN II / PROVIEW can address capability, availability, and modularity. EGEAS/IRP Workstation and Elfin can capture capability and modularity. Delta can capture capability and location. UPLAN III can capture capability and availability, and DYNAMICS and IRP-Manager can address capability.

4.3 ECONOMY-LEVEL ENERGY MODELS

Economy energy planning focuses on broader issues than site specific energy supply or the least-cost electricity generation. The objective is to provide energy supply to meet the economy's energy demand while often taking into consideration such issues as energy security and environmental related problems. Energy supply and demand refer to all sources of energy and not only electricity. The concerned renewable energy technologies are for all end-use sectors where they are cost-effective as compared to options utilizing conventional fuels. In addition to the detailed technology information required for technology-level models, and resource attributes required for electric utility models, there are other factors that need to be considered in the economy-level models. These additional factors are the topic of discussion in this section.

Cost Factors

Cost is an important factor to determine the penetration rate of renewable energy technologies in an economy. Cost factors include both costs of conventional fuels and costs of renewable energy. Cost effectiveness of using renewable energy varies with changes in costs of conventional fuels. As costs of conventional fuels increase, so does the economic viability of renewable energy based systems. The costs of renewable energy must include costs incurred in all aspects of applying renewable energy, for example, equipment costs, installation costs, operating costs, and environmental costs (which are normally a benefit of using renewable energy). Because costs of both conventional fuels and renewable energy have changed over time, the model must also allow for adjustment of such changes.

Non-Cost Factors

There are other factors besides costs that affect the use of renewable energy and should be included in the ideal economy-level energy model. Failure to include these factors will overestimate or underestimate renewable energy penetration. At the governmental level, for example, a renewable energy technology might be promoted, though it is not the least cost option, because of a government policy to diversify the use of energy for security reasons. For consumers, a renewable energy technology might be chosen because of service quality. On the other hand, non-cost factors such as inappropriate energy regulations, inefficient permitting process to implement renewable energy systems, lack of resource assessment, and imperfect flow of information could post major barriers in renewable energy penetration in an economy.

Off-Grid or Grid-Connected Power Generation Options

The options facing economies when they want to electrify an unelectrified area are to use off-grid power generation or to use grid-connected power generation. The options for off-grid power generation could be stand-alone diesel generation, wind power generation, solar power generation, or a hybrid system of diesel, wind and/or solar. The grid-connected power generation option provides the choices of connecting a conventional fueled or renewable energy plant to a grid and transmitting the power through central T&D lines. By having renewable energy connected to the grid, the grid will supply power to the site loads when needed, or absorb the excess power from the renewable energy system when available.

The grid-connected power generation facility involves capital and generation costs from the new power plant plus transmission line costs, which could be very expensive. In remote or inaccessible areas, off-grid generation from renewable energy can be more cost-effective than installing T&D lines to carry electricity from conventional sources.

Rural electrification is in the development agenda of most economies. The choice between off-grid and grid-connected power generation needs to be made and the ideal economy-level energy model should facilitate this need.

Renewable Energy Technologies

While the central focus of electric utility planning has been with renewable energy technologies for power generation, economy-level energy planning should consider all potential renewable energy technology applications in all energy producing and consuming sectors. The economy-level energy model should have functions that can handle the specific characterization of high potential renewable energy technologies in order to have an appropriate balance of the various resource options.

For the purpose of examining the capabilities of the existing economy-level energy models in incorporating potential renewable energy technologies, this study classifies the principal renewable energy technologies into four groups—renewables for electricity generation, renewables for thermal energy, renewable transport fuels, and renewables for direct use.

Renewables for Electricity Generation

Renewable energy based electricity generation could be used for grid connected or off-grid electricity generation. The renewable energy technologies for grid connected electricity generation can be further separated into dispatchable and nondispatchable technologies. Dispatchability refers to the degree of control the utility has over hour-by-hour and minute-by-minute output of a resource. A nondispatchable resource is a resource which the utility has no control over electricity production. The output from a nondispatchable resource can be taken out whenever it is generated. A full dispatchable resource is one over which the utility has complete control over the output of a resource from no production to production at full capacity. In this study, biomass, municipal solid waste, landfill gas, hydropower, and geothermal are treated as being dispatchable. However, it should be recognized that the dispatchability is a function of the resource base, and situations could occur where these technologies are nondispatchable. Wind and Solar with storage or back-up generation are also classified as dispatchable resources. Nondispatchable resources are wind, and solar PV without storage.

The renewable energy technologies for off-grid electricity generation include applications such as hybrid village power or stand-alone PV and/or wind. Most hybrid systems combine diesel generators with PV or wind. In some hybrid designs, batteries are used in addition to the diesel generator. The batteries meet the daily load fluctuation, and the diesel generator takes care of the long-term fluctuation. Stand-alone PV power systems are used to provide electricity to residential areas, for water pumping in the irrigation area, and for telecommunication.

Renewables for Thermal Energy

A number of renewable energy technologies provide thermal energy for uses such as hot water heating or industrial process heat. Examples include solar flat plate collectors, solar focusing collectors, biogas digesters, and biogasification.

Solar collectors are used to collect thermal energy in the form of solar radiation for use at high or low temperatures. Low temperature applications include water and space heating for commercial and residential buildings. An example of a high temperature application is the production of electricity using a steam-turbine-driven electrical generator.

The use of dung or sewage as feedstock into a digester to produce biogas provides benefits of obtaining additional energy and cleaner fuel, and at the same time disposing of unpleasant wastes. For biogasification, its benefit is that the obtained gaseous fuel is much cleaner than biomass since undesirable chemical pollutants can be removed during the processing. In addition, a gaseous fuel is more versatile than solid fuel. Biogas obtained from a digester or gasification process is then combusted to obtain the desired thermal energy.

Renewable Transport Fuels

Renewable based fuels can be a source of energy for transport. Biofuel is any solid, liquid or gaseous fuels produced from organic materials, either directly from plants or indirectly from industrial, commercial, domestic, or organic wastes. Liquid or gaseous biofuel can be used as transport fuels. An alternative to biofuel is the use of batteries and PV for battery charging. At present, the use of PV/batteries is still an expensive option and can store only enough energy for a limited range of travel between recharges. However, developments in PV and battery technology may improve the performance and economics of PV/battery vehicles in the future.

Solar energy based hydrogen is another option for transport fuels. Hydrogen has the advantage that when burned in air, it does not produce CO_2, CO, SO_2, or volatile organic compounds, unlike the combustion of fossil fuels. At present, most hydrogen is produced by conversion from natural gas using steam. In this process, methane is re-formed into hydrogen and has CO_2 as a by-product. However, solar energy based hydrogen can be produced without any CO_2 as a by-product. Currently, the price of hydrogen from renewable energy cannot compete with other fuels. However, it is expected that its price will decrease in the future.

Renewables for Direct Use

Renewables for direct use include, for example, the use of biomass for residential cooking and heating, and biomass for industrial process heating. Here, important advances have been made with increasing the efficiency of biomass stoves.

Examples of the renewable energy technologies based on the classification explained above are shown in Table 4.1.

Table 4.1: Classification of Renewable Energy Technologies

1. Renewables for Electricity Generation
   a) Grid-Connected Electricity Generation
      i) Dispatchable
         - Hydropower, geothermal
         - Biomass[1/], municipal solid waste, landfill gas
         - Solar thermal with thermal storage
         - Wind and solar PV with storage
      ii Nondispatchable
         - Wind
         - Solar PV

- ♦ Central
- ♦ Roof-top

b) Off-Grid Electricity Generation
  i) Hybrid village power with diesel
  ii) PV housing
  iii) PV pumping

2. Renewables for Thermal Energy
   a) Solar thermal collector
   b) Biogas digester
   c) Biogasification

3. Renewable Transport Fuels
   a) Biofuels
   b) PV/battery
   c) Solar hydrogen

4. Renewables for Direct Use
   a) Biomass for cooking and heating
   b) Biomass for industrial process heating

Note: [1/] Including cogeneration and co-firing

4.4 MODELING RENEWABLE ENERGY ATTRIBUTES AND FACTORS IN THE EXISTING ECONOMY-LEVEL ENERGY MODELS

This section discusses the capabilities of the economy-level energy models in capturing the detailed technology information, renewable energy attributes, and the key concerned factors for economy energy planning. The discussions focus more on ENPEP and MARKAL. Since LEAP is an accounting model and does not make decisions among technologies, most of these attributes and factors do not apply to LEAP.

System Design

None of the three models—BALANCE, MARKAL, and LEAP—can be used to design a renewable energy based system. This is because they are not capable of dealing with key characteristics of renewable energy (such as resource intermittency), and of selecting a combination of system components for an energy system at a specific site. However, if the renewable energy systems were selected outside of the models, annual summaries of resource potential that are matched with various classes of renewable energy technologies could be included in the model simulation.

Capability and Availability

BALANCE and MARKAL can model renewable energy resources as either dispatchable or nondispatchable, whereas LEAP models all renewable energy resources as dispatchable generating units.

MARKAL identifies nondispatchable resources (such as wind and solar) as non-load following technologies (NLM). This class of technologies is used to define conversion systems that can meet base-load electric demands but are not forced to have equal day and night production rates, and can operate independently of the load.

Unlike MARKAL, BALANCE does not have a special function to separate dispatchable and nondispatchable resources. To model renewable resource as a nondispatchable unit in BALANCE, it is recommended that the user puts a decision node above the electric sector and then connects the output of the nondispatchable resource to that decision node rather than into the electric sector. In this case, the model uses the electricity from that unit (up to its maximum annual output) and then dispatches the remaining electric sector units to meet the balance of the load. Unless the electricity from the renewable energy process is small, to be accurate the user should adjust the shape of the load duration curve to account for the electricity that is met by the renewable process.

Nondispatchable resources are treated in LEAP as dispatchable generating units. The maximum capacity at which the resource can be operated in each period (for example, each year) must be entered in the model. The maximum capacity will be the total capacity expected to be available after taking into consideration the seasonal and hourly profiles and all interruptions from power generation such as short-term fluctuations. The capacity utilization will be an average usage of capacity in each period.

All three models basically run on a yearly basis and thus cannot modify the resource capability on an hourly basis (for short-term fluctuations) and cannot capture hour-by-hour power delivery. However, MARKAL can capture seasonal effects with the use of seasonal capacity-use factors (for the cases of demand devices or externally-managed technologies) or seasonal availability factors (for the case of conversion or process technologies). The seasonal factor represents the availability of installed capacity expressed as a function of time in use. Therefore, it can be utilized to separate the use of technologies during, for example, winter and summer times, and day and night times.

Factors such as peak supplying capability of the technology can be captured on a yearly basis in BALANCE and MARKAL. BALANCE could capture peak supplying capability by exogeneously estimating total electricity obtained from the system during the peak time for a whole year and linking this output to peak load generation. MARKAL could handle this problem by using “PEAK” tables. The data entered in PEAK tables is a fraction of total capacity of a technology available to supply peak demands for electricity or heat. For example, one might specify that a wind generator is available at 20 percent of peak demand for electricity.

Maintenance requirements can be captured in all three models by estimating the percentage of time that a unit is expected to be unavailable and subtracting this from the total generation time to estimate the maximum generation.

All three models can treat forced outage deterministically whereas more sophisticated utility expansion models treat it probabilistically.[9]

Although the common practice in modeling a renewable resource is to combine all units and all sites and treat them as one single source of renewable energy, all three models can handle a renewable energy project as an aggregate unit by site, or at a specific site as a small, discrete unit. None of the three models, however, can show the resultant impacts on system reliability.

Location

Though not being convenient to do, BALANCE and MARKAL can be used to make a broad location determination such as the trade-off between constructing a mine-mouth power plant or shipping the resource to the demand center. However, they cannot serve the objective of specific location selection for a new power unit. BALANCE and MARKAL will select the mix of resources for power generation for an economy based on costs, other determinants, and specified constraints. The decision to build a renewable based power plant at any specific location has to be made outside the models. The capacity of that renewable plant then can be entered into the models.

BALANCE, MARKAL, and LEAP cannot make least cost decisions for the development of distributed utility systems. The decisions related to the development of distributed utility systems involve tradeoffs not only among many small generation sources, but also between individual system dispatching costs and the cost of power transmission. In addition, distributed utility systems further involve difficult problems of lumpiness and flexibility of investments, which, along with the above problems, make it extremely difficult to analyze by a single model approach.

Modularity

BALANCE, MARKAL, and LEAP calculate a mix of future resources for a given load condition. The load is normally forecast with an assumption of perfect knowledge of future loads. The models will then estimate the mix of resource supply to be used to produce electricity to meet demand over the planning periods. Since the models assume perfect information on load, they reflect none of the benefits inherent in incremental size and short lead-time of renewable energy technologies.

Risk Diversity

The analysis of risk diversity involves the recognition that renewable energy systems are often not subject to fuel cost variation and fuel availability disruptions. This is especially true for resources such as wind and solar but less true for resources such as biomass, which require multiple steps for resource utilization. A typical way of dealing with uncertainty is to conduct scenario analysis, for which ENPEP, MARKAL, and LEAP can be used. However, MARKAL can capture risk and uncertainty in a more advanced way. MARKAL supports stochastics for resource prices/quantities, investment costs, demand levels, seasonal hydro, and emission limits. Probabilities can be assigned to any (or all) of these parameters to capture uncertainty. The result of this is that uncertainty is taken into consideration during a single model run and the appropriate "hedging" strategy identified.

Cost Factors

Cost factors can be included in BALANCE and MARKAL in determining fuel and technology choices. In addition, MARKAL includes the concept of Endogenous Technology Learning within the model. That is, the model allows reduction in technology costs and increases in penetration rates as experience is gained with the technologies. As a result, if a technology is going to be important in the future, the model can encourage early investment in the technology to gain the needed experience to force the price down so that when really needed, that technology is proven and cost-effective. For cutting-edge renewable energy technologies, this is an important consideration that can greatly help their competitiveness against conventional large-scale alternatives.

LEAP, however, does not take into account cost factors in determining fuel mix.

Non-Cost Factors

Specific non-cost factors cannot be included in BALANCE, MARKAL, and LEAP for fuel allocation. However, BALANCE allows the existence of the combined effects of all non-cost factors in determining an allocation of fuels. For MARKAL, the objective function can be designed to include a non-cost factor like security of energy supply or externality costs with the typical objective function of total system cost. With the objective function that accounts for supply security, for example, MARKAL provides a solution which is the balanced optimization of both total system cost and supply security indicators.

The other way to handle non-cost factors in MARKAL is through the use of hurdle rates. Hurdle rates represent the difference between what the model suggests is the economic way to do and what it is observed that people actually do. A government program to try to reduce barriers to implementation of renewable energy technologies, for example, could be expressed in the model by a reduced hurdle rate.

Off-Grid or Grid-Connected Power Generation Options

The choice of building off-grid or grid-connected power generation can be investigated in BALANCE by using scenario analysis. The scenarios, one with grid-connected, and one with off-grid renewable power generation, can be run to estimate the electricity costs of newly electrified areas. The two scenarios can then be compared.

One way to handle this issue in BALANCE is to first add a new electricity demand node in the energy network to represent total new electricity demand. For the scenario with grid-connected power generation, this new demand node is then linked to the allocation node from power plants. The high cost of new T&D lines that need to be built to connect from the power plants to the new demand can be captured by adding a processing node to represent new T&D.

For the off-grid power generation scenario, there will be no additional T&D cost, and thus there is no new T&D processing node. The new demand node will not be linked to the existing plants. Instead, it will be linked to the new power generating units. In this case, however, the off-grid system has to be fueled partly by the resources that are also used in other applications in the energy network so as to keep the off-grid generation connected with the entire energy network. An example of such a link would be when off-grid generation is a stand-alone diesel plant, or a hybrid system of wind, PV, and diesel, where diesel is also used by another application in the energy network which could be diesel power generation or diesel for transport. Since all possible off-grid opportunities in an economy are being modeled together as one demand unit, this does not preclude the possibility of off-grid connected renewable energy resources being part of the overall renewable energy portfolio.

In the case where the off-grid system is run by wind or PV for which the resources are totally separated from the energy network, the modeler could build a separate off-grid energy network to simulate the renewable energy system and compare this scenario with the economy energy network.

MARKAL has the capability to include multiple electric grids which either can or cannot be interconnected. The off-grid generation technologies are classified under decentralized generation system (DCN) where there are no transmission costs but distribution costs. The grid-connected generation technologies are classified under centralized system (CEN) where there are both transmission and distribution costs. In MARKAL, there is no need to add all the off-grid opportunities into a single demand unit. Instead, many independent opportunities can be set up as exist within the area of study. In addition, both the off-grid and grid-connected options can be linked to the same demand centers and the model decides which one is the least-cost option.

Renewable Energy Technologies

Renewables for Electricity Generation

Grid-Connected Electricity Generation

BALANCE and MARKAL can model renewable energy resources for grid-connected electricity generation as dispatchable or nondispatchable units. Hydropower, geothermal, biomass, municipal solid waste, and landfill gas, which are considered as dispatchable units, can be included in the energy network of BALANCE; each is entered as a separated renewable resource node. When coupled with storage, solar thermal, solar PV, or wind are also considered as dispatchable units and can be included in the energy network of BALANCE with pre-estimated total expected electricity output from the system. The added value that can occur by matching the maximum or peak renewable energy generation with peak load can be captured by establishing a resource node that estimates the electricity generation during the peak time of a year and connecting this resource node to peak load generation.

BALANCE can model nondispatchable renewable based grid-connected electricity generation by connecting the output of the nondispatchable renewable energy process directly to the decision allocation node, instead of to the electricity sector. The model does not differentiate between time-dependent resources with storage and without storage by default. Thus it is up to the modeler to ensure that the additional costs as well as the additional benefits of energy storage coupled to renewable energy technology are accounted for properly.

All renewable energy technologies for grid-connected electricity generation can be included in MARKAL in the class of centralized electricity generation (CEN) where transmission costs and distribution costs are included in the cost function. The case where maximum or peak renewable energy generation matches with peak load of demand can be handled in MARKAL by using "PEAK" tables and other refinement parameter (for example, PD(Z)(Y)) to shape the season/day and night contribution to the peak for external load managed technologies.

MARKAL distinguishes nondispatchable from dispatchable grid-connected electricity generation by treating nondispatchable renewable energy resources as non-load following generators (NLM). Technologies with and without storage can be differentiated in several ways. First, a system with storage would have a higher probability of contributing to the peak. Second, a system with storage increases the capital and operating costs. Lastly, in some cases, a system with storage might be considered a load-following technology.

Renewable energy technologies for grid-connected electricity generation can be included in LEAP's Transformation program. LEAP treats dispatchable and nondispatchable resources indifferently.

Off-Grid Electricity Generation

BALANCE can handle off-grid electricity generation by establishing a demand node to represent the expected off-grid demand. The off-grid energy supply is then obtained by setting a resource node to link to a conversion process and to be allocated to the off-grid demand node. As mentioned earlier, the off-grid supply system has to share at least one fuel with the economy energy network. Otherwise, an off-grid energy network has to be built separately from the economy-level energy network.

Off-grid electricity generation can be included in MARKAL by specifying the technology under the class of decentralized power generation (DCN) where distribution costs but not transmission costs are included in the cost function.

LEAP can model off-grid electricity generation by treating it as one of the detailed modules in the Transformation program.

Renewables for Thermal Energy

Examples of renewable energy technologies to produce thermal energy are solar thermal collectors, biogas digesters, and biogasification. In BALANCE, these technologies can be represented in its energy network by using conversion process nodes. Renewable energy resource nodes for solar energy, and biomass first need to be added to the network. The solar energy node will then be linked (as an input) into solar thermal collector conversion processes. The thermal energy output from the solar thermal collectors will be allocated to various demand nodes (for example, hot water, space heating, industrial process heating, etc.) as specified by the modeler. Similarly, biomass from the biomass resource node will be allocated to biogas digester and biogasification conversion processes, for which the thermal energy output will be allocated to relevant consumers. For example, thermal energy from biogas digesters is allocated to cooking demand and that from biogasification process is allocated to a gas turbine for power generation.

Renewables for thermal energy can be easily included in MARKAL by entering them under the "process technologies" set. The task of actually linking these technologies into the Reference Energy System is handled automatically by the naming of the individual energy carrier produced/consumed by the various processes. Therefore, no exchange nodes need to be introduced.

Similarly, renewables for thermal energy are included in LEAP by setting up a module in the Transformation program to represent the renewable thermal energy technology. Solar resource information, such as annual resource limits, needs to be pre-estimated and entered in the model.

Both MARKAL and BALANCE can accommodate the case where electricity backup is required for such applications as solar thermal hot water heating. In BALANCE, the ratio of solar to electricity usage on a yearly basis could be specified for the allocation node connecting to the hot water heating demand node. In MARKAL, the fractions of solar and electricity used as a proportion of total input are determined by using the "Input Energy Carrier Fraction" parameter.

Renewable Transport Fuel

Renewable energy used as transport fuels can be handled in BALANCE by establishing a renewable energy node to represent that transport fuel and linking the node to the conversion process to convert fuel to energy. The energy output from the conversion process is then allocated to relevant transport demand or devices.

Renewable transport fuel can be incorporated in MARKAL by adding the technology in the "process or demand technologies" sets. For LEAP, renewable transport fuel technology must be set up in the Transformation program, and data for the renewable transport fuel such as the annual resource limit and import availability is then required.

Renewables for Direct Use

The direct use of renewable energy such as burning biomass for residential cooking and heating can be easily incorporated in the energy network of BALANCE and the MARKAL Reference Energy System. In BALANCE, this could be done by using a link to connect the biomass resource node to biomass conversion processes (for example, biomass stove) and to the allocation nodes of cooking and heating demands. In MARKAL, all technologies that are used to satisfy a final demand are classified as "demand technologies" where the data required is the energy efficiency of the demand device and the market allocation of the energy carrier for the demand device as proportion of total output.

Renewable energy for direct use can be entered in LEAP in an end-use in the Demand program and by specifying its percentage shares among other fuels in the same end-use.

4.5 CONCLUSIONS

Table 4.2 compares the capabilities of BALANCE, MARKAL, and LEAP in addressing relevant factors and attributes of renewable energy.

Table 4.2: Comparison of the Capabilities of BALANCE, MARKAL, and LEAP

	BALANCE	MARKAL	LEAP
System Design	No	No	No
Capability and Availability			
Peak capability	Yes	Yes	No
Seasonal and hourly profiles	No	Yes/No[1/]	No
Intermittence	No	No	No
Forced outage	Yes[2/]	Yes[2/]	Yes[2/]
Maintenance requirement	Yes	Yes	Yes
Multiplicity of units	Yes/No[3/]	Yes/No[3/]	Yes/No[3/]
Location			
Central stations	No	No	No
Distributed utility	No	No	No
Modularity			
Incremental size	No	No	No
Short-lead time	No	No	No
Risk Diversity	Yes/No[4/]	Yes	Yes/No[4/]
Cost Factors	Yes	Yes	No
Non-Cost Factors	Yes/No[5/]	Yes/No[5/]	No
Off-Grid v.s. Grid-Connected Power Generation	Yes	Yes	No
Renewable Energy Technologies			
Renewable for electricity generation			
Grid-connected—dispatchable	Yes	Yes	Yes
Grid-connected—nondispatchable	Yes	Yes	No
Off-grid connected	Yes	Yes	Yes
Renewable for thermal energy	Yes	Yes	Yes
Renewable transport fuel	Yes	Yes	Yes
End-use renewable	Yes	Yes	Yes

Notes: 1/ MARKAL can capture seasonal profile but not hourly profile.

2/ Forced outage can only be treated deterministically.

3/ The models can handle multiplicity of units of renewable energy resources, but cannot show the resultant impacts on system reliability.

4/ Risk diversity and uncertainty factors can be captured in limited circumstances by using scenario analysis.

5/ Non-cost factors can only be captured in limited circumstances.

In the review of the three models, it was found that no model addresses all relevant factors and attributes of renewable energy. However, given the broad scope and objectives of economy-level energy models, it is not realistic to expect such models to incorporate the technical detail of technology-level or even sector-level models.

In addition, some of the renewable energy attributes are more important for sector-level models but less critical for the economy-level models. Therefore, those attributes could be ignored with the economy-level models without any significant impact on overall model results. For example, fluctuations on subhourly or hourly time scale of wind and solar resources may not be very disruptive and can be ignored in the economy-level models since the objective of using the economy-level models is for long-term planning. In addition, electricity generation from wind and solar resources normally accounts for only a small portion of total electricity generation in an economy. The magnitude of the supply fluctuations is, therefore, likely to be small relative to the short-term load fluctuations and should not cause problems for the system dispatcher.

As a second example, modeling the multiplicity of units of renewable energy is not as critical in the economy-level models since it is not clear anyway that having many small units in a renewable project provides any reliability benefits. Modeling a cluster of renewable units at one site as one resource greatly simplifies the task of modeling a complete renewable facility and probably does not introduce any significant modeling distortions.[10]

The time-dependent nature of the resource should, however, be fully accounted for in an energy model. This is because it affects the dispatch of other system generation and overall production costs which determine the penetration of renewable energy in an economy. Treating nondispatchable renewable resources as dispatchable ones could understate any minimum load problems that may exits.

There are some limitations in modeling renewable energy in the existing energy models. These limitations are due to the special characteristics of renewable energy that are different from fossil fuels. Since the focus of the existing energy models is on modeling characteristics of fossil fuels in detail, they leave out the detailed features of renewable energy. It is also due to the fact that factors involved with the use of renewable energy are more difficult to assess and quantify which makes modeling renewable energy in the existing models difficult.

However, it is fair to say that the existing economy-level models like ENPEP and MARKAL have high capabilities for capturing most of the important factors and attributes of renewable energy. They could present a reasonable picture of the renewable energy potential in an economy, if the necessary information is made available and the models are utilized to their full potentials. This is especially true for MARKAL which has a number of special functions that can be used to capture some of the unique attributes of renewable energy technologies. Examples of the special functions in MARKAL are stochastics for characterizing uncertainty, and Endogenous Technology Learning that allows cost of a technology to be tied to the level of capacity build-up.

A recent study by NREL on *Integrating Renewables into National Energy Planning Models in APEC Economies*[11] proposed a practical way to model renewable energy at the economy level. This approach relies on a strategy of linked models where the data is shared among the models, and the models are not run as a single software system. Based on this approach, the economy-level energy planning model does not have any added detail on renewable energy technologies. The results of the economy energy model are combined with a number of other considerations in developing the economy energy plan. The economy energy model provides projections of energy prices, which are key to the coordination of the separate models.

Technology assessment and a comprehensive renewable resource assessment are then conducted in parallel with the economy energy model. The resource and technology information will help in identifying renewable energy technologies that have potential to contribute to the economy's energy and economic objectives. The costs of energy supply from renewable energy technologies can also be estimated. The utility planning models are an option to be utilized to refine the estimates of these supply costs.

The supply costs from renewable energy and energy costs projected by the economy energy models provide information to estimate market shares of various renewable energy technologies. The estimate of renewable energy quantities depends on environmental and social goals, which are not necessarily quantifiable. Price information and these other factors are thus taken into account in developing estimates (or goals) for renewable energy penetration. These estimates then become part of the economy energy plan.

While a rough estimate of renewable energy penetration can be accomplished from the modeling elements explained above, it should be emphasized that much greater details are required to develop plans for specific renewable energy projects. In addition, more detailed and localized utility planning models are needed to consider specific local renewable resource availability and the characteristics of the local energy supply system in developing a cost-effective resource plan. The results of these locality-specific studies can be used to update and refine the aggregate renewable energy projections used by economy-level models.

The modeling elements described above are shown in Figure 4.1.

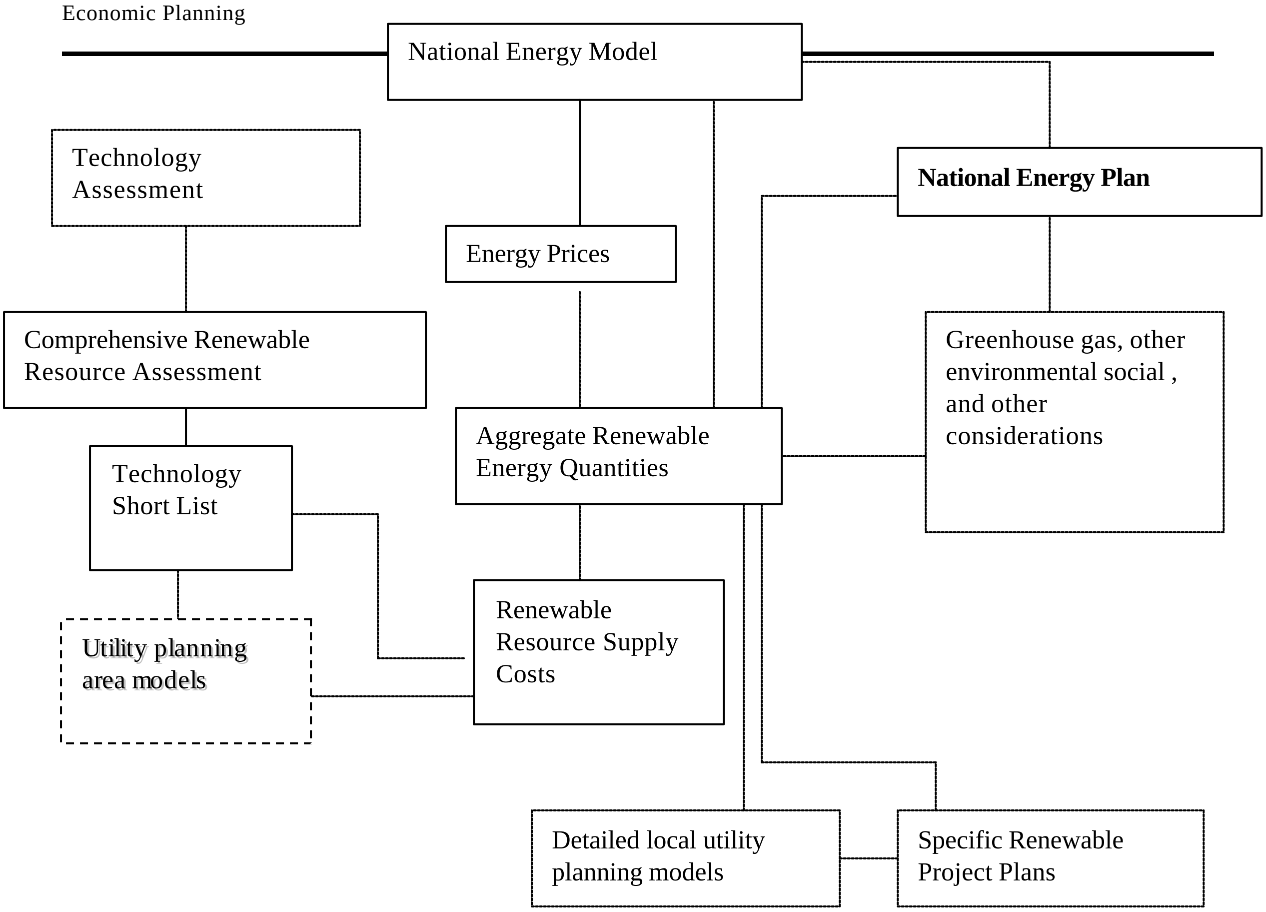

Figure 4.1: Renewable Energy in Economy Energy Planning

Source: Klein, D. *Integrating Renewables into National Energy Planning Models in APEC Economies.*

In general, economy-level models are not utilized to conduct detailed technology-level or sector-level system designs, but rather to show senior policy makers how various combinations of technologies, resources, and governmental policies interact at the economy level on costs, resource consumption, and environmental emissions.

The characterization of renewable energy in planning models should be evaluated in the context of how those models are generally used by energy policy analysts. To serve this purpose, the models are normally utilized for showing impacts of various energy supply and demand scenarios on resource consumption, technology choices, environmental implications, and policy decisions.

- The study of *resource consumption* is to understand the impacts of various energy development policies on total resource consumption or to estimate future resource consumption based on various scenarios of economic activities. An example is the examination of the effect of pricing policy of conventional fuels on the markets for renewable energy technologies.

- The use of the models to facilitate *technology choices* is to understand how the availability or cost of specific technologies could impact total resource use or environmental emissions. An example would be to estimate the reduction in fossil fuel consumption in an economy as a result of new renewable energy technologies.

- The study of *environmental implications* is to examine how the combination of technologies and resource choices affects emissions to the environment, or to understand how environmental constraints can influence technology and resource choices. An example would be to examine GHG emission reduction potential from various renewable energy technologies.

- The use of the models for *policy decisions* is to understand the impacts of economy-wide policies on resource consumption, technology choices, and environmental implications. Examples of such policies could include promoting life extension of existing coal-fired utility plants, allowing nuclear facilities to be built, or looking at the impact on renewable energy production of CO_2 taxes.

Though being different in their design and using different methodologies and model frameworks, the economy-level models such as ENPEP, MARKAL and, to some extent, LEAP can serve the above purposes for aggregate renewable energy analysis through the addition of renewable energy technology options and expansion of scenarios analysis.

END NOTES

[1] Peter Lilienthal, Larry Flowers, and Charles Rossmann. "HOMER Model Description." National Renewable Energy Laboratory and University of Colorado, Golden, Colorado, [Internet, WWW], ADDRESS: http://www.nrel.gov/international/tools/homer.html

[2] "The Hybrid Power System Simulation Model", [Internet, WWW], ADDRESS: http://www.ecs.umass.edu/mie/labs/rerl/hy2/intro.htm

[3] More detail on ViPOR is available at [Internet, WWW], ADDRESS: http://rsvp.nrel.gov/tour/Analytical/model.html

[4] Douglas M. Logan, Chris A. Neil, and Alan S. Taylor. *Modeling Renewable Energy Resources in Integrated Resource Planning*. NREL/TP-462-6436, National Renewable Energy Laboratory, Golden, Colorado, June 1994.

[5] Ibid 4

[6] Predictability is accounted under "capability".

[7] Yves Smeers and Adonis Yatchew, ed. "Distributed Resources: Toward a New Paradigm of the Electricity Business." *The Energy Journal*, Special Issue, 1997.

[8] Yves Smeers and Adonis Yatchew. "Introduction." *The Energy Journal*, Special Issue on "Distributed Resources: Toward a New Paradigm of the Electricity Business", 1997.

[9] The probabilistic analysis of forced outage can be handled by ICARUS, an ENPEP sub-module.

[10] Ibid 4

[11] David Kline. *Integrating Renewables into National Energy Planning Models in APEC Economies*. National Renewable Energy Laboratory, Golden, Colorado, (in press).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to identify, assess, and improve analytic methodologies to incorporate renewable energy options in an economy's energy and economic planning. To serves this purpose, the study first reviewed three economy-level energy models—ENPEP, MARKAL, and LEAP—to examine their methodologies and assumptions regarding the inclusion of renewable energy technologies. These three models were selected because they are widely used in many APEC member economies as well as non-APEC member economies worldwide. Four APEC member economies—Thailand, Indonesia, the Philippines, and the People's Republic of China—were then selected as case studies. The energy models of these four economies were re-run with the original data sets, and the data and assumptions used in the models were reviewed in detail to investigate how an economy utilizes the modeling techniques to incorporate renewable energy in their energy planning. Finally, the study examined renewable energy factors and attributes that influence the decisions to adopt renewable energy in an economy and assessed the capabilities of the existing energy models to account for those factors and attributes. The results of the study are expected to improve the understanding of issues and problems involved with modeling renewable energy technologies, and allow APEC member economies to take advantage of the existing modeling techniques in modeling renewable energy technologies at the economy level.

5.1 CONCLUSIONS OF THE STUDY

The main conclusions of the study are summarized below.

- Each energy model reviewed in this study has advantages and disadvantages that users have to trade off. The existing energy models are designed to be used for long-term energy planning. With the fact that these models were originally designed and applied in developed economies where renewable energy accounted for only a small portion of the overall energy use, renewable energy systems are not the central focus of any of the three models. However, each model provides special features that facilitate the inclusion of renewable energy technologies.

- Renewable energy was earlier recognized as an important resource in the energy sector of the four economies being reviewed. In the past, the shares of renewable energy in the total primary energy of each economy varied between 25 percent to 42 percent. Based on their own forecasts, renewable energy supplies were expected to increase in the future. However, the share of renewable energy in terms of total energy supply in each economy was expected to decline over time—to be between 8 percent to 14 percent of total primary energy. This decrease in market shares for renewable energy occurred, in large part, because traditional biomass fuels were replaced by high quality commercial fuels. Thus a challenge for energy models is to demonstrate how traditional fuels such as biomass can be cost effectively converted into high quality fuels such as gas or electricity.

- The economies forecast that the future use of renewable energy in traditional applications such as biomass consumption in the residential sector (for example, cooking and heating) would decrease. The renewable energy technologies that had the highest potential to penetrate into the economies were those for power generation such as hydropower, wind, and solar energy.

- The principal renewable energy resources included in all models were biomass and hydropower. Geothermal resources were included in the Philippines, Indonesia, and the PRC. Wind and solar were included in the PRC in the base case scenario, and in the Philippines in the mitigation scenarios. In both the PRC and the Philippines models, wind and solar were used for power generation only.

- The renewable energy technologies included in all economies were simple technologies. Their uses included power generation, cooking and ironing in the residential sector, and heat and steam production in the industrial sector. Other renewable energy technologies such as solar water heating, solar thermal power generation, or renewable-based transport fuels were not considered in any model reviewed. There was no use of renewable energy technologies in the commercial, services, transport, or agricultural sectors.

- Each economy was faced with the same problems, though in varying degrees, when modeling renewable energy. First of all, renewable energy was expected to have a declining trend contribution in the economy's energy mix as industrialization gave rise to the demand for higher quality energy resources. Therefore, because of time and budget constraints in doing research, the economies did not look in detail at renewable energy for their economy energy models.

- The limitation in modeling renewable energy was also influenced by the fact that necessary information to model renewable energy, such as resource data, technology characterization, technology performance, and costs, was not available to most economies. In all cases, the business-as-usual scenario follows the government's energy plans. If there are no government plans to implement renewable energy projects, a modeler will not volunteer to include them in his/her model. In the mitigation scenario, although the modeler is not precluded from suggesting renewable energy technology options, if the economy has not already completed detailed resource assessments and economy specific renewable energy technology cost estimates, the modeler as part of his/her work could not be expected to develop the needed information.

- Energy models could be classified into three categories—technology-level (such as HOMER, Hybrid 2, and ViPOR), sector-level (such as, MABS, MIDAS, and PROVIEW), and economy-level energy models (such as ENPEP, MARKAL, and LEAP). These three levels of models have different objectives. The technology-level model is used to select individual components of a single system. The sector-level model, such as an electric utility model, is adopted to define the least-cost fuel mix for electricity generation to meet an economy's future electricity demand. In comparison, the economy-level model is utilized to simulate the decisions needed to define the necessary energy supplies to satisfy the future economy-wide energy demand at the least cost by taking into consideration other issues such as energy security or environmental related problems. Information required and factors influencing the decisions in the planning process are thus different among these three model levels.

- The economy-level model could not be utilized to conduct an energy system design like the technology-level model. Neither could the economy-level model capture all attributes of renewable energy (such as capability, availability, location, modularity, and risk diversity) that were significant in the comparison of renewable energy resources with conventional supply-side and demand-side options for utility's integrated resource planning. This is not surprising. Given the broad scope and objectives of economy-level energy models, it is not realistic to expect such models to incorporate the technical detail of technology-level or even sector-level models. In addition, some of the renewable energy attributes are more important for the sector-level models but less critical for the economy-level models. Therefore, those attributes could be ignored for the economy-level model without any significant impact on overall model results.

- There are some limitations in modeling renewable energy in the existing energy models. These limitations are due to special characteristics of renewable energy that are different from fossil fuels. Since the focus of the existing energy models is on modeling characteristics of fossil fuels in detail, they leave out the detailed features of renewable energy. It is also due to the fact that factors involved with the use of renewable energy are more difficult to assess and quantify which makes modeling renewable energy in the existing models difficult.

- However, it is fair to say that the existing economy-level models like ENPEP and MARKAL have high capabilities for capturing most of the important factors and attributes of renewable energy and could present a reasonable picture of renewable energy potential in an economy, if the necessary information is made available and the models are utilized to their full potential.

- The economy-level models such as ENPEP, MARKAL and, to some extent, LEAP can serve the purposes for which models are normally used by energy policy analysts. Those are to show impacts of various energy supply and demand scenarios on resource consumption, technology choices, environmental implications, and policy decisions.

- The final conclusion of the study is that the inadequacies of the existing economy-level energy models in characterizing renewable energy technologies were only a minor impediment to showing the potential penetration of renewable resources into an economy's resource mix. The other factors responsible for low penetration of renewable energy in an economy are lack of necessary information (both for resource characterization and technology definition and performance) and lack of policies which support the many aspects of renewable energy technology development and implementation.

5.2 RECOMMENDATIONS FROM THE STUDY

From the review of the economy-level models, and the examination and running of the four economies' models with original data sets, it was learned that modeling-related factors are responsible only partly for the low penetration of renewable energy technologies in an economy. The other factors contributing to the same problem are non-modeling factors. These non-modeling factors could be classified into four groups—resource factors, technological factors, economic factors, and institutional factors. It is difficult to say which factor is the most important. One factor could be relatively more important for a given economy than the other factors. However, lack of any one of these factors would significantly obstruct the penetration of renewable energy in the economy.

This section provides recommendations concerning options which could be taken to increase the use and future penetration of renewable energy technologies. The recommendations are separated into recommendations for future modeling and recommendations associated with the non-modeling related factors including resource factors, technological factors, economic factors, and institutional factors.

Recommendations for Future Modeling

As also discussed in the recent NREL study on *Integrating Renewables into National Energy Planning Models in APEC Economies*,[1] adding the same level of detailed resource information and energy demand as the technology-level model, or attempting to capture all the attributes of renewable energy as the utility models, into the economy-level energy model would not be practical, nor is it required to accomplish the objectives of the economy-level model.

For the economy's energy planning purposes, the economy-level energy model requires a reasonable projection of the total availability of renewable energy resources along with the total availability of conventional fuels and other data to assess the overall implications on the economy's resource consumption, technology choices, environmental impacts, and policy decisions. However, to develop a reasonable projection of the total availability or energy output of renewable energy in the economy involves detailed information.

The energy output obtained from a renewable resource depends on various factors. For example, energy output from wind resources depends on wind speed and the wind technology used,[2] the electrical power output from solar photovoltaic depends on photoconversion efficiency of the PV cell and solar power impinging the cell, and energy from biomass depends on the conversion technology and biomass characteristics (each type of plant has a different energy and moisture content).

To forecast the total availability (or capacities) of these resources over the study periods even poses challenging tasks since the future values of other related factors need to be firstly known. The future use of wind resources for power generation in an economy depends on, for example, future capital costs of wind technology, and future cost of conventional fuels such as oil, gas, and coal. As another example, future use of biomass in cogeneration depends on costs of obtaining biomass for use as an input in the process, value of biomass for uses in other applications, and prices of conventional fuels that can be used for cogeneration.

> **Recommendation (1):** Because of the details required to estimate total resource availability (or capacity), specialized resource assessment models should be used in conjunction with the economy-level energy models. Specific resource assessment models should be used to pre-estimate the total resource availability (or capacity) over the study periods. This information will then be entered into the economy-level energy model for evaluation of fuel competition.

Designing an energy system requires very detailed resource information and energy demand at specific sites. It would not be practical to include these features into the economy-level model.

> **Recommendation (2):** The technology-level renewable energy models that can design the electric system should be utilized. The results of the system design should then be transferred to the economy-level energy model for further analysis. The regional models should be used to evaluate resources to be utilized at each specific site. A good example of this level of modeling is a recent APEC study, which examined the potential for renewable energy retrofit options to existing diesel mini-grids.[3]

At present, there are various renewable energy technologies for every end-use sector that are commercially available. Table 5.1 shows renewable energy options in various end-use applications. These renewable energy technologies could be more cost-effective than competitive conventional fuels in some situations. Their potentials for future use thus should be realized and incorporated in the energy models.

Table 5.1 Renewable Options in End-Use Applications

Resource	Technology	End-Use Applications				
		Electricity	Industry[1/]	Buildings[2/]	Transport	Agriculture
Solar	Photovoltaics	X				X
	Solar Thermal	X	X			X
	Passive/Active Heating			X		X
	Daylighting			X		
Wind	Wind Turbine	X				X
Biomass	Direct Combustion	X	X	X		X
	Gasification/ Pyrolysis	X	X		X	X
	Anaerobic Digestion	X	X	X		X
	Fermentation				X	X
Geothermal	Electric	X				
	Heat Pump			X		X
	Direct Use		X	X		X
Hydro Power	Conventional	X				
	Pumped Storage	X				
	Micro-hydro	X				

Notes: [1/] Include commercial uses
[2/] Include residential uses

Source: Adapted from the presentation by Dr. Jim Ohi of the National Renewable Energy Laboratory, "Integrated Analysis of Renewable Energy Options", presented at the US Country Studies Mitigation Assessment Workshop, Berkeley, California, April, 1995.

> **Recommendation (3):** When designing the modeling energy networks, end-use demand should be broken into detailed applications, instead of being estimated only in an aggregated manner by demand sector. By having disaggregated end-use demand, it will allow for better definition of renewable energy technology options and better capture of potential renewable energy technology uses in the economy energy model.

Recommendations Associated with Resource Factors

The availability of renewable energy resources in an economy is a critical factor to determine the use of renewable energy in that economy. This is due to a fundamental difference in resource availability between conventional energy resources (such as coal, oil, and gas) and renewable energy resources (such as wind, solar, geothermal, and hydro) which is that conventional energy resources can be imported but renewable energy resources, in general, cannot. An economy can have diesel power plants although diesel is not produced in that economy. In contrast, an economy cannot use wind energy if wind resources are not available in the economy. Biomass can be imported from neighboring economies but in most cases it is not an economic option. The renewable energy projects to be selected in an economy thus depend on domestically available resources.

Besides the availability, location is also an important factor. Renewable energy resources (wind, solar, geothermal, and hydro) cannot be transported and must be used at the site. Site selection is thus a crucial step in project implementation to ensure the availability of resource supply and sufficient energy demand in the same area. Geographical constraints thus play a critical role in renewable energy utilization.

Renewable energy resource assessment provides the benefit of determining renewable energy resource potential at different locations and for different time periods. It also determines the availability of energy for specific renewable energy technologies, as well as provides input to optimal design of systems at specific location. Resource assessment is the important first step in renewable energy development since the information on renewable energy resources is crucial for the successful implementation of renewable energy technologies.

A recent study sponsored by the APEC Expert Group on New and Renewable Energy Technologies surveyed the quality and completeness of resource assessment data for the APEC economies.[4] It concluded that "a basis for understanding renewable energy resources is currently available for essentially all the economies, although there is a significant need to apply improved and updated resource assessment techniques in most. For example, most wind resource assessments rely on data collected at national weather stations, which often results in underestimates of the true potential wind resource within an economy. As a second example, solar resource assessments in most economies rely on an analysis of very simple sunshine record data, which results in large uncertainties in accurately quantifying the resource. National surveys of biomass, geothermal, and hydro resources are often lacking; in most cases, resources for these technologies were discussed for site-specific studies only".

> **Recommendation (4):** None of the modeling efforts reviewed cited comprehensive renewable energy resource assessments. Therefore, addressing the issues identified in the APEC report cited above is a good first step in developing better modeling capabilities. In addition, the level or detail of resource assessment required needs to be better matched to the level of modeling anticipated. It should not be expected that an initial wind assessment at the economy level would require the same level of detail as a site specific planning study.

Recommendations Associated with Technological Factors

Cost-effective and reliable technology is needed in order to make use of renewable energy resources. Identifying the appropriate technology is a key step in developing a successful renewable energy project. Besides technologies to utilize renewable energy resources, technological factors include the know-how to install, operate, and maintain the technologies being adopted. Technical training to improve local capabilities is necessary because oftentimes the project fails due to improper use and lack of understanding of the technology. Technical training is especially important for medium- and large-scale projects.

Technology characterization involves obtaining information on performances and costs of various renewable energy technologies. This information is necessary for determining cost-effectiveness of a renewable energy project. The costs and performances of some renewable energy technologies can be shared among economies. For example, a developing economy could utilize the information on cost and performance of a solar PV technology from a developed economy (which is both a producer and consumer of the technology) since this technology might have to be imported from abroad anyway. However, costs of some renewable energy technologies (such as solar thermal) could easily vary by a factor of two or three across economies by using local labor and materials.

A recent study by the World Bank on renewable energy development in China[5] mentioned that lack of awareness among decision-makers of potentials for commercial applications of renewable energy technologies was a major constraint to renewable energy development. This stems from lack of awareness of recent technical advances and existing successful commercialized applications in other economies.

> **Recommendation (5):** The lack of information has consistently been identified as a priority constraint that slows the adoption of cost-effective renewable energy technologies. APEC could promote information dissemination by highlighting recent technology advances, successful applications, and new information sources at its biannual meetings. This would enable APEC representatives to question presenters on applications to their economy and to provide feedback to developers on current technology needs. Although much information is available over the Internet, there is often a lack of matching the information to real problems.

> **Recommendation (6):** There is a real need to develop cost information on renewable energy technologies which takes into consideration economy specific factors such as local content and local labor rates. The US Department of Energy has made a good start by putting together a summary of costs for renewable energy technologies for power generation.[6] However, the other types of renewable energy technologies need to be covered. If centralized databases are developed, they should include adjustments for local factors. This would affect the evaluation of technologies such as solar thermal (both for hot water heating and power generation), that have the potential for high local content, much more than technologies such as photovoltaic electricity generation (although cost advantages could still be seen with this technology based on local production).

Recommendations Associated with Economic Factors

The use of renewable energy is preferable to conventional energy if it is economically competitive since renewable energy is often an indigenous resource and environmentally friendly. Competitiveness of renewable energy over conventional energy greatly depends on resource abundance, and efficiency and suitability of the renewable energy technologies selected for the project. A detailed economic analysis needs to be performed to identify competitiveness between renewable energy technologies and conventional energy technologies before encouraging actual renewable energy projects.

In addition, energy prices need to reflect the true cost of producing energy. All costs related to the project need to be taken into account, including environmental costs to society in producing and delivering energy to consumers. By subsidizing fossil fuels and/or ignoring their environmental costs, it will restrict competitiveness of renewable energy, and reduce renewable energy potential in an economy.

> **Recommendation (7):** Case studies need to be developed on an economy specific basis for each of the basic sources of renewable energy, identifying which are the most cost effective for a given economy. These case studies could then be used by economy-level modelers in generalizing the potential of renewable energy technologies across their economies.

Recommendations Associated with Institutional Factors

Government policies and institutional support are important for promotion of renewable energy projects in an economy. For example, a government's high imported tax policy will make a renewable energy project which requires imported components or technology less attractive to an investor, or inefficient permitting processes needed to implement renewable energy systems will defer project implementation.

Institutional factors include activities such as end user financing, development and strengthening of the in-country renewable energy industry and entrepreneurs, development of renewable energy policies, in-country training (which would include training financial institution staff for making renewable energy technology loans), and improvement of information dissemination mechanisms. A recent study for the United States Agency for International Development (USAID)[7] to assess the potential for renewable energy deployment in the key global climate change countries/regions[8] identified such institutional factors as key constraints to renewable energy implementation.

Renewable energy technologies normally require high up-front capital investment but low O&M costs. The same USAID study[9] highlighted that lack of capital is the most critical barrier to improved use of renewable energy technology in the countries/regions.

> **Recommendation (8):** To understand the impact of these factors on APEC member economies, a survey of the status and needs associated with institutional

factors in APEC member economies should be undertaken. This survey could also identify priority actions which should be undertaken to foster the development of cost effective renewable energy technologies

5.3 CONCLUDING REMARKS

Recent major international studies indicate significant growth-potential for renewable energy, particularly in scenarios where environmental constraints are imposed, for example on CO_2 emissions. A study by the International Energy Agency[10] indicated 7.5 percent to 8.5 percent annual growths in the commercial use of energy from “new” renewables to 2010. The World Energy Council[11] forecast the growth of renewable energy to reach from 18 percent to 21 percent of world needs by 2020 in the Business-As-Usual scenario, and from 18 percent to 30 percent in the ecologically driven scenario. The United Nations Solar Energy Group on Environment and Development[12] forecast that 30 percent of world energy needs would be met by renewable energy by 2025, and 45 percent by 2050. In addition, the Group Chief Executive of BP[13] and a Managing Director of the Royal Dutch/Shell Group[14] commented that renewable energy could be providing up to half of the world’s total energy needs within 50 years time.

In contrast to the aforementioned forecasts of high renewable energy utilization, all four economies reviewed expected only a small increase in renewable energy consumption in their economies. This led to a declining share of renewable energy in their total energy supplies. This has pointed to the fact that the economies may not fully realize the potential use of renewable energy in their economies, and thus there is a real need for the APEC member economies to examine, in more detail, the future potential for increasing the use of renewable energy technologies.

Capital costs of renewable energy technologies are high, and in many applications still could not be competitive with conventional fuels. However, those costs have been reduced by half over the last decade and are expected to be halved again over the next ten years.[15] Renewable energy could likely become more competitive with conventional fuels in the future and could play an increasingly important role in an economy’s energy mix. Therefore, energy planners should make a special effort to understand and incorporate renewable energy technologies in their long-term energy planning.

END NOTES

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