Introduction to the EnFore System: A Computerized Decision Support System 3-E Model for Taiwan

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and

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A paper prepared for the International Energy Workshop, to be held 24-26 June 2003
at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Update: 20th May 2003

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ABSTRACT

Although the experience of Taiwan has shown energy to be one of the major driving forces behind its economic development and social modernization, the island must nevertheless rely upon imports for around 97 per cent of its energy usage. According to the predictions of many global experts, crude oil, coal and natural gas are seriously limited and are set to become exhausted in the foreseeable future. Thus, it is important for Taiwan to adopt policies aimed at immediately minimizing the negative impacts from the use of energy; these will necessarily be based on the reliable forecasting of energy demand and effective supply planning supported by computer technology. The purpose of this paper is to introduce a computerized decision support system, the Energy Forecasting System (EnFore), which provides valuable, fundamental information on the complex and various economic, energy and environmental (3-E) policy problems currently existing in Taiwan.

The design principle of the EnFore system integrates a relational 3-E database with methodological solution models, providing users with time-based, flexible and structured functions for forecasting, planning and simulation, which are presented as user-friendly interfaced software. An essential aspect of the EnFore system is the hybridization decision support system tool of economic, statistical and technological models, supported by a shared database, which is characterized by significantly lower data and information management costs. The database is designed base on a relational database concept to serve all forms of access by system models and enquiry modules. Models are designed in different linkages to provide professional functions for different purposes.

The EnFore system has now been adopted by Taiwanese government officials as an effective energy management tool, using it to perform energy demand forecasting and supply planning, to enquire energy related data, index and information, and to undertake 3-E policy simulations as a means of supporting the policy decision making of administrative energy officials. This paper will illustrate the design concept and application of the EnFore system, along with a description of the framework, features and functions. Case studies are presented as an example of the operation of the energy policy simulation functions of the system.

Keywords: Decision support system, 3-E policy, computer simulation, database, systems model, Taiwan

INTRODUCTION

Rapid technological progress has given rise to a new age of advanced efficient computing, with a wide range of decision support systems (DSS) having been defined and developed from as early as the 1970s, aimed at improving decision-making effectiveness within various industries. Crude oil, natural gas and coal are severely limited energy resources, which, according to many predictions, are set to become exhausted in the foreseeable future. We therefore recognize the urgent need to minimize the negative impacts from the use of fossil energy in Taiwan, and to adopt policies based on reliable energy demand forecasting and energy supply planning, with the aid of modern computer technology. The Energy Forecasting (EnFore) System, a computerized decision support system, was therefore developed with the aim of providing fundamental, but extremely valuable, information for the various complex economic, energy and environmental (3-E) policy problems now existing in Taiwan.

Recent decades of developmental experience in Taiwan have shown energy to be one of the major driving forces behind the island’s economic development and social modernization; however, since the island is not endowed with rich natural resources, it must rely upon imports for around 97 per cent of its energy usage. Taking 2001 as an example, the domestic supply of energy in Taiwan amounted to 3.158 million kilo-liter oil equivalent (KLOE), about 2.9 per cent of the island’s gross energy supply, whilst imported energy stood at around 105.363 million KLOE, accounting for the remaining 97.1 per cent. Of all primary energy supplies, crude oil and oil products were the major energy source, accounting for more than half of the island’s total energy supply (approximately 51.4 per cent). Despite the island’s renowned success in the creation of an economic ‘miracle’, Taiwan has also witnessed considerable destruction of the environment upon which people have traditionally relied for their subsistence. The increasing consumption of energy has simultaneously led to steadily worsening environmental quality (air, soil and water pollution) with the emission of controversial greenhouse gases severely compounding the growing problem of global warming.

Although government officials, as well as academic researchers, are extremely concerned about current 3-E problems and their growing level of complexity, the formation of a solid basis for policy decision making is not an easy task. The huge amounts of 3-E data required represent an enormous cost burden, in terms of actual data collection costs, whether through field studies or laboratory experiments. Even when such work is completed and a database has been set up, this needs to be continually updated and maintained, whilst the follow-up work of data analysis is again, no easy task. Building a suitable model can indeed cost a fortune, and this then requires suitable intellectual minds to operate and maintain both the model and the database, representing a further stretching of government resources. Clearly, however, given the limitations of government budgets, and the fact that many other administrative departments wait in line for the attention of government officials, there is a need to develop a computerized DSS which can help to find an effective solution to the current fundamental 3-E problems. This has been the major driving force behind the development of the EnFore system in Taiwan since 1995, and indeed, it is very likely that the same needs have been driving the 3-E modeling experiences of many other countries.

A review of the literature reveals that, following the proposal of the DSS concept in the early 1970s, the subject has since undergone considerable advancement. A great deal of effort is now being put into research on all the necessary components of the various decision support systems. Such systems have also been implemented in many different industries, where they are used mainly for scheduling, planning, data access and simulation works. In the early days, however, there was some controversy over the interpretation of the definition for the decision support system. Little (1970) defined a DSS as a model-based set of procedures for processing data and judgments to assist managers in their decision-making tasks. Gorry and Scott-Morton (1971) regarded it as a function system for problem solving. A DSS was then defined by Alter (1980) as a flexible objective system for line and staff management, in the sense of both the present and the future. With regard to a particular decision maker or a specific situation, and based on the structured nature of the concept, Moore and Chang (1980) saw a DSS as an extendable system capable of supporting *ad hoc* data analysis and decision modeling, and used at irregular, unplanned intervals for future planning. Sprague (1980) expressed his disagreement with the general DSS definitions and summarized the introductory definition of a DSS in an editorial article; in order to avoid any misinterpretation, he proposed a clear defining comparison, explaining the key attributes that a DSS must possess.

At present, discussion is also under way on the issue of DSS design, in terms of the databases and modeling used, highlighting in particular, the design difficulties encountered in the implementation of an effective DSS (Moore and Chang, 1980). Many papers have also been published telling of the problems of modeling for all possible industries and fields; however, for the designers of a DSS, it is always important to consider user needs and to present the models in a way that will maximize their utilization. Bonczek, et. al. (1980) illustrated the roles that models play in a DSS, and developed a schema to classify these roles into two main types, directing computation and directing data manipulation. They also illustrated how the successful design of the system interface can help to develop the roles of the models within the system.

As more and more researchers have become involved, the subject of design support systems has managed to break away from the problem of disagreements on suitable definition, towards the issue of various designs, methods of implementation and testing, and their application. Studies have shown that a database management system is an important element of a DSS, since it is a warehouse for accessing, analysis, mining and visualizing data, and also provides important support for the operations of the other modules in the system. Methods have therefore been developed for appropriate modeling and analysis of the problems within a DSS. In the last decade, the focus had generally been on the investigation of scheduling, planning and simulation problems, in real practice, with some degree of success having been achieved in the support of effective decision making in the manufacturing industries. There were also reports of systems being put into good use in other organizational fields, such as medical, transportation, finance and military-related management fields. Indeed, it has been noted that computer simulation models can be used to enhance an organization's decision-making processes, and thereby enable it to see the impact of its future choices over both the short and long term (Agatstien and Rieley, 1998).

Many of the works on decision support systems in recent years have pushed this area of study into the arena of intelligent systems, wherein we are now not only looking at a DSS in terms of it being model-based, but also knowledge-based, such that concepts of 'artificial intelligence' and 'expert systems' are being introduced. Truban and Aronson (2001), for example, have clearly described the fundamentals, development and application of such intelligent systems. Decision support systems have also been developed for energy planning and environmental management, such as the EDSSF, a decision support system for electricity peak-load forecasting (1997) and GIS, a decision support system developed for the evaluation of the potential of renewable energy resources and the financial analysis of renewable energy investment (1998). MESAP is a decision support system used at local, regional and national level to carry out energy and environmental management, demand side management, integrated resource planning, life cycles and fuel chain analysis (1999), and the PRIMES decision support framework-based software system is used by the European Commission to support the seamless integration of data management, policy analysis, and model running and reporting (1999).

The EnFore system is a time-based DSS that effectively integrates economic, energy and environmental databases, algorithmic models, statistical models and mathematical programming simulation modules, and then presents through an extremely user-friendly interface. The system provides government officials, energy managers and researchers with a set of analytical forecasts and interactive simulation results on energy supply and demand, which are subjected to economic and technology constraints, for use as a reference in policy decision making. Users of the EnFore system are able to construct energy policy scenarios by setting appropriate parameters and variable values; the corresponding data reports and figures can then be extracted as required.

In short, EnFore is a hybrid 3-E system model of economics, statistics and engineering with a powerful database, simulation tools and a user-friendly interface, but characterized by significant cost-effectiveness. The design concept and application of the system, along with a preliminary description of the framework, features and functions will be illustrated in detail, and the application of this DSS will be demonstrated through an operation of the policy simulation functions of the EnFore system.

DESIGN PHILOSOPHY

The establishment of any system goes from the phase of system design, followed by implementation phase, and finally, the testing phase. In order to fulfill the need for the development of a computerized decision support system that can help to develop solutions for fundamental 3-E problems, other work must be done prior to launch the design phase of the system.

It is always important to determine the needs of users first as establishing a DSS system, that means we need to know what functions are required by the users, and they are aware of what the system can do for them, before any design works started. In this case, the system users would be the government officials, researchers or energy managers, and so the holding of discussion groups, meetings or interviews, are the first essential task for figuring out their priority needs. The resolution of these tasks provides system designers with sufficient information to build up the system framework, features and functions, and the most user-friendly system interface. According to the business needs of the eventual users, the system must have the following functions: (i) a 3-E database to provide data enquiry; (ii) short-, mid- and long-term secondary energy demand forecasting functions; (iii) long-term primary energy supply planning capability; (iv) energy policy simulation functions, including energy demand and supply due to external shock; (v) CO_2 emissions estimation; and (vi) 3-E indices information.

As soon as the designers know what the users' needs, the next to do involved researching the problem models in accordance with these needs. A further task was the collection of important data thoroughly checked for correctness. Once these preparatory tasks were completed, the EnFore system design tasks could then get under way. The overall process of establishment of the EnFore system is shown in Figure 1.

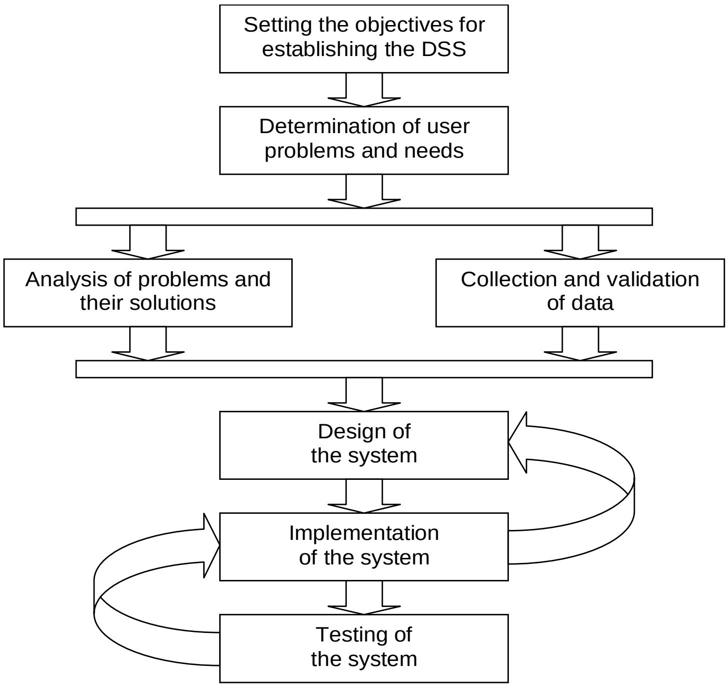

Figure 1 The process of establishment of the EnFore system

In order for the system to provide data enquiry, it was necessary to construct a comprehensive database to provide valuable 3-E information (the establishment of this database will be described in detail later). Clearly, information on future energy demand and supply is a prerequisite for government officials involved in setting policies, and also for researchers or experts involved in the evaluation and validation of these policies. Appropriate models were therefore built to provide solutions to these needs. The design concept of the system will be described in detail in the next section, which includes the design of the system database, models, functions and interfaces.

THE DESIGN PHASE

The design phase can be divided into four not clear-cut steps, the system framework design, the system database design, the problem models design, and the system function and interface design. The first step of the system design work started with a broad sketching out of the system, which enabled the establishment of the general framework of the system from the investigation done in the preparation works, that the type of data involved, and the lists of functions requested by system users were first determined. Based on this general system framework, the design and construction of the system database was then undertaken, followed by modeling of the problems and how the models can provide the solutions to these problems. The decision variables of these models are the results of certain problem scenario settings. As the models were set up, the design of the system functions and their interfaces with the reports and charts were integrated into the functions of the models and the database, thus then the whole system design was basically completed. The four steps of the system design (Figure 2) are described next.

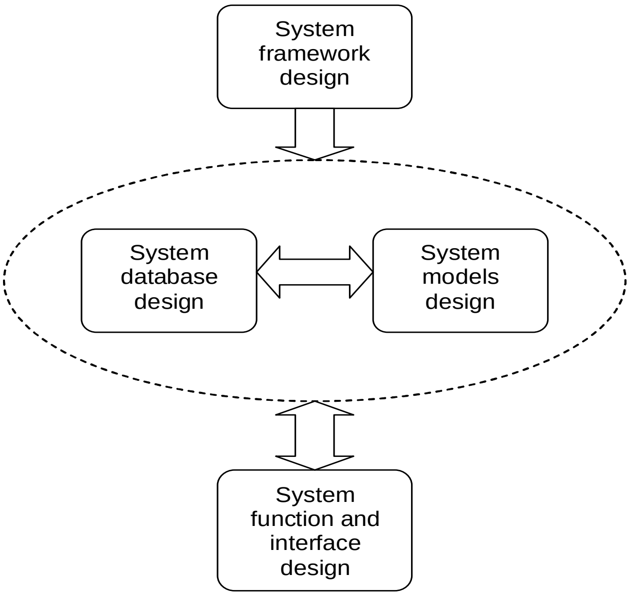

Figure 2 The design phase of the EnFore system

System Framework Design

According to the results of our investigations, the essential functions of the system can be grouped into five sub-systems according to their different roles. Integration of the five sub-systems must provide users with: (i) information enquiries; (ii) supply and demand with statistical analysis of related economic factors; (iii) short, mid, and long term energy forecasting and planning; (iv) policy simulations; and (v) index calculations. Only one database would be set up and the five sub-systems were established to share it independently, with linkages being built between the five subsystems where interactive support is required (Figure 3).

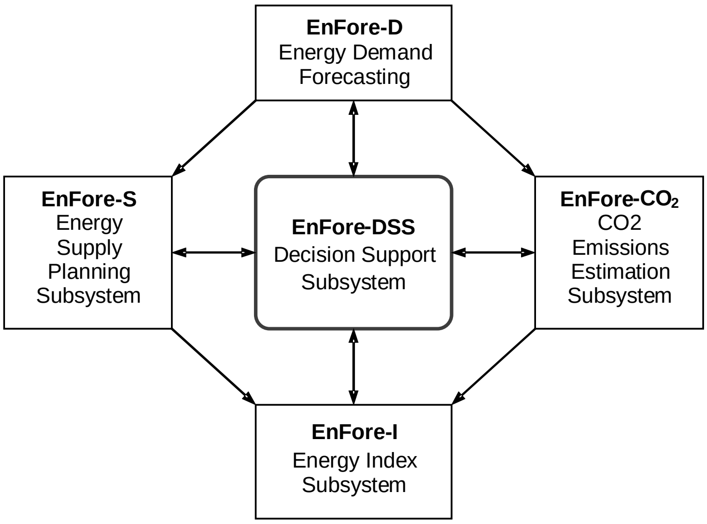

Figure 3 The framework of the EnFore system

The EnFore system comprises of the following five sub-systems:

1. *Secondary energy demand forecasting sub-system (EnFore-D).* This sub-system deals mainly with secondary energy demand forecasting problems, including short-, mid- and long-term forecasting. For each time span, secondary energy demand forecasting is carried out both by specific energy type, and by industrial sector type. Within the EnFore-D sub-system, the monthly and quarterly energy demand forecasting works independently to provide short- and mid-term forecast information on secondary energy demand (under both specific energy needs and specific industrial sectors).

2. *Energy supply planning sub-system (EnFore-S).* This sub-system deals mainly with long-term primary energy supply transformation problems such as power generation, crude oil refinery, the transformation processes of coke and liquefied natural gas (LNG).

Annual energy demand forecasting provides results on long-term secondary energy demand both by energy sector, and by industrial sector, for the long-term planning of primary energy supply in the EnFore-S sub-system.

3. *CO_2 emissions estimation sub-system (EnFore-CO_2).* This sub-system deals mainly with the calculation of CO_2 emissions and associated environmental problems. The estimated CO_2 emission calculations are supported by the results of both energy demand forecasting and supply planning within the EnFore-CO_2 sub-system.

4. *Energy index sub-system (EnFore-I).* This sub-system deals mainly with 3-E sustainable development index problems. The information and results of energy demand forecasting in EnFore-D, the supply planning provided by EnFore-S and estimated CO_2 emissions provided by EnFore-CO_2, are all used in the calculations of 3-E indices in the EnFore-I sub-system.

5. *Decision support sub-system (EnFore-DSS).* This sub-system provides functions for all kinds of energy policy simulations relating to energy demand and supply. The EnFore-DSS sub-system makes use of the models and results of the other four sub-systems to provide a platform for the energy policy simulations, which are subsequently performed by setting the policy scenario parameters. Simulation results, in the form of energy demand, energy supply, or information on CO_2 emissions, are provided by the sub-system dependent upon user needs.

Each of these five sub-systems is described in detail in the following sub-sections, with the mathematical expressions of the key models within the sub-systems being provided in the appendices to this paper.

Energy demand forecasting sub-system (EnFore-D)

The EnFore-D sub-system helps users to carry out monthly, quarterly or annual forecasts of secondary energy demand. It also provides reports and figures on historical data and forecasting results, by energy type, or by industrial sectors, for both on-screen enquiries and printed format. Monthly and quarterly forecasting models basically make use of historical data on energy consumption, applying time series or end-use analyses to provide forecast results for periods of twelve months or eight quarters.

The annual energy demand forecasting model is a twenty-five year hybrid model, which includes factors relating to energy, industries and the environment, combined with energy consumption and technological advancements. The forecasting results provide decision makers with information on future demand for secondary energy. The results also provide details on meeting energy demand for the energy supply planning models of EnFore-S, as well as the calculation basis for the CO_2 emissions estimation model of EnFore-CO_2. The concise mathematical expressions of the key models of Enfore-D are provided in Appendix 1.

Energy supply planning sub-system (EnFore-S)

The energy supply planning sub-system is aimed at minimizing the risks involved in total national energy supply decision making, under the assumption of being able to meet local secondary energy demand. The key decision variables are the overall cost and security of national energy supply. The sub-system comprises of four supply models covering electricity, oil, coal and LNG supply, to provide decision makers with information on energy supply planning for the subsequent twenty-five years. Factors such as supply costs, energy security reserves, production technologies and procurement policy are all taken into consideration in the models. The energy supply planning results provide the calculation base for the CO_2 emissions estimation model of the EnFore-CO_2. The concise mathematical expressions of the key models of Enfore-S can be found in Appendix 2.

CO_2 emissions estimation sub-system (EnFore-CO_2)

The main objective provided by the ratification of the United Nations Framework Convention on Climate Change in 1992 was the agreement to maintain greenhouse gases at a stable concentration so as to avoid endangering global climatic conditions. Although Taiwan is not a signatory to the convention, the island’s government does recognize that the protection of the earth’s environment and climate is important for all nations hoping to achieve sustainable development. There are, however, a number of interactive effects between environmental protection and economic growth; therefore, the CO_2 emissions estimation sub-system in the EnFore system aims to provide fundamental information on twenty-five year trends in carbon dioxide gas emissions, for both the past and the future, for use by decision makers (subsequent sections will provide a further in-depth explanation of the EnFore-CO_2 methodology).

Energy index sub-system (EnFore-I)

The energy index sub-system comprises of two index calculation models, the energy efficiency index model, and the sustainable energy development index model. The calculation schema of the two models adopts energy issue perspectives and combines the energy demand forecasting results of the EnFore-D and the CO_2 gas emissions estimation results of the EnFore-CO_2, with the factors affecting both the economy and the environment. The calculated indices within the sub-system provide decision makers with various reference viewpoints to assist in policy-making. The concise mathematical expressions of the key models of Enfore-I are provided in Appendix 3.

Decision support sub-system (EnFore-DSS)

The decision support sub-system is a policy simulation sub-system which uses the database and models of the other sub-systems to provide a user interface within which the setting of energy, economic and environmental related parameters can be undertaken according to different policy simulation scenarios. The resultant policy simulation estimates can provide decision makers with a reference guide for setting appropriate energy policies. Four simulation modules are used within this sub-system, to set the functions, long-term trend policy simulations, VAR macroeconomic policy simulations, expert system policy simulations (Dephi technique) and energy supply technical policy simulations. The concise mathematical expressions of the key models of Enfore-DSS are shown in Appendix 4.

System Database Design

The design of the system database is clearly the most important stage in the successful establishment of the EnFore system, since a well-designed database will provide rapid and accurate access to data for enquiries, updating and processing. The selection of the database structure was based on the nature and sources of the data. It has already been determined that 3-E data comprises mainly of numeric, alphanumeric or image items, thus the EnFore system database was designed in accordance with the concept of a relational database (see Figure 4).

The 3-E data was organized into data tables according to data classes. Each data table represented a class of data, where all the attributes of that class of data were put. Each attribute of the data class was placed into columns, that column was a data field in the data table. Each row contains individual records made up of several data fields; for example, data on crude oil, such as place of import, date of import, quantity and CIF, along with all other import data relating to crude oil was placed into a data table entitled ‘Import crude oil’. The places of import were put into the table in a column field entitled ‘Import place’, and the corresponding import quantity data was entered as another

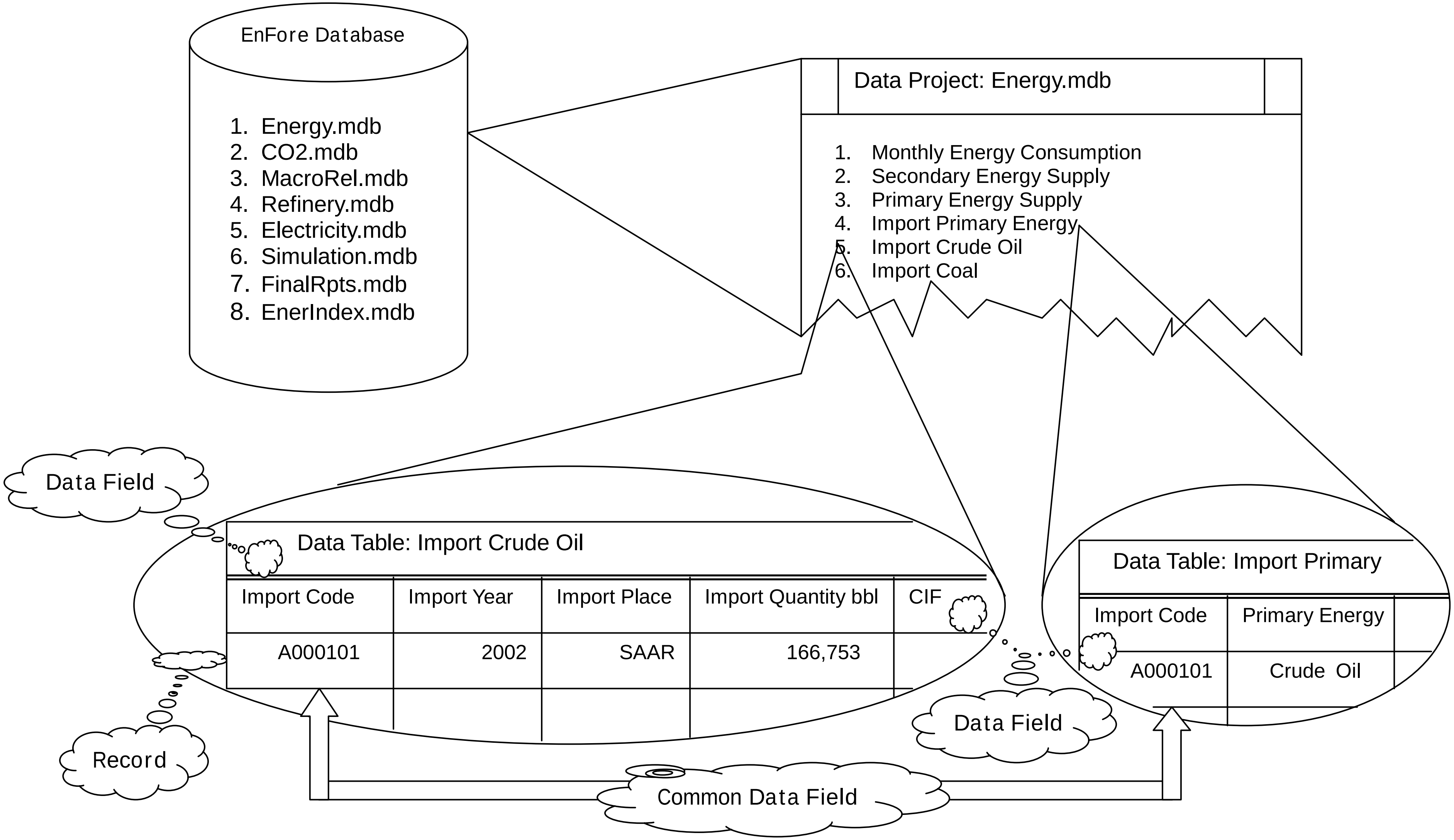

Figure 4 The relational database in the EnFore system

column field entitled ‘Import quantity’. Thus, each row of the table ‘Import crude oil’ was one record of data on crude oil imports, made up of unique date and place of import.

The EnFore database comprises of many such data tables, with each table representing one class of data, and several data tables being related by means of a common data field found in the other two (or more) data tables. The common field names must spelled exactly the same, and with the same size (number of bytes) and type (data attributes, e.g. alphanumeric or dollar). This setup means that tables are interrelated with the same data fields. For example, there are two data tables in the EnFore database, ‘Import primary energy’ and ‘Import crude oil’. These are related by the field ‘Import oil code’, where this common field is data identifying each unique import record of crude oil energy. Other data tables are related to the table ‘Import crude oil’ in terms of their relevance to the place or date of import.

Given the sheer magnitude of the data, it must clearly be organized in a very systematic manner so as to facilitate rapid and accurate access. Using Microsoft Access database software, and setting up the database according to establishment needs, the completed EnFore system database comprised of eight projects, each of which was made up of several data tables, with each table representing one class of data. The eight projects are: (i) Energy.mdb: a data project comprising of various energy consumption and supply data; (ii) CO_2.mdb: a data project comprising of all data relating to CO_2 emissions; (iii) MacroRel.mdb: a data project comprising of all macro economic and environment related data; (iv) Refinery.mdb: a data project comprising of all oil refinery skills related data; (v) Electricity.mdb: a data project comprising of all electricity generation related data; (vi) Simulation.mdb: a data project comprising of all simulation used parameters and related data; (vii) FinalRpts.mdb: a data project comprising of all output results related data; (viii) EnerIndex.mdb: a data project comprising of all energy index related data.

MODEL DESIGN

Modeling is a key element in the EnFore system, since it is, after all, a model-based decision support system. Each problem is modeled with its own specific solution methods and techniques according to the nature and characteristics of the problem. The models in the system are categorized into five groups, based upon their purpose, these are: (i) energy demand forecasting models; (ii) energy supply planning models; (iii) CO_2

emissions estimation models; (iv) energy index models; and (v) energy policy simulation models (Figure 5). The design of these models is described, according to their classification, as follows:

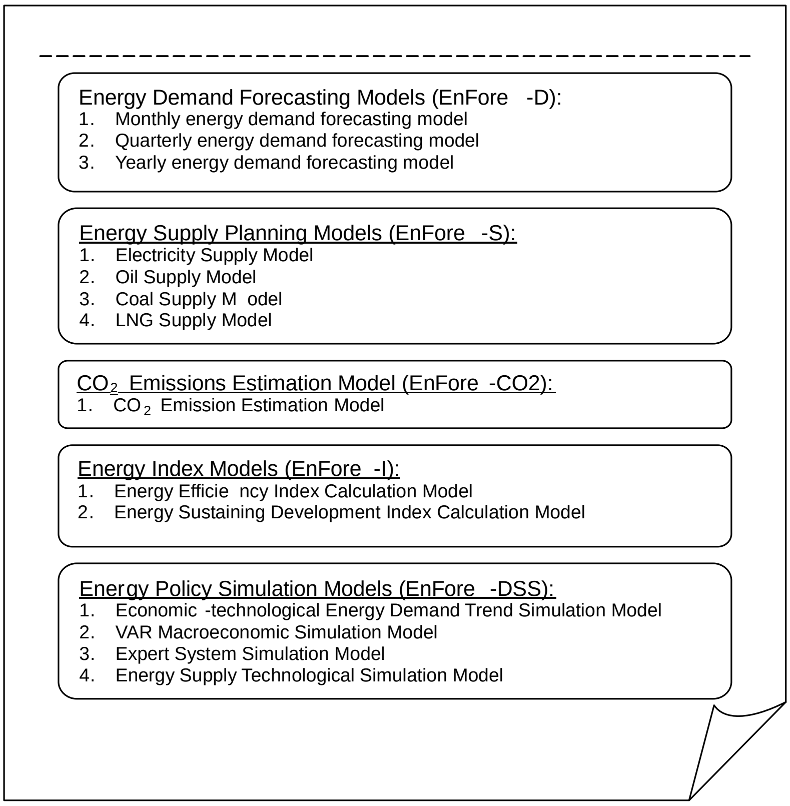

Figure 5 The model groups in the EnFore system

Energy Demand Forecasting Models

There are three energy demand forecasting models in the EnFore system, based on the forecasting period, i.e., monthly, quarterly and annual energy demand. These are all designed on a statistical basis with different solution methods. Since the monthly and quarterly historical energy demand shows seasonal patterns, Winters' exponential smoothing method, Box-Jenkins ARIMA, and the naïve method (see Appendix 1) are therefore used as the solution methods for the problems of short-term forecasting. Therefore, within the system, the monthly and quarterly energy demand forecasting models are built on the basis of these three solution methods utilizing the Regression Analysis of Time Series (RATS) system, a powerful and focused time series software, as the main computation tool.

The monthly and quarterly forecasting models are based on two different function designs aimed at satisfying two main types of users. The first of these provides an automatic forecast processing mode, whilst the second requires users to set the parameters for the forecast model prior to execution of the model. These models were designed in this way because of the expectation of two types of users of the EnFore system, those familiar with time series methods, and those who have no experience with such methods. Those who are familiar with the time series methods can use either the automatic or user-defined parametric settings forecasting modes, whereas those who are unfamiliar can choose the option of the automatic mode. The user-defined parametric settings mode in the short-term forecasting model also provides flexibility in terms of handling cases where there are changes in the energy demand pattern.

The results of research into the annual historical energy demand showed no clear seasonal pattern; however, certain macroeconomic factors did have some significance in the energy demand mode. In order to ensure accurate forecasting of long-term energy demand, economic factors affecting the energy consumption structure must be considered in the model; therefore, a time series solution model relying only upon energy consumption information cannot be satisfactorily applied to these situations. Instead, a hybrid model of both econometric and time series methods for long-term energy forecasting is required to deal with the reality of energy demand (see Appendix 1).

Energy Supply Planning Models

As already noted, crude oil, coal and LNG are the three primary sources of energy consumption in Taiwan providing secondary energy for local use, and since the energy supply industry has now been deregulated, such that private corporations are now operating within this industry, administrative officials are deeply concerned about the potential uncertainty of supply of these primary sources of energy in the future. It is therefore clearly necessary to provide energy supply planning models to meet the needs of policymakers. The end products in energy consumption come primarily from electricity generation, oil refining, coal coking and LNG transformation, with the effective throughput of these energy products being significantly affected by production technologies. Thus, it was recognized that four master planning models for each type of energy supply industry would be required as the technological base.

Given the specific conditions of Taiwan’s energy market, rather than making profits, policymakers are more concerned with the long-term security of primary energy supply to satisfy local demand, so the objectives of the supply models were set to pursue minimum supply cost and the lowest level of security reserves. The planning period was constructed in twenty-five stages in order to provide results for the subsequent twenty-five years, to make them useful for long-term policymaking. Following in-depth research work on the nature of energy supply problems, the models were designed in the form of optimal programming models, with the minimization of costs in energy production being the programming objective. The technology involved in producing and/or transforming secondary energy products would provide the constraints for the programming solutions. The selection of programming solution models for each supply model was dependent upon its production characteristics (see Appendix 2). The models use aggregated technical data and are solved with the General Algebraic Modeling System (GAMS) optimization package, a powerful mathematical programming package for solving linear and nonlinear optimization problems.

The electricity supply model is a long-term planning model, established by using deterministic dynamic programming, which provides twenty-five stage (i.e. 25-year) solutions for power mix, fuel consumption and plant capacity planning, with a time span of one year, or a defined period, for each stage. Since the main concern is on the mode of annual supply to satisfy local electricity demand, the objective of the power supply model was to pursue least cost generation. Analysis of both the generation technology of power plants, and the operational environment, revealed that generator capacity, load factor, heat rate, peaking capability, fuel consumption, the amount of imported fuel resources and the timed development emphasis of generators, were all significant limitations on Taiwan’s overall power supply.

The oil supply model is a twenty-five stage planning solution model for total crude oil imports for both refinery demand and total petroleum products demand, established under linear programming modeling with a time span of one year or a defined period for each stage. Since the outlets for refined petroleum products are basically domestic oil-fired power generation, industrial demand and final demand, the oil supply model was built with the objective of achieving the lowest cost for imported crude oil and imported petroleum products to meet both refinery and local demand. The planning was constructed to provide programming results for the subsequent twenty-five year period, with the model being designed to include constraints based on the findings of investigations of both plant refinery technology and the operational environment. The capacity of refinery units, heat conversion, refinery loss, amount of imported petroleum products, and limits on imported crude oil from defined areas, represented significant limitations on petroleum product supply and are the key constraint factors in the model. The modeling was completed after being coded under the GAMS package solutions language.

The coal supply model is a combination of two sub-models, the coking coal and steam coal supply models. Both sub-models were established by using mathematical linear programming, being combined and built to provide a twenty-five stage planning solution for total importation of coking coal and steam coal to meet the needs for coking, coal-fired power generation and local end-use for the subsequent twenty-five year period.

The LNG supply model was established as a mathematical formulation model using algebraic formulae, and built under parameters of engineering skills and the limitations of supply facilities, such as gas and LNG storage capacity. The LNG formulation model transforms the demand from gas-fired power generation, industrial and final consumption, into the total amount needed, and then solves the equation to obtain the amount of supply.

CO_2 Emission Estimation Models

The combustion of fossil fuels activates the carbon atoms inside resulting in oxidation, and thus releasing both heat energy and CO_2 gas into the atmosphere. However, the increasing CO_2 gas emissions in recent decades have given rise to the ‘greenhouse effect’, which has led to dramatic changes in the global climate pattern. It has therefore become necessary to estimate CO_2 gas emissions so as to formulate appropriate policies for their reduction.

The CO_2 estimation model contains two emission estimation methods. The first of these is the reference approach, which was provided by the Inter-Governmental Panel on Climate Change (IPCC), and involves a method for computing the energy supply side of CO_2 emissions (IPCC, 1997). The benefit of this approach is that it is relatively easy to monitor energy information on each country from international trade data, and therefore also relatively easy to ensure that each country uses a consistent method that will facilitate worldwide comparison. However, the main drawback of the IPCC reference approach is that it is unable to provide information on CO_2 emissions for each sector.

The second method is the newly developed EnFore-C computation method, where the estimation is based on secondary energy consumption within each sector by using the EnFore-D forecasting results. The result is that the EnFore-CO_2 sub-system not only increases the accuracy of the estimates of emission levels, but is also consistent with the pursuit of equity established under the ‘polluter pays principle’. In addition, the EnFore-C method could provide valuable information for policy makers in assessing and formulating reasonable industrial policies for the reduction of CO_2 emissions. The two methods are coded together to give the CO_2 emissions estimation model solutions for both supply and demand perspectives of CO_2 gas emissions through energy transformation.

Energy Index Models

A number of problems are generally encountered during the process of exploitation of energy resources, such as exhaustion of such resources, an imbalance in the demand and supply of such resources, or the destruction of the ecological environment. It is clearly necessary, therefore, to establish a model of sustainable energy indices for application in Taiwan, in order to avoid further degradation of the environment, whilst pursuing the sustainable use of energy resources.

The EnFore-I system comprises of two kinds of energy index models, the energy efficiency and sustainable energy development index model. There are two sub-models within the energy efficiency index model, the first of which is the end-use energy efficiency index, constructed mainly on the basis of the energy efficiency index formulae provided by the International Energy Agency (IEA, 1997). Although the basic principle in EnFore is to follow up the IEA’s standard definition of end-use energy efficiency indicators, the EnFore-I also aims to develop a consistent and simple methodology for the simultaneous calculation of economic and physical energy efficiency indicators. By adopting such a methodology, the energy administrative agency can easily build up a family tree of energy efficiency indicators from national level, down to sector or even product level. These family tree indices, performing much like a doctor’s thermometer to check on the basic condition of a patient, can then be used for comparison with other general time-series economic statistics published by the government and as a reference of fundamental energy policymaking (See Appendix 3).

The second sub-model in the energy efficiency model is the gross efficiency index, which focuses on the gross efficiency of the transformation of energy, from primary to secondary energy. The basic dilemma is that when calculating the energy efficiency for a nation or a region, we need to avoid the problems of double counting and inconsistency, which are common errors in many energy efficiency decomposition studies. Since primary energy does not enter the final energy consumption market, there is no way of determining compatible economic data to match the primary energy data; thus, some suitable mathematical transformation and modeling work is needed in order to adequately measure the primary energy transformation efficiency indicators. The methodology relies heavily upon the concepts of physical energy balance tables and economic input-output tables (See Appendix 3).

Construction of the sustainable energy development index model was based mainly on the ‘Indicators for Sustainable Energy Development, (ISED)’ (IAEA and IEA, 1999). Using the Delphi technique, candidates for the index are evaluated and selected on the basis of their appropriateness to the local situation and are then communicated to the international sustainable index scheme. Both the energy index models in the EnFore system are designed to provide automatic calculation of these indices within the computer system whenever corresponding data is updated.

Energy Policy Simulation Models

As our living standards rise, the conflict between economic development and energy conservation clearly become much more intense. Within all nations, therefore, energy policies are now playing an increasingly important role in overcoming this paradox; however, the world is now changing at an extremely rapid pace, so in order to conserve energy resources and protect the earth’s environment without any degradation of economic growth, it was clearly necessary to develop an effective computing tool, such as the EnFore system, as a means of providing information and a source of reference for energy policy decision making. The policy simulation models were constructed in order to further enrich the utility of the system, enabling decision makers to define their own scenarios, so as to provide further supporting guidance and information.

The design of the policy simulation models involved interrelated models, within which the primary targets were the effects on energy demand and supply. Factors affecting energy demand will in turn affect supply, so the models need to be combined and built into sets of simulation modules once the simulation models have been completely established. Four basic simulation models are provided under the EnFore-DSS sub-system for economic/technological energy demand trend simulations, VAR macroeconomic simulations, expert system simulations and energy supply technical simulations. The first three of these simulations are designed to provide results on energy demand, whilst the latter is aimed at providing simulation results on energy supply. They are, however, designed for use for many different purposes and to satisfy many different cases.

The reasons for the establishment of the economic/technological energy demand trend simulation model were to simulate long-term GDP and energy intensity trends, and to measure the effects on future changes in the pattern of energy demand, under certain situations, from GDP and energy intensity. The demand trend simulation model was designed to combine the GDP and energy intensity simulation models with the energy demand forecast model. The GDP simulation model is executed first so as to provide three sets of GDP estimates, in accordance with three different scenarios, with the knowledge being based on in-depth research. These three default sets provide a reference and are subjected to changes based upon the inputs of the simulators. A similar design was applied to the energy intensity simulation model, with three default sets of energy intensity being provided for further amendment. The demand trend simulation model first of all simulates GDP and energy intensity, and then continues with the simulation to provide the results on energy demand and the pattern of demand.

The VAR macroeconomic simulation model is simulated to determine the effects on energy demand by the shock of macroeconomic changes. It is generally accepted that industrial production and energy prices will affect energy usage; therefore, the VAR macroeconomic simulation model is constructed by combining the GDP simulation models, the total industrial production indices, and total energy price indices, with the energy demand forecast model. The element of the model comprising of the GDP model, production indices and total energy price indices, is executed to provide a set of simulation values to which users can add their own inputs. Thereafter, the VAR method is used to measure how any sudden change (i.e., shock) to the economic environment will impact on the demand for coal, oil, LNG and electricity (see Appendix 4).

The expert system simulation model is designed to cover any defect stemming from the inability of the defaults to sufficiently forecast energy demand. Since there are always uncertainties in the energy market which may be due to certain unforeseen circumstances, we can hardly hope to design statistical energy demand forecast models that will reflect reality at any given time; therefore, in order to overcome this major defect, the Dephi technique provides the core method for the expert system simulation model, within which the energy demand opinions of seven experts are added into the model. These are then compared with the results of the statistical energy demand forecasting model, in an effort to make amends for the inherent flaws of the system default.

The energy supply technological simulation model combines four sub-models, the electricity supply, oil supply, coal supply and LNG supply simulation models, to provide a complete supply simulation model capable of determining the supply situation based on the effects of demand changes, or changes in supply technologies. The design of the energy supply technological simulation model allows for user-defined parametric setting of the energy supply according to various policy scenarios. The energy demand factor in the model was designed in response to the changes in demand pattern provided by the energy demand simulation models, or the default demand forecasted by the annual energy demand forecasting model of the EnFore-D sub-system. The simulation methods used in the supply simulation model are the same as those used in the energy supply technological model of the EnFore-S sub-system.

Integrated Design of System Functions and Interfaces

With the completion of the framework design, the database and the system models, the final stage of the design phase involved the integration of these designs into automatic functions for user operation, whilst ensuring the provision of user-friendly interfaces. The design of this stage was carried out using Visual Basic (VB) as the system language. The advantage of using VB for the integration design is that it provides tools for convenient access to the database system and models by use of other software languages such as GAMS, RATS, and Mathematica. Furthermore, using this system ensures that the user interfaces are clear and easy to operate, with the resultant efficient execution of the programs. Other advantages include the user-friendly interfaces of the design dialogue, report design flexibility, the ease with which the program codes can be packed into software and the ease and rapidity of the setup procedures.

Six main function groups, data updating, data enquiry, short- and mid-term forecasting, long-term forecasting and planning, energy index and energy policy simulation, were designed to integrate the database and models of the EnFore system. The data updating function group enables users to update the system database in order to be well prepared to perform any other functions within the system. The data enquires function group provides access to historical energy data for reports. The short-term forecasting function group is designed to enable users to perform monthly and quarterly energy demand forecasting with outputs as data reports and trend figures. The long-term forecasting and planning function group includes annual energy demand forecast functions, along with energy supply planning and CO_2 emission forecasts. The energy index function group enables users to calculate the energy efficiency indices and sustainable energy development indices within the system. The simulation modules of

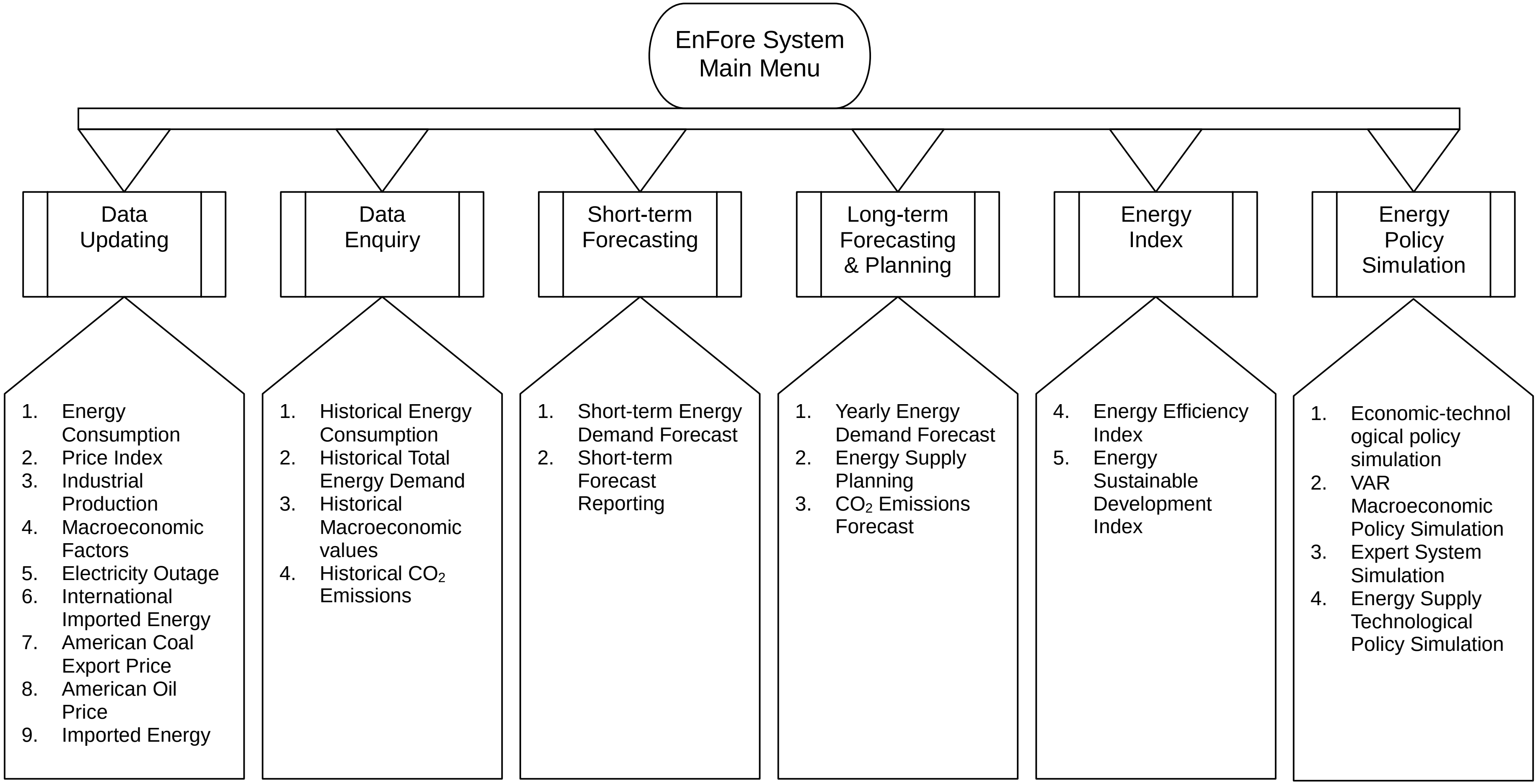

Figure 6 The functions of the EnFore system

the policy simulation function group provide users with platforms to simulate energy policy scenarios using the demand and supply simulation models. These six function groups are listed, by title, on the main menu function bar; the functions of each group are illustrated in Figure 6.

APPLICATION OF THE ENFORE SYSTEM POLICY SIMULATION

Through the energy policy scenarios provided, the EnFore system is designed to provide simulations performed at different levels, from an energy demand or supply perspective, with either a demand-supply package, or a demand-supply package complete with CO_2 emissions estimation. Users can therefore select a package according to their needs, and can choose to operate the economic/technological policy simulation, the VAR macroeconomic policy simulation, the expert system policy simulation function from a demand perspective, or the energy supply technological policy simulation function from a supply perspective.

The system also provides three demand-supply simulation packages which enable users to run their scenarios by first operating the economic/technological policy simulation function, and then having the energy supply technological policy simulation function as one of the package options. The remaining two packages are the VAR macroeconomic policy simulation and the expert system policy simulation, both of which provide an energy supply technological policy simulation function. These three function packages can be further enhanced, with the CO_2 emissions estimation being simulated following the use of the energy supply technological policy simulation function.

CASE STUDIES

The following sections introduce two case studies in an effort to demonstrate how users can utilize the EnFore system to simulate scenarios for policy guidance. The first case study demonstrates the use of the VAR macroeconomic policy simulation function as a means of analyzing the impact on the Taiwan energy market arising from a quick end to the crude oil price shock caused by the 2003 invasion of Iraq by coalition forces from the US and the UK. The second case study uses the energy supply technological policy simulation function to investigate the ways in which the pattern of supply would change under a scenario of early retirement of three of the four nuclear power stations in Taiwan.

Scenario 1 The impact on the Taiwan energy market from a quick end to the crude oil price shock caused by the 2003 war in Iraq

The invasion of Iraq began soon after US President Bush made the first announcement at 10.15 a.m. on 19 March 2003 (US time), and most analysts and commentators remarked at that time that the coalition army would attack Baghdad and successfully overthrow the Saddam Hussein regime, thus bringing the war in Iraq to a very rapid conclusion, and ensuring minimum disruption to the global supply of crude oil. However, it is widely understood that since Iraq is the second largest crude oil exporting country in the world (second only to Saudi Arabia), irrespective of how short the duration of the war was, fluctuations in the global price of crude oil would have some impact.

Since Taiwan is almost totally dependent on the importation of crude oil supplies, any fluctuation in the global price of crude oil must also have some impact on the C.I.F. price in Taiwan, which would of course have a knock-on effect on the price of main petroleum products in the Taiwanese energy market. Therefore, there is clearly a need to analyze such a scenario; we therefore used the EnFore system to perform the simulation. Based on the general comments across the world prior to the outbreak of the war, a scenario was set up to reflect the conditions at that time, with the war being over very quickly and the global effects of inflation in crude oil prices returning to normal within a period of six months. Clearly, the simulation topic involved a limited-term shock on the Taiwanese energy market, thus the VAR macroeconomic policy simulation function of the EnFore system was used. The following describes how the system undertook the simulations and helped with our analysis work on 19 March 2003.

The scenario assumed that the war would end quickly and that the effects on the stability of the world oil supply would be limited, such that the global price of crude oil would rise to US$40/bbl for six months. Hence, in this scenario, the average price of crude oil in 2003 was expected to be US$33.08/bbl, with an average rate of increase of 26.46 per cent, whilst the imported costs of crude oil would rise at an average rate of 5.64 per cent. Given the existence of long-term contracts, the average impact on the C.I.F. of import costs would be much smaller than the spot market price during this relatively short period.

The VAR macroeconomic policy simulation function within the system began performing a statistical simulation on the three macroeconomic factors as soon as the new imported crude oil cost was given. According to the simulation results for the three factors in the VAR macroeconomic simulation model, the total domestic energy price index would increase at a rate of 6.02 per cent, the change in the rate of real industrial production index (with 1996 as the base year) would be a reduction of 0.771 per cent, and the change in the real GDP index rate (with 1996 as the base year) would be a reduction of 0.772 per cent for 2003, as compared to the case without any sudden rise in the price of crude oil. Similar impacts would also occur in 2004 to 2006 (see Table 1).

Table 1 The impact on real GDP and total industrial production indices in Taiwan from a rapid end to the 2003 war in Iraq

Year	Real GDP Index[1]			Index of Real Total Industrial Production[1]		
	Baseline[2]	Scenario[3]	% Change	Baseline	Scenario[3]	% Change
1996	100.00	100.00	-	100.00	100.00	-
1997	106.68	106.68	-	107.43	107.43	-
1998	111.55	111.55	-	110.26	110.26	-
1999	117.60	117.60	-	118.76	118.76	-
2000	124.49	124.49	-	127.52	127.52	-
2001	122.12	122.12	-	118.19	118.19	-
2002[4]	126.09	126.09	-	128.39	128.39	-
2003[5]	130.65	129.64	-0.772	135.76	134.71	-0.771
2004[5]	136.02	134.50	-1.112	142.94	141.36	-1.105
2005[5]	141.39	139.36	-1.431	150.38	148.23	-1.430
2006[5]	146.76	144.17	-1.762	158.07	155.29	-1.759
Avg. growth rate (%)	3.87	3.41	-	5.34	4.87	-

Notes:

[1] The base year for each index is 1996.

[2] The baseline case for the Real GDP index is forecasted by the EnFore system.

[3] The scenario for each index represents the simulation results of an increase in crude oil prices to US$40/bbl for 6 months.

[4] indicates preliminary data.

[5] indicates forecast data.

The system provided the three new macroeconomic factors and thereafter, the simulation continued until the energy demand results were provided. The resultant data reports showed that the respective demand for coal, oil, LNG and electricity would decline by 0.71 per cent, 1.32 per cent, 1.05 per cent, and 0.09 per cent, giving a total reduction in energy demand of 1.04 per cent in 2003; however, because of the complementary relationship between coal and either oil or LNG, there would be a rise in the demand for coal in 2004 to 2006, as compared to the case without the sudden rise in crude oil prices in 2003 (Table 2). The figures further indicate that the negative impact on the energy demand market would be more significant than the economic cycle.

The simulation results reveal that the reduced demand for oil products would be the first impact to be felt on the secondary energy demand structure. The demand for oil products, LNG and electricity demonstrate a positive relationship (complementary products) with a negatively changing pace in the demand for coal (substitute product). Given the reduced demand for electricity, then oil, LNG and coal would be the three main fuels used for electricity generation. Therefore, inflation in the global price for crude oil would result both in a reduction in the demand for oil products and a structural change in electricity generation fuels.

Scenario 2 The effects on the energy supply pattern from the early retirement of the nuclear power stations

Since assuming power in May 2000, the new government in Taiwan has been aggressively campaigning for a nuclear-free environment, with the aim of freeing the island from nuclear waste and danger. Indeed, it has been suggested that the three existing nuclear power stations will have to be retired seven years earlier than the expected completion of their proposed life cycles. Nevertheless, such early retirement of the nuclear power stations may well lead to changes in the electricity generation power mix. For this case study, the energy supply technological policy simulation function in the EnFore system was used to determine the effects.

Within the energy supply technological policy simulation function, there are several parameters which users can use to set their own scenarios; however, the policy for newly established generators is now confined to the use of coal and LNG as electricity generating fuels. It should be noted that the government has decided to give up the proposed new setting of oil-fired power generation, and its new policy on nuclear power generation will be launched in the near future, thus, users can set the related parameters of generation capacity using only coal, LNG and nuclear fuel as the generation means. Generators using oil as fuel are fixed in number; since there will be no additional generators built, only replacement of the existing machines; therefore, users do not have the option of setting their own energy supply technological parameters relating to oil as the electricity generating fuel.

According to information provided by the Energy Commission and Taipower Company, each of the three nuclear power stations have two generators, with their initially proposed retirement dates being the end of 2018 and 2019 for No.1 Nuclear Power Station; the end of 2021 and 2022 for No.2 Nuclear Power Station; and the end of 2024 and 2025 for No.3 Nuclear Power Station. The early retirement date proposed for both of the generators in No.1 Nuclear Power Station is now the end of 2011, whilst for the generators in No.2 Nuclear Power Station it will be the end of 2014, and the end of 2017 for the two generators in No.3 Nuclear Power Station. The normal retirement date for the three nuclear power stations provides us with the baseline case, and their early retirement dates provide the simulation scenarios. At the end of the year 2002, on

Table 2 The impact on secondary energy demand from the 2003 war in Iraq

Unit: thousand KLOE

Year	Coal & Coal Products			Oil & Oil Products			Natural Gas			Electricity			Total		
	Baseline	Scenario	% Change	Baseline	Scenario	% Change	Baseline	Scenario	% Change	Baseline	Scenario	% Change	Baseline	Scenario	% Change
2001	10,535	10,535	-	36,758	36,758	-	2,401	2,401	-	45,135	45,135	-	94,828	94,828	-
2002[1]	10,824	10,824	-	38,926	38,926	-	2,622	2,622	-	46,662	46,662	-	99,034	99,034	-
2003[2]	11,463	11,382	-0.71	39,182	38,663	-1.32	2,375	2,350	-1.05	50,280	49,827	-0.90	103,299	102,222	-1.04
2004[2]	11,550	11,568	0.16	40,874	40,172	-1.72	2,437	2,382	-2.26	53,502	52,762	-1.38	108,363	106,884	-1.36
2005[2]	11,896	11,981	0.71	42,419	41,482	-2.21	2,527	2,442	-3.36	56,564	55,491	-1.90	113,406	111,396	-1.77
2006[2]	12,358	12,507	1.21	43,924	42,678	-2.84	2,546	2,435	-4.36	59,600	58,145	-2.44	118,428	115,765	-2.25
Avg. growth rate (%)	3.37	3.68	-	3.07	2.33	-	-0.73	-1.83	-	6.31	5.65	-	4.57	3.98	-

Note:

[1] indicates preliminary data.

[2] indicates forecast data.

Table 3 Changes to the power mix structure

Unit: %

Year	Coal		Fuel Oil		LNG		Nuclear		Hydropower		New Energy		Cogeneration	
	Baseline	Scenario	Baseline	Scenario	Baseline	Scenario	Baseline	Scenario	Baseline	Scenario	Baseline	Scenario	Baseline	Scenario
2002	40.4	40.4	9.1	9.1	7.8	7.8	20.1	20.1	4.6	4.6	1.8	1.8	16.2	16.2
2003	42.8	42.8	7.0	7.0	8.5	8.5	19.1	19.1	4.4	4.4	1.8	1.8	16.5	16.5
2006	44.4	44.4	4.8	4.8	9.9	9.9	20.3	20.3	4.0	4.0	2.0	2.0	14.7	14.7
2012	48.8	51.7	3.0	3.0	12.0	12.1	18.6	15.6	3.4	3.4	2.9	2.9	11.2	11.2
2016	51.6	58.1	2.4	2.5	13.9	13.9	16.1	9.5	3.0	3.0	3.4	3.4	9.6	9.7
2022	58.9	63.7	2.0	2.0	15.5	15.6	9.5	4.6	2.5	2.5	3.5	3.5	8.0	8.0
2026	65.4	65.4	1.8	1.8	16.0	16.0	4.2	4.2	2.2	2.2	3.2	3.2	7.2	7.2

completion of the scenario settings, the system simulation was then carried out and the results compared with the baseline scenario (see Table 3).

Following the electricity planning simulation, when the simulation scenario was compared with the baseline case, the results of the power mix indicated that the early retirement of No.1 Nuclear Power Station in 2012 would lead to a rise in coal-fired generation from 48.8 per cent to 51.7 per cent, and a slight rise in LNG-fired generation from 12.0 per cent to 12.1 per cent; other forms of generation would be likely to remain the same. Similar results are provided for later years following the early retirement of the No.2 and No.3 Nuclear Power Stations. In such cases, those generators using coal and LNG as fuel would provide a substitute for the retirement of the nuclear power generators in accordance with their production costs, supply capacity limitations and peak-load conditions.

The simulation then continued by providing the results of the total energy demand structure. As Table 4 clearly indicates, the total energy needs would be 201,000 KLOE above the baseline case for 2012, rising to 513,000 KLOE above the baseline case in 2016, and falling back to 456,000 KLOE above the baseline case in 2022. That is to say, the early retirement of the nuclear power stations would result in more primary energy sources being required to meet the island's energy demand than if the retirement dates were to remain at their normal expected life cycles. Furthermore, due to the very tight limitations on LNG storage container capacity, the supply of coal imports would have to be increased significantly to counteract the reduction in nuclear energy generation.

Table 4 Changes to total primary energy demand

Year	Baseline	Scenario	Net Change	Change (%)
2002	106,624	106,624	-	-
2003	111,786	111,786	-	-
2006	128,641	128,641	-	-
2012	163,834	164,035	+201	0.123
2016	187,959	188,475	+513	0.276
2022	223,656	224,112	+456	0.204
2026	246,837	246,837	-	-

Since it is recognized that the increased use of coal would exacerbate the problem of CO_2 gas emissions, the simulation was allowed to continue in order to provide estimated CO_2 emissions as a reference. The CO_2 emissions estimation policy simulation calculated the amount, from perspectives of both demand and supply, with the results clearly showing that the total amount of CO_2 emissions stemming from the early retirement of the nuclear power station would be significantly greater than the levels stemming from normal retirement dates (see Table 5).

Table 5 Changes to carbon dioxide (CO_2) gas emissions

Unit: Thousand MT

Year	Baseline	Scenario	Net Change	Change (%)
2002	269,752	269,752	-	-
2003	284,858	284,858	-	-
2006	323,203	323,203	-	-
2012	410,471	419,393	+8,922	2.17
2016	473,907	496,646	+22,739	4.80
2022	585,159	605,407	+20,248	3.46
2026	670,563	670,563	-	-

This result implies the future likelihood of conflict in overall energy policy, and particularly in the area of CO_2 emission control policy. These early warning signs provided by the EnFore system, should be seen by policymakers as an extremely valuable source of risk analysis and assessment.

CONCLUSIONS

Following the 1997 Kyoto Protocol, a reduction in CO_2 emission levels has become one of the most important issues in worldwide environmental protection. In considering sustainable development, there is a need to conduct a review of past economic development, energy use and CO_2 emissions. In recent years, most governments of the developed and developing nations have become aware of the importance of sustainable development and have made appropriate adjustments to their energy policies. An example of such awareness is the improvements in industrial policies that have been carried out concerning the requirements and standards for pollutant emissions and energy conservation; however, due to the lack of precise information on long-term energy forecasting, there are still discrepancies between policies focusing on economic development and those concerned with environmental protection. Thus, with the continuing intensive use of energy, most nations have failed to effectively tackle the complex 3-E problems and overall sustainable development. This has been the fundamental motivation behind the development of the EnFore decision support system in Taiwan since 1995.

In general, two bold and commonly seen categories of models for forecasting energy demand and supply are econometric and engineering models. Models of an econometric type adopt a regressive analysis to conduct their forecast, with the key exogenous variables usually being GDP, industrial production and energy price. As a result of restricted data sources, econometric-type models are often referred to as ‘top-down’ energy forecasting models. Forecasting is first conducted by predicting total energy consumption, followed by the use of allotment to estimate the individual levels of energy consumption within each sector. Conversely, models of an engineering type tend to place greater emphasis upon understanding how energy is consumed by end-users as well as end-use technology, which are then added together for each sector. Thus, they adopt a more end-use method, sometimes referred to as a ‘bottom-up’ approach.

There are advantages and disadvantages associated with both of these energy forecasting models. For example, the major benefit of the top-down method is its ease of use and the provision of economic causes of energy demand; however, the major drawback is the ‘black box’ of energy service technologies. The major advantage with the bottom-up model is the provision of a detailed description of energy service technologies and their possible costs. One clear difficulty is the tremendous burden in the demand for precise data; the requirement to build and maintain a reliable database for all technologies, including both present and future generations, is a tall order. Even where the information exists, the costs involved in collecting it undoubtedly represent a tremendous burden; it is virtually a ‘mission impossible’. The inevitable outcome is that the information used will not be totally precise, and therefore, the forecasting error in a bottom-up model will be significant; thus, subjective manipulation of forecast results will often exist, highlighting a serious problem with the engineering model.

The need to secure the benefits of both models, whilst also avoiding the drawbacks, has been another major push for the development of the EnFore model in Taiwan. As noted earlier, Enfore is a hybrid DSS system which has developed an effective database for integration with model-based information. The successful establishment of the EnFore system now provides administrative energy officials and academic researchers with a powerful computerized decision support system supported by an enriched 3-E database to assist them in their policy decision-making.

User needs are an important aspect of the design of the system, with the main design trend having been a user-friendly interface within which clear instructions are provided and users can enjoy ease of operation. System menus and reports are readily available to support user operations, providing details of the functions of the system and information on the system models and the database. The relational database concept ensures that the maintenance of huge quantities of data and information is a relatively simple task which is also characterized by low cost, with the models and functions being updated regularly to keep abreast of the rapidly changing pace of the energy market, the environment and technological development. Within the models, the methodological solutions are examined from both subjective and objective perspectives, ensuring that they are up-to-date in current use, and also eminently suitable for future use.

In the ongoing study and development of the EnFore DSS system, our first priority will be an attempt to link the system with computable general equilibrium (CGE) techniques, as this will provide an invaluable insight into structural changes within industry. The development of an appropriate methodology for linking the economic CGE table and the physical energy balance table, would not only extend the research dimension from a macroeconomic study to a microeconomic study, but might also help us to determine the technological change factors, such as primary energy transformation technology, and secondary energy use technology.

Looking into, what we hope, is the not too distant future, by connecting to a global database, it is possible that this kind of study will prove to be invaluable in the area of global CO_2 emission control or trading policy simulations. Finally, another future direction would be to extend the pollution database of the EnFore system to include sulfur oxides SO_x and nitrogen oxides NO_x, as well as a whole basket of other energy related pollutants. A shift in this direction would be very useful for future 3-E policy simulation.

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Appendix 1

EnFore-D Models

The following are the five main time-series solution methods used in the establishment of the monthly, quarterly and annual energy demand forecast models in the EnFore-D sub-system. The annual energy demand forecast model adopts only an econometric model, using the spectral method and Hodrick-Prescott filtering, whilst both the short-term and long-term energy demand forecast models adopt Winters' exponential smoothing and the Box-Jenkins' ARIMA method.

Winters' Exponential Smoothing Method

The exponential smoothing of time series is defined as:

$$\begin{aligned} Y_t &= \left(a + bt + ct^2\right) s\left(t\right) + \varepsilon_t \\ a_t &= \omega_1 \times \frac{y_t}{s_{t-1}(t)} + \left(1-\omega_1\right)\left(a_{t-1} + b_{t-1} + c_{t-1}\right) \\ b_t &= \omega_2 \times \left(a_t - a_{t-1} + c_{t-1}\right) + \left(1-\omega_2\right)\left(b_{t-1} + 2c_{t-1}\right) \\ c_t &= \omega_3 \times \frac{b_t - b_{t-1}}{2} + \left(1-\omega_3\right) c_{t-1} \end{aligned}$$

where Y is the forecasting variable; a, b and c are, respectively, the constant, the linear time trend and the non-linear time trend; $s(t)$ is the seasonal factor; and ω_1 , ω_2 , and ω_3 are, respectively, the weights of the constant, the linear time trend and the non-linear time trend, with their values being between 0 and 1.

Box-Jenkins' ARIMA

For non-stationary time series $\{Y_t\}$ are the differences in stationary time series, that for all time *t*,

$$\phi_p(B)(1-B)^d Y_t = \theta_q(B) a_t$$

where a_t obeys white noise process with average 0; variance σ_a^2 is in normal distribution; d is the order of difference; $\phi_p = (1 - \phi_1 B - \cdots - \phi_p B^p)$; and B is the back shift operator, that is $BY_t = Y_{t-1}$. When all the roots of $\phi_p(B) = 0$ lay outside the unit circle, then the condition of the stationary model is fulfilled. Next, if the roots of $\theta_q(B) = (1 - \theta_1 B - \cdots - \theta_q B^q)$, and $\theta_q(B) = 0$ are outside the unit circle, then the reversible condition is satisfied. Therefore, this time series $\{Y_t\}$ is an auto regressive integrated moving average, noted as ARIMA (p, d, q); *p* represents the auto regressive process of order *p*, $AR(p)$; *q* represents the moving average process of order *q*, $MA(q)$; and *d* represents the *d* order difference.

Econometric Model

The econometric model equation for each industry is as follows:

$$\ln Q_t = \beta_0 + \beta_1 \ln P_t + \beta_2 \ln I_t + \beta_3 \ln GDP_t + \varepsilon_t \qquad t = 1, 2, \cdots, T$$

where Q_t is the demand for a specific type of energy within an industry; P_t is the index of real total energy price with 1996 as the base year; I_t is the index of real industrial production with 1996 as the base year; GDP_t is the index of real GDP with 1996 as the base year; and ε_t is the stochastic error term.

Spectral Method

The spectral method uses the frequency domain analysis to normalize the data under the Box-Jenkins' model, with the variable x_t in terms of moving average expression:

$$x_t = c(L)\varepsilon_t$$

where c(0)=1 and ε_0 is the initial point of x_0, using the spectral method for estimation and forecasting by the Fournier transformation formula of *c*.

Hodrick-Prescott Filter Method

Hodrick-Prescott filtering, noted as the HP-filter, is used mainly in the analysis of macroeconomics to obtain long-term forecasting trends. Consider a time series $\{y_t\}$, then the equations of the HP-filter method can be written as:

$$y_t = g_t + c_t \qquad t = 1,2,\cdots,T \quad \underset{\{g_t\}_{t=-1}^{T}}{Min}\left\{\sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})^2]\right\}$$

where $\{g_t\}$ represents the growth component, and uses the sum of $\{g_t\}$ squared second differentiation for smoothing; $\{c_t\}$ represents the cyclical component to test the periodicity of the long-term series.

Technically, the HP-filter method mainly utilizes $\{g_t\}$, the neighbor of $\{y_t\}$, being the two-sided linear filter to minimize the variance of $\{y_t\}$. Therefore, the formula of the H-P filter method can be written as:

$$\underset{\{g_t\}_{t=-1}^{T}}{Min}\left\{\sum_{t=1}^{T} (y_t - g_t)^2 + \lambda \sum_{t=1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})^2]\right\}$$

where λ is a positive smoothing coefficient.

Appendix 2

EnFore-S Models

The energy supply models in the EnFore-S sub-system were established under two mathematical programming solution methods, linear and dynamic programming; linear programming is used to construct the oil and coal supply models, whilst dynamic programming is used to establish the electricity supply model.

Linear Programming

The aim here is to maximize or minimize a target under the constraints of limited resources. The linear programming model comprises of a linear objective function (*Z*) and a set of constraints, with decision variables for solving to obtain optimality. The general form of the linear programming model is:

$$
\begin{array}{llll}
\max \quad (\text{or } \min) & Z = C_1X_1 + C_2X_2 + \cdots + C_nX_n & & \\
s.t. & a_{11}X_1 + a_{12}X_2 + \cdots a_{1n}X_n & \begin{pmatrix} > \\ < \end{pmatrix} & b_1 \\
 & a_{21}X_1 + a_{22}X_2 + \cdots a_{2n}X_n & \begin{pmatrix} > \\ < \end{pmatrix} & b_2 \\
\vdots & & & \\
 & a_{m1}X_1 + a_{m2}X_2 + \cdots a_{mn}X_n & \begin{pmatrix} > \\ < \end{pmatrix} & b_m \\
 & X_j \geq 0, \quad j = 1,2,....,n & &
\end{array}
$$

where Z is the objective value; X_j (*j* = 1,…,*n*) is the decision variable; C_j, a_{ij} (*i* = 1,…*m*) and b_i are the coefficient parameters.

Dynamic Programming

Dynamic programming is used to solve the problems in obtaining the optimality of stages. There is no definitive form for dynamic programming and it can be used for solving both linear and non-linear problems, under deterministic stochastic environments. The recursive relationship can be in either of the following forms:

$$f_n^*(s) = \max_{x_n}\{f_n(s, x_n)\} \quad \text{or} \quad f_n^*(s) = \min_{x_n}\{f_n(s, x_n)\}$$

where $f_n(s, x_n)$ is decided by s, x_n, and $f_{n+1}^*(\bullet)$; n: stage (n=1, 2, …, N); s: state; x_n: decision variable of stage *n*; $f_n(s, x_n)$: the maximum or minimum value of objective function of x_n in stage *n*, starting from state *s*; $f_n^*(s)$: the maximum or minimum value of $f_n(s, x_n)$ for all possible values of x_n

Appendix 3

EnFore-I Models

The following formulae are used to calculate the indicators in the EnFore-I models:

Economic Energy Efficiency Indicator

The economic energy efficiency indicator measures changes in the secondary energy consumption induced by the differences in intensity between the computation year and the base year. The computational equation is expressed as:

$$\%\Delta E_{efficiency} = \frac{A_t \sum S_{it}(I_{i0} - I_{it})}{E_{it}}$$

where, $\%\Delta E_A$ represents the efficiency index; E_{it} is the secondary energy consumption of industry *i* of the industrial sector in the t^{th} year; A_t stands for real GDP of the industrial sector in the t^{th} year; S_{it} stands for industrial structure (A_{it} / A_t) of industry *i* of the industrial sector in the t^{th} year; A_0 represents the real GDP of the industrial sector in the base year; I_{it} is the secondary energy intensity based on real GDP (E_{it} / A_{it}) of industry *i* of the industrial sector in the t^{th} year; and I_{i0} stands for secondary energy intensity of industry *i* of the industrial sector in the base year (based on real GDP).

Physical Energy Efficiency Indicator

The physical energy efficiency indicator measures changes in secondary energy consumption induced by the differences in energy density between the computation year and the base year. This indicator is also the second thermometer-type energy efficiency indicator defined in this paper. The computational equation is expressed as:

$$\%\Delta \tilde{E}_{efficiency} = \tilde{A}_i * \tilde{S}_{e_{i0t}} - 1$$

where, $\tilde{A}_i$ stands for the physical output volume index of industry *i* of the industrial sector in the computation year, such as the physical output volume index of individual industries; and $\tilde{S}_{e_{i0t}}$ represents the secondary energy consumption of industry i of the industrial sector in the base year/aggregative secondary energy consumption of the industrial sector in the computation year.

Appendix 4

EnFore-DSS Models

Several solution methods used in the other sub-systems are also used in the EnFore-DSS, such as Winters' exponential smoothing method, the Box-Jenkins' ARIMA method, the spectral method, the Hodrick-Prescott filter method (see Appendix 1), linear programming and dynamic programming (see Appendix 2). However, the vector autoregressive model (VAR) is also used as one of the solution methods for the simulation models in the EnFore-DSS.

The VAR model is basically a system of simultaneous equations built in the dynamic means. The k^{th} VAR model with lag order p can be expressed as follows:

$$Y_t = \nu + \Theta_1 Y_{t-1} + \Theta_2 Y_{t-2} + \cdots + \Theta_p Y_{t-p} + \varepsilon_t$$

$$Y_t = \begin{bmatrix} y_{1t} \\ \vdots \\ y_{kt} \end{bmatrix}, \ \nu = \begin{bmatrix} \nu_{10} \\ \vdots \\ \nu_{k0} \end{bmatrix}, \ \Theta_i = \begin{bmatrix} \theta_{i11} & \cdots & \theta_{i1k} \\ \vdots & \ddots & \vdots \\ \theta_{ik1} & \cdots & \theta_{ikk} \end{bmatrix}, \ \varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \vdots \\ \varepsilon_{kt} \end{bmatrix} \sim iid\ N(0, \Sigma)$$

where Y_t is the endogenous variable vector, y_{kt} is the element of the vector Y_t; ν is the constant vector, ν_{k0} is the element of the vector ν; ε_t is the error vector, ε_{kt} is the element of the vector ε_t; Θ_i is the coefficient of the vector Y_t, and θ_{ikk} is the element of the vector Θ_i.