MEDEE 2: A MODEL FOR LONG-TERM ENERGY DEMAND EVALUATION

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FOREWORD

The host of factors affecting the rate, level, and profile of energy consumption make the study of that dimension of energy systems exceedingly complex. Such complexity challenges energy systems analysts to develop tools for defining, clarifying, and quantifying the relevant factors. In recognition of this fact of energy-analysis life, the MEDEE approach, developed at the Institut Economique et Juridique de l'Energie (IEJE) in Grenoble, France, by B. Chateau and B. Lapillonne, was brought to the Energy Systems Program at IIASA, and subsequently revised and focused to match the Program's special purposes.

The IIASA Energy Systems Program concentrates on global aspects of the long-term (50 years from now) transition from the present energy system based on cheap fossil fuels to one which may be more sustainable. In this context, energy demand–region by region–must be understood in terms of economic, technical, and life-style factors. It was in order to gain this understanding that MEDEE 2 was implemented at IIASA. This study is part of the project "Comparison of Energy Options, A Methodological Study", sponsored jointly by the United Nations Environment Programme (UNEP) and IIASA.

Presently the MEDEE 2 model is part of the IIASA modeling of energy systems. This modeling exercise makes use of several separate but interconnected models which treat different aspects of energy systems. MEDEE 2 is one of the energy demand models in use, providing inputs to an energy supply and conversion model called MESSAGE. A macroeconomic model, MACRO, provides time trends of GNP and its components for MEDEE 2. The overall objective of the set of models (about 6 or 7 models in total) is to study the dynamics of national, regional, and global energy systems in some detail, and to examine the impact of energy systems on economics during a possible future period of energy transition. The full set of energy models is described in a Research Report by W. Häfele and P. Basile that is in preparation.

This report describes MEDEE 2 as it exists at IIASA. The report is intended to substantiate the philosophy supporting the MEDEE approach, and to illustrate the structure that is thought to represent economy-wide energy demand. The ability to deal with specific policy questions, and energy conservation possibilities, is made clear. The wide applicability of MEDEE 2 to energy demand studies, and to the evaluation of proposed "technical fixes" or policies, is also described.

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SUMMARY

This paper describes a simulation model, MEDEE 2, designed to evaluate the long-term energy demand of a country, in combination with a scenario description of the main aspects of the country's social, economic, and technological evolution. This approach considers in a detailed way a national energy demand pattern and breaks down the total demand in a multitude of end-use categories (e.g., residential space heating, service sector cooling, gasoline for intercity cars). By means of this detailed investigation of energy demand we are better able to take into account the influence on energy demand of changes in social needs, economic growth, government policies, or technologies, especially in the present context of high energy prices. In addition, it makes possible the identification of the potential market (i.e. maximum demand that can be technically met) of each final energy form (e.g., electricity, coal, gas, solar, oil products, and district heat).

The model calculates useful energy demand in each end-use category for which several energy forms can be used, thus determining the substitution possibilities in energy use. This useful energy matches the energy service needed by the consumer (e.g., heat, mechanical energy). Useful energy differs from final energy, purchased by the consumer, by the efficiency of the end-use appliances. Each useful energy demand is then converted into a demand for final energy, taking into account the fuel mix (i.e., the fraction of the demand supplied by each fuel) and the end-use efficiencies of each fuel. This approach—estimating useful energy—is necessary if one wants to account for the differences in fuel efficiencies: for the same service (let us say 1 kWh of heat) the final demand will vary according to the fuel type because of these different efficiencies (e.g., 1 kWh of electricity, 1.35 kWh of gas, 1.50 kWh of oil, and 2 kWh of coal).

The total final demand is projected in MEDEE 2 for the following types of final energy forms: fossil fuel (substitutable use of coal, oil, and gas), electricity, motor fuel, coke, feedstock, solar, and district heat.

MEDEE 2 is driven by a set of scenario elements, the evolution of which is defined in a scenario. The core of the scenario is a characterization through these elements of the development pattern of the country under consideration (life-styles, economic growth patterns, etc.). The scenario description is complemented with technological parameters (e.g., insulation standards, efficiencies, fuel mix), the evolution of which is specified in a way consistent with the macroeconomic assumptions.

CONTENTS

INTRODUCTION

Since the oil crisis of 1973-1974, there has been growing concern about the long-term evolution of energy demand. Many are now asking such crucial questions as: Will energy demand level off in industrialized countries, and at what level? How is energy demand related to economic growth? How can government policies influence the energy demand pattern (i.e., the level of energy and the types of fuels used)? How does energy demand respond to price increases?

Forecasting energy demand over the long term is difficult because of the uncertainty of the future and the complexity of the energy demand pattern. This report deals with this problem and presents a possible approach. Before looking at the future, it is necessary to understand the nature of energy demand.

Determination of Energy Demand

Energy demand is induced by *socioeconomic determinants*--that is, by economic activities and by the satisfaction of social needs (e.g., mobility of persons and temperature in rooms). These determinants lead to a demand for *useful energy* (e.g., process heat and mechanical energy) whose intensity depends on the technologies used to satisfy social needs or to perform the economic activities. The demand for energy commodities or *final energy* (e.g., coal, electricity, and gas) can be calculated from the level of useful energy demand which will depend upon the efficiency of the equipment (e.g., furnaces, boilers, and engines) used to convert the final energy into useful energy. Thus the *final energy demand* of a society is directly related to its social, economic, and technological pattern of development. The determinants of useful and final energy demand are shown in Figure 1.

Three phenomena play a determining role in the long-term evolution of energy demand:

- The development pattern of the society being considered--that is, the economic growth and life-style which shape the evolution of the socioeconomic determinants;
- The technological evolution, which modifies or increases the set of available technologies;
- The energy price evolution, which influences the technological choices as well as the choices among competing fuels for substitutable energy use.

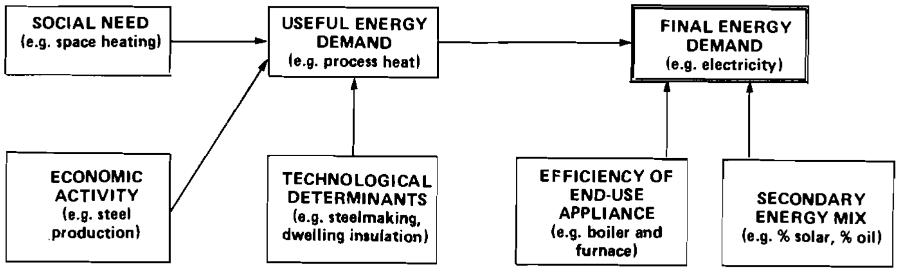

Figure 1. Determinants of useful and final energy demand.

Through an understanding of the major factors determining energy demand, we can better grasp the difficulties of forecasting its long-term evolution. First, this evolution is uncertain and nondeterministic, since the future of a society is a complex phenomenon encompassing changes in the social needs, in the technologies, and more generally in the development pattern. In addition, the recent fourfold increase in oil prices makes the task even more complex; the future influence of high energy prices on technological and socioeconomic development and government policies is difficult to assess.

Traditionally an economic approach has been used to forecast demand, which considers energy demand at a highly aggregated level, deriving total or sectoral energy demand projections from macroeconomic indicators (e.g., gross national product, industrial activities, and income) by means of sophisticated statistical adjustments. This approach leads to a simplified perception of energy demand which accounts for the uncertainty over the long term by considering some of the variables as parameters. In our opinion these econometric methods are severely limited when applied over the long term: they result primarily from the historical evolution of society and are too aggregated to permit a flexible integration of structural and technological changes. These limitations are further discussed in [1].

Owing to these limitations, new techniques have been developed which disaggregate total energy demand into *end-use categories* (e.g., residential space heating, service sector cooling, gasoline for intercity automobiles), and use simulation models and scenarios to project the energy demand evolution.

At IIASA three such techniques are currently being used: MUSE (Modeling Useful Energy)[2]; WISE (Wisconsin Regional Energy Model)[3]; and MEDEE (Modele d'Evolution de la Demande d'Energie). They differ mainly in terms of the level of disaggregation of the social, economic, and technological systems, in the selection of end-use categories, and in the scenario writing process.

This report outlines the general MEDEE approach as developed at IEJE. A detailed discussion is then given of MEDEE 2--the simplified version of MEDEE that was developed at IIASA as part of the energy modeling work of the Energy Systems Program.

THE MEDEE APPROACH

MEDEE was developed a few years ago to span the energy demand in France to the year 2000. The main purpose of MEDEE is to provide a flexible framework for exploring the influence of social, economic, technological, and policy changes on the long-term evolution of energy demand.* The objectives of MEDEE were as follows:

- To identify the major factors determining energy demand;
- To provide a tool for evaluating the influence on energy demand of changes in the evolution of these factors;
- To understand how the recent fourfold increase in crude oil prices could affect energy demand;
- To determine, by means of a scenario, the energy demand growth from the development of multiple aspects of society;
- To make use, in the scenario writing process, of the work of sociologists, economists, and policy analysts on the future evolution of society.

The MEDEE approach involves the following steps (Figure 2):

- A systematic analysis of the social, economic, and technological system in order to identify the major factors determining the long-term energy demand evolution.
- Disaggregation of the total energy demand into a multitude of end-use categories. The selection of the categories to be considered depends upon the objectives pursued by the modeler and on data availability.
- Organization of all determinants into a hierarchical structure, from the macro to the micro level, showing how the "macrodeterminants" affect each end-use category.
- Construction of a simulation model by simplifying the system structure and grouping the determinants into *exogenous determinants* and *scenario elements*. The determinants chosen as scenario elements are those the evolution of which can not be extrapolated from past trends because of possible structural changes in the

*The MEDEE approach is extensively described in French in [4] and is summarized in English in [1,5].

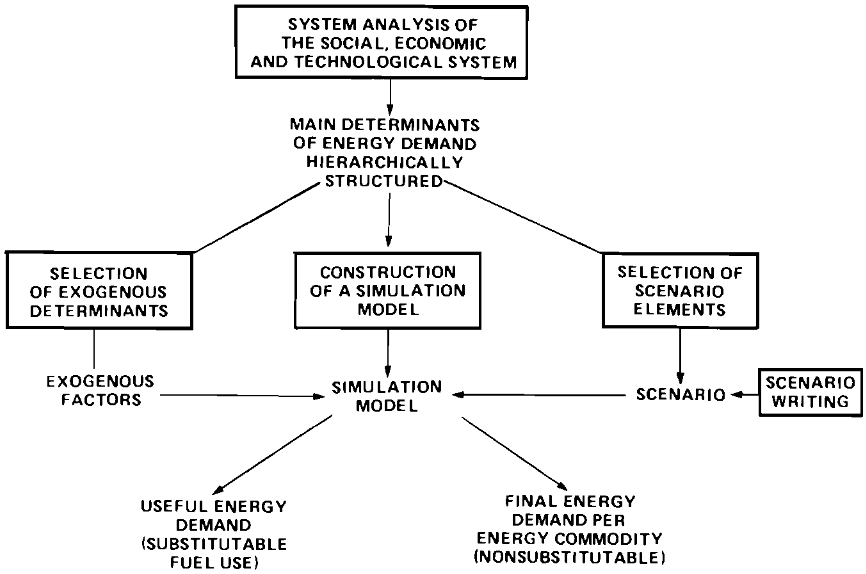

Figure 2. Conceptual scheme of the MEDEE approach.

energy demand growth pattern, as for example, policy measures or energy prices. The evolution of these factors is specified in a scenario. The exogenous determinants encompass those factors the evolution of which is difficult to model (e.g., population growth, number of persons per household) but for which their long-term evolution can be adjusted suitably from past trends or from other studies (e.g., demographic studies).

The MEDEE approach was designed to be applicable to a broad range of countries, and has been applied to Mexico [6] and the USA [7]; its application to the European Community (EC) countries is currently being studied at IEJE. The applicability of the MEDEE approach to developing countries is discussed in [1]. In each case the social, economic, and technological systems have been analyzed at different levels of disaggregation in order to take into account both the particular characteristics of the country and the data available.

From these case studies two computerized simulation models have been developed: MEDEE 2 and MEDEE 3. The latter is a more disaggregated model and is being implemented for the EC [8].

MEDEE 2

Objectives

In designing MEDEE 2 we had the following objectives in mind:

- To reflect structural changes affecting long-term energy demand by disaggregating the social, economic, and technological system so as to be able to take these changes explicitly into account. These include changes in: social needs (e.g., saturation); the international division of labor (e.g., the shift of heavy industries such as steel from industrialized countries to developing countries, resulting in lower costs for energy, raw materials, and labor; government policies (e.g., transportation and energy conservation policies); technology (e.g., substitution of current processes with less energy-intensive ones); energy prices.

- To identify the potential market (i.e., the maximum demand that can be technically met) of each final energy form (e.g., electricity, coal, gas, solar, oil products, and district heat). Table 1 shows how

Table 1. Potential market for final energy forms.

Final Energy Forms	Potential Market	
Solar heat	Hot water Space heat and air conditioning	For use in private single family houses, low buildings, industry
Electricity, Gas, Heat Pumps	Cooling Space heat	
Electric heat	Space heat, hot water, and cooking Industrial furnace (for use in primarily light industries)	
District heat	Space heat, hot water Industrial steam	For use in human settlements (e.g., megalopolises, medium-sized cities)
Coal	Industrial steam District heat Coke, feedstocks	
Liquid fuel	Motor fuels All heat demand Feedstocks	
Gas	All heat demand Feedstocks	

the detailed accounting of the energy demand by end-use categories could be used to identify the potential market of the major energy forms.

- To design the model in such a way that it is easily applicable to many countries. Thus within the model there are switches that permit the use of submodules with various degrees of sophistication. Most of the macroeconomic indicators used in the model are compatible with United Nations statistics.

Scope of the Model

In order to indicate the scope of MEDEE 2, we list some questions that the model can address:

- How will income growth affect energy demand through the increase in the social needs (e.g., mobility, size of dwelling, consumption of goods)?

- How and when in industrialized countries will the saturation of specific social needs influence energy demand?

- How can a modification in the consumption patterns of the population (e.g., the shift to the service sector) affect energy demand?

- How can the evolution of the international division of labor between industrialized and developing countries modify the industrial energy demand pattern in these countries? For example, what will be the effects of the shift in industrialized countries to industrial production with a higher value added and low energy content, and the concentration in developing countries of the production of basic materials such as steel or plastics?

- How could a shift from the use of automobiles to that of public transportation for intercity and urban transportation affect energy demand?

- What potential for energy conservation could result from the retrofitting of existing buildings with better insulation and/or from the construction of better insulated buildings?

- What is the potential market for solar heating, heat pumps, district heating, etc.?

MEDEE 2 does not deal explicitly with the problem of interfuel substitution, although some general guidelines as to the fuel mix can be roughly derived. This is because such a problem should be treated by an energy *supply* model and not by an energy *demand* model since interfuel substitution depends on the relative price of final energy forms, which are calculated endogenously in a supply model.

In MEDEE 2 energy demand is not directly related to energy prices by means of elasticity coefficients. The interdependence between price and demand may be observed by analyzing the technological possibilities for reducing energy demand as energy price increases and by considering the investment costs and the energy savings of conservation. We relied considerably on the many studies carried out since the 1973-1974 oil crisis to identify the social, economic, and technological responses that can be expected for a given range of energy prices. (See [4] for a list of these studies.) For instance, the model does not deduce the gasoline demand from the assumed price of gasoline. This price is used in the scenario writing process as background information for modifying past trends as to the automobile ownership ratio or the annual automobile mileage; the model derives the gasoline demand from the assumed number of automobiles and the distance driven by them.

This could be considered a weakness in the model's approach. However, we have to be aware that in the new energy context characterized by higher energy prices economists are lacking the techniques and empirical data to understand how demand responds to high and increasing energy prices. As the considerable disagreement between the results of numerous prices elasticity studies indicates, the traditional approach in terms of elasticity is no longer satisfactory; these elasticities have been calculated from the past, that is to say, over a period when energy prices were stable or even declining, and are therefore not applicable to the present energy situation. This issue is analyzed in detail in [1].

Description

The general structure of MEDEE 2 is shown in Figure 3. The model is driven by a scenario which is broken down into: 1) a socioeconomic subscenario characterizing the basic features of the social and economic development of the country being considered*; and 2) an energy subscenario specifying energy-related

*For some IIASA applications of MEDEE 2, a GDP model--MACRO--was used to determine the GDP evolution (Y), capital formation (I)--that is, the GDP expenditures in public and private investment--private consumption (C) [9].

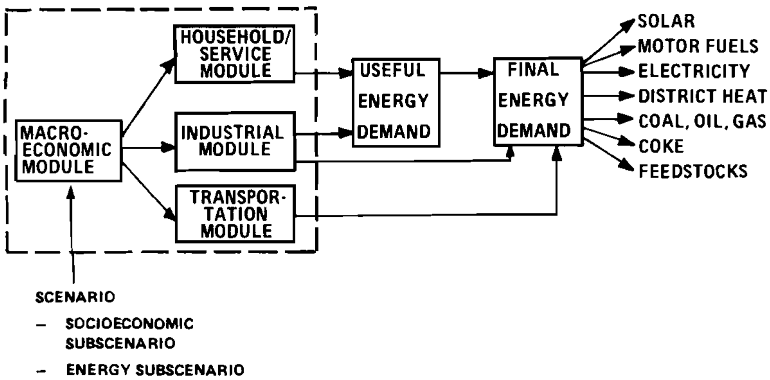

Figure 3. General structure of MEDEE 2.

factors (e.g., end-use efficiencies and market penetration). A macroeconomic module calculates the activity level of the productive sectors considered in MEDEE 2. Energy demand is then calculated for each end-use category in three other modules: household/service, industrial, and transportation, using the value of the social needs and the sectoral activity levels as given by the scenario and the macroeconomic module.

MEDEE 2 is therefore a model for evaluating the energy demand implications of the economic and life-style scenarios describing the long-term evolution of a country. The model is only a very simple framework for deriving the energy demand associated with the scenarios. Because of its high level of disaggregation, the model provides in addition a framework for accounting for the energy uses in a country.

When various energy forms (e.g., solar, electricity, and fossil fuels) can be substituted for a given end-use category, the energy demand is first calculated in useful energy terms, and then converted into final energy, taking into account the penetration of the various energy forms in competition and their end-use efficiencies. For these *substitutable fuel uses* (e.g., space heating, hot water, process heat) the final energy demand is eventually distributed among electricity, solar, district heat, and fossil fuels. The fossil fuel mix among coal, gas, and oil is not accounted for here since the mix depends greatly on the condition of supply and the relative price of these fuels --issues that are outside the scope of the model. The replacement of fossil fuels with new energy forms (e.g., solar, district heat, and electricity) is nevertheless considered since to our mind policy factors will play a determining role in the future in the substitution process. For that reason, we think that this issue can be dealt with only by means of scenario assumptions about these substitutions. Thus the market penetrations of solar, district heat and electricity are defined by means of scenarios.

For *nonsubstitutable fuel uses* (e.g., motor fuel for automobiles, and electricity for electrolysis, lighting, and small engines) only final energy is considered.

For each end-use category, the useful/final energy demand is related to the social, economic, and technological determinants. The energy demand projections results from the evolution assigned to these determinants either in the scenario or in the model. (See Figure 4.)

The Macroeconomic Module

The macroeconomic module of MEDEE 2 is illustrated in Figure 5. The role of this module is to define the general structure of the economy, or, in other words, to express the economic growth, as characterized by the scenario, in terms of growth of the activity of each of the economic sectors in MEDEE 2.

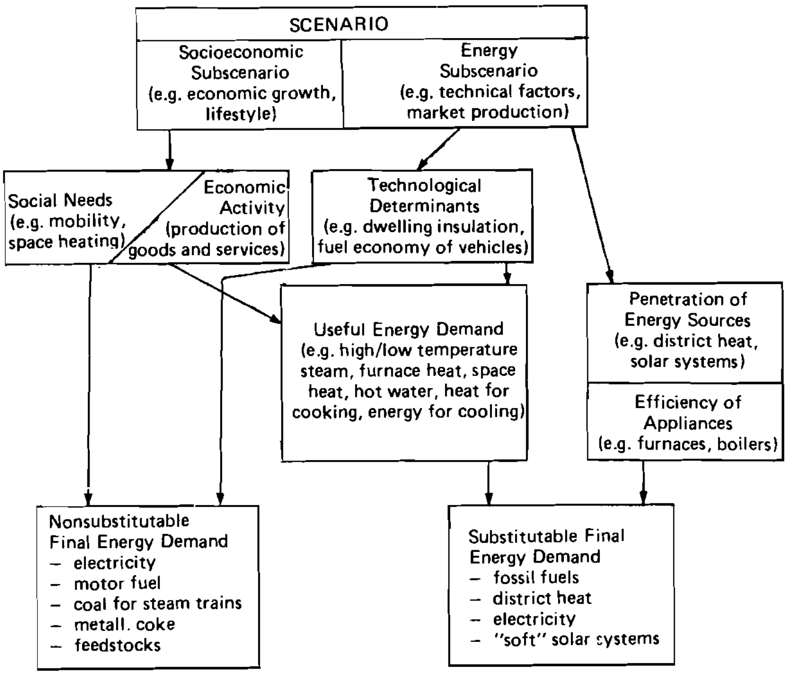

Figure 4. Scheme for projecting useful and final energy demand in MEDEE 2.

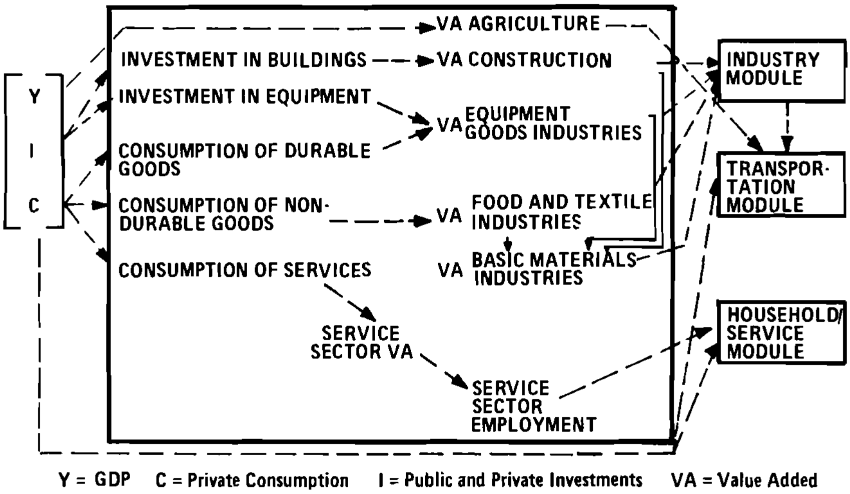

Figure 5. Macroeconomic module of MEDEE 2*.

*Only a selected group of sectors and subsectors has been shown for the sake of simplicity.

Six economic sectors are considered in MEDEE 2: agriculture; mining; energy; manufacturing; service (including banking, commerce, schools, hospitals, and public administration); and construction. The manufacturing sector is divided into four subsectors: the equipment goods industries (i.e., industries producing predominantly capital goods and durable goods such as transportation equipment or electrical machinery industries); the food and textile industries; the basic materials industries (such as steel, building materials, and chemicals); miscellaneous industries.

The macroeconomic module derives the required level of activity of each sector from investment in construction and equipment and from private consumption of durable goods, nondurable goods, and services. This approach implicitly assumes for the future similar trends in foreign trade as have been observed in the past. The calculated activity levels can then be modified interactively (by means of a scenario) to account for changes compared to past trends, as for example, in the foreign trade of basic materials. As is envisioned, a "new economic order" would lead to exports of basic materials from developing countries to industrialized countries. These imports cannot be deduced from the macroeconomic module and therefore have to be assumed exogenously (by means of a scenario).

Most of the equations of the module are statistical expressions of the balance between the activity of a sector (e.g., value added of equipment goods industries) and the use of its output (e.g., investment in equipment and consumption of durable goods). Because of this feature, the adjusted relation should normally have a high correlation coefficient.

Although the macroeconomic module is simple, it provides a consistent economic framework for evaluating alternative socioeconomic scenarios. An alternative would be to use an input/output model, but its complexity is not worthwhile over the long term, compared to the uncertainty in the evolution of the technical coefficients. Specifically, this module permits the assessment of the impact on energy demand of changes in the rate of capital formation (e.g., the fraction of GDP that goes into investment) or in the private consumption patterns (e.g., durable goods versus nondurable goods versus services).

Energy Demand Modules

The three energy demand modules in MEDEE 2 are: household/service, industrial, and transportation. Energy demand is calculated for each end-use categories in each of these modules. Each module has been developed in a similar way: End-use categories have been identified by taking explicitly into account the major social, economic, technological, and policy changes that can appear over a long term and dramatically affect energy demand. The end-use categories in MEDEE 2 are given in Table 2.

For each category the socioeconomic determinants that create the final and useful energy demand have been identified as well as the major factors that influence the evaluation of these determinants.

The Household/Service Module

The breakdown of the household/service module is shown in Table 3.

Our objectives in disaggregating the module are as follows:

- To identify homogeneous end-use categories from the point of view of future types of energy supply commodities--that is,
  - space heating and hot water in low density population areas: electricity, oil, gas, and solar;

Table 2. Categories of energy use considered in MEDEE 2.

TRANSPORTATION MODULE*	
Personal transportation	
Urban	Automobile (motor fuel, electric) Mass transit (motor fuel, electric)
Intercity	Automobile (motor fuel) Airplane (motor fuel) Bus (motor fuel) Train (steam, diesel, electric)
Freight transportation	
Long distance	Train (steam, diesel, electric) Barge (motor fuel) Truck (motor fuel)
Local	Truck (motor fuel)
Miscellaneous	
Military	(Motor fuel)
International	(Freight and passenger, air and maritime traffic)
HOUSEHOLD/SERVICE MODULE	
Household	
Space heating†	Pre-/post-1975 dwellings Multifamily/single family dwellings
Water heating†	
Cooking†	
Cooling†	
Electrical appliances*	
Service	
Thermal uses†	(Pre-/post-1975 dwellings)
Cooling†	
Electrical appliances*	
INDUSTRIAL MODULE	
SECTORS	PROCESSES
Agriculture Construction Mining Manufacturing: Basic materials Equipment Food and textiles Miscellaneous Energy§	⟷ Motor fuel use* Specific electricity uses*‡ Thermal uses: Steam generation Furnace operation Space and water heating Coke use for iron ore reduction* Use of feedstocks*

*Final energy
†Useful energy (energy sources competing: fossil fuels, district heat, electricity, solar systems)
‡By definition in the model, all present uses of electricity (lighting, motive power, electrolysis, electric furnaces) are included here.
§The energy sector is considered separately only if statistics are available. Its energy consumption is not considered here since it should be accounted for in the conversion from final to primary energy.

Table 3. Household/service module.

HOUSEHOLD SECTOR

Space heating for four human settlements categories. (In this instance, the following categories have been considered: cities of more than 1 million inhabitants; cities of more than 250,000 and less than 1 million; cities of between 50,000 and 250,000; and rural areas and cities of less than 50,000.) For industrialized countries the following dwelling categories are distinguished:

-- Pre-1975 and post-1975 dwellings
-- Multifamily and single family
-- Dwellings with central heating or individual heating

Hot water for the above four human settlement categories

Air conditioning

Cooking

Electrical appliances

SERVICE SECTOR

Heat (hot water and mainly space heating) for the above four human settlements categories. For countries with data on the building inventory, the heat demand evolution is simulated for buildings built before 1975 and for the new construction (post-1975 buildings).

Air conditioning

Electrical appliances

- space heating and hot water in high density population areas: electricity, oil, gas, and district heating*;

- cooling: electricity, and solar;

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*The type of district heating that can be developed (nuclear, coal, or geothermal) depends mainly on the density of the population and the size of the potential market. For this reason, the heat demand (space heating and hot water) is calculated for different human settlements categories (e.g., different city-size categories).

- electric appliances (household appliances, computers, lifts, etc): electricity;

- cooking (household): electricity, and gas.

- To determine both household and service-sector energy demands since their respective driving forces do not grow at the same rate: in the case of households the driving force is the demography (e.g., the population and number of households); in the case of services, it is the economic activity in the service sector.

- To consider building types that are homogeneous with respect to heat requirements (e.g., dwellings and buildings built before the oil crisis or afterwards; multifamily and single family dwellings). This means that the evolution of the building inventory must be simulated. For developing countries the heating demand is generally not very significant, since the majority of these countries are located in tropical or subtropical areas and few data are available on the building inventory. Thus the types of buildings and dwellings will not be accounted for.

For the substitutable use of energy the energy demand was projected in terms of useful energy rather than final energy in order to account for the discrepancies in the end-use efficiencies of the various competing fuels.

To get an idea of the aggregate final energy demand of this module and of its possible energy supply mix, the calculated useful energy demand is converted into final energy by assuming a certain fuel mix for the supply of this demand and taking into account the efficiencies of each fuel. In order to simplify the calculations, only two categories of energy commodities have been included in the group corresponding to their end-use efficiencies: (1) solar, district heat, and electricity, with an assumed efficiency of 100% (at the consumer level); and (2) fossil fuels (coal, oil, and gas), the efficiencies of which vary according to the scenario [10].

Since the long-term energy supply worldwide will be characterized by a progressive shift from oil and gas to other energy sources such as solar, coal, or nuclear, we have made the following distinctions in the model: fossil fuels (mainly oil and gas), electricity (coal or nuclear), and solar and district heat (nuclear or coal).

The development of electricity, solar, and district heat is assumed in the following way: for each end-use category the potential market share of electricity, solar, and district heat is specified by means of scenario elements. For instance, for household space heating the potential market of solar energy is defined as the space heating demand of all single family houses built after 1975. In the scenario, a coefficient specified the market share captured by solar each year. Such an approach allows us to envision different energy policies for the development of new energy sources by varying the market penetration rates with the scenarios. This is particularly relevant since the development of new energy sources will be mainly determined by policy factors. By definition, fossil fuel demand is equal to that demand which is not met by the sum of electricity, solar, and district heat. This fossil fuel demand is not broken down into oil, gas, and coal because of supply problems of these individual fuels, which are not accounted for in the model.

The structure of the household/service module and the equations of its simulation model are described in detail in [10].

The Industrial Module

The industrial module consists of the following sectors: agriculture; construction; mining; manufacturing; and energy. The manufacturing sector is further divided into four subsectors: basic materials industries; equipment goods industries; food and textile industries; and miscellaneous industries. According to the data available these subsectors can be further disaggregated.

These subsectors are considered for several reasons as discussed below.

First, the industries have homogeneous energy patterns. The energy pattern of the equipment goods industries is characterized by large requirements of electricity per unit of output and by a demand for heating fuels almost evenly distributed among space heating, furnaces, and steam production. The basic material industries are large energy consumers, and their contribution to the total energy demand of the industrial sector generally exceed 50% and, in some developing countries, can be as high as 80%. In addition, the high share of energy costs in their production costs makes these industries sensitive to energy price increases. Thus, dramatic reductions of the energy requirements per unit of output can be expected in the future, especially since significant reductions in these requirements were achieved in the past when the energy prices were stable. In the food and textile industries the energy demand is mainly for steam and warm water--about 75% of the fuel demand for thermal purposes.

Secondly these subsectors are key sectors of an economy, the relative development of which characterizes the development pattern of the economy. By breaking down the module, the model can simulate the influence on energy demand of changes in the economic development pattern of both industrialized and developing countries. In the case of developing economies, different industrial growth patterns can be envisioned according to priorities given to domestic production versus imports/exports for basic materials, equipment goods, or consumer goods. The model can express these changes in the industrial structure (i.e., as the share of each sector in the industrial value added) in terms of both total demand and structure of the demand (e.g., steam furnace, and space heating). Also, through this breakdown, one can account for changes in the international division of labor and the possible reshaping of a new economic order with all the repercussions on energy demand. For example, in the industrialized countries such a change could induce both a slower growth of the basic materials industries--since in this perspective some developing countries would have a significant export capacity of such goods--and a higher growth of other activities such as equipment production, know-how, and engineering services. The energy demand pattern of the industrial sector of these countries could therefore be dramatically affected.

Thirdly, any change in the capital formation ratio will influence the growth of these subsectors directly for the equipment goods industries; indirectly for the food and textile industries, since a modification in capital formation affects private consumption; and indirectly for the basic materials industries, since the latter's growth depends mainly on the growth of the other two industries. This approach to modeling the manufacturing sector makes it possible to evaluate the effects on energy demand of changes in the capital formation ratio, as for example, the shift in the energy supply from fossil fuels to nuclear and solar energy.

And finally, life-style can be characterized by the way people spend their incomes, and more precisely by the type of goods they purchase. In MEDEE 2, the structure of the individual private consumption is an indicator of life-style. A life-style is defined by the distribution of private consumption among energy, durable goods, nondurable goods, and services. Most often statistics are not detailed enough to permit isolation of "energy" in which case energy will be accounted for in the other categories of goods or services. It is then possible to evaluate the influence of life-style changes on the industrial structure (this is the role of the macroeconomic module) and upon the energy demand of the industrial subsectors. In addition, we can assess the effect on energy demand of increasing the durability of goods.

If MEDEE 2 is coupled to an input/output model it is worthwhile to break down these subsectors further. The gain in terms of better knowledge of the industrial processes and energy uses is offset by greater uncertainty as to the growth of the detailed industrial subsectors. We will therefore distinguish two versions of the industrial module; one *with* an input/output model and one *without* (see Table 4).

Table 4. Industrial module.

WITH INPUT/OUTPUT MODEL

Agriculture
Construction
Mining
Manufacturing
  Basic materials industries
    Steel
    Nonferrous and metal products
    Building materials and mineral products
    Chemical and chemical products
    Pulp and paper
  Equipment goods industries
    Machinery (mechanical industries)
    Transportation equipment
  Food and textile industries
  Miscellaneous industries
Energy

WITHOUT INPUT/OUTPUT MODEL

Agriculture
Construction
Mining
Manufacturing
  Basic materials industries*
  Equipment goods industries
  Food and textile industries
  Miscellaneous industries
Energy

*According to the characteristics of each country, some large energy consuming industries such as steel, cement, or fertilizer can be taken out from this group of industries and treated separately.

The industrial module, as well as the macroeconomic module which generates the inputs to the industrial module, are further described in [10].

For each of the sectors, the energy demand is calculated in terms of final energy for the nonsubstitutable use of energy (specific use of electricity, coke, feedstocks, and other miscellaneous uses of fossil fuels), and in terms of useful energy for the substitutable use of energy (steam, furnace, space heating and hot water). The energy demand is derived from the activity of each sector, measured by the value added for the major sectors. It may also be measured by the physical output for specific basic materials industries (e.g., steel), and from a coefficient of energy intensiveness that measures the energy requirements per unit of activity. The useful energy demand is then converted into final energy demand by taking into account the fuel mix of fossil fuels, electricity, district heat, and solar using the same approach as has been outlined for the household/service module.

The Transportation Module

Before describing this module, we will briefly explain how it was designed and consequently justify the choice of the end-use categories.

The energy demand in the transportation sector is induced by the demand for transportation. For a given transportation demand, the final energy demand depends upon the modal split--that is, the distribution per mode of transportation, the specific energy requirements (energy use per vehicle per kilometer), and on the load factor for each mode of transportation.

Our basic objective in designing MEDEE 2 was to be able to account for major changes which, in the long term, could drastically affect energy demand patterns. In the field of transportation these changes as compared to past trends might be as follows:

- The levelling off in industrialized countries of the intercity passenger needs or at least the slowing down of their growth;

- The levelling off of the urban passenger transportation demand as a result of the stabilization of the urban population;

- Changes in human settlements leading to the growth of medium-sized cities with a lower urban transportation demand and a different modal split;

- The relative decrease of automobile traffic in cities for many reasons including the implementation of policies favoring mass transit because of congestion and pollution and the population response to increased gasoline prices, etc;

- For long-distance transportation, the replacement of automobiles and trucks with less energy-intensive modes because of increasing prices of motor fuel;

- The development of electric modes of transportation for urban transportation (either automobiles or mass transit);

- The decrease in freight traffic per unit of GNP as a result of the shift of economic activity from agriculture and heavy industries to services and light industries.

The transportation module has been broken down into several submodules which have all been modeled in a similar manner (see Table 5).

The modeling was carried out in four steps as follows:

- Determination of the transportation demand growth by relating this demand to macroeconomic factors: population and private consumption for intercity passenger transportation, value added of industry and agriculture for freight transportation, urban population for urban transportation. The saturation can be accounted for by means of scenarios.

- Modeling of the evolution of the modal split. Because changes in the modal split are mainly determined by government policies or by individuals' behavior, all changes compared to past trends are specified exogenously by means of scenarios. If no change is envisioned, the modal split is calculated from functions adjusted from past trends.

- Modeling of the evolution of specific energy requirements and load factors. Except for automobiles, for which dramatic changes can be expected in terms of fuel consumption, the specific

Table 5. Transportation module.

Long distance surface freight traffic*--pipes, trucks, trains and barges
Local transportation by trucks
Urban passenger transportation--automobiles, mass transit
Intercity passenger transportation--automobiles, buses, planes, trains
Miscellaneous (e.g., military) and international freight and passenger transportation

*Air freight transportation is not accounted for since the energy demand for this type of transportation is, and will remain, negligible compared to the total energy demand of an economy. This type of transportation is restricted to special types of goods and areas.

energy requirements evolution is deduced from past trends. In order to simplify the model and the number of functions needing adjustment, these energy requirements are specified exogenously--rather than by a function--for the specific years for which the energy demand is calculated. The load factors, which are strongly dependent on transportation policies and on the fuel economy of automobiles, are specified as scenario elements.

- Calculation of the final energy demand evolution for motor fuels and electricity.

THE SCENARIO

The long-term energy demand of a country greatly depends on its social, economic, and technological development pattern. Since the evolution of this pattern will eventually be shaped by governmental policy and changes in social values (i.e., by unpredictable factors), it is impossible to model this evolution. Rather by means of a scenario we can make assumptions about possible evolutions that can be anticipated over the long term from current changes, crises, or tensions. In the MEDEE approach a *scenario* is viewed as a consistent description of a possible long-term development pattern of a country, characterized mainly in terms of the long-term direction of governmental, socioeconomic policy. Our conception of a scenario differs from what is commonly meant by a scenario, in that we regard a scenario as more than the combination of assumptions on exogenous factors: it is a means for describing the development pattern of an economy. A more detailed description of the scenario approach in MEDEE can be found in [4,5].

Figure 6 shows the scheme of the scenario writing process. This process starts with a qualitative description of the basic features (mainly policy objectives and life-style) of a country's development pattern, taking into account possible constraints or influences from the international environment (e.g., oil prices, and trade patterns). The consistency of the scenario rests on the formulation of a consistent development pattern, combining, for instance, compatible assumptions about the long-term objectives of the government. Then to further ensure consistency, the qualitative scenario descriptors are organized in a hierarchy according to their importance. Thus at the top of this hierarchy are the descriptors that have a determining influence on the other descriptors, but which cannot be significantly affected by them either because of their strong inertia (e.g., life-style, and human settlements patterns) or because of outside constraints (e.g., oil prices). Table 6 lists the qualitative descriptors considered in the MEDEE approach, and shows their structure.

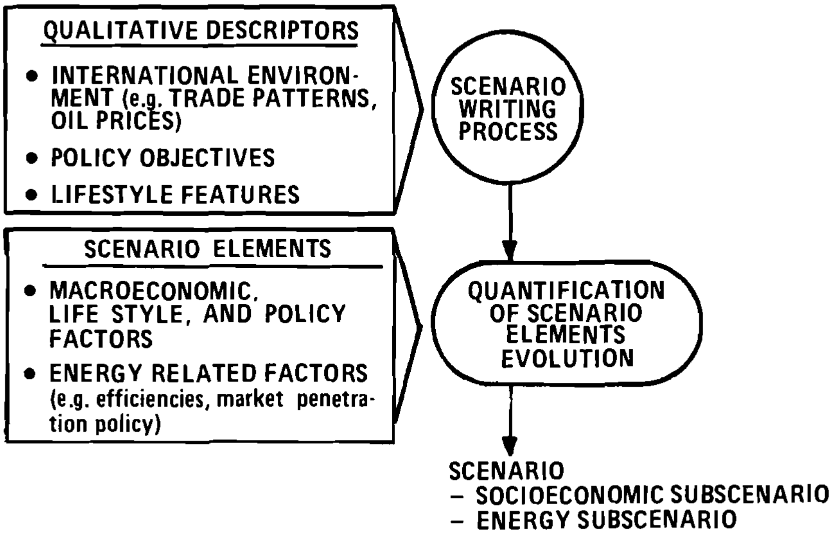

Figure 6. Scenario writing in MEDEE 2.

The qualitative scenario description is then used to quantify the evolution of the scenario elements. The scenario elements in MEDEE 2 are organized on two levels: demographic, social, economic, and policy factors that characterize the development pattern of a country from the point of view of its energy demand (the socio-economic subscenario); and the energy-related factors (the energy subscenario).

Table 7 lists the major scenario elements characterizing the MEDEE 2 subscenarios. A complete list of the scenario elements in MEDEE 2 is given in the Appendix.

In order to understand and to easily describe the scenario, it is desirable to reduce as much as possible the number of scenario elements. This is achieved by discarding from this category those factors that only slightly influence total energy demand. These are considered exogenous determinants, which means that an intermediate evolution is postulated exogenously and assumed to be the same whatever the scenario.

The scenario writing consists of formulating assumptions about the evolution of the scenario elements. In order to come up with a limited number of alternative assumptions, an analysis of the likely future evolution of each scenario element must first be made. This analysis should make broad use of the findings of all long-range studies of the country being considered (e.g., studies on transportation needs, on the saturation of social needs,

Table 6. Structure of qualitative descriptors in the MEDEE approach.

H1 INTERNATIONAL ENVIRONMENT	Primary energy prices	
	Technological innovations	
	New International Economic Order	*Strategy of multi-national companies*
		Policy of the developing countries block
H2 SLOW MOVING TRENDS*	Economic growth	
	Human settlements	
	Life-style features	
	Industrialization type	
H3 GENERAL POLICY OF THE GOVERNMENT	Transportation policy	*Objectives* *Infrastructure of Transportation*
	General energy policy	*Objectives* *Energy conservation policy (standards, pricing, etc.)*
	Environment policy	*Objectives* *Recycling policy, etc.*
H4 ENERGY SUPPLY CHARACTERISTICS	Final energy price characteristics	
	Role of new energy sources (solar, district heat...)	
H5 TECHNOLOGIES	Technological changes	
	Energy efficiencies	
	Fuel mix (market penetration)	

*Slow moving features of the society.

on the evolution of the industrial structure). The scenario is built up by choosing stepwise assumptions for each scenario element, from the top of the hierarchy to the bottom. The main advantage of this systematic scenario writing process is to force the scenario writer to account for the interdependence of the scenario elements and therefore to reduce the risks of inconsistencies.

Table 7. Major scenario elements characterizing MEDEE 2 scenarios.

Socioeconomic Subscenario		Energy Subscenario
	Scenario Elements	Scenario Elements
Human settlements	Population per city size	Fuel economy of automobiles (intercity and urban travels)
Economic growth	GDP growth rate/yr GDP expenditure (private consumption, investments, etc.) Industrial and economic structure (contribution of each sector to the GDP)	Degree of retrofitting of existing buildings Insulation level of new construction Efficiencies Penetration of electricity, heat pumps, solar and district heat on the heat market
Life-style features	Private consumption structure (durable goods, food and textile goods, services and energy) Automobile ownership Electrical household appliances ownership Mobility	
Energy policy	Degree of intervention for the implemention of energy conservation practices and the development of new energy sources (qualitative)	
Transportation policy	Attitude vis-a-vis road transportation (qualitative)	

GENERAL COMMENTS

This report has described an energy demand model that evaluates the influence on energy demand of social, economic, technological, and policy changes, and identifies the market potential of each final energy form. This model is only a calculation tool interrelating the major determinants of both useful and final energy demand. Although it contains many variables and relations, MEDEE 2 is quite transparent and simple as can be seen from its description.

It is important to stress that the scenario writing must be carried out *after* a careful analysis has been made of the long-term evolution of the social, economic, and technological system for which one wants to project energy demand. Since very often such an investigation is not possible within the sole frame of an energy demand study, the scenario writer should try to incorporate in the scenario what has been analyzed by experts in the various relevant fields.

In MEDEE 2 the scenario is viewed as a transcription of a long-term technological, economic, social and policy analysis of the society into quantitative values concerning the evolution of the scenario elements. The model then translates the scenario (i.e., the "projection" of the society) in terms of energy demand. This model is therefore not a forecasting tool but rather it provides a framework for calculating the evolution of the energy demand pattern associated with a given scenario.

MEDEE 2 was designed so as to be applicable to a wide range of countries. Several features can be identified that give it a general scope:

- The structure of the model--that is, the organization of the energy demand into a multitude of end-use categories, and the modeling of the energy demand pattern within each category.

- The lists of determinants and scenario elements used to characterize the development pattern of a country from an energy demand standpoint as well as the technological alternatives that can influence the useful and final energy demand of a country;

- The scenario method consisting in the construction of consistent technological, social, economic, and policy scenarios by means of a hierarchy of scenario elements;

- The data base--that is, the quantified information collected or provided for the countries studied. These may include:

- some quantified relations among economic indicators (e.g., industrial activity and freight transportation demand) or among physical or geographical factors and economic factors (e.g., city size and transportation needs, floor area in the service sector per worker);
- most of the technical data concerning the energy requirements and their evolution--for industrial processes, space heating equipment and modes of transportation*.

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APPENDIX

DATA REQUIREMENTS OF MEDEE-2

This section summarizes the data required as input for MEDEE-2 in the original version as implemented at IIASA by B.Lapillonne. The model variables are divided into three categories:

i) the "constants" include all the initial values as well as some variables which are assumed in the model to remain constant;

ii) the "exogenous determinants" encompass factors the evolution of which is difficult to model (e.g. population growth, evolution of the average household size, etc.) but for which their long term evolution can be adjusted from the past and present trends in an acceptable way. The reason for introducing such variables is to simplify the structure of the model by avoiding quite a number of submodels or functions;

iii) the "scenario elements" are variables whose evolution cannot be extrapolated from the past because structural changes might affect them in the long term, with significant effects on the energy demand growth.

For all variables except the constants, their evolution over time must be specified. I.e., if the energy demand calculations are to be performed, for example, for the years 1975 (base year), 1985, 2000, and 2025, the values of the exogenous determinants and of the scenario elements have to be specified for these years.

A1) Constants (Initial values)

Variable	Unit	Explanation
DW75	10^6dwellings	total number of dwellings in 1975
SHDWO(I)	10^3kcal/dw/yr	space heat requirements for pre-75 dwellings (useful energy)
I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating
DD	degree-days	population-weighted average number of degree-days
TAREA75	10^6m^2	total floor area of service sector buildings in 1975
HAREAO	$10^3kcal/m^2/yr$	specific heat requirements of pre-75 service sector buildings
EI(I,J)		specific energy requirements (useful or final energy, respectively) for process J per unit of value added in industry I. The energy sector is not considered here; its energy consumption should be accounted for in the conversion from final to primary energy.
Manufacturing:		
I=1		basic materials
I=2		equipment goods
I=3		food and textiles
I=4		miscellaneous
Other Sectors:		
I=5		mining
I=6		construction

I=7 agriculture

(a) without detailed data on industrial processes:

in terms of useful energy:

J=3	10^3kcal/$VA	all thermal uses (steam generation, furnaces, space and water heating);

in terms of final energy:

J=4	kWh/$VA	specific uses of electricity (lighting, motive power, electrolysis);
J=5	10^3kcal/$VA	motor fuel.

(b) with detailed data on industrial processes:

in terms of useful energy:

J=1	10^3kcal/$VA	steam generation;
J=2	10^3kcal/$VA	furnace use;
J=3	10^3kcal/$VA	space and water heating;

in terms of final energy:

J=4	kWh/$VA	non-substitutable uses of electricity;
J=5	10^3kcal/$VA	motor fuel.

The following data of the file "constants" contain coefficients for the econometric equations in the model, that are used to calculate the GDP formation, the value added contributions of the manufacturing sectors (if they are not specified exogenously through the variables YREL and VAREL, respectively), the service sector labor force, the demand for freight transportation, the quantity of steel produced, the feedstocks needed by the petrochemical industries, and the motor fuel consumption for international and military transportation. Up to four coefficients can be used. The unit refers to the result of the econometric equation.

These equations should be considered as default-approximations. They may be adapted to better suit the situation of specific countries. If input-output or other econometric models are available for the country or region under consideration, the activity levels should be determined by these models and their results introduced into MEDEE-2 as exogenous information.

FYAG 10^9\$ GDP contribution of agriculture

with

FYAG = C(1) + C(2) * Y

and

Y ... total GDP

FYMIN 10^9\$ GDP contribution of mining

with

FYMIN = C(1) + C(2) * YMAN

and

YMAN ... GDP contribution of manufacturing

FYMAN 10^9\$ GDP contribution of manufacturing

with

FYMAN = C(1) + C(2) * GCF + C(3) * TPCG

and

GCF ... total investments

TPCG ... private consumption of both durable and non-durable goods

FYB 10^9\$ GDP contribution of construction

with

FYB = C(1) + C(2) * GCFB

and

GCFB ... investment into construction

FYSER 10^9\$ Service sector GDP contribution

with

FYSER = C(1) + C(2) * TPCSER

and

TPCSER ... private consumption of services

FVAMAN $10^9\$$ value added by manufacturing

with

FVAMAN = C(1) + C(2) * YMAN

and

YMAN ... GDP contribution of manufacturing

FVAIG $10^9\$$ value added by manufacturing of basic materials

with

FVAIG = C(1) + C(2) * YB + C(3) * VAM + C(4) * VAC

and

YB ... GDP contribution of construction

VAM ... value added by manufacturing of equipment goods

VAC ... value added by manufacturing of food and textiles

FVAM $10^9\$$ value added by manufacturing of equipment goods

with

FVAM = C(1) + C(2) * GCFM + C(3) * TPCDG

and

GCFM ... investment into equipment goods

TPCDG ... private consumption of durable consumer goods

FVAC $10^9\$$ value added by manufacturing of food and textiles

with

FVAC = C(1) + C(2) * TPCNDG

and

TPCNDG ... private consumption of non-durable consumer goods

FVAMIS 10^9 \$ value added by miscellaneous industries

with

FVAMIS = C(1) + C(2) * Y

and

Y ... total GDP

FLSER 10^6 workers manpower in the service sector

with

FLSER = C(1) + C(2) * YSER

and

YSER ... Service sector GDP contribution

TKFRT 10^9 ton-km demand for freight tranportation

with

TKFRT = C(1) + C(2) * (YAG + VAMAN)

and

YAG ... GDP contribution of agriculture

VAMAN ... value added by manufacturing

FPST 10^6 tons steel production

with

FPST = C(1) + C(2) * VAIG

and

VAIG ... value added contribution by intermediary goods industries

FFEED 10^6 tons feedstock consumption by the petrochemical industries with

FFEED = C(1) + C(2) * VAIG

and

VAIG		... value added by manufacturing of basic materials
FINTMF	10^{12}kcal	motor fuel consumption for international transportation (ship, plane)

with

FINTMF = C(1) + C(2) * Y

and

Y		... total GDP
FMILMF	10^{12}kcal	motor fuel consumption for military and other transportation

with

FMILMF = C(1) + C(2) * Y

and

Y		... total GDP

A2) Exogenous determinants

(i) Transportation sector

Variable	Unit	Explanation
TRAEF	fraction	fraction of rail freight traffic (ton-km) worked on electric trains
DTRAF	kcal/ton-km	energy intensiveness of diesel freight trains (for electric freight trains, the model assumes 1/3 of the intensiveness of diesel freight trains)
DTRU	kcal/ton-km	energy intensiveness of trucks (long-distance)
DBA	kcal/ton-km	energy intensiveness of barges (ships)
LFIC	pkm/veh-km	load factor of cars for intercity trips
LFP	fraction	fraction of plane seats occupied
DBU	1/100veh-km	energy intensiveness of buses (intercity)
DTRAP	kcal/veh-km	energy intensiveness of passenger trains (for electric passenger trains, the model assumes 1/3 of the intensiveness of diesel passenger trains)
DPLA	kcal/seat-km	energy intensiveness of planes
TRAEP	fraction	fraction of rail passenger transportation (pkm) worked on electric trains
DU	km/cap/yr	average distance travelled in urban areas per person per year (in case one has no detailed data on trip generation per day in urban areas, this variable replaces the two following variables)

DT	km/trip	average length of trips in urban areas
TU	trips/cap/day	average number of trips per person per day in urban areas
LFUC	pkm/veh-km	load factor of cars in urban areas
ELUC	kWh/veh-km	energy intensiveness of electric cars
DMT	1/100veh-km	energy intensiveness of buses in urban areas
ELMT	kWh/veh-km	energy intensiveness of electric mass transit
UMTE	fraction	fraction of urban mass transit (pkm) performed by electric modes (if this variable is zero, all mass transit will be assumed to be non-electric)
UCE	fraction	fraction of electric cars in the total number of urban cars
DTRUL	kcal/ton-km	energy intensiveness of trucks for local transportation
TRUL	fraction	fraction of local truck transportation in the total service (ton-km) performed by trucks

(ii) Household/Service sector

Variable	Unit	Explanation
PO	10^6 people	total population
CAPH	cap/dw	average household size
NEWDW(I)	fraction	fraction of dwellings of type I in dwellings constructed between the previous and the current model year
I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating

PREDW(I)	fraction	fraction of dwellings of type I in pre-75 dwellings
I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating
DEMDW	fraction	average demolition rate of dwellings over a 5-year period between the previous and the current model year
DWS(I)	m^2/dwelling	average floor area heated in post-75 dwellings of type I
I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating
HWCAP	10^3kcal/cap/yr	specific consumption of useful energy for hot water preparation
DWHW	fraction	fraction of dwellings with hot water
COOKDW	10^3kcal/dw/yr	specific consumption of useful energy for cooking in dwellings
ACDW	10^3kcal/dw/yr	specific consumption of useful energy for cooling in dwellings
DEMAR	fraction	average demolition rate of the floor area of service sector buildings over a 5-year period between the previous and the current model year
AREAL	m^2/worker	average floor area per worker in the service sector
ELARO	kWh/m^2/yr	specific electricity consumption in pre-75 service sector buildings
ELARN	kWh/m^2/yr	specific electricity consumption in post-75 service sector buildings

AREAH	fraction	fraction of the service sector floor area heated
AREAAC	fraction	fraction of the service sector floor area with air conditioning
ACAREA	10^3kcal/m^2/yr	specific requirements of useful energy for cooling in the service sector
PLB	fraction	fraction of floor area in low rise buildings relative to the total floor area of apartment and service sector buildings
ISOSOL	fraction	fraction of heat demand reduction in solar heated homes relative to other post-75 homes, due to better insulation
STSHI	fraction	approximate share of the steam and space heat demand in the total industrial substitutable fuel uses
FIDS	fraction	fraction of the annual industrial steam and space heat demand that can be supplied with solar energy
LTH	fraction	share of low temperature heat in the total industrial demand for steam and hot water
STI	fraction	approximate share of the steam demand in the total substitutable fuel uses in industry
FDSHS	fraction	fraction of the useful energy needs for space heating supplied with solar energy in a solar heated house
FDHWS	fraction	solar contribution to hot water needs
FDHS	fraction	fraction of the useful energy needs for space and water heating supplied with solar energy in a lowrise service sector building

A3) Scenario Elements

(i) Macro-economic indicators

Variable	Unit	Explanation
DISPOP(S)	fraction	fraction of the population living in agglomerations of size S
S=1		over 1 million
S=2		200000 to 1000000
S=3		cities under 200000
S=4		rural areas
Y	10^9\$	total GDP
I	fraction	fraction of GDP spent in gross fixed capital formation
P	fraction	fraction of private consumption in the total GDP
PCDG	fraction	fraction of total private consumption spent on durable consumer goods
PCNDG	fraction	fraction of total private consumption spent on non-durable goods
PCSER	fraction	fraction of total private consumption spent on services
IB	fraction	fraction of total investment spent on construction
IM	fraction	fraction of total investment spent on equipment
YREL(I)	fraction	structure of GDP formation
I=1		share of agriculture
I=2		share of mining

I=3		share of manufacturing
I=4		share of construction
I=5		share of services
VAREL(I)	fraction	share of subsector I in the total value added by manufacturing
I=1		basic materials
I=2		equipment goods
I=3		food and textiles
I=4		miscellaneous
CO	pop/no.of cars	car ownership ratio
DI	km/cap/yr	average distance travelled per person per year, intercity trips
DIC	km/car/yr	average distance driven per car per year, intercity trips
PBU	fraction	fraction of intercity public transportation (pkm) performed by bus
PTRA	fraction	fraction of intercity public transportation (pkm) performed by train
PLA	fraction	fraction of intercity public transportation (pkm) performed by plane
LFBU	pkm/veh-km	load factor of buses, intercity
LFTRA	pkm/veh-km	load factor of passenger trains
UC	fraction	fraction of personal transportation in cities (pkm) performed by car
UMT	fraction	fraction of personal transportation in cities (pkm) performed by mass transit (UC and UMT need not necessarily add up to 1 because of non-commercial modes of transportation)
LFMTB	pkm/veh-km	load factor of buses, urban

LFMTE	pkm/veh-km	load factor of electric mass transit
TRU	fraction	fraction of total ton-km transported by truck
FTRA	fraction	fraction of total ton-km transported by train
BA	fraction	fraction of total ton-km transported by barge
PIP	fraction	fraction of total ton-km transported by pipeline
ELAPDW	kWh/dw/yr	specific electricity consumption per dwelling (consumption of household appliances other than for space heating, water heating, cooking, and cooling)
DWAC	fraction	fraction of dwellings with air conditioning

(ii) Technological factors

Variable	Unit	Explanation
EIRATE(J)	fraction	ratio of the energy intensiveness of industrial process J to the 1975 level (1975=1)
J=1		steam generation
J=2		furnaces
J=3		space and water heating
J=4		non-substitutable uses of electricity
J=5		motor fuel
EICOK	kg/ton iron	coke requirements per ton of pig iron
IRONST	tons/ton steel	pig iron requirements per ton of steel
BOF	fraction	fraction of steel produced in non-electric furnaces

EFFIND(K)	fraction	fossil fuel efficiency relative to electric efficiency in process K
K=1		steam generation in industry
K=2		furnace operation in industry
K=3		space and water heating in industry
K=4		thermal uses in industry (in case there are no detailed data about industrial processes, this variable is used instead of EFFIND(1) to EFFIND(3))
ELPIND(K)	fraction	electricity penetration in process K, K=1,2,3,4 (where index K denotes the same processes as for the variable EFFIND above)
HPI	fraction	penetration of heat pumps into the fraction of useful energy demand for steam generation and space heating in industry which is met by electricity
EFFHPI	XXX	COP (coefficient of performance) of heat pumps in industry
IDH	fraction	district heat penetration for steam generation and space and water heating in industry
SPLT	fraction	solar penetration for low temperature steam generation in industry
SPHT	fraction	solar penetration for high temperature steam generation in industry
GIC	1/100veh-km	specific fuel consumption of cars in intercity traffic
GUC	1/100veh-km	specific fuel consumption of cars in urban traffic
ISO(I)	fraction	fraction of the space heat demand reduction in pre-75 dwellings of type I, relative to the 1975 level, due to better insulation

I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating
K(I)	kcal/h/ C/m^2	specific heat loss of dwellings of type I built after 1975
I=1		single family homes with central heating
I=2		apartments with central heating
I=3		dwellings with room heating
ISOSV	fraction	fraction of the space heat demand reduction in pre-75 service sector buildings, relative to the 1975 level, due to better insulation
HAREAN	10^3kcal/m^2/yr	specific heat requirements of post-75 service sector buildings
EFFHS(K)	fraction	fossil fuel efficiency relative to electric efficiency in process K
K=1		space heating in dwellings
K=2		hot water preparation in dwellings
K=3		cooking in dwellings
K=4		heating in the service sector
ELPHS(K)	fraction	electricity penetration in process K, K=1,2,3,4 (where index K denotes the same processes as for the variable EFFHS above)
HPHS	fraction	penetration of heat pumps into the fraction of useful energy demand for space and water heating in the household and service sector which is met by electricity
EFFHPR	XXX	COP (coefficient of performance) of heat pumps in the household/service sector
EFFAC	XXX	COP (coefficient of performance) of

		air conditioners
DHPH	fraction	district heat penetration for space heating in urban areas
SPSH	fraction	solar penetration for space heating in post-75 single family dwellings
SPHW	fraction	solar penetration for hot water preparation in dwellings
SPSV	fraction	solar penetration for service sector heating in post-75 lowrise buildings areas (household and service sector)

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