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System Analysis and Scenario Approach for Detailed Long Range Energy Demand Forecasting

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SYSTEM ANALYSIS AND SCENARIO APPROACH FOR DETAILED LONG RANGE ENERGY DEMAND FORECASTING

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ABSTRACT

This paper describes a method of energy demand forecasting based on a system analysis of the economy and a scenario description of its development. After a brief analysis of the limits of the traditional econometric tools, the method is described in detail. An application carried out for the French economy is briefly outlined to show more concretely the feasibility and practicality of such a method. To conclude, some general features of the method are reviewed so as to see how its adaptation to other countries could be envisioned. In this vein, a concrete extension to developing countries is proposed.

AUTHOR'S NOTE

The conceptual framework of the method presented here as well as its application to the French economy are the results of collective work carried out with B. Chateau at the Institut Economique et Juridiqu de l'Energie (Grenoble, France). Only the last part of the paper has been developed more recently at IIASA.

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I INTRODUCTION

In recent years, some research efforts have been made to work out new methods for long term energy demand forecasting. Their main originality is an attempt to leave out the traditional techniques of the econometric approach widely used until now to tackle this problem. These researches were motivated by a desire to take into account, at a very disaggregated level, the set of relations (political, economic and technological) existing between the economic growth pattern of a country and its resulting energy demand evolution. Even if, until the oil crisis, it was not completely justified to develop new forecasting tools in developed countries because of the relative stability and regularity of their economic development, this issue was quite different for developing countries. In effect, the industrialization of these countries will cause a disequilibrium and structural societal change whose influence on energy demand cannot really be accounted for with the traditional econometric methods.

The oil crisis with all its repercussions on the energy supply now mades necessary a deep investigation of all possible changes which might be induced by this strong increase of the average energy price, and their integration in the energy demand forecasting methods. Among the main changes, the following can be quoted: development of less intensive energy technologies (mainly in the industry), relocation of heavy industries in some developing countries with low energy prices (OPEC countries for instance), implementation of energy savings policy in industrialized countries, substitution of electricity for conventional fuels ... . In other words, the oil crisis has emphasized even more the acute need for very detailed and disaggregated tools for energy demand forecasting*.

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*The limits of econometric forecasting methods in the current energy context have been further developed in [1].

In this context, new forecasting techniques must be developed to replace or supplement the econometric forecasting methods.

One possible approach is based upon the "energy analysis concept" which has already been widely investigated* . As far as we know, this method has never been applied to energy demand forecasting; rather it has been limited to the study of specific aspects of this demand: energy demand for food, cars, power plants, and even for energy strategies. In other words, these analytical accountings have never been gathered into an integrative and operational approach. Two major limits can explain the difficulty in applying energy analysis to the totality of energy demand. First of all, if this energy accounting is feasible for basic materials and some equipment or consumer goods, as soon as we try to encompass the total energy flow within a country, the quantity of data required and the number of components to analyze very quickly makes the work intractable.

Moreover, the way in which the industrial energy demand is represented (i.e. through what is called the "indirect" and "investment" components) doesn't allow proper accounting for technological changes (substitution processes) or major changes in the industrial production policy (import or export of products), and therefore requires the assumption of a static energy content. This is very questionable for long-term periods. For instance, the energy content of a French car in the year 2000 will probably be very different from that of a 1976 French car (depending, for instance, on the way steel is produced, on the origin of the steel, on the quantity of steel used, ...). The energy analysis approach without modification, does not allow reliable assessment of the future energy content.

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* We can particularly mention the works of P.F. Chapman (Open University, Milton Keynes, U.K.), R. Herendeen and E. Hirst (Oak Ridge Laboratory, U.S.A.), G. Leach and M. Slesser (University of Strathclyde, Glasgow, Scotland), and J.P. Charpentier (IIASA, Austria).

The purpose of this paper is to describe another possible approach* (called MEDE) which lies between the energy analysis and the econometric techniques. This method is based upon a very detailed analysis of the major energy consuming sub-systems of an economy (heavy industries, space heating). It forecasts the energy needs in terms of useful energy for the process where a competition between energy sources may exist, and of final energy demand where there exists a demand for a specific energy source. For the sub-systems not analyzed in details the energy demand is based upon econometric forecasting. The way in which the energy demand of an economic system is looked at is very close to the forecasting tools used in some planned-economy countries [2]. Such an analysis has also the same philosophy as a method developed in the University of Wisconsin[3]. In addition to this analysis a scenario approach has been set up to account for the long term development of the economy.

The detailed analysis of the energy demand is carried out to bring out the main macro and micro socio-economic, as well as political and technological factors (the energy demand determinants), which drive the long-term evolution of the demand. In this prospect the socio-economic system is broken down into a certain number of hierarchical sub-systems in order to come up, at the ultimate step of disaggregation, with "modules" which are homogeneous with respect to their energy needs development. The main factors acting upon the evolution of the energy demand of each module are identified and organized in a hierarchical structure (macro level to micro level).

The demand forecasting is then based upon the description of the long-term development of the society by means of the scenario technique. The use of scenarios seems absolutely essential as it is clear that the future of a society cannot be forecast over a long period of time. As a general rule, the scenario technique implies a consistent description of the

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* The MEDE method has been developed for the past three years at the Institut Economique et Juridique de l'Energie in Grenoble. It has been designed under a contract with three French energy companies, ELF ERAP (National Oil Company), Electricité de France (EDF) and the Centre d'Energie Atomique (CEA). Several publications have been devoted to the presentation of the method as well as to particular aspect of the energy demand analysis [1,4-10].

evolution of a system by fixing, through exogenous assumptions, the evolution of certain variables characteristic of this system--the scenario components. All the difficulty is therefore in the selection of these components and in the formulation of consistent assumptions. To cope with this problem the scenario components are first selected among the energy demand determinants and organized in a hierarchical structure derived from the determinants structure. Each scenario is then based upon assumptions about the macro-determinants (also called basic determinants) describing a consistent strategy of development for the country under consideration. The formulation of assumptions on other scenario components is then carried out, by going down in the hierarchy and by defining each assumption in relation to assumptions already formulated. This scenario-writing process considers, therefore, the assumptions about the alternatives describing the pattern of development of the economy as the central frame of each scenario and the main source of consistency.

The calculation of the energy demand change over time is then carried out with a simulation model driven by the scenario components. The principle of the method is presented in Figure 1.

In this paper we will first elaborate on the limits of the econometric energy demand forecasting methods and introduce in detail the MEDE method. Although this approach was primarily worked out for a specific country, France, its basic principles as well as its conceptual framework are general enough to envision its implementation for other regions, whatever the economic growth pattern. To emphasize this aspect we will conclude the paper by outlining how MEDE could be adapted to developing countries.

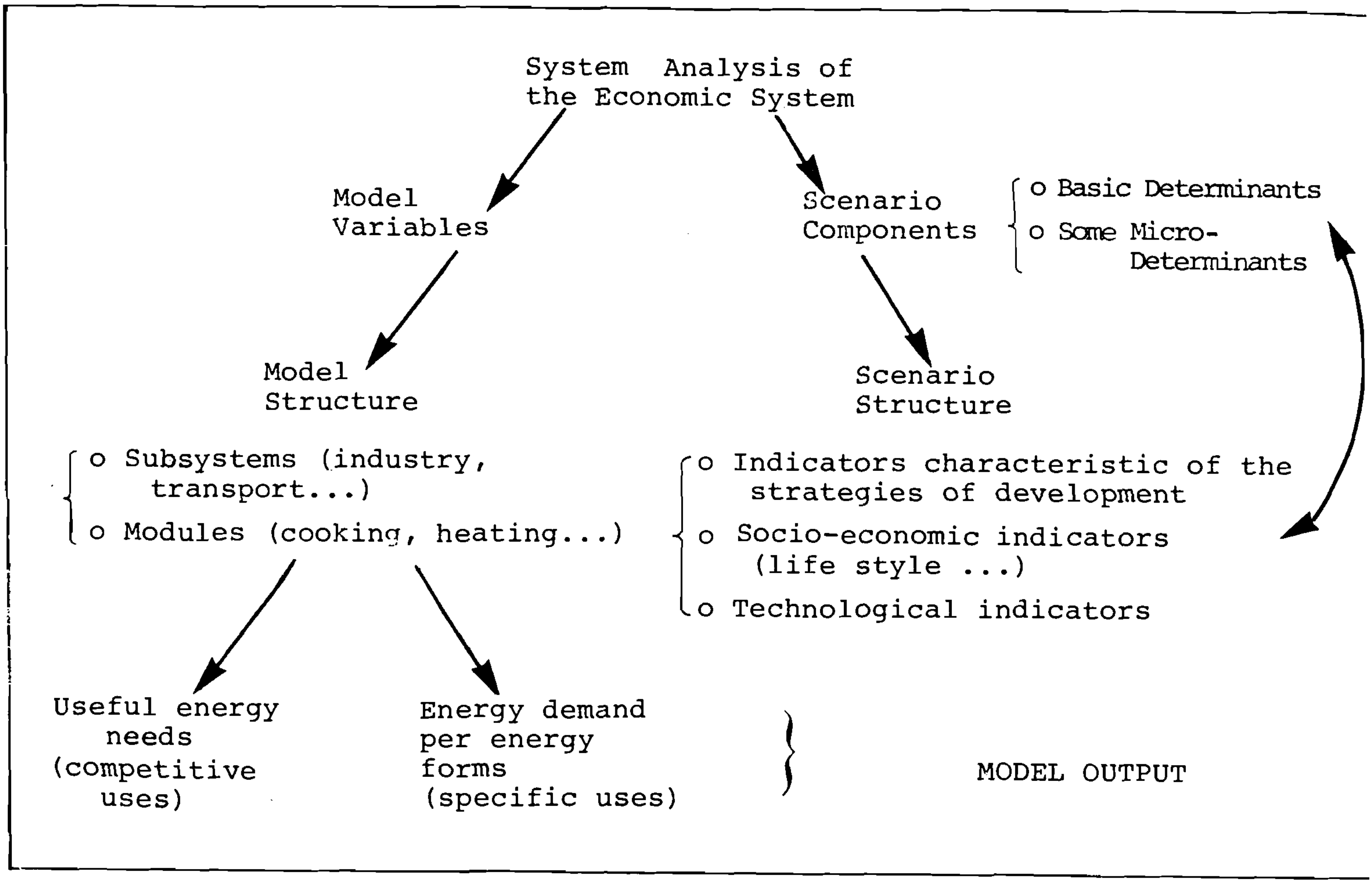

Figure 1: Conceptual Scheme of the MEDE Approach.

II LIMITS OF THE ECONOMETRIC APPROACHES

The main methods used up until now for energy demand forecasting have been designed in a relatively stable energy and economic context, dominated by the following characteristic features:

- a steady economic growth;
- low energy prices compared to other production factors, with even a slightly declining price trend in some cases;
- a strongly partitioned energy market, especially between conventional fuels and electricity, permitting separate forecasts for these two energy commodities.

This relative stability partly explains the success of econometric forecasting methods. Because everything was changing slowly and steadily, it was almost justifiable to assume that the causal relations statistically observed in the past could be extrapolated, and hence to base the energy forecasts on econometric models.

The "energy crisis" brought on by the quadrupling of the crude oil price, considered as the leading price of energy commodities because of its important share in the world energy market, has caused a break in past trends and hence has substantially shortened the time period for which econometric methods can be considered as reliable. This break can be analyzed through several phenomena:

- The relative costs of some technologies, mainly in the industrial sectors, have been affected by the substantial rise in hydrocarbon prices; this will lead to the development of technologies which are either less energy intensive (substitution energy/capital) or based upon different energy sources.
- Because of the discrepancies in the energy prices between industrialized countries and oil producing countries, some heavy industries - such as steel and petrochemicals - may be relocated in these latter countries. This phenomenon might even be accelerated as developing countries feel more acutely the necessity for attracting heavy industries (cf.the so-called Lima objectives *).
- The governments of countries which are very dependent on energy imports (in fact, most of the industrialized countries) are now trying to implement energy savings measures with the two-fold objective of reducing their energy dependence and limiting their expenditure in currency (for example, passing of insulation standards for space heating).

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*Lima Conference of the Non-Aligned Countries (March 1975).

- Finally, the change in the relative price of oil and electricity, in a way more advantageous to the latter, will radically modify the conditions of competition between these two commodities and cause the boundary between their markets to disappear.

In view of these difficulties, the introduction of price variables into econometric models could be envisioned through medium- or long-term elasticities. The utilization of long-term elasticities in econometric models to account for the socio-economic system response to the energy price increase is infeasible because of the difficulty of statistically measuring the energy demand price elasticities. The NERA study [11] showed that what we could in fact measure was the energy consumption elasticity, which differs from the demand elasticity one would need.* Moreover it is statistically very difficult to measure price elasticity when the price remains stable, which was the case for energy. In addition, the use of these calculated elasticities to analyze the consumer reactions to a very strong and abrupt price increase is also questionable.

Apart from the limits previously outlined, another basic criticism of the econometric methods is their rigidity. By rigidity is meant that they do not really allow taking into account the influence of alternative long-term economic growth pattern (industrial development, urbanization trends, modes of transportation, life style,...) on the energy demand level. To be more specific, econometric methods capture in a too rough and aggregated way the interface between energy demand and economic development. In the case of developing countries, for instance, their development and their industrialization could be based upon very contrasting patterns ranging from the American pattern

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*The reasoning can be quickly summarized as follows: statistical series only allow energy consumption and energy prices to be plotted, each point capturing the intersection of a supply curve and a demand curve. In other words, demand and consumption curves are not identical.

to the Chinese pattern; as most of these countries are not committed to one of these courses, very flexible forecasting tools have to be used to integrate the multitude of alternatives and help in the evaluation of the respective energy patterns. Though on a lower scale, the same problem is faced in the industrialized countries where the saturation of some material needs and the development of new values might also lead to alternative futures and hence alternative energy patterns*.

III DESCRIPTION OF THE METHOD

1. System Analysis of the Energy Demand

The system analysis of the socio-economic system is implemented in three hierarchical steps which can be briefly outlined as follows:

- *Partitioning of the system* as a whole into a set of sub-systems corresponding to identical types of energy needs and to the same economic function (either production of industrial goods or agricultural products, or a service, or else final consumption).
- *Decomposition of these sub-systems into homogeneous groups, or energy modules,* in which the mechanisms of energy demand growth can be analyzed in an aggregated way.
- *Analysis of the factors which can influence directly or indirectly the energy demand evolution of each module;* the interrelationships between all these factors (hierarchy, causal dependence and contradiction) are then analyzed and organized into a logical structure showing their interactions. After simplification this structure is used to set up a simulation model.

A. System analysis of the socio-economic system

The principle of this analysis consists in "disassembling" the total system into homogeneous pieces in order to bring out

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*The famous Ford Foundation Study has recently pointed out the necessity of linking the energy demand growth of the US with social and economic development patterns. This showed the wide range of variation of the US energy demand for alternative socio-economic scenarios.

the largest sub-systems or "energy modules" where the energy demand analysis can be carried out in an aggregated way. The objective of such a partitioning is to identify modules where the energy consumer behavior can be considered as homogeneous with respect to their energy requirements. Before presenting this system analysis in detail it is helpful to recall the induced character of the energy demand, as it is a major point emphasized in this approach, justifying the way in which the system is analyzed. The total energy demand of an economic system results on the one hand from the satisfaction of what can be called "cultural needs"* of the individuals, and on the other, from the economic activity of the system (production of goods and services) in a given technological context. In the first case, energy is consumed as a final commodity (electricity for the operation of electrical appliances, heat for space heating and hot water,...), and in the second as an intermediary commodity or a production factor such as manpower or capital with which it can be replaced.

As a consequence of this specific aspect of the energy demand, it is possible to characterize each type of cultural need or economic activity by its associated energy needs or "useful energy needs". This useful energy corresponds to the real energy requirements of the consumer (i.e. heat, high temperature, horsepower,...). Its level depends on the original cultural need or economic activity and also on the technologies used for its satisfaction: a given production of steel requires various quantities of thermal energy, according to the process used (direct reduction or blast furnace, for instance).

These useful energy needs lead then to the final demand for energy commodities or end-use demand through the equipment used for their satisfaction (furnaces, space heating appliances,

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*These "cultural" needs refer to the subjective needs and differ therefore from the basic or physiological needs of people. They are closely related to the level of development of the society.

engines,...). For instance, the heat requirements for space heating are transformed into an electrical, oil, or gas demand through heating appliances.

This conceptualization of the final energy demand formation is shown in Figure 2 for the case of residential space heating.

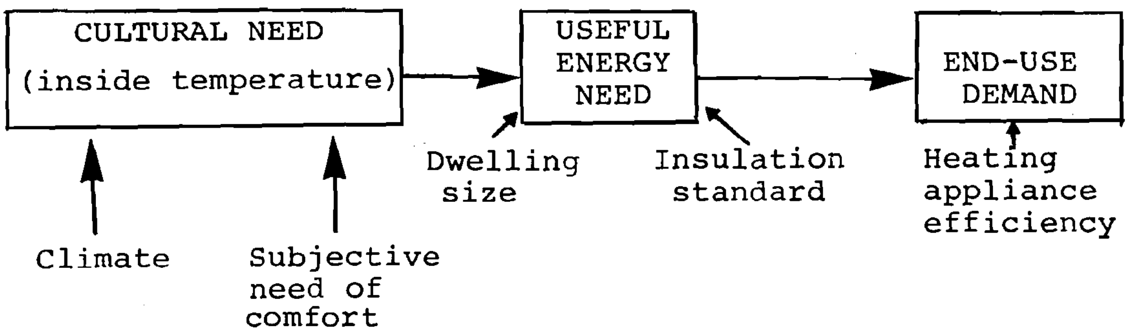

Figure 2. Residential Space Heating Energy Need Analysis.

- *The first partition* of the economic system begins with an identification of the main energy needs* existing in the system under consideration. In order to avoid coming up with too wide a range of energy need types, one should only consider explicity those which currently represent, or might represent in the future, a significant fraction of the total energy demand. The less important needs are then aggregated into one or more categories.

- *The second level of partition* aims at isolating homogeneous energy modules. In light of what was said before, these modules should correspond to groups of energy consumers having homogeneous cultural needs or economic activity and likely to use the same kind of technologies. Therefore the following criteria have been considered to identify these modules:

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*From now on in the text, energy need will mean useful energy need.

(i) Homogeneity of the underlying "cultural needs" (if energy is consumed as a final good) or of the economic activity (if energy is an intermediary product). For instance, the temperature requirement inside homes or the dwelling size are very different according to the level of income of the households. For this reason, three classes of income have been distinguished in the French study. In the same way, the energy requirements per worker or per unit of value added are very different in the heavy industries, the light industries, or the service sector; therefore they must be considered separately.

(ii) Homogeneity in the behavior of energy consumers, with respect to their choice of technologies and energy equipment. For instance, the behavior of industrialists in the face of energy saving technologies, as well as their concern for their energy expenditures, is completely different in the heavy industries, where energy costs represent between 10 and 50% of the production cost, and the light industries where they do not generally exceed 5%. In order to better look at the possible technological changes in these heavy industries, very detailed investigations must be carried out for the main high energy content products (steel, aluminum, cement,...) [6].
The necessity of considering the three classes of income for households also holds for this criterion, as the types of space heating appliances or modes of transportation utilized are closely related to income (for space heating, for example, this appears indirectly through the choice of dwellings).

(iii) Homogeneity of the alternative technologies in competition for the satisfaction of the energy needs under consideration. For transportation, for instance, it is clear that the choice of mode of transportation is strongly related to the purpose of the travel and its distance for passenger transportation (professional purpose or tourism), and to the type of freight which is carried and the distance for freight transportation. For that reason passenger and freight transportation energy needs were split into a certain number of modules, which are listed in Table 1. In the same way the various modes of intracity mass transportation, as well as of space heating systems, which can be economically developed are completely different according to the city size: for instance the utilization of nuclear heat in district heating networks is more economical in larger conurbations than in smaller cities; the development of subways can only be envisioned for cities of more than one million inhabitants, and tramways for towns of about 500,000 inhabitants.

As an illustration of what has been presented, the energy needs and modules explicitly considered in the French study are listed in Table 1.

B. Analysis of the energy demand growth within each energy module

The objective of such an analysis is to identify the main factors acting directly upon the energy demand growth pattern within each module. By this is meant a very analytical and systematic study of the evolution mechanisms of the cultural needs or economic activities underlying the demand on the one hand, and their mode of satisfaction or technologies on the other hand.

The identification of these "determinants" is organized around the three following points:

(i) Analysis of the energy prices' influence on the energy demand, through the analysis of the consumer behavior with respect to their consumption on one hand, and their technological choice on the other hand: for instance, the possibilities of reducing the energy expenditures in the industry have been extensively investigated, especially for the heavy industries which are particularly sensitive to all energy price changes (steel, cement,...).

Table 1: System Analysis of the Energy Demand for the French Case

ORIGIN OF THE ENERGY NEEDS	ENERGY NEED TYPES	ENERGY MODULES
SATISFACTION OF INDIVIDUAL "CULTURAL NEEDS"	• space heating • intracity person transportation • hot water • electrical appliances • intercity transportation • cooking	18 modules(crossing of 3 groups of households according to income level and 6 human-settlement categories.*) 3 modules (3 household groups) 1 module 2 modules (professional purpose, tourism) 1 module
INDUSTRIAL PRODUCTION	• electrical appliances • medium temperature (steam) • high temperature • chemical uses • space heating • freight transportation	10 modules corresponding to large energy consumer industries (steel, aluminum, cement, glass pulp & paper, chloride, nitrogen, ethylene & plastics , other basic chem. prods. & ferroalloys, + 4 modules corresponding to 4 aggregated sectors in light industries. 8 modules international oil transportation; other international freight transportation; domestic transportation of crude oil and gas; transportation for distances less than 50km, transport of building materials, oil products, agricultural products, and other industrial goods for distances of more than 50km.
SERVICE PRODUCTION	• electrical appliances • space heating and hot water	1 module 1 module
AGRICULTURAL PRODUCTION	• aggregated	1 module

*Large conurbation (Paris area), four city sizes (more than one million inhabitants; between 500,000 and one million; between 200,000 and 500,000; less than 200,000, and the rural areas).

NOTE The underlined module corresponds to those for which the energy demand was roughly correlated to socio-economic indicators, that is to say for which econometric forecasting was used . For the others, the energy demand evolution has been analyzed in detail (technological changes, social changes).

(ii) Identification of the technological changes and their effect on energy demand (industrial processes in the large energy consumer industries, modes of transportation,...). All these processes have been analyzed at the engineering level, in order to characterize all types of energy requirements and their possible variation over time. The constraints on the development of these new processes have been carefully analyzed, as well as those related to the penetration of electricity in the industrial market [8,9].

(iii) Analysis of the influence of the main decision makers' policies on the factors acting upon the energy demand (government, municipalities, large companies, transportation companies,...).

Two types of factors or determinants* emerge from this analysis:

(i) Determinants characteristic of the modules

These factors encompass first technological determinants defining the link between the energy needs, the possible alternatives available for their satisfaction and the resulting final demand. They also include socio-economic determinants expressing the consumer behavior (values, economic rationale, psychological factors, concept of the future,etc.), the number of consumers, and the economic origin of the energy needs (economic activity such as steel production, cultural need such as the desire for a certain temperature,...). Finally, they encompass political factors which reflect the choices of decision makers and economic agents: technological choices (process, equipment, mode of transportation), industrial location choice, etc....

(ii) State variables pertaining to the total economic system

They encompass macro-economic variables (economic growth rate and structure, income level and distribution, energy prices...), organizational variables (human settlement pattern, level of

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*From now, these factors will be most often referred to as "determinants" as they contribute to the determination of the level and structure of the energy demand, as well as its long-term evolution.

decentralization/centralization, transportation infrastructures), political factors characterizing the major choices of the government, and finally social variables (social organization, social values...). These variables will be also referred to as "basic variables" or "basic determinants".

The analysis has also led to the identification of interactions existing between these factors: either deterministic or causal relations. Among these relations, there exist political relations which show on the one hand the influence of decision makers or economic agents on the determinants they control, and on the other hand the interactions between decision makers (power relations, institutional relations...).

This set of variables and relations defines the structure of the modules. Figure 3 indicates the general structure of a module. As an illustration, Figure 4 describes the structure of a particular module: freight transportation for distances of more than 50 km (for which competition exists between water, road, and rail transportation).

The association and superimposing of all the module structures lead to the structure of the global system.

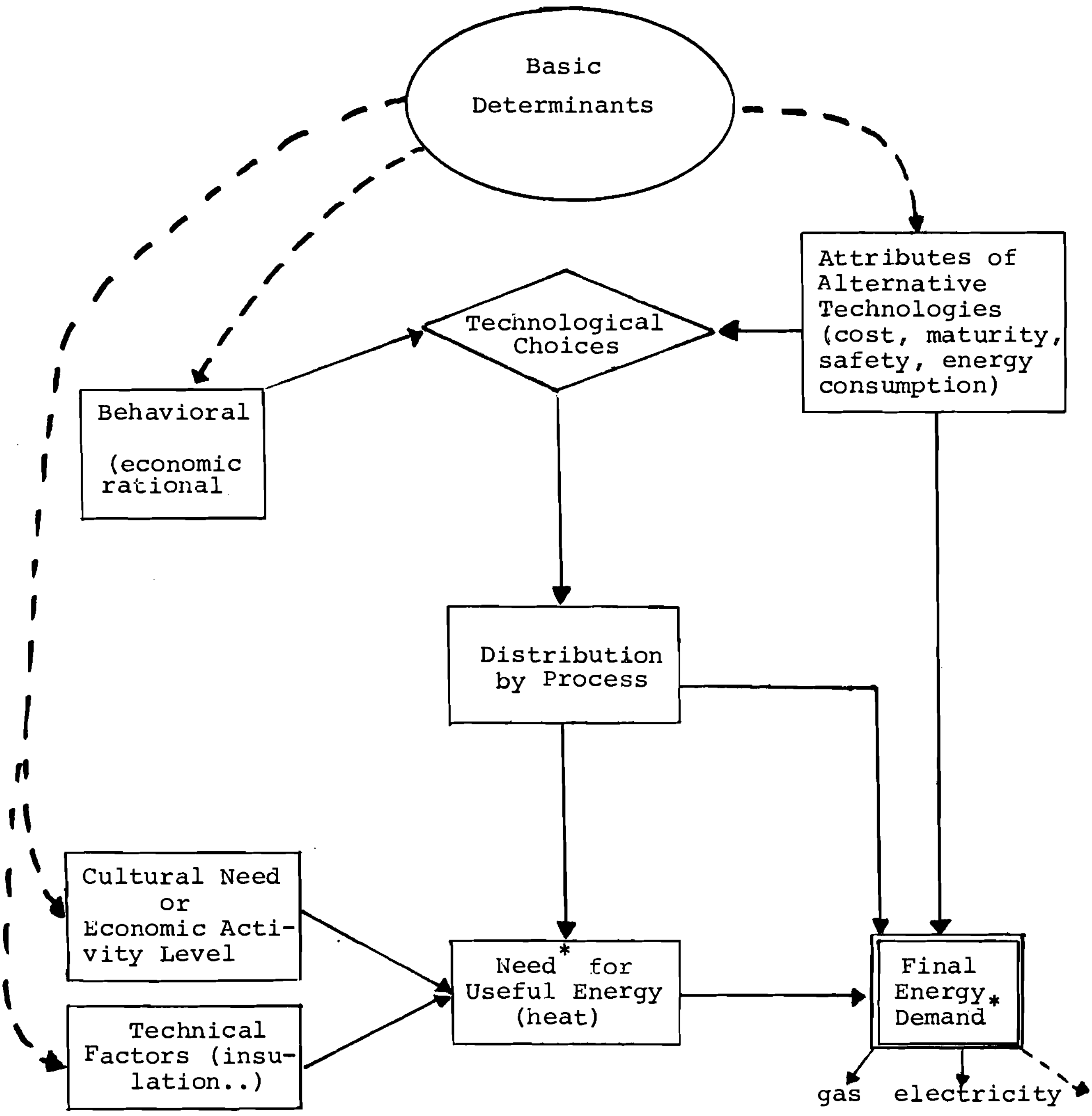


Figure 3: Simplified Structure of a Module.

*The effective distinction between useful energy need and final demand is not always possible (transportation for instance) but this does not change the principle of this scheme.

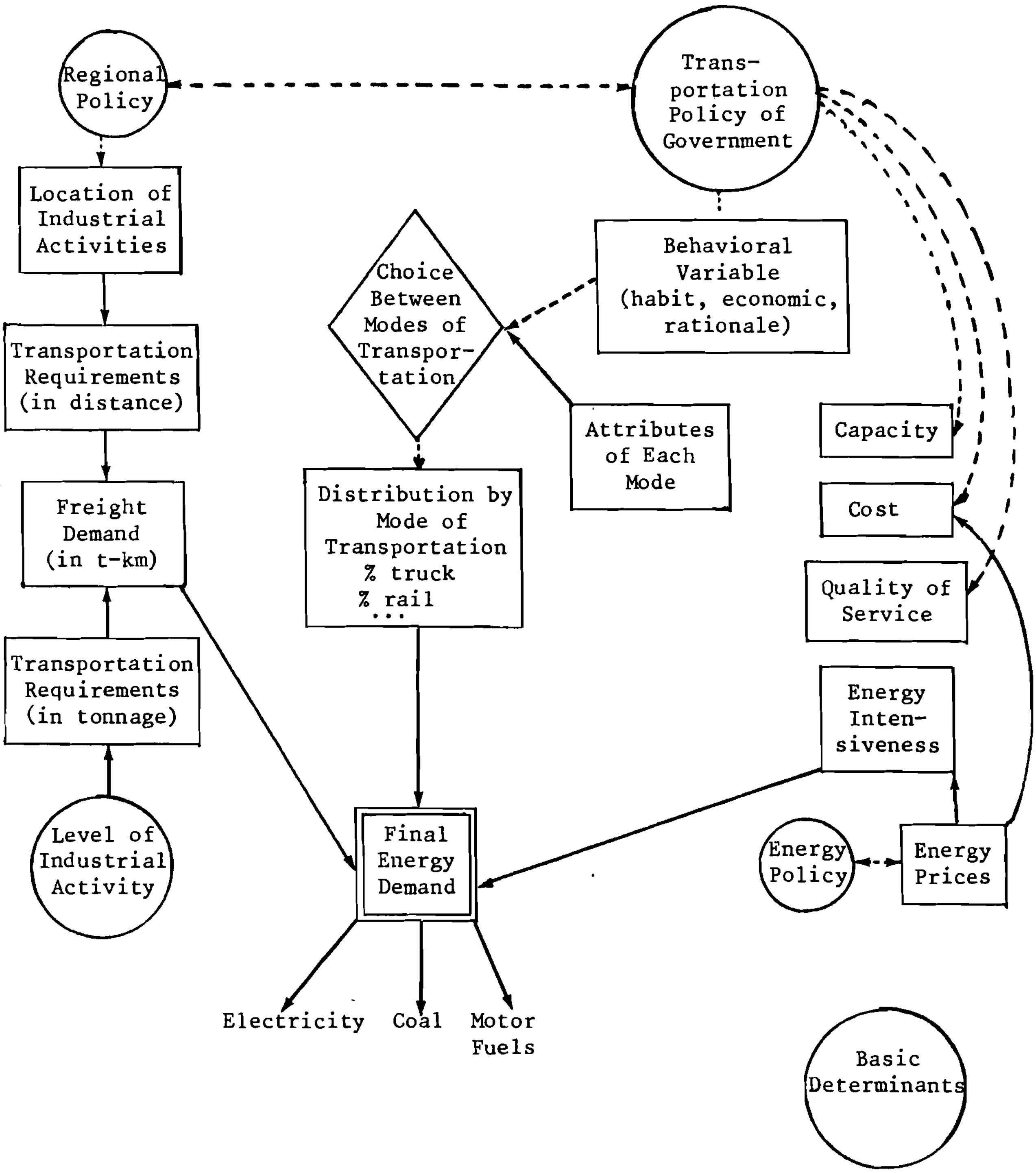


Figure 4: Simplified Structure of Freight Transportation Modules for Distances of more than 50 km.

2. Scenario Technique and Simulation of the Energy Demand Development

The general structure of the socio-economic system combining all the determinants, describes the mechanisms of evolution of the energy demand. Some factors are purely qualitative such as the political or behavioral factors. The next step is therefore to simplify the structure and to characterize each qualitative determinant by an indicator which can be quantified. For instance a transportation policy can be characterized by the rate of investment in the railway or road infrastructures, or else by certain objectives of distribution of the traffic between modes of transportation.

As the time horizon of the forecasting extends quite far into the future, it is clear that it is impossible to quantify or formalize the evolution of all its variables. The necessity of making assumptions about the long-term evolution of the economic system has already been stressed. In addition, there exist some other variables whose mechanisms of growth are too complex or too uncertain to be quantified; therefore their evolution has also to be specified by means of assumptions (mainly technological factors, and life-style indicators).

If all the assumptions formulated for the scenario components are randomly combined, the chances are that a fairly large number of combinations will come up, among which some may be unlikely, others completely inconsistent. The question of consistency should be considered very carefully, accounting for subtle or not immediately obvious contradictions or feedbacks which may exist. Before explaining how we have tried to write consistent scenarios, it is helpful to specify the main sources of inconsistencies which usually appear in the scenarios:

- Combination of assumptions on the policies of a given decision maker corresponding to different and contradictory goals and objectives: for instance, a high environmental protection policy, aiming mainly at reducing pollutant emissions, associated with an energy policy based upon extensive development of electricity without incentives for waste heat recovery. We are perfectly conscious that in the real world it may happen that contradictory decisions are made by decision makers. But it is clear that their basic and long-term decisions are based upon consistent objectives, even if most often these objectives cannot be clearly put forward.

- Combination of assumptions leading to conflicting strategies or choices between different decision makers: for instance, a low recycling policy associated within a given scenario with a very aggressive development strategy for developing countries owning natural resources, characterized by high prices for their resources and a control of their production level.
- Combination of inconsistent assumptions on different factors: for instance, high rate of old building demolition with a low growth of the building material industry.

To cope with these difficulties, a hierarchical scenario approach has been set up. It is designed according to three basic rules:

- The assumptions about the determinants describing the pattern of development of the economy (basic determinants) represent the central frame of each scenario. All assumptions about other determinants should be defined in relation to the assumptions formulated for the basic determinants, which appears therefore as the major source of consistency and cohesion;
- Each assumption about scenario components is defined in relation to the others so as to take into account the fact that some assumptions are incompatible with others or determine the content of other assumptions. This is achieved in two ways. First, all the scenario components are interrelated within a hierarchical structure describing that

interdependence. This structure is derived on the one hand from the system structure, because it indicates the dependence relations between all the determinants, and a fortiori, between the scenario components; and on the other hand, from a decisional structure, characteristic of the system, which accounts for institutional and power relations between decision makers. Secondly, the scenario-writing process (formulation of assumptions) is carried out progressively: it begins with the variables located at the top of the hierarchy and, at each step, the assumptions are stated such as to be consistent with the assumptions already made (i.e., for variables higher in the hierarchy);

- The range of assumptions attached to each scenario component is as limited as possible. This is achieved by basing these assumptions upon a very detailed qualitative analysis of the phenomena and factors capable of accelerating or slowing its evolution.

For a given country, the whole set of scenario components and their alternative assumptions can be gathered in a general frame and presented in the same form as a questionnaire. Such a presentation allows a certain flexibility when alternative scenarios are envisaged since all the scenario elements are clearly listed along with their associated assumptions. It is clear that new assumptions can be added without any difficulty, if their consistency with the other assumptions is checked. The use of such a questionnaire also makes the description of the scenarios and surveys of their content easier.

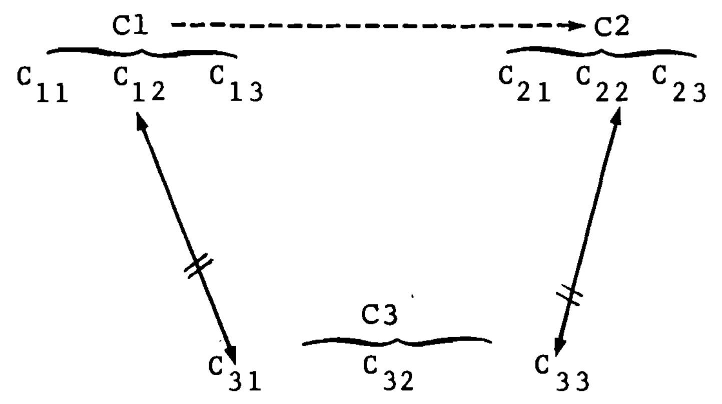
The scenario-writing will then consist of picking out one assumption for each component of the "questionnaire" and controlling at each level what assumptions are forbidden or what assumptions must be selected (see Figure 5).

The scenario frame or "questionnaire" is organized in four main levels. Their content is described in Table 2.

Table 2: Scenario Structure for the French Study.

H1	International environment	. primary energy prices . technological innovations . new international economic order { strategy of multi-national companies; policy of the developing countries block }
H2 Socio-economic scenario	Regional development pattern	. general policy goals . social values - - - - - - - - . demography . economic growth { industrial policy; GNP structure; employment distribution } . income distribution . urbanization { rate of urbanization; fraction of the total urban population by city sizes } . location of industrial activities . transportation policy { objectives; infrastructure of transportation } . general energy policy { objectives; energy conservation policy; use of waste heat etc. } . environment policy { objectives; recycling policy, etc. }
H3	Energy Supply Characteristics	. production constraints . final energy prices . decisional structure for energy companies . state of regional engineering and R&D
H4	Energy demand* (assumptions related to the models)	. technological changes . life-style indicators . social and economic determinants

*It would be too long to describe all the assumptions at this level (more than 100 assumptions were considered for the French study [2,5]).



C_i scenario component i

c_{ij} assumption j on component i

⟷ inconsistent assumptions, for instance c_{22} and c_{33}

------► dependence relation between components; for instance C2 depends on C1, which means that the assumptions made on C2 must take into account the assumptions made on C1: $c_2=f(c_1)$

Figure 5: Scenario Structure (Example with Three Components)

IV APPLICATION OF THE METHOD TO THE FRENCH ECONOMY

In order to illustrate and specify some points which might remain somewhat vague after this methodological presentation, we will now briefly outline how this method was applied in the French context. The method has been applied primarily to two contrasted scenarios of development of the French society. These two scenarios, selected in agreement with representatives of several French energy companies* , were above all designed so as to determine two extreme values between which the French energy consumption might lie in 2000. Since then, other scenarios have been written in the frame of the WAES program**.

Short description of the two contrasted scenarios:

i) The first scenario (referred to as S1) can be characterized as a trend scenario; in other words, no major change is assumed to take place in the distribution of labor between developing countries and industrialized countries, in the raw materials price or in the general policy of the government. Extended up to 2000, such a scenario is intentionally exaggerated, but this matches the objectives of coming up with extreme levels for the future energy consumption.

ii) On the contrary, the second scenario (S2) is characterized by a break with the past trends, on the one hand with respect to the relations between rich countries and developing countries, and on the other hand in the development pattern of the French economy. The government policy aims at trading off, in a very determined and authoritative way, a lower economic growth with higher standards of quality of life. Progressively developing countries become exporters of basic materials

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*See note page 3.

**The Workshop on Alternative Energy Strategies (WAES) is an international project involving seventy-five experts from fifteen countries. Its objective is, through the use of scenarios, to span a wide range of likely future energy supply and demand patterns at the world level (outside CMEA and China). This study is being carried out under the leadership of Prof. Carroll L. Wilson (M.I.T.).

(steel, aluminum, petrochemicals), industrialized countries where the production level of these materials remains stable.

Table 3 specifies the assumptions made respectively for S1 and S2, for the three first levels of assumptions, previously identified in the scenario structure (Table 3). The results have been extensively presented and discussed in [5].

V EXTENSION OF THE METHOD TO DEVELOPING COUNTRIES

At first sight, this method may appear rather complex as it implies the handling of a great many variables and data, the formulation of many assumptions and the management of a complex simulation model. But one should not forget the organized and hierarchical character of this apprach which actually allows the study of the energy demand at any level of disaggregation. If for the French study, disaggregation has been attempted as much as possible, it does not mean that for another region or country such a detailed investigation should be carried out. On the contrary, this method is rather flexible, as for each application the degree of sophistication can be adapted to the data available. The preliminary Mexican study has shown that the data availability was not a limitation to its implementation*.

After the presentation of the method previously outlined in this paper, it is useful to point out some characteristics of the method which definitely have a general scope:

1. the energy demand analysis which consists of disassembling the total demand into homogeneous pieces,
2. the scenario technique, based upon the construction of consistent technological, socio-economic and political scenarios through the utilization of a hierarchy between the scenarios components,

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*Tentatively, an application of the method to Mexico has been tried. The preliminary results are recorded in [12] and [13].

Table 3: Description of Two Scenarios for France.

	S 1			S 2			
H_1 - H_{12} Price of Primary Energies:	1975	75-2000		1975	75-2000		
$H_{12.1}$ Oil	3.5 c/th	+1%/year		3.5 c/th	+ 2% /year		
$H_{12.2}$ Nuclear	6.5 c/th	see H_3		6.5 c/th	see H_3		
H_{13} Demography	1975	1980	1985	1990	2000		
$H_{13.1}$ Total Population 10^6	53	55.5	58	60.5	64		
$H_{13.2}$ Households 10^6	17,3	18.5	19.6	20.7	22,9		
H_{14} Long Term Trends	75-85	85-2000		75-85	85-2000		
$H_{14.1}$ Economic Growth GNP	5%	4%		3%	2%		
$H_{14.2}$ Urbanization	Stability of the rural pop. to $4.5\cdot10^6$ households						
H_2 - H_{21} Income Distribution		75 - 2000		1980	1985	1990	2000
	I_1	35 %		32%	29%	26%	20%
	I_2	40 %		44%	48%	52%	60%
	I_3	25 %		24%	23%	22%	20%
H_{22} GNP Structure	1975	1985	2000	1975	1985	2000	
Agriculture	5.5%	5 %	4 %	5.5%	5.5%	5.5%	
Services	35 %	37 %	40%	35 %	37 %	40 %	
Building & Public Works	11 %	11 %	11%	11 %	11 %	11 %	
Materials Ind.	7.5%	7 %	6%	7.5%	6.5%	5 %	
Other Ind.	34.5%	34 %	34%	34.5%	34 %	34 %	
Energy Ind.	6.5%	6 %	5%	6.5%	6 %	4.5%	
H_{23} Regional Planning							
$H_{23.1}$ Urbanization Scheme	Growth of towns > 10^6 inhab. 6 towns of $1.5\cdot10^6$ inhab. on average by 2000			Growth of towns of 200,000-500,000 inhab. About 50 towns of 350,000 inhab. on average by 2000			
$H_{23.2}$ Industrial Localization	Tendency to concentration around urban zones			Tendency to decentralization, small-scale industrial units spread through the territory			

Table 3 (cont.)

	S 1	S 2
$H_{23.3}$ Transport Infrastructure	Development of railway and fast road networks between the development areas	Intensification of railway and small roads network in the whole territory
H_{24} Environment	Minimum action to satisfy public opinion	Very strict law for the different economic agents
H_{25} Energy Policy	Liberalism	- Law for energy conservation - Incentive for development of new energy sources for energy recovery.
H_3 - H_{31} Supply Capacity for Different Energy Commodities in 2000	Nuclear 50% Gas, hydrogen 20% Oil 20% Coal 5%	40% 15% 20% 5%
	Hydraulic, Geothermal, Solar 5%	10%
	Heat, Heat from recovery -	10%

H_{32} Price of Different Energy Products	S 1: 1980	S 1: 1985	S 1: 2000	S 2: 1980	S 2: 1985	S 2: 2000
Elec. BT		0.95 level 1973	-2%/ year		0.95 (1973)	+1%/ year
HT		1.05 level 1973			1.05 (1973)	
Fuel Oil*	0.45	0.3		0.45	0.3	
Motor Fuel	1.15	1.0		1.15	1.0	
Gas		Price of oil products +20%			Price of oil products +20%	

*Figures indicated here represent the difference between oil products and crude oil prices .

3. the list of variables, identified as having a significant influence on the long-term evolution of the energy demand, the set of macro-indicators used to characterize the qualitative aspects of a regional development pattern, and ultimately the set of modules, all representing a very helpful starting point for the investigations of a new region or country.

Moreover, some quantified information collected or produced for the French study could be useful for other applications:

1. some quantified relations between economic indicators (industrial activity and freight transportation demand for instance) or else between physical or geographic indicators and economic indicators (e.g. city size and transportation needs, floor area in the service sector per worker),
2. most of the technical data concerning the energy requirements and their evolution--for industrial processes, space heating equipment and modes of transportation [7,9,10].

The case of developing countries is somewhat different than that of industrialized countries; on the one hand because of the lack of a very detailed statistical base, and on the other because of the importance of the social and economic changes which could result from their industrialization, and which, moreover, could widely vary according to the development pattern which they will follow.

With regard to the data problem, it seems that, as a first step, it would suffice merely to decompose the total energy demand into several types of energy needs and reason at this level of dissaggregation (see Table 1 for the French case). If, for some energy needs, the available statistics would allow a more detailed investigation , it would still be possible to disaggregate these particular energy needs into modules, based on the same pattern as for the French study. For industry, it nevertheless seems essential to break down the total energy needs in order to explicitly account for the needs of some heavy industries which might have a significant impact on the energy demand of the country, particularly if they are rapid-growth industries. This point is particularly important for countries possessing natural resources or cheap energy resources because they might become large exporters of basic materials to industrialized countries (steel, aluminum, petrochemicals), but at the same time large energy consumers (OPEC countries, Zaire...).

We will now briefly describe how this method could be practically applied to developing countries and outline a preliminary model. Figure 6 shows the final scheme we arrived at for the adaptation of the method to developing countries. In order to simplify the presentation, the system analysis which led to the identification of the major factors acting upon the energy demand evolution will not be presented in this paragraph. We will therefore successively describe by means of tables the scenario structure and the simulation model structure. (See Appendix I and II respectively.)

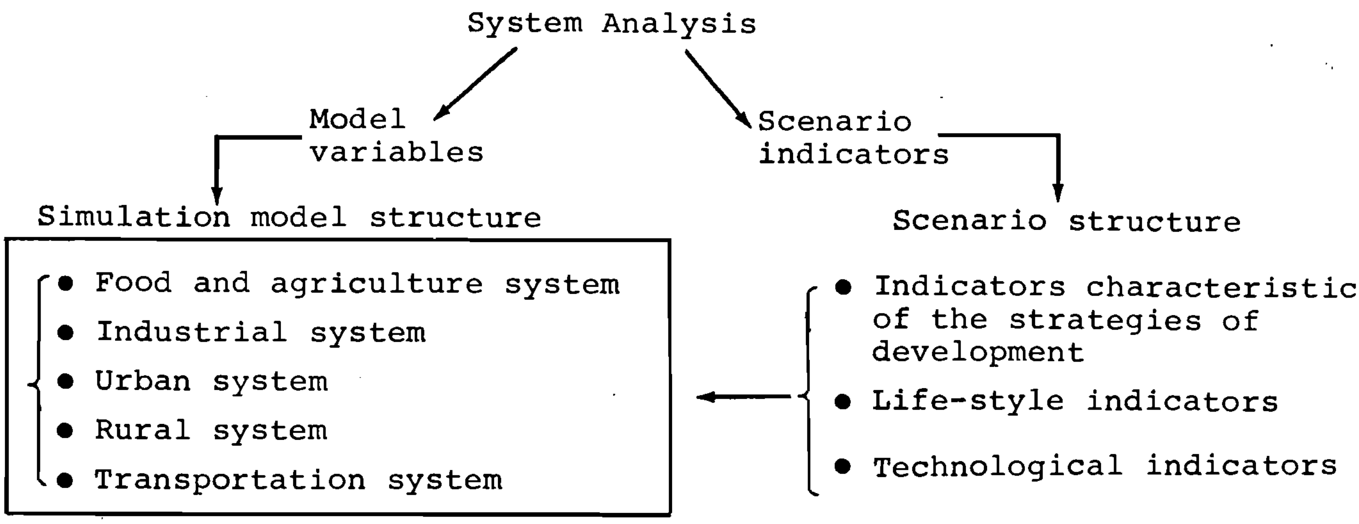

Figure 6: Extension of MEDE to Developing Countries: General Scheme.

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APPENDIX I

SCENARIO STRUCTURE FOR DEVELOPING COUNTRIES

All scenarios are structured around a certain number of components or indicators which are hierarchized from the macro - level and political level to the micro- and technical level:

Socio-Economic Scenario (S)	1) Indicators characterizing the strategy of development 2) Life-style indicators
Technological Scenario (s)	1) Indicators specifying the process mix 2) Indicators specifying the specific energy needs per process

All scenarios are defined as the combination of a Socio-Economic Scenario and a Technological Scenario (S + s). For a given economic scenario, several technological scenarios should be envisioned to span the range of alternative technologies, and therefore alternative energy patterns which can be associated with a given economic growth. The assumptions constituting the socio-economic scenario encompass the major issues that national decision makers have to consider to define their development policy; these assumptions are therefore highly related to a political project. On the contrary the technological assumptions are less dependent on political choices.

The set of indicators selected for developing countries will now be presented; for each of them the interactions with other indicators or assumptions will be emphasized.

1. INDICATORS CHARACTERIZING THE STRATEGY OF DEVELOPMENT

Policy Issues Considered*	Indicator Name	Symbol	Scenario-Writing Process: Comments on the Formulation of a Consistent Set of Assumptions for the Indicators**
• Economic Growth			Dependence of the indicator on:
	GNP	Y	
	Contribution of Agricultural sector to GNP	a	Indicators interrelated with classical equilibrium macro-economic equations
	Contribution of Industrial sector to GNP	b	
	Contribution of Service-Commercial sector to GNP	c	
Trade-off between collective investment and private consumption, between capital accumulation and consumption	GNP fraction spent in investment	i	
	GNP fraction spent for private consumption	p	
• Industrial Policy			
	Distribution of industrial value added between		
Degree of priority in industrial development, degree of dependence on imports (e.g. for equipment)	Building and public works ind.	b_1	
	Materials industries	b_2	
	Equipment industries	b_3	Assumptions about imports of these industrial goods, about the GNP share between investment and consumption
	Consumer goods industries	b_4	
Strategy of valorization of natural resources (exports of crude resources vs exports of higher value products)	Fraction of mineral production processed into basic materials for		Assumptions about the evolution of the international economic relations, i.e. about the relation between developing countries and industrialized countries; about the degree of cooperation between developing countries (association of mineral-producing countries), about the strategy of multinational companies (location of their investment in all countries or only in "safe" countries like Brazil and Australia).
	Iron ore	mp_1	
	Oil	mp_2	
	Gas	mp_3	

*The policy issues considered here are issues for which alternative, and very often contrasted, choices exist with significant impacts on the energy demand growth. Moreover from one choice to the other, the order of magnitude of these impacts can vary greatly.

**All these indicators are more or less interdependent; to avoid inconsistencies in the scenario-writing process (formulation of assumptions on these indicators), it is necessary to account for these interrelations. Therefore the scenario writing process has a hierarchical structure, each assumption being formulated according to the assumptions already made.

1. INDICATORS CHARACTERIZING THE STRATEGY OF DEVELOPMENT CTD...

Policy Issues Considered	Indicator Name	Symbol	Scenario-Writing Process: Comments for the Formulation of a Consistent Set of Assumptions for the Indicators**
• Income Distribution Social policy	Population distribution per social class* Fraction of private consumption** per class	po_j p_j	Dependence of the indicator on: GNP growth rate (assumptions about the reduction of inequalities more consistent with assumptions of a moderate GNP growth rate)
• Transportation Policy Preference for collective versus individual mode of transportation; priority in infrastructure investment between rails and roads	Fraction of freight transportation per truck Fraction of freight transportation per train Fraction of intracity transportation by car Fraction of intercity transportation by car Fraction of intercity transportation by train Fraction of intercity transportation by bus	tru ftra uc ic ptra bu	Ratio between investment and consumption (assumptions about a high penetration of trucks and cars more consistent with assumptions on a ratio of investment/consumption, favoring consumption)
• Demographic and Human Settlement Policy Mode of industrial development: concentration around big ind. and urban poles/versus decentralization	Total population Fraction of urban population Fraction of urban population in cities of more than 1 m. inhabitants	PO u u'	

* Two classes for rural population and three classes for urban population (see the description of the rural and urban systems, respectively).

** The private consumption is considered here as an indicator of "income", i.e. the amount of money people will spend on consumer goods.

2. LIFE-STYLE INDICATORS

Name	Symbol	Comments about the Choice of the Indicators (Importance for Energy Demand)	Indicator depending on:
Number of people per house for class j	h_j	The residential demand is better related to the number of houses than to the total population	Income***
Food consumption per capita (calories or protein)	FC	The basic determinant underlying the energy demand for agricultural production and fertilizer production is the need for food	Income***
Energy use for cooking per house	eck	In the poorest countries the major energy need in the houses comes from cooking (cf. India)	Constant+
Energy use for hot water per house for class j Energy use for lighting per house for class j Electrical use for secondary appliances per house for class j Energy use for space heating per house for class j in zone z Energy use for air conditioning per house for class j	ew_j $e\ell e_j$, eke_j $eape_j$ eh_{zj} ec_{zj}	These indicators allow the evaluation of what might be the energy implications of the satisfaction of the individuals' needs for housing. The major determinant of the rate of satisfaction of these needs is the rate of increase of household incomes. To better capture the relation between incomes, standard of living and housing energy use, 5 social classes have been identified. Different consumption budgets characterize these classes*. For space heating and air conditioning, climatic conditions should be considered in addition to income criteria, to better forecast the residential energy needs.**	Income***
Fraction of rural houses using commercial energy Electrification rate	h_c he	One of the major issues related to the residential energy demand for developing countries is the rate of substitution of commercial energy for non commercial fuels	
Car ownership ratio/capita Average distance of intercity trips/capita for class j	poc d_j	Determinant of the energy demand for intercity transportation	Population density and income ***

*See the urban and rural system description for an approximate outline of the current conditions of these budgets in developing countries.

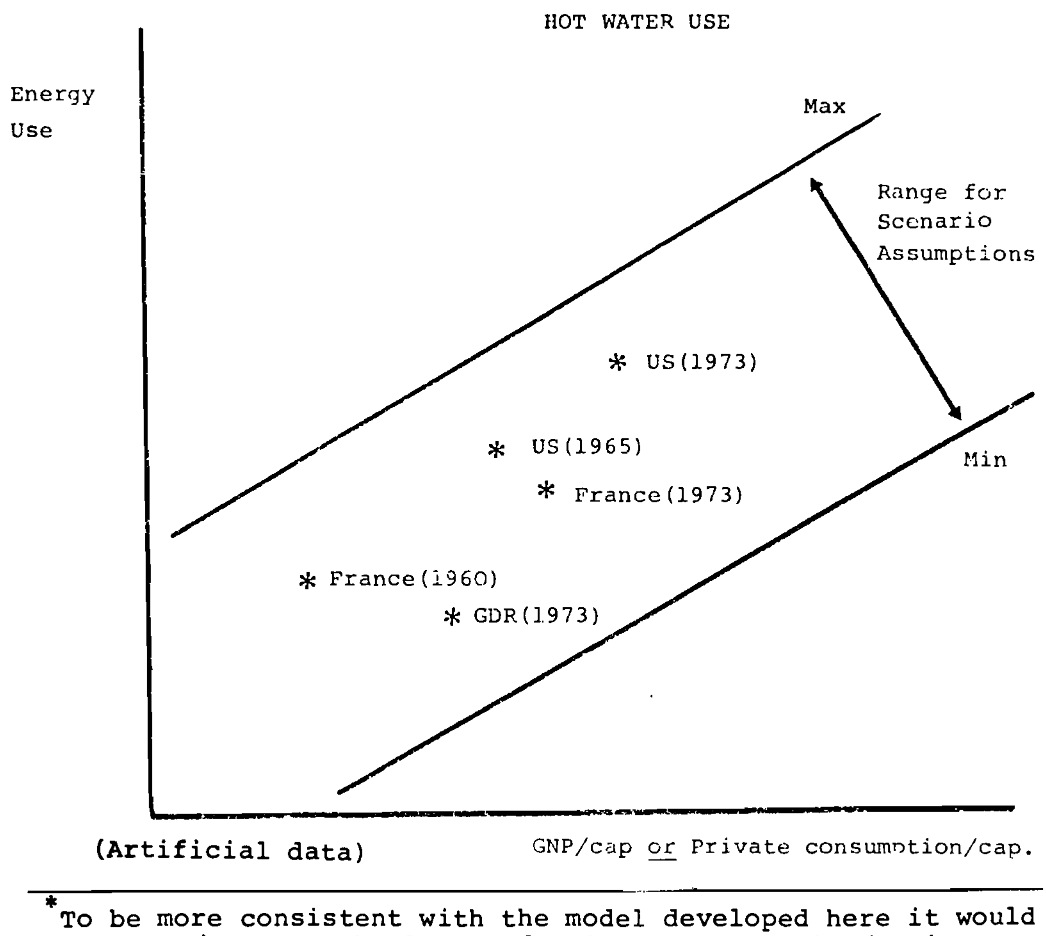
** A large population in developing countries is concentrated in tropical and subtropical areas where heating is not always required. This should lead to different energy budgets than in industrialized countries for the same level of development.

*** See next page for the formulation of assumptions on these indicators.

+ In a first step these indicators can be considered as constant.

COMMENTS ON THE FORMULATION OF ASSUMPTIONS ABOUT LIFE-STYLE INDICATORS RELATED TO THE INCOME LEVEL

The method proposed is to make assumptions by using as a reference base the relation observed in some industrialized countries between the indicator under consideration and the income level. This means that for each indicator the level of GNP/cap* and the resulting values for the indicator will be first plotted for different countries and different years. Therefore it will be possible to get some orders of magnitude as well as the extreme values observed in the past for a given income level. Then, according to the philosophy of the scenario it will be easier to formulate the assumptions required. This does not mean at all that values are transposed from developed countries to developing countries, but that the values observed in developed countries are used as information or as an input to formulate assumptions about the possible values in developing countries. The following figure indicates what kind of information we should arrive at.



(Artificial data)

* To be more consistent with the model developed here it would be better to use the level of private consumption/capita.

3. TECHNOLOGICAL INDICATORS

	Symbol
Process mix	
Process mix in steel production	p_iS
in ethylene production	p_iE
in nitrogen production	p_iN
Fuel mix for trains	tcf, tdf, tef
Fraction of electric intracity mass transit	mte
Specific energy requirements	
Gasoline consumption of cars for intracity trips	gu
Gasoline consumption of cars for intercity trips	gi
Others	
Number of tractors per ha	tr
Load factor for intercity mass transit	ℓfi
Load factor for intracity mass transit	bfu
Fraction of electric intracity mass transit	mte

APPENDIX II

II. SIMULATION MODEL STRUCTURE FOR DEVELOPING COUNTRIES

PHYSICAL CHARACTERISTICS*

Indicator	Symbol
Land area (km^2)	L
Fraction of the population living in a zone** where:	
-- space heating is needed	ℓ_1
-- cooling is needed	ℓ_2
-- no cooling and no heating is needed	ℓ_3

*These variables are constant factors for the model.

**Each country has therefore to be divided into four zones. Heating is assumed to be needed if the average minima are lower than 10°C and cooling is required if the average maxima are higher than 25°C.

The fraction of the population living in each of these zones will be assumed constant over time whatever the human settlement pattern.

$\ell_1 + \ell_2 + \ell_3 \geqslant 1$ because some zones may require both cooling and heating.

FOOD AND AGRICULTURE SYSTEM

	Symbol	Mode of Determination of Each Variable or Indicator*
System Variables		
Agricultural sector value added	YA	$YA = a \times Y$
Arable land	AL	f(t)***
Food consumption per capita (protein and cal/cap)	FC	f(S)**
Fraction of agricultural products in food(+) consumption	CA	f(t) or constant
Agricultural yield (prod. per hectares)	PA	$PA = f(CA)/AL$
Module Variables		
-- Fertilizer use module		
Nitrogen fertilizer consumption (tons of nitrogen/ha)	Fc	f(YA)
Total nitrogen fertilizer consumption (tons of nitrogen)	FC	$FC = Fc \times AL$
-- Farming Module		
Number of tractors per ha	tr	f(s)**
Total number of tractors	TR	$TR = tr \times AL$
Motor fuel use per tractor	eTR	f(t) or constant
Total motor fuel use	ETR	$ETR = eTR \times TR$
-- Possible Extension		
Energy required for irrigation		
Energy required for fishing (motor fuels for boats)		
Distinction of major food products in the food consumption (wheat, rice,...)		

*By definition an indicator is a variable whose value is defined by means of scenarios assumptions.

**f(S) means: variable whose value is defined by socio-economic scenario S. f(s) refers to technological scenarios s defined within the socio-economic scenario.

***f(t) means: variable whose value is exogenously specified as a function of time.

(+)The rest of the food consumption is meat, fish, eggs,....

INDUSTRIAL SYSTEM

	Symbol	Mode of Determination of Each Variable or Indicator
System Variables		
Industrial sector value added	YI	$YI = b \times Y$
Building and public works ind. value added	YB	$YB = Y \times b \times b_1$
Materials ind. value added	YMI	$YMI = Y \times b \times b_2$
Equipment ind. value added	YEI	$YEI = Y \times b \times b_3$
Consumer goods ind. value added	YCI	$YCI = Y \times b \times b_4$
Module Variables		
-- Steel industry module	SI	
Steel consumption	CS	f(Y)
Steel production	PS	$f(mp_1)$
Steel ind. value added	YS	f(PS)
Process mix	p_iS	f(s)
Energy use/process	e_is	f(t) [or f(s)]
Energy demand	ES	$ES = PS \times \Sigma_i p_iS \times e_iS$
-- Petrochemicals module		
Ethylene consumption	CE	f(Y)
Ethylene production	PE	$f(mp_2)$
Ethylene ind. value added	YE	f(PE)
Process mix	p_iE	f(s)
Energy use/process	e_iE	f(t) [or f(s)]
Energy demand	EE	$EE = PE \times \Sigma_i p_iE \times e_iE$
Nitrogen consumption	CN	Agriculture module
Nitrogen production	PN	$f(mp_3)$
Nitrogen ind. value added	YN	f(CP)
Process mix	p_iN	f(s)
Energy use per process *	e_iN	f(t) [or f(s)]
Energy demand	EN	$EN = PN \times \Sigma p_iN \times e_iN$

ctd....

INDUSTRIAL SYSTEM

ctd ...

	Symbol	Mode of Determination of Each Variable or Indicator
-- Miscellaneous materials module	MI'	
Value added	YMI'	YMI' = YMI-(YS+YE+YN)
Energy intensity**	eMI'	f(t) or constant
Energy demand	EMI'	EMI' = YMI' × eMI'
-- Equipment intensity module	EI	
Value added	YEI	System indicator
Energy intensity**	eEI	f(t) or constant
Energy demand	EEI	EEI = YEI × eEI
-- Consumer goods industry module	CI	
Value added	YCI	System indicator
Energy intensity**	eCI	f(t) or constant
Energy demand	ECI	ECI = YCI × eCI

Comments: The model could be further extended by considering in detail other materials such as aluminium, cement, glass, and pulp and paper. It would also be interesting to consider explicitly the food and automobile sectors so as to relate their growth to the transportation and agricultural sector development.

*Energy use expressed by three values: feedstock consumption, fuel and electricity consumption.

**Energy use expressed by three values: steam consumption, electricity consumption, energy use for kilns and space heating (competitive market between electricity and fuel). Average value should be deduced from industrialized countries.

URBAN SYSTEM *

	Symbol	Mode of Determination of Each Variable or Indicator
System Variables		
Total urban population	POU	$POU = u \times PO$
Urban population belonging to class** j (j=3,4,5)	PO_j	$PO_j = POU \times po_j$
Number of houses in class j(j=3,4,5)	H_j	PO_j/h_{j_5}
Number of houses in urban area	HU	$HU = \sum_{j=3} H_j$
Modules Variables		
-- Cooking		
Energy use/house	eck	f(t) or constant
Total energy use for cooking	ECKU	$ECK = eck \times HU$
-- Hot water heating		
Energy use/house	ew_j	f(S)
Total energy use for hot water heating	EWU	$\sum_{j=3}^{5} ew_j \times H_j$
-- Lighting*** & secondary appliances		
Annual electricity use/house for class j	$e\ell e_j$, $eape_j$	f(S)
Total electricity use	ELEU	$ELEU = \Sigma(e\ell e_j + eape_j)H_j$
-- Space heating		
Energy use/house for each zone and for each class	eh_{zj}	f(S)
Total energy use	EHU	$EHU = \sum_{j=3}^{5} \sum_{z=1}^{3} ec_{zj} H_j$
-- Air conditioning		
Energy use/house for each zone and for each class	ec_{zj}	f(S)
Total energy use	EC	$EC = \sum_{j=3}^{5} \sum_{z=1}^{3} ec_{zj} H_j$
-- Possible extension		
Take into account several degrees of insulation		
Consider explicitly the average size of houses (number of m^2/house)		

ctd ...

URBAN SYSTEM

ctd ...

*The consumption of non-commercial energy sources will be neglected in the urban system because its level is very low and rapidly decreasing.

**Three classes are considered: the poor people (j=3) for which the satisfaction of their basic needs (water, food, housing, etc.) is not ensured, the rich people (j=5) who live with the same standards as in the industrialized countries and finally between these two classes, the middle class (j=4) which gathers the mass of the people. According to this classification, the development of the countries will increase the population of the middle class and at the same time increase their average incomes. The consumption pattern of these countries will mainly depend on this class.

***It will be assumed that, on the one hand, all urban houses have access to electricity, and that on the other hand, the use of other fuels for lighting can be neglected.

SCHEMATIC DESCRIPTION OF THE STANDARD OF LIVING PER SOCIAL CLASS

(Current Conditions)

Class j	Rural Households		Urban Households		
	j=1 (poor)	j=2 (others)	j=3 (poor)	j=4 (middle class)	j=5 (rich)
Hot Water	--	N	N	V	European or American Standards
Space Heating: Zone 1	non-commercial	non-commercial	one room heated	V	
Space Heating: Zone 3	--	--	--	--	
Lighting, Secondary Appliances	--	N	N	V	
Cooling: Zone 2	--	--	--	--	
Cooling: Zone 3	--	--	--	--	
Intracity Transportation	--	--	Transportation home work by mass transit	Transportation home work by mass transit	
Intercity Transportation	--	N	N	Transportation by train or bus	

N	Negligible
--	Zero
V	Variable level

*This presentation does not intend to be comprehensive and very precise. The objective is more to differentiate the "energy budget" of these 5 classes of consumers in order to better capture the influence of the shift of people from one class to another.

TRANSPORTATION SYSTEM

	Symbol	Mode of Determination of Each Variable or Indicator
Module Variables		
-- <u>Intracity passenger transportation</u>		
Average distance of intercity transportation/cap:		
for cities of less than 1m.	tru_1	constant*
for cities of more than 1m.	tru_2	constant*
Passenger traffic in cities of less than 1m. inhabitants	PKU_1	$PKU_1 = tru_1 \times POU$
Passenger traffic in cities of more than 1m. inhabitants	PKU_2	$PKU_2 = tru_2 \times POU$
Total intracity passenger traffic	PKU	$PKU = PKU_1 + PKU_2$
Gasoline consumption of cars for intracity trips (per passenger-km)	gu	f(s)
Total gasoline consumption	GU	$GU = PK \times gu \times uc$
Load factor for mass transit	ℓfu	f(s)
Diesel consumption for non-elec. mass transit per seat	dmt	constant
Fraction of electric mass transit	mte	f(s)
Electricity consumption for elec. mass transit per seat	emt	constant
Diesel consumption for mass transit	DMT	$DMT=\frac{dmt \times PKU \times (1-mte) \times (1-uc)}{\ell fu}$
Elec. consumption for mass transit	EMT	$EMT=\frac{emt \times PKU \times mte \times (1-uc)}{\ell fi}$
-- <u>Intercity passenger transportation</u>		
Average distance of intercity trips/capita for class j*	d_j	f(S)
Passenger traffic for intra-city transportation	PKI	$PKI = \Sigma po_j \times d_{ij}$
Gasoline consumption of cars for intercity trips per passenger km	g_i	f(s)

ctd...

	Symbol	Mode of Determination of Each Variable or Indicator
-- Intercity passenger transportation (ctd)		
Gasoline consumption for intercity trips	GI	$GI = PKI \times gi \times ic$
Diesel consumption per seat for buses	dbu	constant
Energy consumption per seat for train	etrap	constant
Load factor for intercity mass transit	ℓfi	f(s)
Diesel consumption for bus	DBU	$DBU = bu \times PKI \times dbu/\ell fi$
Fuel distribution for train:		
coal fraction	tcf	f(s)
diesel fraction	tdf	f(s)
electricity fraction	tef	f(s)
Coal consumption for train	CTRAP	$CTRAP = \frac{tcf \times etrap \times ptra \times PKI}{\ell fi}$
Diesel consumption for train	DTRAP	DTRAP= ....
Electricity consumption " "	ETRAP	ETRAP= ....
-- Freight transportation		
Freight traffic in t-km.	TK	f(pop. density, industrial and agricultural value added)
Diesel consumption of trucks per t-km	dtru	f(t) or constant
Energy consumption of train per t-km	etraf	constant
Diesel consumption of trucks	DTRU	$DTRU = TK \times tru \times dtru$
Coal consumption of trucks	CTRAF	$CTRAF = TK \times trap \times etraf \times tcf$
Diesel use of trains	DTRAF	DTRAF ......
Electricity use of trains	ETRAF	ETRAF ....

*These transportation needs can be considered in a first approximation determined by trips home/work; therefore their intensity mainly depends on the size and density of the towns rather than on life style criteria.

**Assumed to be the same whatever the mode of transportation used. As a consequence the car ownership rates can be assumed to be equal to the fraction of intercity transportation per car.

RURAL SYSTEM

	Symbol	Mode of Determination of Each Variable or Indicator
System Variables		
Total rural population	POR	POR = (1 - u)PO
Rural population belonging to class 1*	PO_1	$PO_1 = POR \times po_1$
Number of houses	H_1	$H_1 = PO_1/h_1$
Fraction of rural houses using commercial energy	hc_1	f(S)
Modules Variables		
-- Cooking	CKR	
Energy use/house**	eck	f(t) or constant
Total commercial energy use for cooking	ECKR	$ECKR = hc_1 \times H_1 \times ech$
-- Hot water heating	WR	
Energy use/house	ew_1	f(S)
Total commercial energy use for hot water heating	EWR	$EWR = ew_1 \times H_1 \times hc_1$
-- Lighting and secondary appliances		
Annual electricity use per house for lighting, sec. appliances	$e\ell e_1$	f(S)
Annual kerosene use/house	$e\ell k$	f(t) or constant
Fraction of houses connected to an electric network	he	f(S)
Total electricity use for lighting	ELER	$ELER = he \times H \times (e\ell e_1 + eape_1)$
Total kerosene use for lighting	ELKR	$ELKR = e\ell k \times (hc-he)H_1$
-- Space heating		
Energy use/house for space heating	eh_1	f(S)
Total energy consumption for space heating	EHR	$EHR = eh_1 \times \ell_1 \times H_1$
-- Possible extension		
See Urban System		

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RURAL SYSTEM

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*Two classes are distinguished: the first one (index 1) refers to people who live above the level of satisfaction of their basic needs (sufficient nutrition) and whose life style is affected by technical progress. The other one corresponds to very poor people or people of marginal civilizations. As a result of this distinction it can be assumed that the poor class does not consume and is not a potential consumer of commercial energy. This population will therefore not be explicitly taken into account; all variables related to rural population will refer to the first class (index 1).

**The energy use for cooking does not vary in a significant way with the level of incomes. Therefore, for simplification purposes it will be assumed to be the same for rural and urban areas whatever the social class.