LARGE-SCALE INTRODUCTION OF ENERGY SUPPLY SYSTEMS: Issues, Methods, and Models in Some National-Regional Impact Evaluations in Sweden

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PREFACE

Energy planning has become one of the most important elements of contemporary long-term planning. The central role of the energy sector in economic development has been stressed by politicians, policy makers, and researchers.

The discussion in many countries of policies for introducing at a larger scale renewable energy resources into their energy systems has a clear regional connotation. In spite of this fact most energy studies lack the regional dimension. There are several reasons for introducing regional elements in an energy analysis in a country like Sweden. Renewable energy resources are located in sparsely populated areas. The energy-dependent parts of the economy are concentrated geographically in regions other than those which are rich in renewable energy resources. The climatic conditions make the heating of buildings necessary, and differentially costly in different parts of the country.

The current paper gives examples of regional impact studies of national energy scenarios. It outlines the long process of formulating the long-term Swedish energy policies. It relates to the investigations in Sweden of the consequences on the economic, regional, environmental, and social development of dispensing with nuclear power. It contains a presentation of a case study describing an implementation of the long-term national-regional energy policies in the Stockholm region. The methodological aspects of these large-scale impact studies are stressed in the presentation. The general features of these regional energy impact studies are characterized. A judgement is also made with regard to their coverage of aspects relevant for policy making and theoretical understanding.

The paper is a part of the background material in an international comparison of issues, methods, and models in national-regional impact evaluations of large-scale energy supply systems.

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1. INTRODUCTION AND CONCEPTUAL SETTING

1.1 Impacts, Control Theory and Systems Analysis

In a control theory setting, impact analysis relates the response pattern of a regulated system to disturbance shocks. Step functions are introduced into the system via different input channels and its response pattern is traced over time, possibly multidimensionally. In a (globally) stable system the shocks would cause no lasting effects but only produce oscillations, fading out after a period of time determined by the inertia of the system. In an unstable system the impact of the shocks would be a transfer of the system to a state other than the initial one after the oscillations have been dampened. Also, cyclic fluctuations might occur. The stability properties may depend on the initial state. Modern theories of structural stability stress the coexistence of smooth and catastrophic behavior in both simple and more compound control systems.

One way to look at an impact analysis in a complex economic and social system would be to regard it as a measuring of effects of a superposition of a large set of disturbance shocks, with a peaked distribution at a certain point in time. This paradigm of impact analysis rests on the assumption that it is possible to disentangle the individual relationships so that a certain profile of multidimensional causes can be related to a profile of multidimensional effects. One of the most significant deficiencies of this approach to impact analysis is the absence of considerations of interdependencies. Especially since causes and effects enter and drop out in a dynamic process, it becomes necessary to recognize that cause and effect mix over time. Primary effects might become secondary causes at a later stage, leading to unexpected or uncontrollable system trajectories.

The impact analyses applicable to large-scale energy supply systems cannot be of marginal type. Therefore, it is not useful to look upon these issues as a superposition of a set of independent marginal changes. A system perspective has to be adopted both with regard to the energy supply system and the areas for comprehensive impact evaluations.

Some of the interdependencies we wish to emphasize are to be found within the energy system itself. For example, the introduction of coal as a primary energy source into the energy system cannot be analyzed without considering at the same time the competing fuels. Moreover, the logistics of the different parts of the energy system must be taken as constraints. The interdependencies are also central to the study of the short- and long-term responses of the economic and social systems to energy supply options. It is evident that the interconnections and indirect effects are different in different time-perspectives. A third class of interdependencies arises from the organizational relationships between the decision-making bodies involved in the construction and operation of the energy systems. There is a substantial time-lag between the decision to invest and the actual completion of the new energy system component, for example in view of the process of giving building permits, and other interventions of the public sector.

1.2 Dimensions of Energy Systems Impacts

In the current paper we will adopt a philosophy of impact evaluation of large-scale energy projects outlined in Figure 1. We will distinguish between three impact dimensions, organized as follows:

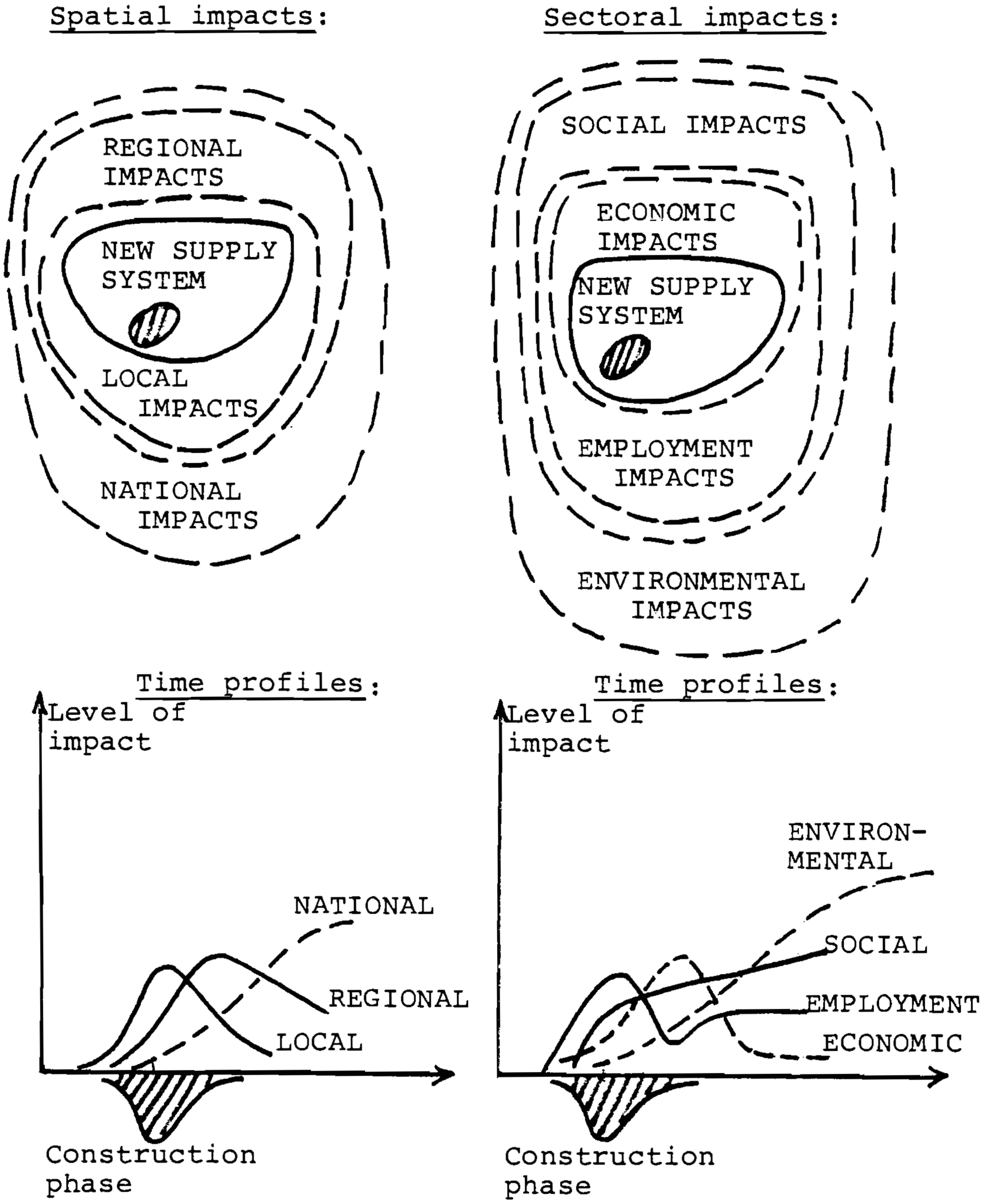


Figure 1. Impacts caused by the introduction of large-scale energy supply systems.

- spatial consequences, i.e. consequences for the geographical distribution of benefits and costs,
- sectoral consequences, i.e. consequences for different activities or resources directly or indirectly involved in the energy system development,
- temporal consequences, i.e. consequences of an energy project occurring in different time perspectives.

We do not regard these dimensions as independent but, on the contrary, would like to stress the importance of considering their interdependence. Thus, direct employment impacts fall out locally and in the short-term, during the construction phase. On the other hand, environmental impacts may occur only after a certain time of operation, and occur both at regional and local levels.

The above classification of impacts shall be looked upon as a checklist of considerations. Table 1 gives an example of a systematization of these ideas. A qualitative analysis must reveal which boxes in that table need to be more thoroughly investigated than others. There is, however, another important observation to be made in relation to the scheme in Table 1. It concerns the definition of supply system alternatives. The set-up of the whole impact analysis depends crucially on a proper specification of those alternatives.

Above we have stressed the need for a non-marginal analysis in the context of new energy supply system components. Thus, when we speak of the large-scale introduction of alternative energy supply systems, we basically mean the whole introduction process from research and development, over system design to implementation. We also conceive this process to be large in scale, that is we do not emphasize the marginal character of the introduction of a particular component of the new supply system.

The actual specification of alternatives must be done in conjunction with the real issues in Swedish energy planning. To arrive at that level of concretion we will give a background picture of the current Swedish energy system, and the policies

Table 1. Combination of impact evaluations of large-scale introduction of energy supply systems.

Impact	Supply System 1		Supply System 2		Supply System 3	
	short term	long term	short term	long term	short term	long term
Economy						
local						
regional						
national						
Employment						
local						
regional						
national						
Environment						
local						
regional						
national						
Social Structure						
local						
regional						
national						

formulated to guide it to a sustainable long-term one, based on an increased portion of domestic renewable resources. That presentation will also involve a critical evaluation of the methods used for the nuclear power abolition referendum in 1979. The national-regional interactions in the Swedish energy system will be the subject of a further section. The role of the Stockholm region will be principally stressed. In the core of the paper the methodology in some major energy supply system studies for Stockholm will be presented and assessed. We will conclude the paper with a summary evaluation and critique of the impact studies with reference to the structuring made in this introductory section.

2. LONG-TERM ENERGY POLICIES FOR SWEDEN IN CHANGING PERSPECTIVES

2.1 The Process of Formulating Long-term Energy Policies

Before 1973 the formulation of national energy policies was performed in a context of continued growth in GNP, employment, and energy use. Nuclear power was intimately associated with that growth philosophy, and its safety, and long-term contribution to the Swedish energy system, were already hot political issues. The energy planning of the 1960's had led to a massive construction of nuclear power plants, at least if measured relative to the size of the Swedish economy. However, when the first oil crisis occurred, the reaction was not to engage in an even stronger support of the nuclear option but to intensify the campaign against it. The energy issue was brought up onto the political surface, and caused a continuing surveillance in the media, which in its turn made reactor technology a topic on everyone's lips for a number of years. In fact it was not until the nuclear referendum was held in Sweden in 1979 that the political debate settled down. The oil crises, and the Harrisburg reactor accident, were events that had an enormous impact on the policy formation process.

Figure 2 intends to highlight the official investigations of the energy issue and their accompanying government propositions. In the work of the 1970 Energy Committee it was still assumed that energy demand would continue to grow at a faster rate than the GNP and that an expansion of electric power was necessary. In particular, the hydroelectric peak-load stations were planned to be complemented by nuclear- rather than oil-based condensation plants for the base-loads.

The 1973 oil crisis precipitated a new set of energy demand forecasts in 1974-1975, based on a large investigation, which materialized into the government proposition of 1975. The main ingredient of that (social-democratic) document was a proposal to start a massive research and development campaign directed towards both demand and supply of energy, and focusing on the new technology options. Energy demand forecasts indicated that a restriction on electricity consumption would be needed.

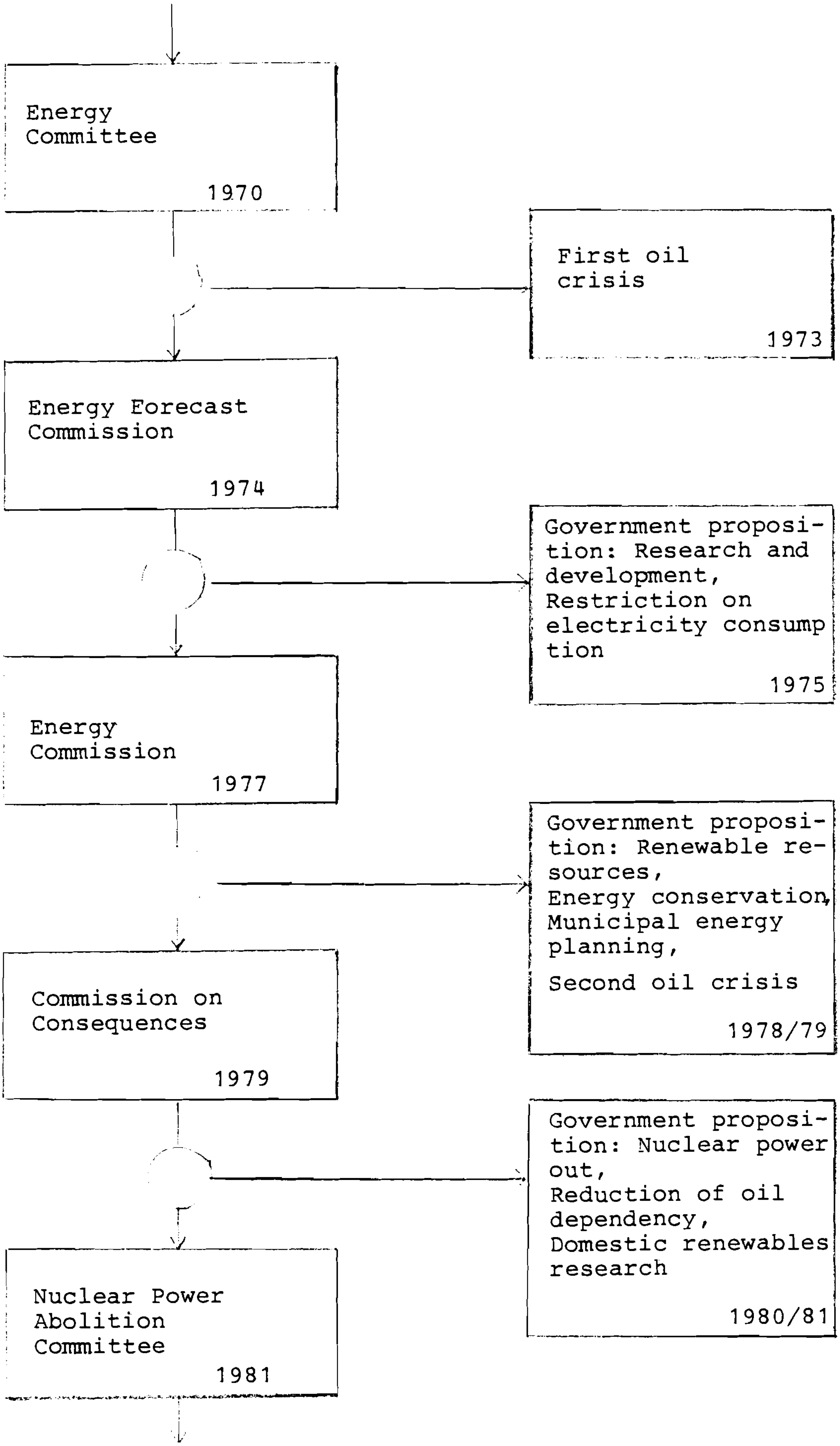


Figure 2. The process of formulating Swedish energy policies during the 1970's.

Speculations were formulated about a situation with zero growth of energy use in the 1990's without any substantial quantitative underpinning.

Research and development activities were started on a broad scale and several energy research coordination bodies were installed, none of which paid much attention to regional and energy conservation issues, however. A new major investigation was made by the Energy Commission which was put together on a parliamentary basis. This work led to a new government proposition in which the role of energy conservation was stressed and substantially increased responsibilities for energy planning were placed with the municipalities. At the same time the debate on nuclear versus renewable resources led to a government crisis on top of the second oil-price shock.

A referendum on the pros and cons of nuclear power emerged as the only viable alternative in view of the political stalemate. The Commission on Consequences prepared important parts of the background material for that referendum during 3-4 months in the autumn of 1979. The referendum finally led to a narrowing down of Swedish energy policies. The majority, which voted for keeping nuclear power during the 25 year lifetime of the currently existing plants, including the ones under construction, was as slim as 58 percent. The government proposition which followed the referendum started a nuclear power abolition committee to prepare for the phasing out of the nuclear technology. This most recent policy document stressed the necessity of reducing oil dependency even at the cost of substituting imported coal. The research on domestic renewables was intensified.

During the process described above, strategic decisions about investments in the energy system had been halted for a long time. In many regions and municipalities such decisions were needed. One example is the Stockholm region. The lack of regional considerations in the national policy documents led to an uncertainty and ambiguity about the possibilities of actually implementing the policy measures suggested in the national analysis. The current paper will address this issue further in the sequel.

2.2 Changing National Perspectives of Energy Demand and Supply.

The relationship between economic growth and energy use has differed between time periods. Per capita energy use in Sweden grew substantially more rapidly than GNP per capita during the post-war period up to the end of the 1960's. Thereafter the growth rate of per capita energy use has steadily fallen below the GNP per capita growth rate. At the same time the economic growth process itself has slowed down both for structural and business cyclic reasons. In the period around 1980 Swedish GNP did not in fact increase at all but rather tended to decrease.

Figure 3 illustrates how this process reveals itself in the forecasts of total energy demand. The years indicated in the figure can be found also in Figure 2. The picture shows a persistent over-shooting of total energy demand. Over a ten-year period the forecast of energy use for 1990 has decreased by more than 300 TWh or some 60 percent of the energy use in the middle of the 1970's.

There are at least three types of explanations to these observations and forecasts. They can be illustrated by distinguishing between a growth effect, a structural effect, and a technological effect. The first factor points at the stagnation of total economic growth as a moderation factor. We have already indicated that the growth of the Swedish economy has been very sluggish during the 1970's.

The second factor stresses the explanation that structural change in the economy will give rise to altered energy use levels even at a constant GNP level. Such restructuring processes are evident in the post-industrial society. Table 2 indicates the composition of energy demand in Sweden over more than 20 years. Industrial demand has grown more slowly than the average, while the demand from transport, heating and other service sectors has grown at a faster rate. Electricity use has grown much more rapidly than the average, especially after 1965. The electricity component is therefore the most essential one to forecast. Much of the debate about nuclear power is related to the use of electricity.

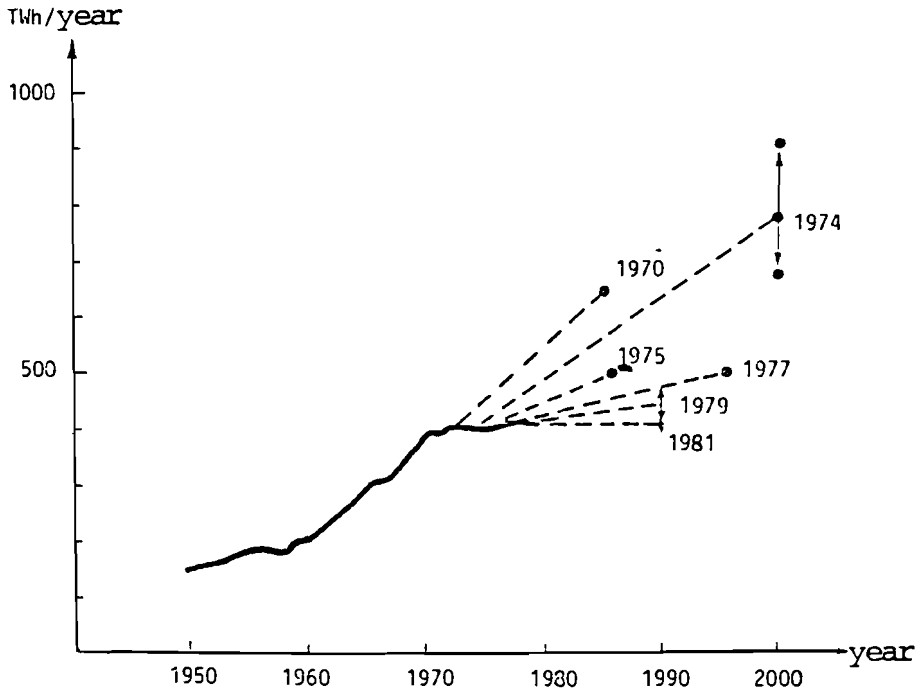


Figure 3. Forecasts of total energy use in Sweden. The years indicate when the forecasts were published.

Table 2. The development of energy use in Sweden 1955-1978.

	1955 TWh	1965 TWh	1978 TWh	Yearly change 1955-78 (percent)
Manufacturing	78	125	147	2.8
Transports	27	45	67	4.0
Other sectors	69	115	171	4.0
Total energy use	174	285	385	3.8
thereof electricity	21	42	81	6.0
Population (1000 persons)	7,262	7,734	8,276	0.6
Energy use per capita (kWh)	24,000	37,000	47,000	2.9
Electricity use per capita	2,900	5,400	9,800	5.5

The third and most difficult factor to discern behind the growth and stagnation of energy demand is the technological development. That process may give rise to a lowering of total energy use even at a constant GNP level, and an unchanging mix of demand types. Technology is a strategic issue which does not only relate to cost-optional substitution processes within industry but also to dwelling supply amendments, and changes of human behavior. Technological change in the energy component of dwelling services is often termed energy conservation. The conservation is always tied up with investment cost, however, so that there is always a technical change component. The still acting national policy in this respect, is to reduce energy use in the buildings existing in 1978 by 25-30 percent in a ten-year period. It has turned out that this goal is quite hard to implement uniformly in all Swedish municipalities. Figure 4 shows an estimated relationship between investment sacrifices and gross energy conservation level. That curve, estimated for the whole of Sweden, indicates exploding marginal conservation costs at an energy conservation level above 25 TWh per year.

Technical change in the industrial sector is related to both capital embodied and disembodied processes. Machinery may be installed with lower specific energy demand and production processes may be trimmed, for example via new computing equipment. New plants may replace old ones, thus pushing the average towards the current best practice technology. The speed of this substitution process is by no means independent of the economic growth rate even though technical change can also occur at zero growth. Figure 5 illustrates the considerable span in energy demand arising from the technological effect at constant GNP level and economic structure. It is based on detailed studies of the least energy intensive technologies (now) available in the different economic sectors. An introduction of the currently known best-practice technology would lead to a considerably lower level of energy demand than the one estimated for 1990. Figure 5 describes the large gap between technological feasibility and economic competitiveness. It points out the constructive role of planning in guiding Sweden's

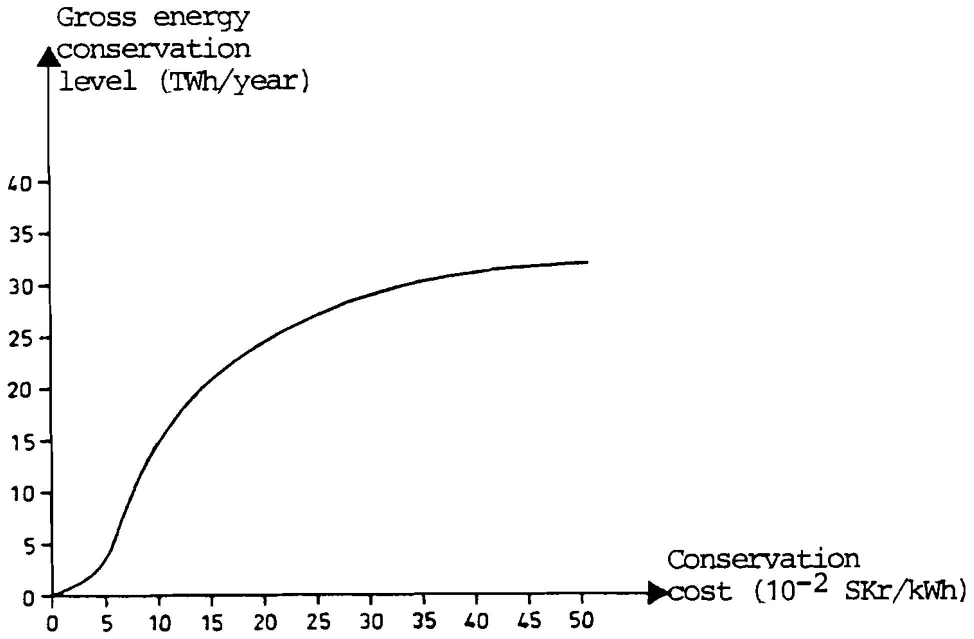


Figure 4. Energy conservation levels in the Swedish dwelling stock at different conservation cost levels. The curve is based on passive technology, e.g. insulation, and does not include active technology, e.g. small heat pumps.

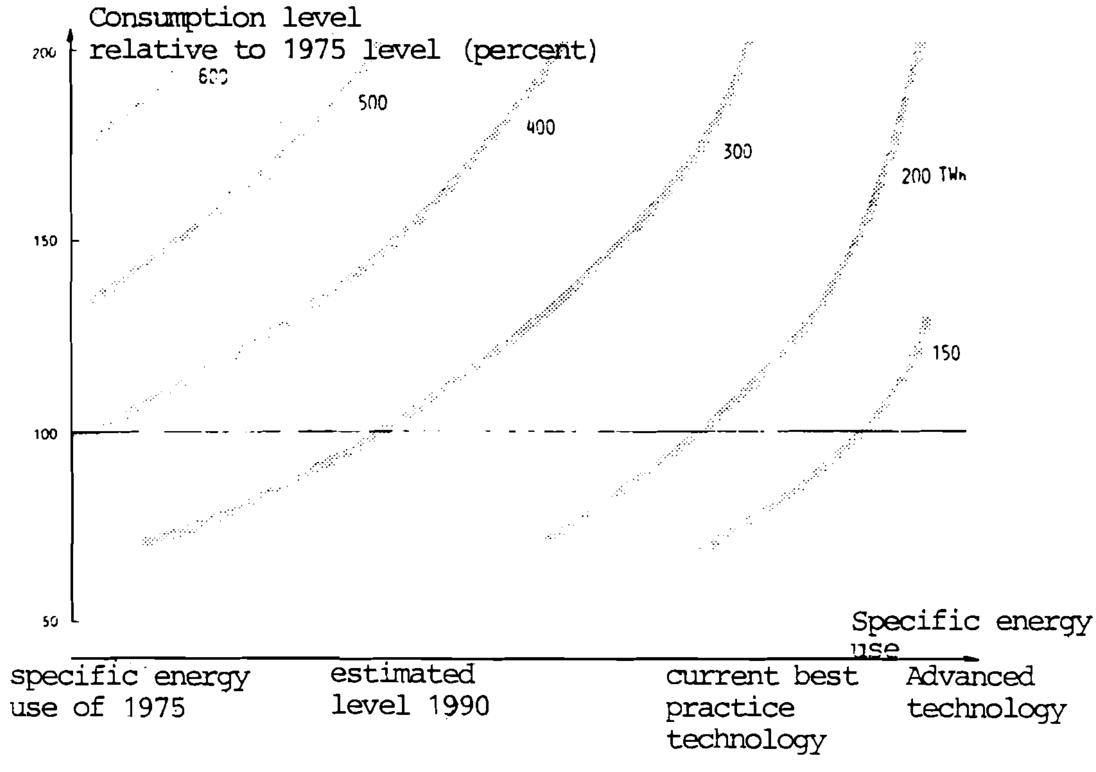


Figure 5. Relationship between consumption level, specific energy uses, and total energy use in Sweden. The figures on the curves denote TWh per year.

realization of a sustainable energy system faster than can be obtained if the market forces are left alone to work that scenario out.

Synthesizing a national energy supply system is a complex planning issue. This is especially so in a situation when economic factors force a speeding up of its restructuring. New technological options will have to be considered before they are economically mature. This has been a dilemma of the Swedish energy supply policies during the 1970's. As mentioned, a massive research and development campaign was started already in 1975. This effort is now in its third stage, in which local energy resources are brought into the energy system as a result of earlier research activities.

One might say that the future energy supply system for Sweden has stayed more stable than the total demand level during the several stages of investigation in the 1970's. Tables 3 and 4 show the reference scenario up to the turn of the century, as foreseen around 1980, with regard to the combination of energy resources and the composition of the electricity supply subsystem, respectively. Both tables contain the nuclear power option since they do not go behond year 2000. Thus, the phasing out of the nuclear capacity from the system is not considered. In fact, that long-term issue has not been treated fully as yet.

The central oil reduction goal is supposed to be fulfilled by increasing the share of coal in the energy system. As may be seen from Table 3 the domestic renewable resources--wood, straw, and peat--are pointed out as the main complements. No massive introduction of wind and solar power is realistic in Sweden in the time-perspective adopted. It should also be noted that the scenario of Table 3 still assumes a slow increase in the total energy supply. A comparison with Figure 3 indicates that the scenario might be high.

Table 4 shows the important role played by hydropower for the Swedish electricity system. The potential for farther development is less than 10 TWh. The two remaining untouched main rivers would have to be exploited for this to be feasible. The expansion of the nuclear sector is way above demand in the 1980's, if demand continues to develop according to the current

Table 3. Gross supply of primary energy resources in a reference scenario of the energy system development 1980-2000 (TWh)

Energy Resource	1980	1985	1990	2000
Oil, oil products, and methanol	313	266	225	179
Coal	3	21	40	83
Metallurgic coal	17	19	20	24
Hydropower	62	64	65	65
Wind	-	-	1	4
Solar	-	1	3	6
Back pressure	37	38	41	41
Wood, straw	3	13	25	37
Peat	-	1	4	20
Nuclear	23	47	58	58
TOTAL	458	470	482	517

Table 4. The electricity supply subsystem in a reference scenario for the period 1980-2000.

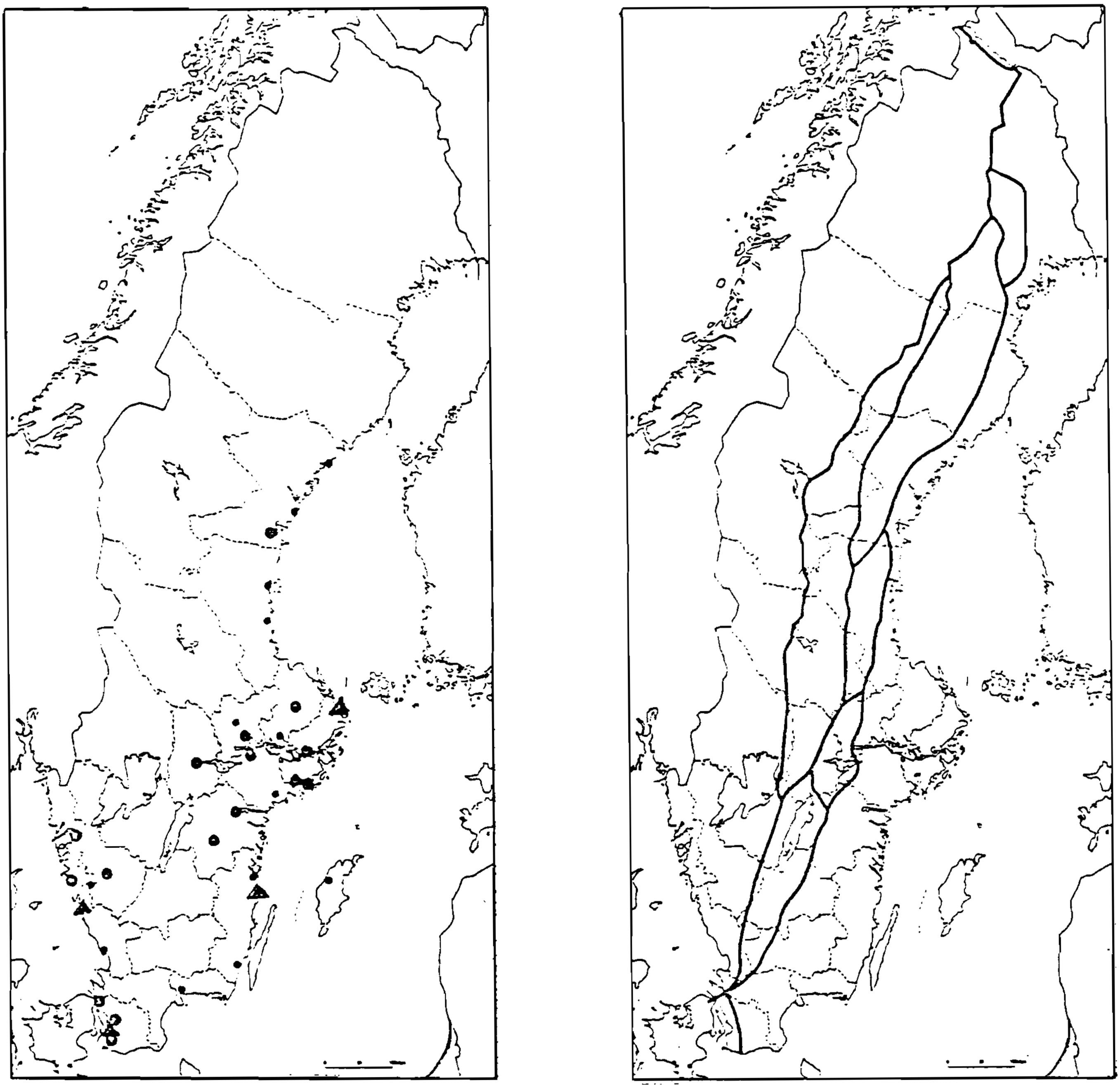
Energy source	1980		1985		1990		2000	
Energy source	MW	TWh	MW	TWh	MW	TWh	MW	TWh
Hydropower	15,000	62	15,900	64	16,200	65	16,200	65
Nuclear power	3,700	23	8,400	47	9,450	58	9,450	58
Industrial back pressure	900	5	1,000	5	1,200	7	1,500	9
Combined heat and power	2,150	6	2,450	4	2,450	6	3,750	15
Oil-based condensation	3,100	4	3,000	1	2,500	1	800	-
Coal-based condensation	-	-	-	-	-	-	3,000	3
Gas turbines	1,800	-	1,800	-	1,800	-	1,800	-
Wind power	-	-	-	-	(300)	1	(1,300)	4
Pump power	-	-	-	-	-	-	500	-
Sum	26,650	100	32,550	121	33,600	138	37,000	154
Final electricity use		91		110		125		140
Distribution losses		9		11		13		14

trends. It is a major dilemma for Sweden that nuclear power is currently so competitive that only taxation can remove a massive tie to that technology. The most characteristic property of the energy supply system is the expansion of cogeneration of heat and electric power. This has to do with the campaign for introducing district heating systems as replacements for individual oil boilers for dwelling heating. Cogeneration makes both heat and power generation effective and flexible. It also represents a technology which must be assessed in a local and regional context since remote heating systems are only viable in regions with a high enough energy density.

2.3 The Regional Implementation of National Policies.

The long-term national goals for the Swedish energy system stress the adaptivity and flexibility aspects rather than the efficiency one. Thus, ultimately, we should arrive at a sustainable and differentiated energy system based on domestic, renewable resources. In the latest government propositions the oil reduction goal has been given more priority than before. The earlier policies aimed at a decentralization of comprehensive energy planning at the municipal level. The new policy means that many municipalities see the reduction of oil-dependency as the major objective. A slowing down of the development of competance in the field of comprehensive energy planning has been the result. Also, at the regional level, planners experience an increasing uncertainty about the implications of the national policies for their particular region.

Figures 6 and 7 are meant to illustrate this local and regional predicament. In the figures the typical sectoral fashion of computing the potential for introducing new energy resources into the system is illustrated. Figure 6 gives examples of decentralized fixed capital investments leading to nation-wide import problems. If all these cogeneration projects are to take place the coal transport problem will be of national significance. Its solution will depend on the spatial distribution of cogeneration projects, which are not necessarily nationally induced.

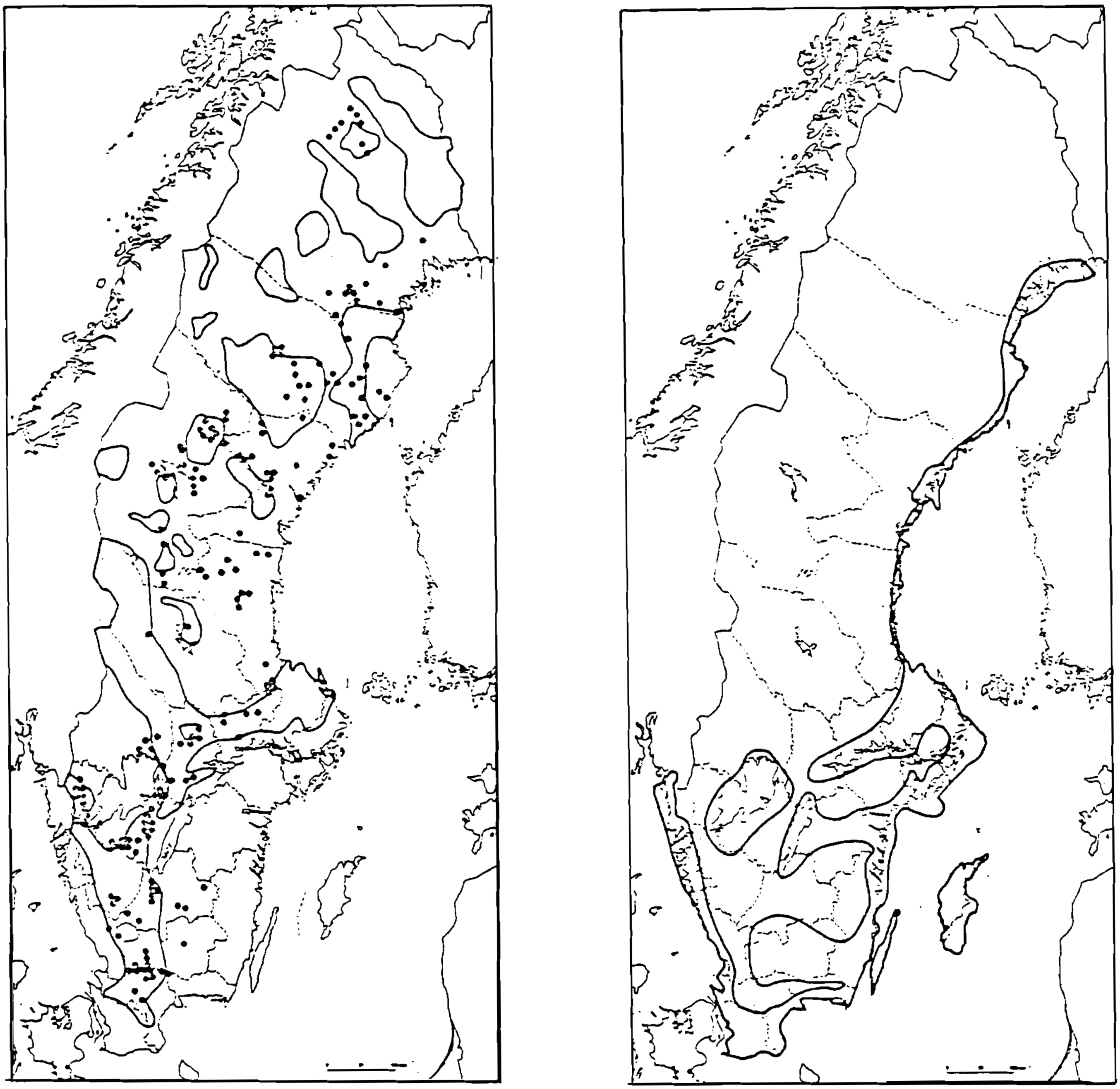


o combined heat and power stations planning to use coal in 1990

Δ Location of nuclear power plants

▬ Alternative locations for gas pipelines through Sweden

Figure 6. Alternatives for introduction of new components in the energy supply system in Sweden, and location of nuclear power plants to be closed down around the year 2000.



○ Larger areas with peat production potentials

• Applications for concession of peat extraction

○ Areas with a wind speed exceeding 6 metres per second

Figure 7. Potentials for peat and wind power extraction in Sweden.

Figure 6 also gives an example of national projects relating to new energy distribution networks. The location of such a gas pipeline will be influenced by the decision to transit gas from Norway to the continent only, or to distribute gas also to Swedish consumers. The national networks will influence the conditions for local energy planning.

Figure 7 indicates the region in Sweden where peat may be economically extracted, mainly for local use because of the costly collection system. It also shows the coastal districts where wind power might be technically feasible. Both maps show the situation from a national perspective. They are of a somewhat spurious relevance for municipal and regional energy planning for at least two reasons:

-- the competition between the potential sources and systems is not spelled out, not even at the national level,

-- the local variations in costs and resource availability are not shown in enough detail.

Thus, even though such inventories are useful as a starting point for national regional energy policy considerations, they are by no means enough. Such questions will have to be solved by special energy studies where national, regional, and local systems are distinguished from one another. Such studies have been started since the completion of the studies of the Commission on Consequences, for example the ones for the Stockholm region to be further described below. However, as shown in Figure 8 the studies of the Commission on Consequences are still unique as regards the national-regional perspective. It is therefore appropriate to go on to describe the organization and contents of these large-scale impact studies somewhat further.

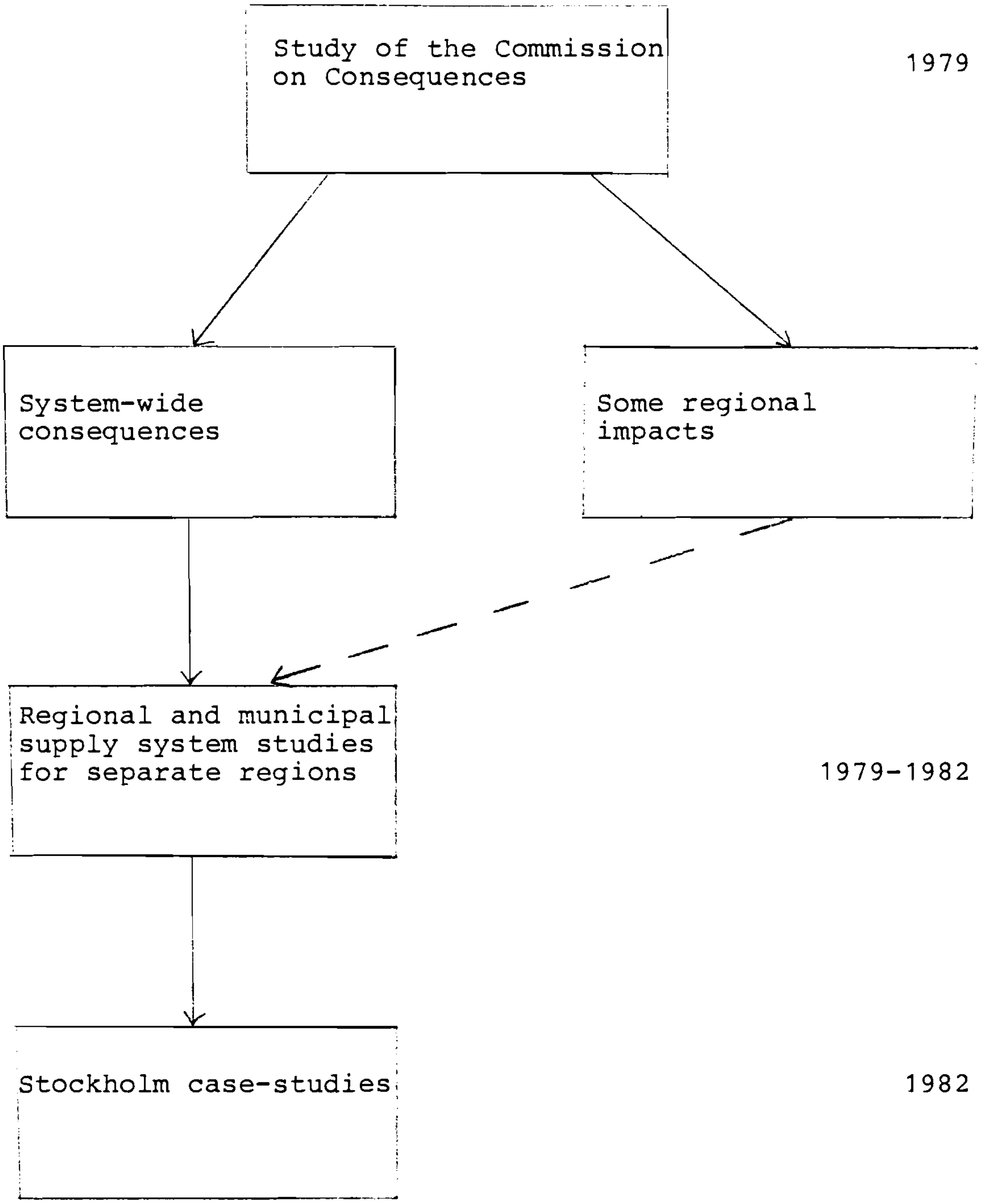


Figure 8. Some linkages between national and regional energy studies.

3. IMPACT ASSESSMENT METHODOLOGY IN THE COMMISSION ON CONSEQUENCES

3.1 The Commission on Consequences - Alternatives Investigated

The basic methodological problem faced by the Commission on Consequences was to conjure up a set of alternative scenarios of how to provide the Swedish economy with energy and to compare their positive and negative effects. Thus the line of attack chosen was to elaborate a reference scenario, in line with the current economic development trends *and* the current nuclear power program, and then to specify alternative energy system scenarios in which nuclear power is abolished before 1990. These energy system descriptions were presented for a period of twenty years, up until the turn of the century.

Since the nuclear power plants primarily produce electricity (no nuclear waste heat is yet used in remote heating systems), the alternative energy systems may be compared by describing the electricity production subsystems and by assessing the structure of electricity demand, at equilibrium, in various cases.

The *reference* case implies that existing plans will be put into effect yielding a final electricity consumption of 91 TWh in 1980 and 125 TWh in 1990. Twelve nuclear power plants will be in operation during their service life but no longer. In 1990 nuclear power will produce 58 TWh electricity, which, as mentioned above, is more than a doubling of the 1980 level. The structure of electricity consumption will change towards a more intense use of electricity in the 'miscellaneous' sector. A considerable portion of this increase relates to the expansion of electric heating of dwellings and work-places.

The *abolition* alternative has two variants, one yielding 105 TWh electricity use in 1990 and the other 95 TWh. The total level of electricity consumption is lower in both of these in 1990 and 2000 than in the reference case. This stems from the difficulties in completely replacing nuclear power over a period of ten years.

The 105 TWh level may be attainable by 1990. However, it presupposes a swift expansion of coal-fired production, and there may be difficulties in establishing and commissioning the necessary plants with sufficient speed. No expansion of electric heating of the housing stock will be allowed. The 95 TWh level by 1990 represents a situation in which the growth in electricity consumption is heavily restricted. It presupposes a particularly strong emphasis on saving in the miscellaneous sector. This alternative has been advocated by those desiring the rapid closure of the nuclear power sector.

The abolition of nuclear power will mean that resources will have to be applied to expand other electrical energy production systems and to conserve energy in homes, in industry, and elsewhere. In addition, more coal and oil will have to be imported. Sooner or later this will have to be paid for in terms of lower living standards for the population than those of the reference case. The Commission has assumed that the cost of abolition will have to be met from private consumption because even in the reference case growth of the public sector has been kept very low. Another conceivable recourse would be to reduce other investments or to increase international borrowing, thus deferring some of the costs to future generations. This was considered to be unacceptable.

The central result of the Commission on Consequences was that the total cost to the Swedish society, in terms of private consumption, would correspond to some 2-3 percent less private consumption in 1990 than if the nuclear power sector were retained. This means a capital loss of 20,000 Swedish Crowns per worker for the period 1980-2000. Another important result is that if labor-market policies are implemented such that full employment is attained, no drastic effects can be isolated for the development of different production sectors. The case of electricity price increases for industry at the 95 TWh level is an exception, with strongly negative effects in the pulp and paper industry. Price increases in the order of 50 percent for households and 30 percent for industry were deemed necessary to keep aggregate electricity demand at the required supply level during the phase of replacement of nuclear power (1980's).

3.2 Organizational Decomposition

The Commission on Consequences worked under a heavy time constraint. Therefore, no major model development work was attempted. Instead, the work was organized among various groups, which had suitable models and methods available at the outset of the investigation. These tools were used as a basis for drawing conclusions about the magnitudes of the consequences resulting from the closure of nuclear power plants. A serious problem occurred because of this organizational framework: How were the analyses of the separate working groups to be integrated?

In Figure 9 an outline of the links between the working groups is given. The division into working groups may be seen as concomitant with a division of the systems analytic problem of developing a set of models and techniques to cope with the complex problem of assessing effects in an interdependent system. The Commission on Consequences provides a good example of an organizational as well as a factual problem solution.

In the same way that a decomposition approach to mathematical programming consists in isolating subsystems, the internal workings of which need not be fully considered at the superordinate level, so it was *not* necessary for each subgroup of the commission to deliver to the other subgroups all its information but only those items of central importance.

The idea was that a number of reiterations of this information would lead to a fully consistent impact analysis. However, the time constraint implied that such an overall consistency could not quite be achieved.

The iteration scheme in the analysis began with a forecast of the development of electricity demand (I). This initial forecast was consistent with earlier Swedish energy consumption forecasts although the total demand level of 125 TWh in 1990 implies a lowering of earlier results. This forecast was conveyed to subgroups II and III, dealing with synthesizing energy systems and assessing economic consequences.

The next step (II) in the iteration procedure was the specification of energy systems capable of producing the energy

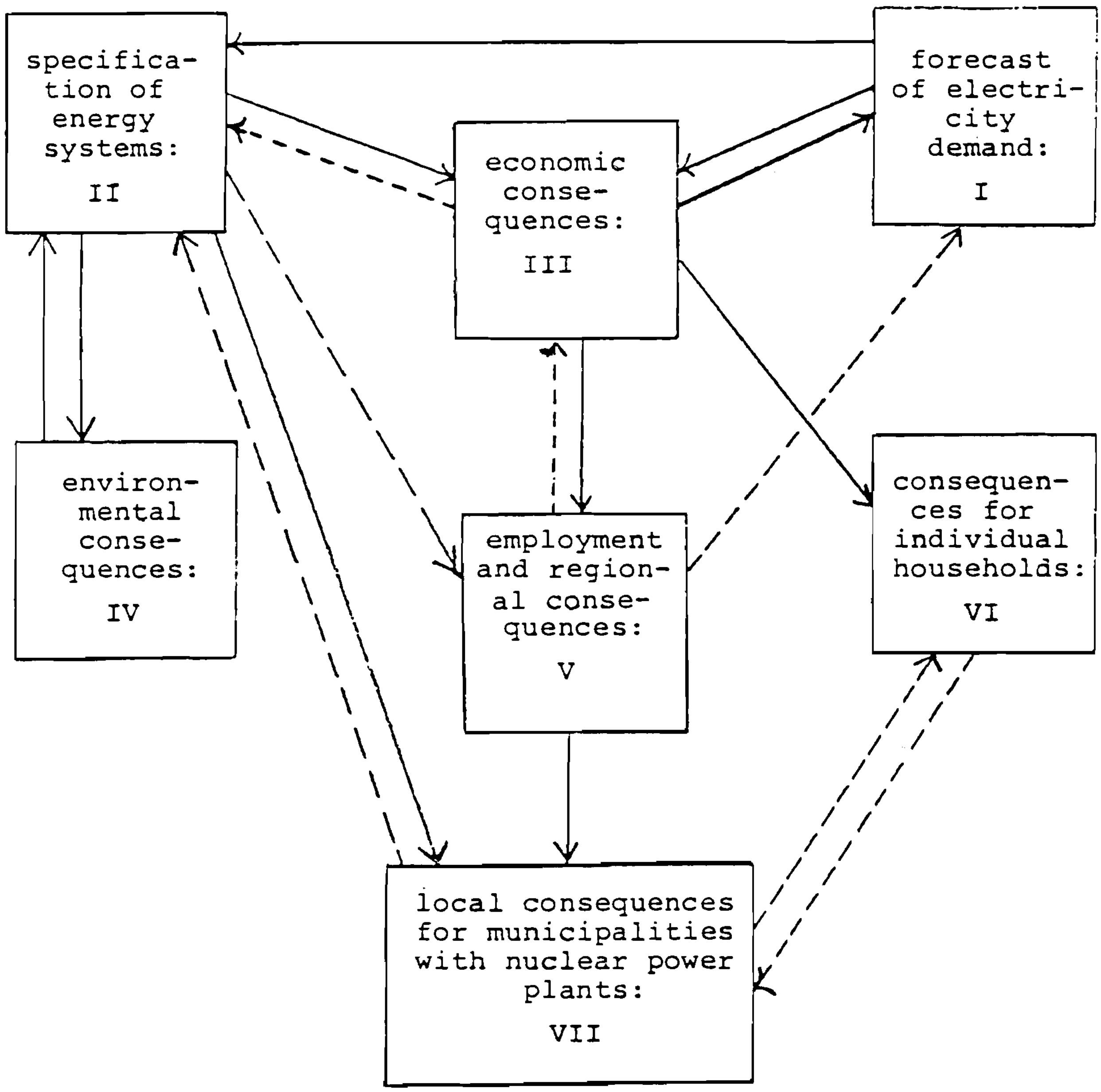


Figure 9. Work group organization in the Commission on Consequences.

demanded at minimum production costs, under environmental, regional, local, and other external constraints. The results of the analysis in subgroup II were then reported to subgroups III (investment costs, composition of primary energy supply), IV* (size and location of plants and primary energy sources),

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* In effect, there was no explicit subgroup IV in the Commission, but some members of the existing working groups formed an informal one.

V (size and location of energy production facilities), and VI (location of new energy production plants at former nuclear power plant sites).

An important stage in the whole investigation was the pooling of information from subgroups I and II into an overall analysis of economic consequences in subgroup III. There the total costs of transition to a new energy system were evaluated in a short-, medium-, and long-term perspective. The costs were measured in terms of the level of private consumption that could be attained for alternative electricity demand levels and different energy production systems. The results of these analyses were reported back to subgroups I (scarcity prices, production structure, etc.), V (production structure), VI (Level of public and private consumption), and VII (local impacts).

The next step in the iteration scheme was an analysis of the results of other subgroups in the environmental, regional and household groups. A strong feedback was exerted from the environmental to the energy systems subgroup. Criteria were applied to see whether the energy production scenarios were permissible from an environmental point of view. Information about the degree of fulfillment of regional efficiency and welfare goals was also fed back from the employment and regional group to subgroups II and III. An example of such a feedback was the cost-benefit analysis of an alternative location in the northern-most part of Sweden for a coal-fired condensation plant.

As mentioned earlier, this organizational framework was actually used in the investigation, with explicit deadlines for the reports of external information between the subgroups. It is fair to say that some integration actually was achieved in this way, although no complete consistency could be attained. One reason for this was the time limit, but institutional frictions also played a role.

3.3 Some of the Models Used

The description of the work organization given above does not reveal the extent to which the subgroups used quantitative models or other quantitative analytical techniques in their work.

Quantitative analyses were attempted in all of the working groups. However, these analyses were conducted at very different levels of sophistication. The methods used in groups IV, VI, and VII were quite rudimentary from a mathematical point of view, amounting to a more or less systematic application of various types of multipliers and ratios. They are not necessarily internally or externally consistent.

In subgroup II, models were employed, for example, to find an efficient way of using renewable, domestic primary energy resources in industrial processes. In these models, for instance, local bio-fuel sources such as peat were considered as alternatives to coal and oil in combined heat and power production facilities.

By far the most sophisticated set of models were used in the economic analyses. The model exercises included the use of both the medium- and the long-term economic forecasting models of the Swedish Ministry of Economic Affairs. The medium-term model is of an input-output Keynesian type, with consumption and import functions but with exogenous investment variables. The long-term model is a variant of multisectoral growth models with linear energy demand and export and import functions. The core model used in the investigation, however, was the general equilibrium model of Bergman and Por (1980), (see also Bergman (1981)). One reason for choosing this as the central model was the fact that it simulates more effectively than other models the substitution possibilities over the long-term in an open economy, when the production factor energy becomes more expensive in real terms.

The economic models used in the investigation are almost one order of magnitude more complex than the regional models, at least with respect to their applicability to the problem of assessing the impacts of different energy scenarios.

The result of the general equilibrium model is a balanced situation in the national economy. Production factors are used such that no excess supply or demand exists. This situation is of course attainable only in the long-term, especially if the current situation is characterized by economic imbalances.

The idea behind the economic model exercises at the national level is simply to compare the equilibrium states in the economy in terms of the room for private consumption and the equilibrium economic structure for different energy scenarios. The impact of the abolition of the nuclear power sector is simulated by a higher depreciation rate for capital in the nuclear energy production sector. The output of the model contains both factor inputs, production levels, capital stocks, foreign trade data, and employment. Employment is measured in terms of the input of work-hours needed in the various sectors.

The task of the breakdown model is to transform these employment results into forecasts of the total number of persons needed to perform the necessary work-hours. Furthermore, these figures are to be disaggregated to the regional level. Thus, the aim of the breakdown model is to outline the consequences of alternative national energy scenarios with respect to total employment--or rather, total demand for labor--at the regional level.

A. How will the total labor demand in the regions be affected by changing equilibrium patterns of production and employment by sector at the national level?

B. What are the direct effects--and the succeeding indirect ones--of varying regional developments in individual sectors, for example in the energy producing sector?

In these exercises, the breakdown model was used in conjunction with the medium- and long-term economic forecasts in Sweden (Snickars, 1979). In the economic forecasts a judgement is also made about the regional development of the labor supply. Since this is assumed to be independent of the energy system, the current application amounts to a comparison of different labor demand scenarios.

An aggregated breakdown model of the type described above is too coarse to identify all the regionalized labor demand consequences, even though it is theoretically possible to build in a submodel for each sector where more detailed knowledge about that sector is included. In the nuclear power application, a significant result was that scarcity prices had to be used to keep down electricity demand for households and industry. This implies that a closer investigation should be made concerning the electricity-dependence of energy-intensive firms at the regional level.

Such an analysis is especially warranted in a country such as Sweden, with its large surface area and low population density. Many small towns and villages in Sweden are dependent on only one dominant industrial enterprise, a situation most common in the northern and middle parts of Sweden. A further complicating factor is that these firms are most common in energy-intensive sectors. Economies of scale have led to a concentration of production in, for example, the pulp and paper industry, the metal industry, and to some extent in the chemical industry in a few large plants.

In the Commission on Consequences, a special study was performed to assess the effects of a 50 percent price increase in electricity on energy-intensive industries. The results showed that the scrap iron works would be the most seriously affected branch of the steel sector. Some 1,200 jobs would have to disappear within a five-year period as a result of this price shift. However, in the reference case some of these jobs are also likely to disappear. This illustrates the basic methodological problem in performing an impact analysis without a comprehensive modeling framework within which to evaluate, in a consistent way, various direct and indirect effects.

It should be strongly emphasized that the studies of energy-intensive sectors were regarded as a useful complement to the macro breakdown model exercises of the Commission. Since one central result of its economic analyses was that only small effects on the sectoral structure of the whole of Sweden could be expected (assuming a situation of full employment), the regional effects were also rather small as shown by the breakdown model. At least this was true for large regions and for the total demand for labor. The micro-oriented sectoral studies indicated a considerable negative effect at the local view in certain industrial sectors.

Since the measurement of the effects operates at different levels of aggregation, it is not possible to ascertain offhand whether or not they are consistent. The fact that the micro analyses are rather short-term also makes them to a lesser degree comparable to the medium-term macro analyses. In an attempt to reconcile the two approaches, interregional input-ouput analysis was applied to estimate the total indirect employment effects in the regional production system of the disappearance of job openings in industries with a high dependence on electricity.

It should be emphasized that an assessment of the consequences in the medium- and long-term of different energy scenarios is of course subject to a considerable degree of both static and dynamic uncertainty (international economic development, energy prices, stabilization problems). It is also self-evident that an ideal set of models could sharpen the results further. Such models would have to be specially designed as a set, whose major feature should be that it produces internally consistent results. Using such a set of models, the number of sensitivity tests performed on exogenous data could be increased, which would in fact tend to reduce the degree of uncertainty in the results. The success of an integrated model system would depend on whether the approach as such were accepted by the working group members.

It might well be the case that such a set of models should operate at the regional level. This should definitely be the case in a country where there are large regional differences in the economic conditions and structures. In a country where no large regional differences in factor endowments and demand conditions exist, for example for the energy sector, such a regional specification may not be necessary.

Returning to the Swedish study, it is quite clear that an integrated regional analysis of national energy scenarios would be warranted. Sweden has considerable resources of renewable energy with a non-uniform regional distribution. It has a regionally varying production structure. This means that the regional impacts of different national and regional energy scenarios should vary, at least if the effects are evaluated in dimensions other than that of employment.

4. REGIONAL IMPLEMENTATION OF ENERGY POLICIES FORMULATED ON THE NATIONAL LEVEL: The Case of the Stockholm Region

4.1 National Frames for the Stockholm Region

In 1978, before the 'Commission on Consequences' had started its work, the Swedish Parliament adopted a plan according to which the energy consumption in the existing stock of buildings should be reduced by around 25 percent. The implementation of the plan was delegated to the individual municipalities.

In 1981, after the referendum on the long-term nuclear power policy, the national energy policy of Sweden was reformulated so as to make a reduction of the oil consumption a primary goal. One important reason for this was the greatly increasing relative price of oil in Sweden which to a large extent was caused by a gradual depreciation of the Swedish currency. The long-run objective was to prepare for a non-nuclear future of the country.

The objective with regard to the period 1980-1990 was specified to include a reduction of the current annual imported volume of oil (27 billion tons) by 45 percent. It was assumed that this could be obtained by (i) conservation efforts covering 25 percent of the reduction, and (ii) substitution of oil for other fuels including domestic solid fuel, and introduction of heat pumps, district heating, etc.

The Stockholm Energy Studies (SES) have been initiated and continued on the basis of the national energy policy decisions described above. Several of the connected studies are still going on. The common objective is to examine and evaluate (alternative) new energy supply systems for the Stockholm region which consists of more than 20 municipalities, of which Stockholm is one.

The Regional Planning Office (RPO) has summarized the most important national restrictions as follows:

- The energy used for heating existing buildings shall be reduced by 30 percent before 1990.
- The consumption of oil must be reduced as described above.
- All nuclear power stations will be closed down before 2010.

Since the capacity for generating electricity from nuclear power stations is still increasing, one may foresee a potential excess capacity as regards the production of electricity which is later on changed to a shortage of capacity. It has been taken as a constraint that the Stockholm region shall keep its share of the increasing supply of electricity during the next ten-year period.

4.2 Energy Provision and Regional Development

The Stockholm region (County of Stockholm) contains around 1/5 of the Swedish population and its share of the total income of the country is almost 1/4. More than 25 percent of the total employment in the service, trade, communication and transportation sectors, respectively, are located in the region. Despite having the largest manufacturing sector among the Swedish counties, the region only employs a little more than 10 percent of the total labor force in this sector. During the recent five-year period (1975-1980) the following sectors have shown a strong expansion: social and health care, consulting, education and research, cultural activities. The number of persons employed in almost all manufacturing sectors has been declining during the seventies.

Figure 10, below, gives a summarized description of a reference scenario of the population change in the region. The reference scenario displays a growth of the total population from 1.5 million inhabitants in 1980 to 1.6 at the end of the century. It implies a slowly growing and at the same time ageing population. Moreover, the corresponding labor force will grow at an annual rate of 0.5-1.0 percent. Associated with the scenario is an increasing share of one- and two-person households which have revealed a marked tendency to move towards the central parts of the town (Stockholm).

The urban structure of the region is characterized by a comparatively strong concentration of workplaces and dwellings in the central areas. The structure is illustrated in Figure 11 which shows that the number of persons employed in different sectors is falling as a function of the distance from the center of the town. The number of dwellings is instead increasing with the distance from the center.

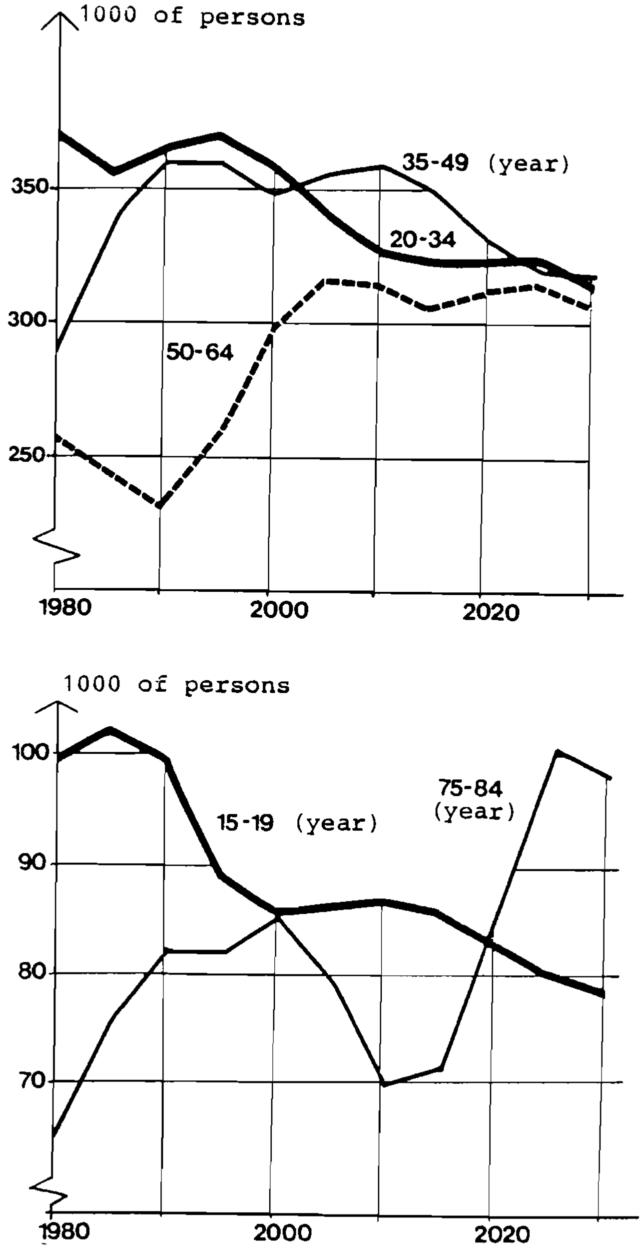


Figure 10. Reference scenario of the population development in the region for five age groups.

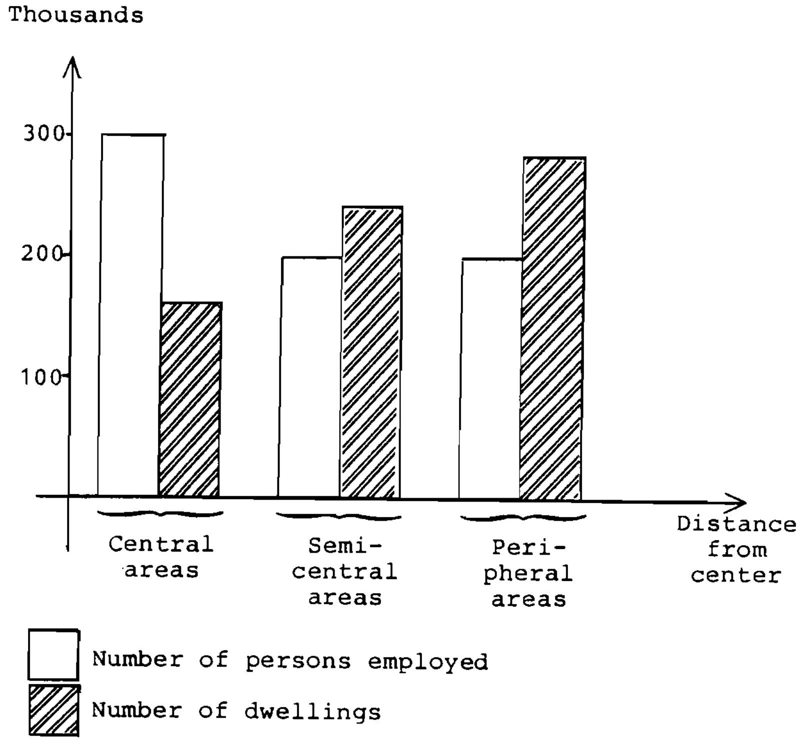


Figure 11. Distribution of employment and dwellings over areas in Stockholm county, 1975.

The heating system in the Stockholm region was, at the end of the seventies, extremely dependent on imported oil; almost 90 percent of the system was using oil as an input, of which 1/3 was used in individual (one-house) boilers. Moreover, the district heating system which expanded rapidly during the seventies, has mainly been using oil. Table 5 describes the structure of oil consumption. The distribution of different techniques in the existing heating system of the region is illustrated in Table 6.

As a result of an expanding supply of electricity and an associated low relative price, the consumption of electricity for the heating of dwellings has increased since 1965 by 20 percent annually in Sweden as a whole. This process was accelerating during the seventies as an effect of the nuclear power

Table 5. Input of oil products in the Stockholm county. Distribution over sectors, 1980.

Sector	Proportion in percent
Single-family houses	7.9
Industry	10.5
Multi-family houses	15.8
Power and heat generation plants	18.4
Private and public service	21.1
Transportation and communication	26.3
TOTAL	100.0

Table 6. The distribution of heating techniques.

	Dwellings	Workplaces	Total
Individual boilers	32	42	35
Electricity heating	11	3	8
District heating	38	44	39
Small-scale district heating	19	11	18
TOTAL	100	100	100

program. In the Stockholm region, one can also observe a fast extension of the district heating network. This is described by Table 7.

Table 7. District heating system in the region, 1975-1980 (Twh).

Type of buildings		1975	1980
Housing		2.8	4.5
Workplaces		1.4	2.4
	TOTAL	4.2	6.9

During the last ten years the requirements with regard to energy-related planning have been increasing in a step-wise manner. The adaptation to the successively new requirements has gradually made the planning system less well-structured. A picture of the main planning organizations during the period 1978-1982 is given in Figure 12. The company "STOSEB" has evolved during this period

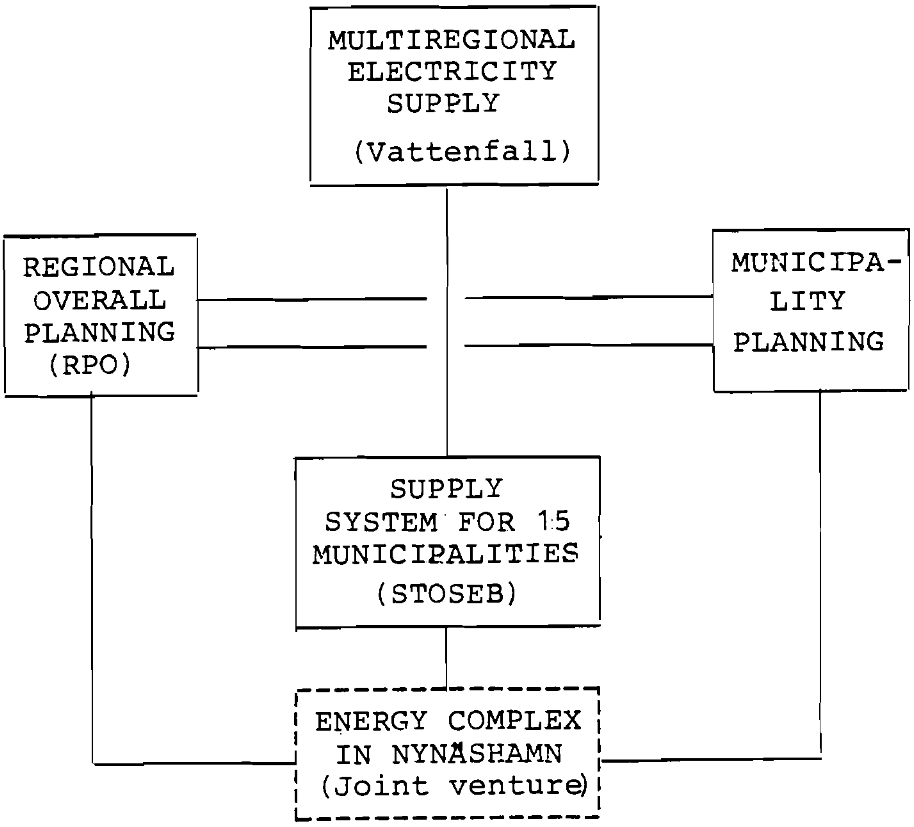


Figure 12. Organizations involved in the energy planning for the Stockholm region.

and is responsible for the energy supply system of a subset (15) of the municipalities in the Stockholm county. The long-run overall planning is done by RPO. The electricity supply system is planned from a national, multiregional level by a national utility company (Vattenfall). Associated with the nested planning efforts in the system described, a separate planning organization has been set up for the energy complex in Nynäshamn, located south of Stockholm at the coast.

4.3 Organization and Interaction Between the Different Studies

Four basic alternative energy systems have been proposed by STOSEB. All of them imply large-scale district heating systems which will cover around 4/5 of the demand for heating. These alternatives are (i) hot water from the existing nuclear power station in Forsmark (north of the region), (ii) decentralized coal-based power generation system, (iii) centralized system of the same kind, and (iv) heat pump system with the atmosphere, lakes and waste-water as energy sources.

The national utility company Vattenfall has been proposing a large pipeline system from its station in Forsmark. This option includes that a coal-based power station is built in Forsmark when the nuclear power station is closed down.

The option with an energy complex has been designed by the "Nynäs research group" in such a way that it may be included in all the alternatives mentioned above.

Referring to Figure 13, one may conclude that the STOSEB research team has tried to integrate the research and planning effort from the energy authorities in the different municipalities, from SIND (the Swedish Industrial Board of the Ministry of Industry), and from the Nynäs group.

The planning area of STOSEB contains 15 of the municipalities in the Stockholm region. The Regional Planning Office is covering all the municipalities of the region in its planning of land-use (buildings, transportation, energy supply and demand). The research activities of RPO have covered broader aspects of the energy policy options than STOSEB and have in particular focused

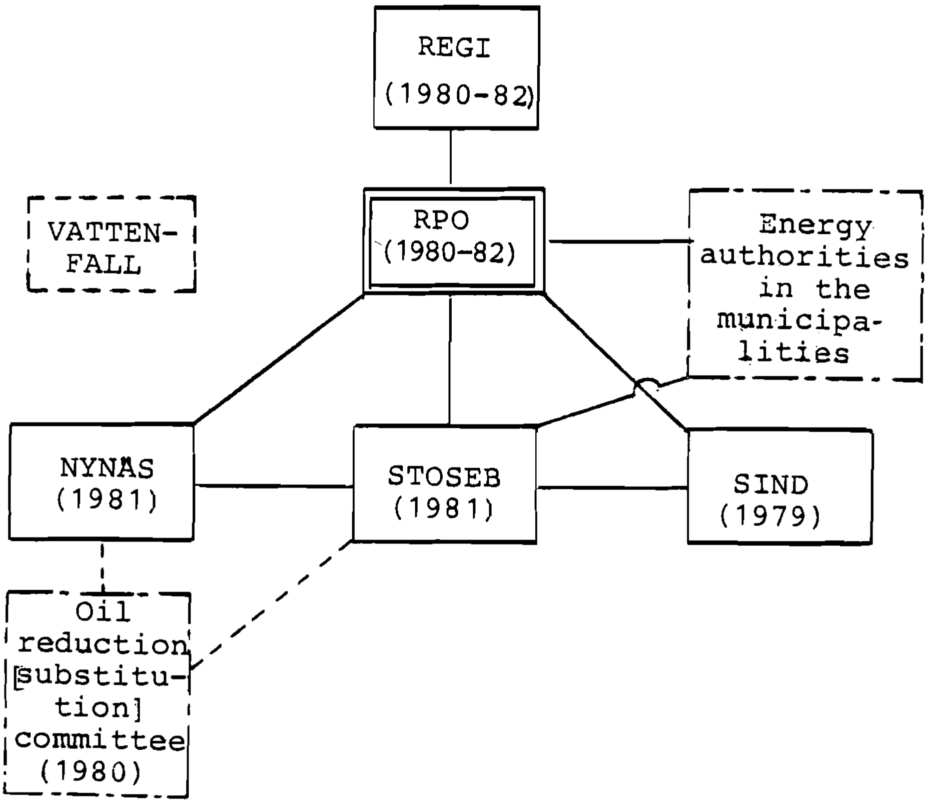


Figure 13. Connection between different impact and scenario analyses of large-scale energy systems in the Stockholm region (the dates of important reports are specified within brackets with regard to each research group/ organization.

on dynamic, long-term issues. In addition, RPO has been responsible for a long-term research project, REGI, which was initiated by the Swedish Council for Building Research and RPO, and which is financed by these two parties.

As a part of its ongoing research/planning activities, RPO has made a comprehensive evaluation of the STOSEB studies. When doing this, RPO has also examined a broader class of energy system options than STOSEB. In the sequel, we shall report about two partly separated aspects of the RPO activities:

- The assessments of the STOSEB studies, including the report from the Nynäs group.
- The ongoing, not finalized, long-term study of the interdependency between energy planning and general planning of regional development.

5. ASSESSMENT METHODS IN THE STOCKHOLM ENERGY SYSTEM STUDIES

Section 5 is organized in the following way: An outline of the structure of the energy system of the region is followed by a presentation of the REGI-project. Since this research is still an ongoing activity, we shall have to report on some model exercises which are not yet finalized or which have not even started. Thereafter, the associated assessment of the STOSEB study is presented. In this way, we are describing how the same project is planned to be carried through in its "not time-restricted" version, and how it had to adapt in order to produce interimistic decision supporting results (with limited time) in the very midst of the long-term studies.

5.1 Regional Implementation of the National Energy Policy: Structure of the Energy System

An implementation of the national energy policy (as described earlier) implies a complete restructuring of the energy system in the Stockholm region. This presupposes a systems analysis approach: The region is an integrated part of the national electricity system and of the import-dependency of the country. The number of potential technical solutions is large. The technical and economic durability of the investments is long and creates time profiles of restrictions on the development of the localization of buildings and activities. The energy transformation has environmental effects which require a detailed control in a densly populated region. The durability and large-scale of the investments may, together with the associated environmental problems, create conflicting interests and opinions of different groups in the region.

In order to analyze the problems addressed above, one has to specify the energy system in a well-structured way. Figure 14 illustrates how this was done in the project.

5.2 Methodological Approaches of the REGI-project

The standard case of an impact analysis may be sketched as follows: (i) a given project is characterized over time; (ii) thereafter the multidimensional consequences are derived or traced over the space and time dimensions. The Stockholm studies do not fit this standard form. There are several reasons for this. Firstly, the

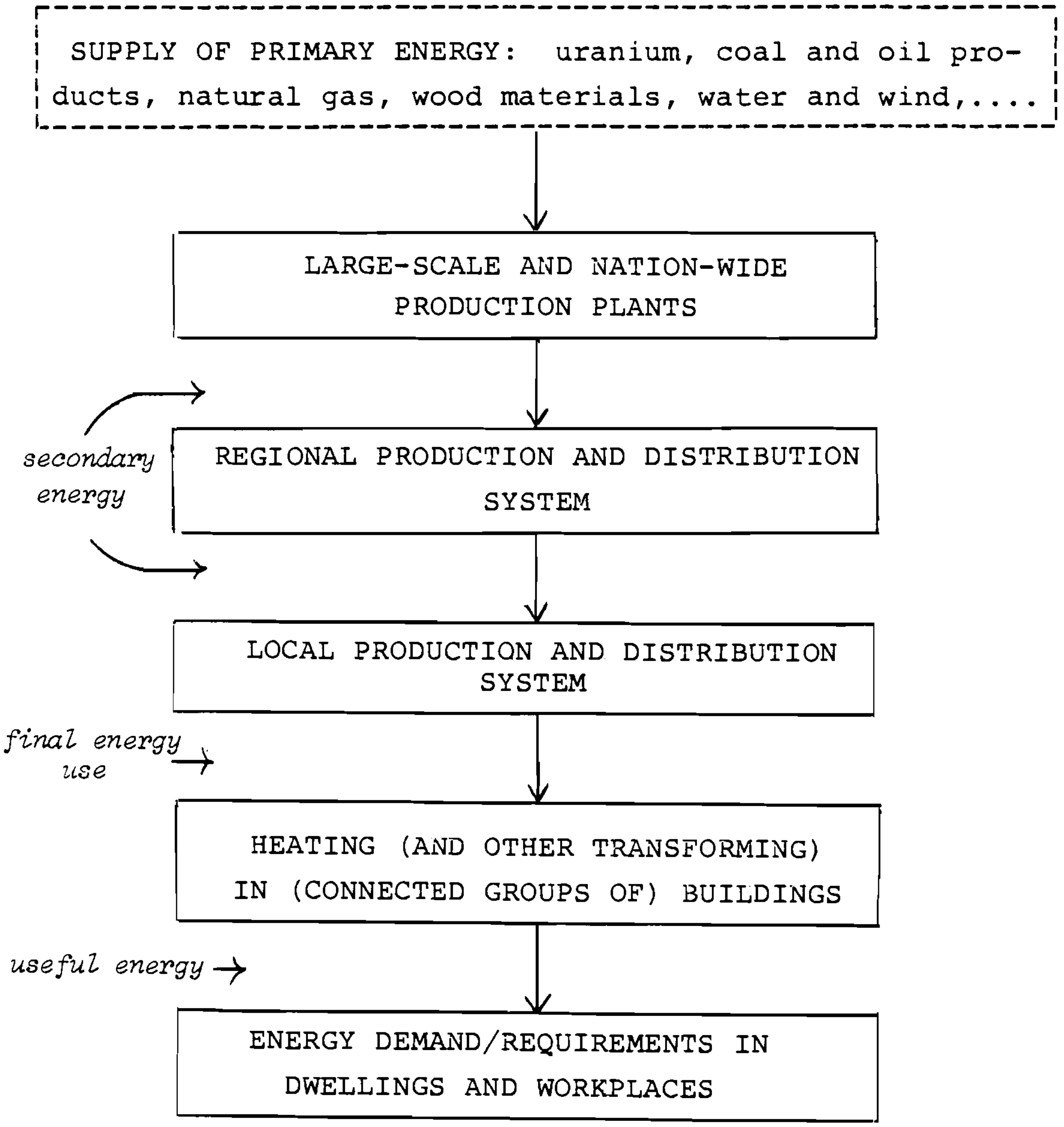


Figure 14. The structure of the energy supply system in the Stockholm region.

studies include a comparison and evaluation of many alternative (competing) large-scale projects. Secondly, the studies are also searching for future structures of the region which are compatible with a certain energy system alternative. Determining policy decisions which may ensure that such a future structure is obtained, implies that the impacts of these decisions become central. The complex structure of this approach is decomposed into a sequence of subsystem analyses. A scheme for this process is illustrated in Figure 15.

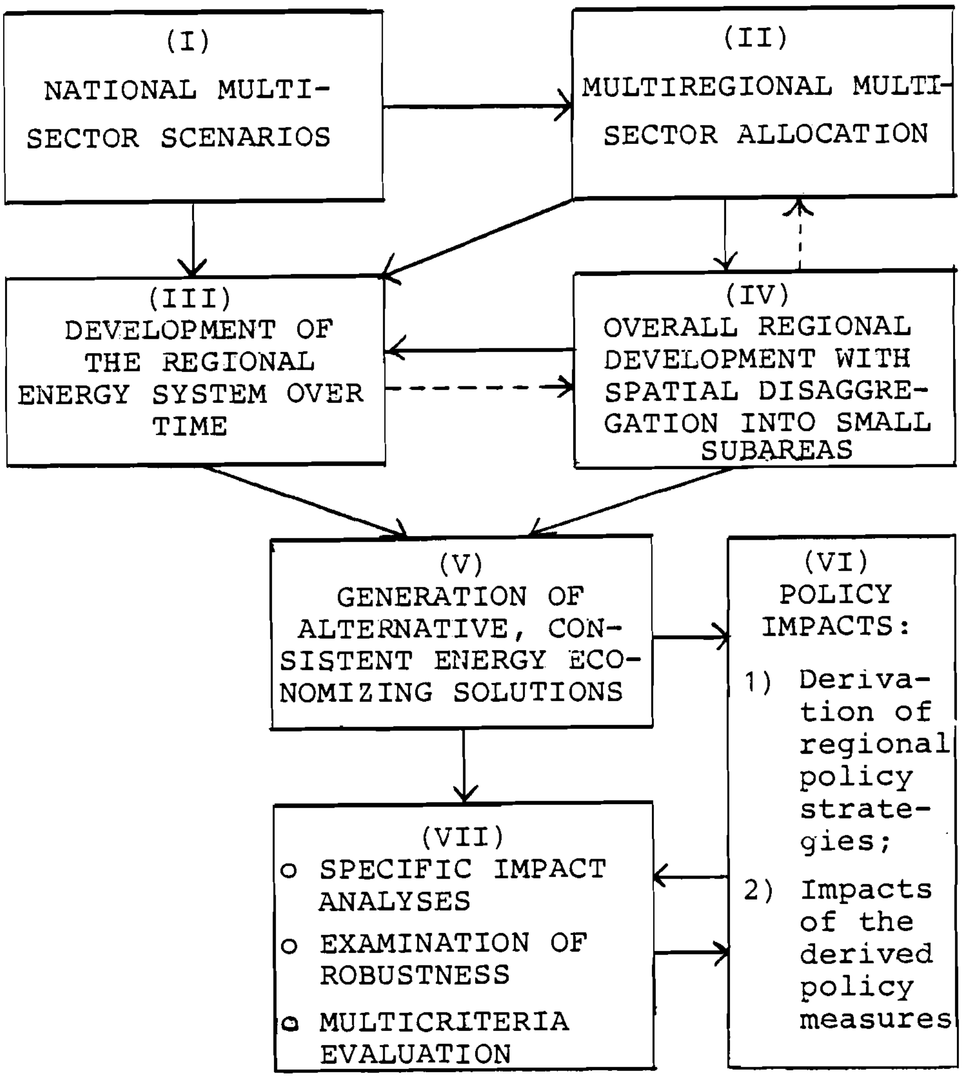


Figure 15. Scheme describing the impact analysis and planning process of the REGI-project.

As indicated in Figure 15, the interlinked "subsystems" are analyzed sequentially in the following order:

(I) Scenarios of the sectoral development on the national level can be obtained by means of dynamic multisector non-linear input-output models. Two alternative equilibrium models of this type are available.

(II) The national scenarios provide constraints on the analysis of the multiregional development. At this stage, the demand and supply of energy are distributed over regions with the help of two different multisectoral programming models.

(III) The analysis of the energy system development in the region has to be based on information from (I), (II) and (IV). This includes information about relative prices (including energy prices), and energy densities in subareas of the region.

(IV) The analysis of general regional development includes distribution of activities (housing, production, transportation, etc.) over subareas, changes in end-use energy techniques and consumption levels, and an associated pattern of energy densities. In this case, alternative development paths are generated. It is also possible to consider an interaction between subsystem (III) and (IV) as well as (II) and (IV).

(V) In step (V) one combines each system-(IV) configuration with the energy system solution which is "optimal" given the scenario for system (IV).

(VI) A given development of subsystem IV can, to a certain degree, be stimulated and enforced by means of regional policy measures such as land-use policies, etc. In this sense a certain alternative in (V) implies a certain set of policy measures which is an impact in itself. Moreover, each set of policy instruments has itself an impact on regional and national dimensions (III) and (IV). Therefore, the final assessment has to be analyzed in step (VII)

(VII) The final evaluation is done in step VII which uses information from step (V) and interacts with the policy impact analysis in (VI). The evaluation is based on a multidimensional comparison between each generated combination of (i) an energy system solution, (ii) a regional development scenario, (iii) the associated policy measures and (iv) the specific impacts of (i)-(iii).

The time scale for the system of models consists of a sequence of periods starting in 1980 and ending in year 2020-2025. The length of time periods have been varied so as to match already nationally or technically determined points in time at which certain strategic decisions must be made.

The multiregional models operate with a subdivision of the country into 6, 8 or 20-25 regions. With regard to the specification of areas within Stockholm, different degrees of spatial disaggregation have been utilized ranging from around 105 up to about 1000.

5.3 An Overview of Basic Models in the REGI Project

The ambition of this section is to present some of the most important parts of the network of the REGI models. Also, with this limited objective, we are forced to confine ourselves to a general characterization of the models. For each group of models the presentation has the following form: (i) model structure, types of consequences and time-scales, and (ii) data systems, estimation and calibration.

Multisector, Multiregional Scenarios

The two alternative multisectoral models of input-output type have a set of common features. They both apply for each commodity group export and import functions which have the ratio between the domestic and the world market prices as an argument. The private consumption functions are derived from a linear expenditure system. For both these models the development of world market prices is given by exogenous scenarios.

One of the models, the "Bergman" model falls into the class of MSG-models (Johansen, 1974). An early version of this model which was utilized in the studies of nuclear discontinuation in Sweden is described in (Bergman, 1981). In this version the unit cost level of each sector is derived from a nested Cobb-Douglas/CES production fucntion with electricity, fuels, labor and aggregate capital as inputs. The model is a static equilibrium model and the impacts of variations in exogenous factors (such as world market prices on primary energy) are defined in terms of differences between equilibrium allocations of capital and labor over sectors and the associated activity levels. The nature of the model prohibits an analysis of the adjustment process over time. Instead, it generates a tereminal point solution 10-20 years ahead. The model is primarily based on information from the Central Bureau of Statistics.

The second national multisectoral model is called MACROINVEST (see Persson and Johansson, 1982. Like the "Bergman" model, this model has general equilibrium properties; in particular, relative prices are determined endogenously. It allows for a study of adjustment processes such as introduction and removal of production capacities and associated employment changes. It recognizes a distribution of production techniques in each sector, where each technique displays constant elasticity of scale within the capacity limit of the technique, while the aggregate technique of a sector exhibits variable elasticity of scale. Removal and introduction of new capacities are determined by the endogenously given (i) profit of each technique, (ii) investment cost, and (iii) demand for total production capacity. For each sector a unit of investment has a distinct commodity composition. The model is designed to generate a sequence of five-year solutions. It is connected with an information system which contains data on production techniques and which is updated annually. These data also have a location index (see Johansson and Stromqvist, 1981).

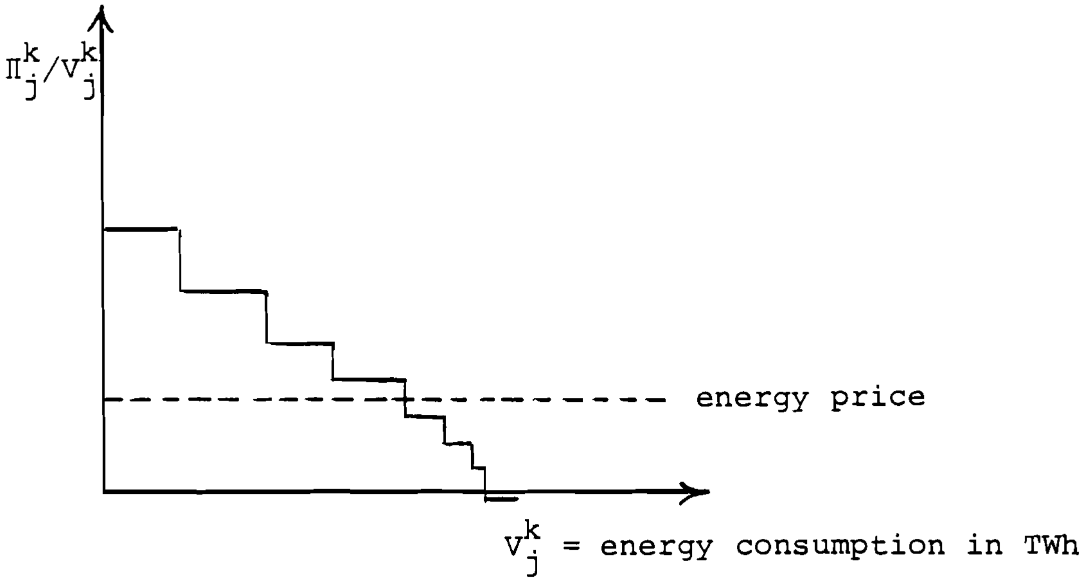
Impact outputs from the national models contain sector allocation of employment, production, investment, shut-down, energy use, etc. This type of information provides an input to the following two multiregional models:

- MORSE which is a multiregional and multisectoral model (Lundqvist, 1981). The basic structure is obtained through a break-down technique applied to input-output information onthe national level, together with various constraints on the regional level. (Snickars, 1978).
- PROMISE which is a multiregional model containing 19 industry sectors with a potential disaggregation to around 100 sectors (Johansson and Strömqvist, 1981, and Forsund, Karlqvist and Strömqvist, 1982). With regard to industrial statistics this model utilizes the same information system as MACROINVEST.

Both models are solved by linear programming techniques. MORSE is dynamic and has been applied to generate sequences of five-year periods. It has 8 regions and the economy of each region is divided into 9 sectors. A bottom-up approach is utilized with regard to consumption and to the majority of production sectors. A top-down relation is used in particular for energy consumption, capital formation and international trade. In the REGI project, the model will be used to assess impacts of energy supply systems and oil price increases. In particular, the impacts may be generated in the form of trade-offs between different criteria.

PROMISE has been constructed with the help of an information system for the manufacturing and mining industries containing data on production techniques for around 1500 groups of production units (establishments) from the period 1968 to 1980. It includes estimates of removal and introduction of new techniques. This information is also included in MACROINVEST and it recognizes for each available (existing and potential) technique the input of electricity and liquid fuels.

The model is based on a vintage type production theory and combines production efficiency criteria with (i) regional constraints and (ii) national scenario inputs from national models of the type presented above. Potentially, an interactive approach may be utilized. The model contains 6 regions for which in a second step the analysis can be disaggregated to the county level. The model generates energy impacts in the form of energy composition and ability to cover the energy costs over techniques of each sector in each region as described by Figure 16.



Π_j^k = gross profit of technique class k, before energy costs have been deducted; observe that Π_j^k is determined as an explicit function of prices and wages, and that V_j^k is specified both for electricity and liquid fuels.

Figure 16 Energy impact in PROMISE, distributed over production techniques in the industry.

Regional Development of Energy Demand and Supply

The regional analysis has two system components, i.e. supply and demand. For each given spatial configuration of the energy demand, the supply analysis provides a cost minimizing solution over time. This has made it important to generate a set of internally consistent alternative scenarios of the spatial distribution of activities and the associated energy densities. In this way, one may generate "optimal" pairs of combined supply-demand solutions. One may also search for a supply solution which is robust with regard to variations in the spatial demand for energy over time. For each solution there is a need to examine the consistency between the intraregional/regional and multiregional/national levels. This interface is specified in Table 8.

The fundamental objective of the intraregional analysis in the model system is to derive a spatial and temporal distribution

Table 8. Interface between national and regional scenarios/ impacts.

NATIONAL AND MULTIREGIONAL ANALYSIS

- o World market prices on primary energy
- o National and regional prices on secondary energy
- o Quantity constraints with regard to supply of energy and other resources
- o Activity level of sectors in the region

↑ ↓

REGIONAL AND INTRAREGIONAL DEVELOPMENT

- o Energy supply solutions: Impacts on
  - (i) national energy prices
  - (ii) demand for input of primary energy
  - (iii) export of energy carriers
- o Energy demand alternatives: Impacts on the import to the region of energy and other resources. Interregional consistency

of demand for useful energy with regard to heating. In practice, this has been done by specifying energy densities in around 100 areas of the region at different points in time (1980-2020). To perform this task four components have to be analyzed and put together in consistent development paths:

- o Development of population, household formation and housing demand;
- o Development of activities and jobs;
- o Development of the building structure (housing, workplaces, transportation);
- o Land use planning and location decisions.

The model of household formation and housing demand utilizes population scenarios as inputs. These scenarios are generatated by a multiregional demographic model which may be characterized as a transition model of Markov type. It includes, besides standard demographic change probabilities, interregional and international migration. The approach makes use of a set of alternative estimates of the transition structure--each referring to a socio-economic situation. Therefore, each population scenario may be selected contingent on an overall economic development path for the country (see Andersson and Holmberg, 1980).

The population anlaysis is connected with the household/housing analysis as indicated by Figure 17. The household formation is analyzed by means of a transition model based on population censuses which take place every five years. The demand model has the form of a logit model. The market analysis can be carried out with two alternative models using similar information: (i) a linear programming model which maximizes consumer surplus and a constrained entropy type of model (see Hårsman, 1981).

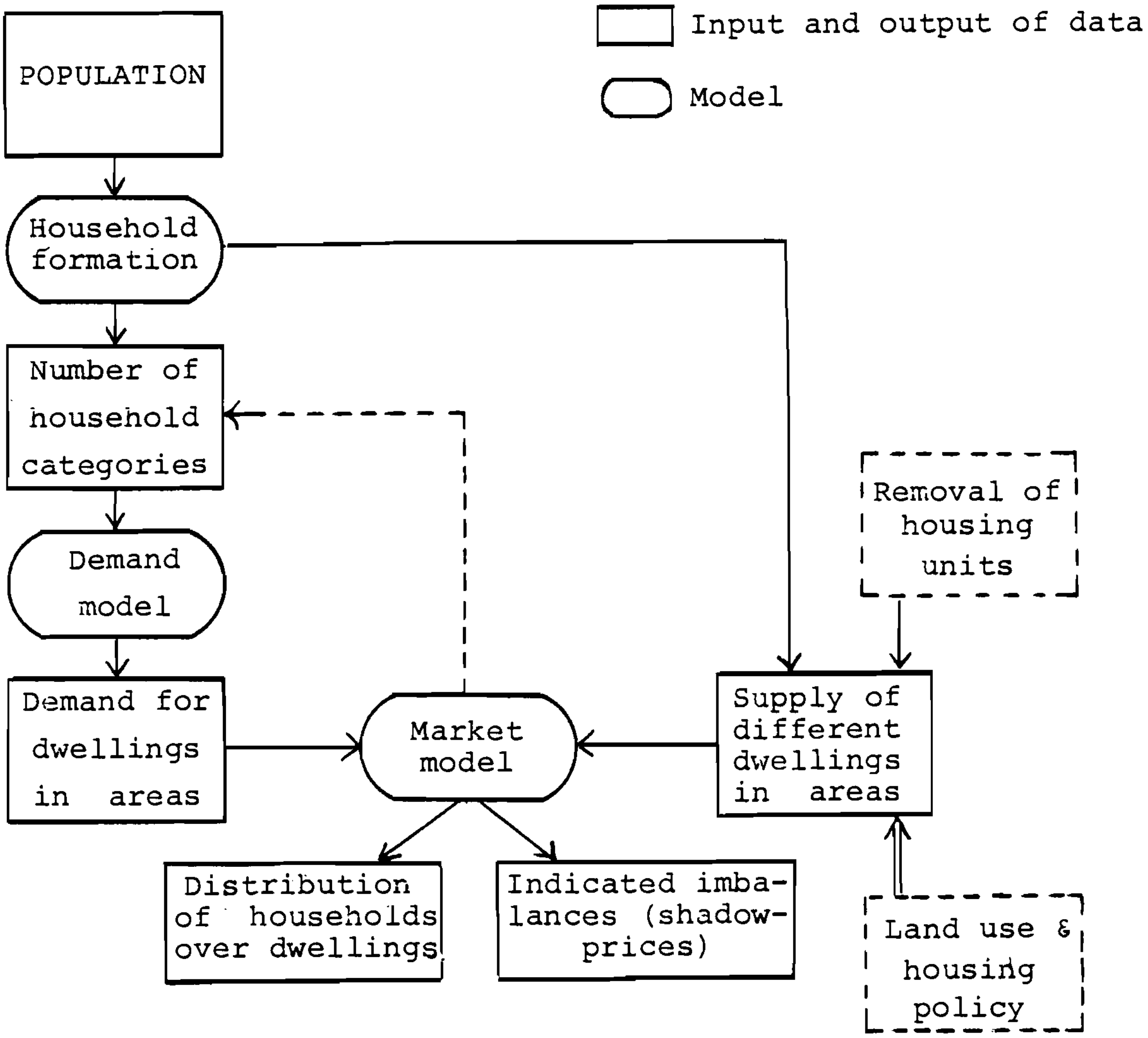


Figure 17. Household formation, housing demand model system.

In particular, one should observe that the land use policy influences the solution. If this policy is formulated with regard to the energy system requirements, then the household/ housing model system generates the housing market impacts.

The forecast of the building structure has two dimensions. One utilizes an age-dependent removal rate for different types of buildings (including housing). The other dimension is the creation of new buildings on the basis of projections with regard to activities and the associated employment. In particular, these building projections have to be allocated over the set of subareas of the region.

This analysis has the form of a combination of traditional land use planning and two supplementing models: BOLOK (Lundqvist and Mattsson, 1982) and ISP (Roy and Snickars, 1982). ISP is a land allocation system which can be used interactively within the frames of traditional land use planning. Given scenarios forming constraints on the future land use pattern, ISP provides an allocation which minimizes the deviation from the existing structure. The allocation mechanism is based on an entropy maximizing formulation. The model is designed to allow for a fine subdivision of the geographical space and simultaneously recognize a sectoral disaggregation.

Table 9 describes four alternative physical structures for which one may design associated energy system soltutions. ISP may be used to generate solutions of this type in such a form that performance indicators may be defined to measure the multidimensional impact of each specific solution.

The models and techniques for planning land use presented may be utilized to generate a sequence of 5-10 years solutions in the form of a development path. The outcome of the analysis is twofold. Firstly, it provides alternative restrictions for the energy system analysis. Secondly, it generates information for the evaluation/assessment analysis in terms of welfare and performance criteria.

With regard to the energy system analysis the outcome has the form of a calculated distribution of energy densities of the subareas of the region as indicated by Figure 18.

Table 9. Four alternative structures of the region.

HOUSING AND WORKPLACES CENTRAL AND DENSE	HOUSING AND WORKPLACES PERIPHERAL AND DENSE
o Many multi-family houses and many offices o Increased public transports with a small amount of cross-city trips o Large district heating systems o Balance between North and South, between housing and workplaces o Economizing use of the existing infrastructure	o Many multi-family houses and many offices o Increased share of public transports and cross-city trips o Smaller district heating systems o Balance between housing and workplaces for individual sectors o Requires infrastructure investments
HOUSING AND WORKPLACES PERIPHERAL AND NON-DENSE	HOUSING PERIPHERAL AND NON-DENSE, WORKPLACES CENTRAL AND DENSE
o Smaller share of multi-family houses o More industry o Large share of private transports o Increased commuting o Many options as regards alternative "energy technologies" o Balance between housing and workplaces for individual sectors o Requires infrastructure investments	o Smaller share of multi-family houses and offices o Large share of private transports o District heating in the center and new energy technologies in the periphery o No balance between housing and workplaces o Requires infrastructure investments

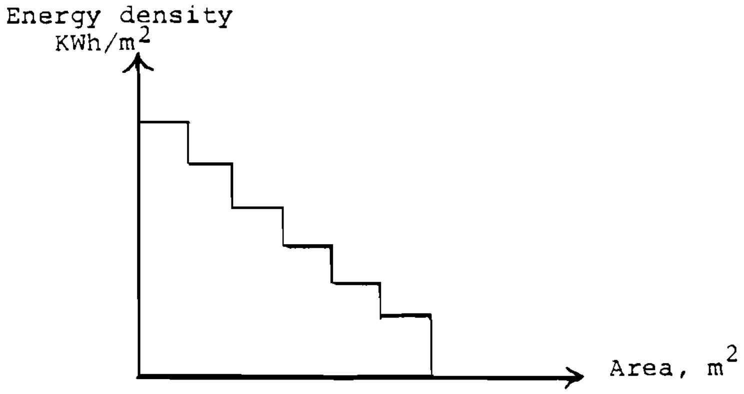


Figure 18. Energy densities in subareas (useful energy for heating).

Energy system model

The assessment of energy system solutions has been constrained by several background factors such as (i) the oil reduction plans, (ii) the national electricity market, (iii) the existence of the nuclear stations in Forsmark and, (iv) the planned Nynäs energy complex. Since the electricity supply is increasing during the next 15 years, there is a short-term problem as regards the most economical use of the excess electricity supply. In the longer term, the successive close-down of nuclear plants may instead create a situation with a shortage of electricity. This defines a truly dynamic nation-wide problem which is affected by the decisions for the Stockholm region.

Oil reduction implies coal-based production of energy for heating. This may include large-scale pipelines from Forsmark supplying hot water from the nuclear plants in the short-term and from coal-based plants in the long term. Another option contains hot water pipelines from Nynäs combined with decentralized hot water production and heat pumps.

The model utilized to evaluate different feasible solutions has its background in energy system modeling at IIASA. The "Stockholm model" is called MESSAGE II (or METRO MESSAGE). It is a dynamic linear programming model that reflects the essential stages of the energy chains which range from primary energy supply to the final energy requirements (see Figure 5).

An essential part of the model specification consists of formulating relevant constraints which have to comprise restrictions on the speed of structural changes, availability of new technologies and energy import ceilings. A basic constraint comes from the requirement that the model solutions must conform to the existing energy supply system.

Environmental effects are associated with each technology considered in the model. This type of information is then transformed into constraints in the model. This means that the final evaluation of environmental impacts is restrained within a bounded set of impacts.

The basic set of available technologies considered in the study so far contains almost 100 distinct technologies of which more than one third refers to end use technologies. Over time the model changes and adjusts useful energy demand according to the endogenously calculated final energy supply costs, which means that the model switches from one heating technology to another when energy supply costs vary. Conservation is included in the models in the form of a "supply technology" (e.g., insulation).

The model also allows for the treatment of mixed integer problems. It generates solutions with minimal costs given the applied constraints. The costs include operation and capital costs. The basic impact from the model is investment decisions over time and the associated costs. The time horizon 1980 - 2020 has been divided into 7 periods of different lengths. The division into periods has been determined on the basis of gestation lags for certain large investments. It has also been affected by points in time at which the production capacity in the nuclear power system will be reduced due to political decisions. For a distinct technology in the chain from primary to final energy use (see Figure 14) the time path of the introduction and close down of capacities may have the form indicated in Figure 19. Hence, the time scale is long enough to admit that technologies which are introduced earlier are scrapped in a later phase, to be introduced once again in a more distant future.

Figure 19. Introduction and removal of capacities of a given technology.

One should observe that the energy system analysis in fact operates with two time scales. For each period the model has to select technologies which combine into a system that can match the variation in the load over the seasons of the year. This is illustrated by Figure 20, which shows the effect of the energy complex and the heat pumps which will be fully introduced in 1988.

The data of the energy system model have been obtained from STOSEB, the Nynäs research group, and the overall regional planning together with technical information, from different European sources.

Nynäs energy complex

The report from the Nynäs research group does not contain any detailed and formal description of the methods utilized. However, already from Figure 21 one gets a picture of the necessary systems analysis carried out in the study. Three different input markets are considered (coal, waste oil and biomass). The output markets depicted in the figure are the markets for transportation, chemical processing and heating. The basic impacts analyzed with regard to these markets are in terms of cost effects. However, also the effects on the balance of trade are considered. Moreover, the long run positive influences from the project on the chemical industry in Sweden are deliberated on.

The methanol production process necessitates significant cooling requirements. This forms the connection between the Nyhäs project and the Stockholm energy system. The latter will simply function as the cooling system of the energy complex.

The Nynäs project will reduce the imports of oil products in Sweden. If started it must be complemented by national decisions which guarantees a methanol market in Sweden. Such a market is obtained if a government act demands that gasoline shall be mixed with methanol. (This is suggested by the oil reduction committee). According to these plans, the Swedish methanol market will increase rapidly between 1990 and 1995 to a level which is equivalent to around 60 percent of the total demand in the European market economies 1980, in which the demand at this time was almost the same as in the USA.

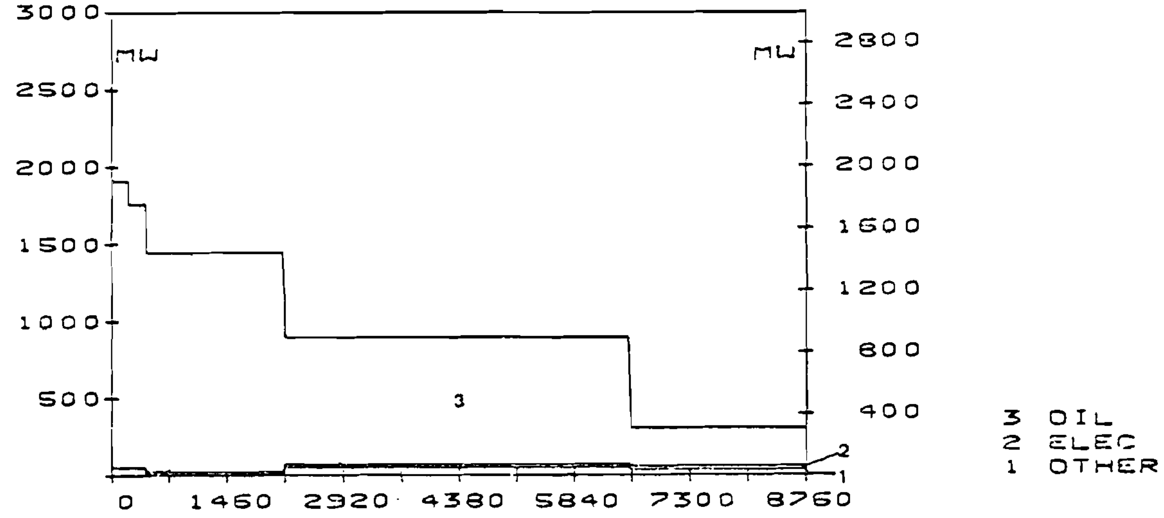


Figure 20a. FE - Forsmark electric scenario
District heat production load curve for 1980.

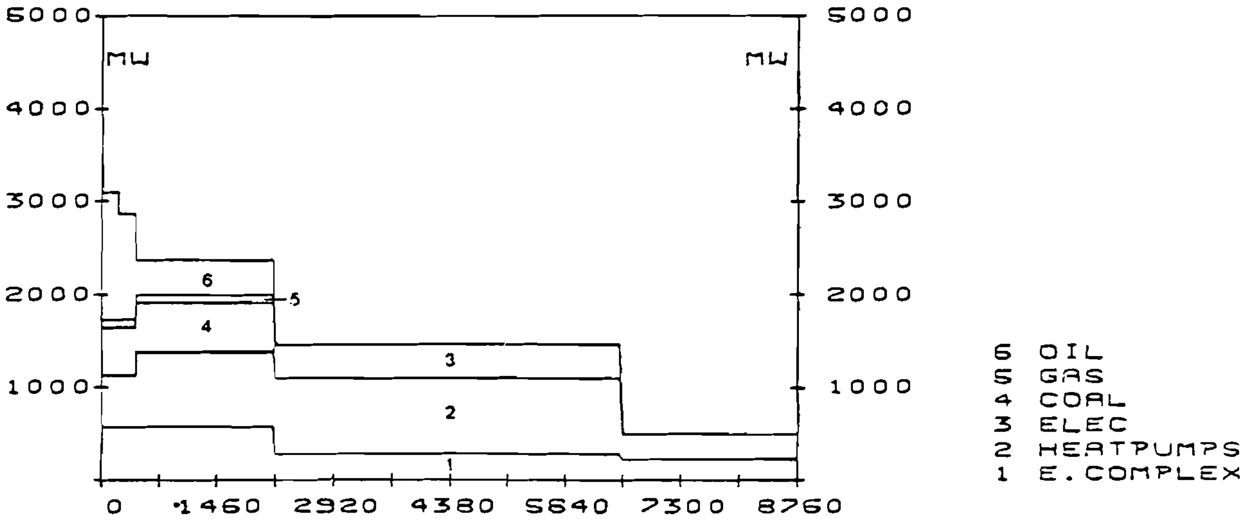


Figure 20b. FE - Forsmark electric scenario
District heat production load curve for 1988.

The environmental aspects of the Nynäs project have been analyzed on the basis of detailed knowledge about the processes. The location has been regarded as suitable for this type of industry in earlier national land use plans.

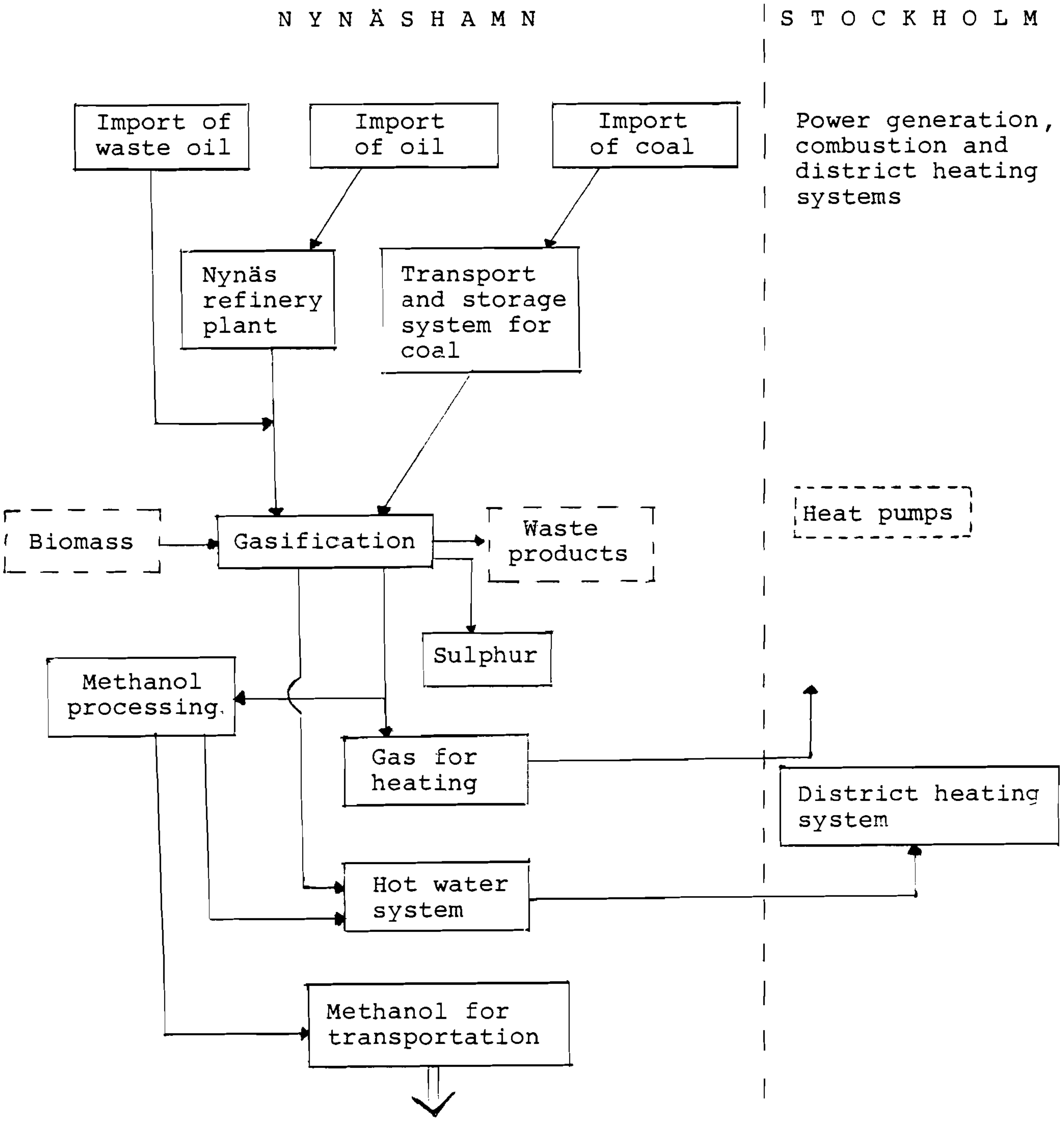


Figure 2.1. Components of the Nynäs energy complex.

5.4 The Assessment of the STOSEB Study

An important part of RPO's activities consists of evaluating policy alternatives for the region. Therefore, when the STOSEB project presented its final report "STOSEB 80", RPO had to switch from the more research oriented and systematic schedule of the REGI-project in order to provide an assessment analysis of STOSEB 80. One conclusion in this study was that a detailed planning for the FORSMARK option should be initiated as soon as possible. This option includes the construction of a long-distance large pipeline for hot water from the nuclear power plants in Foresmark and replacement of these plants with coal based power generation stations in the future.

The RPO analysis focused on several weak parts of the STOSEB study such as (i) projections of future world market prices on primary energy, (ii) the analysis of the market for electricity, (iii) the population, household, housing and work place scenarios, and (iv) the associated calculation of energy demand and energy densities over areas. Moreover, the basic methodology of the STOSEB study was criticized. In particular, it was stressed that the study is based on comparative cost analyses of the various energy options with the additional remark that the comparisons are not made simultaneously for the whole energy system. In the STOSEB study, "components" are compared one by one, eliminating marginally costlier options. Such an approach does not recognize that options eliminated in this way may become attractive when the whole energy system of the region is considered.

The RPO evaluation was based on the following type of studies:

- National scenarios of the economic development and of the long run national energy policy: This study had the character of collecting already existing scenarios and energy policy analyses.
- Projections of the change of the stock of dwellings and work places: These analyses made use of the population model described earlier. They could also partly rely on already existing applications of the model system for household formation, housing demand,

etc. Less sophisticated methods were utilized to obtain the work place projections. A new model of housing removal was applied. This model generated potential removals which in the analysis could be counteracted by either renewal of ageing houses or construction of new ones (see Figure 22).

- Land use planning: RPO prepared as an input to the energy system analysis four alternative land use structures as described in Table 9.
- Economic evaluation of STOSEB's alternatives: This evaluation made use of an existing linear programming model [Bergman, 1976]. A cost benefit approach was applied. This study also includes a discussion of impacts with regard to (i) the energy, labor and housing markets in the region; (ii) the national markets for electricity, and fuels for transportation and heating; (iii) the national capital market and the balance of trade. One may observe that each energy system option requires investments summing up to more than half of the total annual industry investments in Sweden.
- Labor market effects of STOSEB's alternatives: Time profiles of labor market impacts were calculated in the STOSEB study on the basis of detailed project descriptions. A similar calculation was made for the Nynäs energy complex project. Although the effects vary considerably over time, they are small in relation to the whole labor market in the region.
- Heat pump technologies: RPO initiated a set of studies investigating the potential resources in different subareas with regard to heat pump systems. The basic resource in this case is the large water systems in the region. Two small studies focused on solar collector installations and introduction

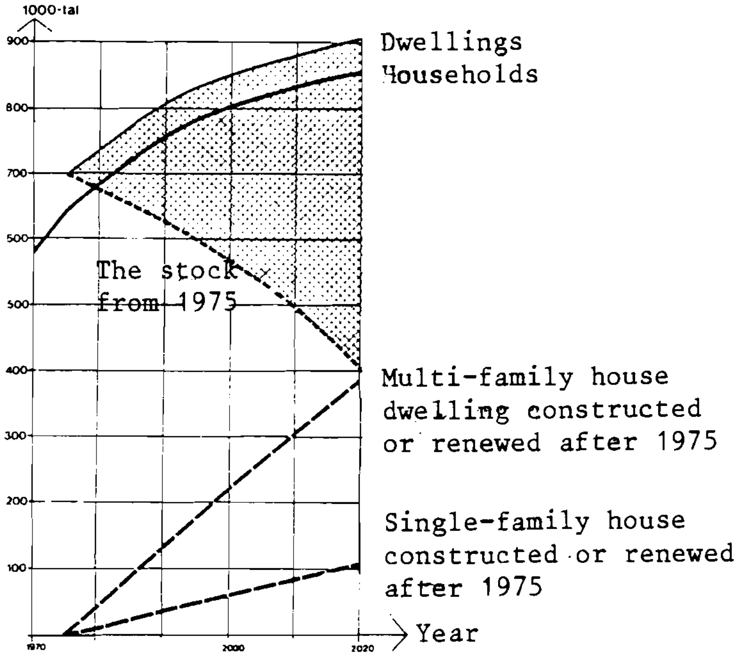


Figure 22a. Development of households and dwellings assuming population growth and a high rate of renewal.

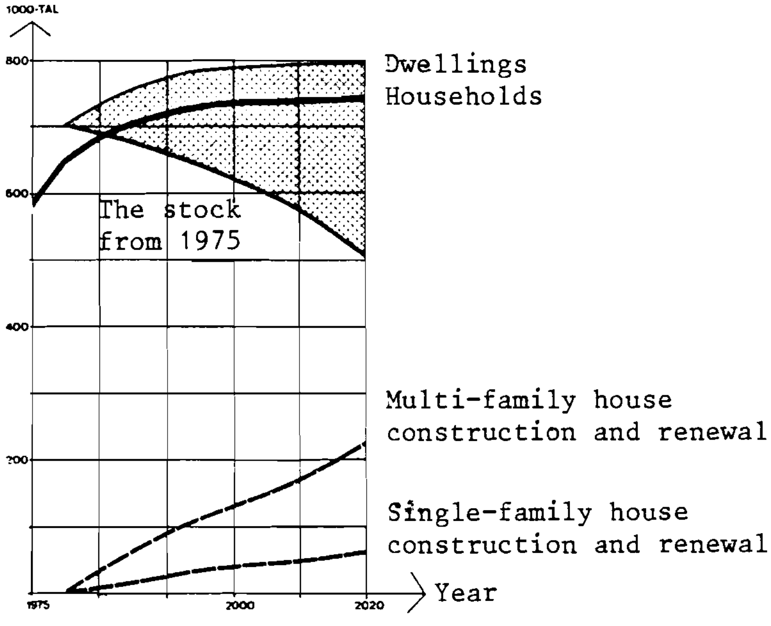


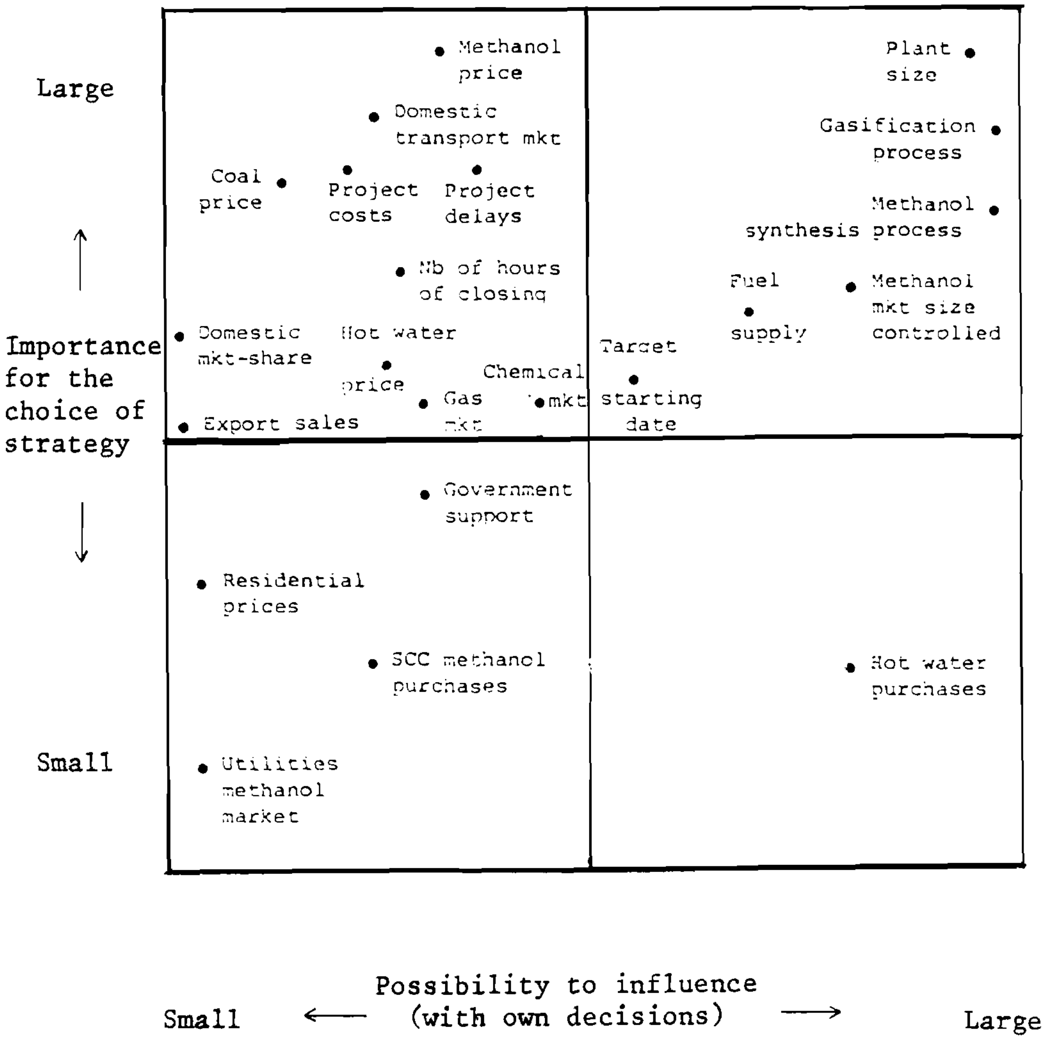
Figure 22b. Development assuming unchanged population and a low rate of renewal.

of wind power stations. These studies provided an input to the energy system analysis as well as to the overall regional analysis.

- The Nynäs energy complex: RPO's assessment of this study concentrates on the economic risks associated with the project. A risk chart technique is utilized as illustrated in Table 10. It is concluded that the project is not robust with regard to variations of the assumptions about future markets.
- Environmental effects: The STOSEB study contains diffusion studies with regard to air pollution from coal processing. The RPO assessments specify a broad set of aspects of environmental effects not considered in the STOSEB and the Nynäs group studies. The need for basic research in this area is also demonstrated. This concerns effects on the water system from (i) heat pumps; (ii) coal combustion (sulphur and metals); (iii) storage of waste products from coal gasification etc.
- Energy system analysis with MESSAGE II: In this case the STOSEB alternatives were re-examined with the help of a comprehensive model using data from the STOSEB study. This part of the assessment formed a summarizing evaluation of the STOSEB study, by incorporating results from the other parts of RPO's assessment efforts. At this stage the gains from RPO's systems analysis approach became obvious.

In terms of the chart in Figure 15, one may conclude that RPO's assessment study ended in part (V) of REGI's project scheme. The final impact analyses and the selection of techniques for this remain as problems to be solved in the REGI project.

Table 10. Nynäs energy complex. A risk chart.



6. EVALUATION AND CRITIQUE: Research and Policy-Making

6.1 Research Ambition, Conflicting Interests and Policy Relevance

The research groups of the Commission on Consequences and RPO's assessment of the STOSER study were all working with heavy time constraints. Moreover, both studies were followed by groups, organizations and companies with vested interests. This was especially marked with regard to the Commission study. Finally, both studies have explicitly been initiated with the clear objective to be used as guidelines for political decisions. Comparing these studies with other similar studies one may ask: what shape has the obvious "trade off" between policy relevance and research ambitions? How does the existence of explicitly recognized conflicting interests affect (i) the research ambitions and (ii) the policy relevance? As a general statement, it seems possible to conclude that the methodological development between the Commission study and the RPO study has made it possible to increase the research/scientific ambitions and still retain the same or an increased level of policy relevance.

In order to be somewhat more specific, let policy relevance denote or indicate the degree to which

(i) the results provide answers to the questions posed by the clients;

(ii) the results increase the understanding of the problem - irrespective of which the initial questions were;

(iii) the results are transferred and translated properly to different users in the society (including public opinion in general);

(iv) the results are utilized in actual decision-making.

By research ambitions we may understand the strive for models and methods that satisfy the demand for better (theoretical) understanding and more reliable forecasts, together with comprehensiveness and consistency.

The commission on consequences

The Commission on Consequences had the objective to trace the effects of alternative scenarios for the future use of nuclear power in Sweden. Being initiated to provide a background material to a referendum, the study became a central focus in a comparatively seen, intensive opinion/policy formation process.

From certain points of view the commission studies may not be recognized as remarkably comprehensive, reliable etc. However, in one respect they have to be recognized; the level of ambition is impressive. Several lasting experiences were made in this context. Firstly, researchers and clients became aware of the necessity and possibilities of as well as the difficulties in applying a system analysis approach. One important aspect was that model builders experienced that interlinking different types of models implies that the different models and methods mutually have to satisfy very specific requirements. The greater the failure is in this respect, the more is lost of the systems perspective.

This problem may be illustrated by the second lesson from the study. Consistency between the national and multiregional level can in general not be obtained without model formulations which allow or, rather require, endogenous consistency through interaction or interlinkage between the two levels. In the Commission study, certain regional model exercises had to be excluded since they revealed "inconsistencies" on the aggregate (national) level. As an example one may mention that calculations of capacity removal based on detailed regional information did not correspond to or match results from the aggregate models. The type of system change, studied by the Commission on Consequences, has the character of a shock to the system. It represents a large-scale disturbance of the system. Especially during the period followed by the Commission research, policy-makers have come to note the two stages in such a change. The impacts of introducing a new, alternative energy system in a country has a "static equilibrium" dimension of the following kind: once the system has been introduced, one may investigate the properties of the socio-economic system when it has been adjusted to the new energy system. But this is only one side of the problem. The new system cannot be introduced without policy measures which create stimuli, incentives and regulations which bring about the desired changes. And these stimuli in the form of changed prices, taxes and subsidies, etc. must be applied over an extended time period. This constitutes "disturbances" of the system which themselves have strong impacts on the system. During the period 1979-1982, this Janus face of the system change has become more and more obvious.

RPO's assessment analysis

To a large extent one may identify an ideological tension in the public opinion in connection with the nuclear power policy issue and the large-scale energy systems discussed as options for the Stockholm region. This tension has also been explicitly observable among researchers. It may in a somewhat simplified way be described as a polarization between small-scale and large-scale solutions. However, the studies indicate that when a large set of small scale energy production and supply techniques are applied, the social and environmental effects still retain a large-scale feature. Moreover, model experiences and techniques for analysis tend to provide more precise and definite results when applied to large-scale projects. An illuminating example of this is the environmental and ecological uncertainties with regard to the suggested heat pump system for the Stockholm region.

The energy system options for the Stockholm region have been analyzed in several different studies sponsored by clients with at least partially conflicting interests. From a bird's-eye view it seems inevitable to conclude that this situation has created more benefits by broadening the perspectives than costs by causing double work and contradicting results. In particular, the interaction between some of the municipalities, STOSEB and RPO has stimulated the research efforts. However, such a multi-organization decision problem also needs a unifying or coordinating effort. This was to some extent obtained through RPO's assessment of STOSEB's analysis. It is possible to show that the results in RPO's assessment reports have influenced the decisions of several parties involved, e.g., several of the municipalities.

The fundamental problem raised in the REGI-project may be summarized as follows: with the help of a systematic land use policy, the regional planning may facilitate certain energy systems solutions. Such an interaction between energy system changes and spatial configurations, including capital and activity location, is a long-term process and the different adjustment processes take place on different time scales. Hence, one has to search for planning strategies and sequential policy measures which are able to match and control the interlinked change processes.

6.2 Long-Run Impacts on Research Policy

One basic impact of the studies of the Commission on Consequences and the associated decisions was the initiation of new research projects. New research financing organizations were formed and existing ones were influenced to give a higher priority to energy-related studies. A marked example is provided by the Council for Building Research which in recent years has been allocating about half of its total budget to energy-related problems. One of the projects initiated in this way was the REGI-project.

One may also observe how the researchers who participated in the commission studies have continued to refine their old models and develop new ones in directions which have been influenced by experiences from the initial research efforts. Several of the models and many of the ideas behind the REGI project have exactly this background.

One may in this context also identify an increasing interest from researchers and policy-makers for multiregional analysis, network related studies, and intraregional land-use analysis. This process has also placed energy related spatial issues in the focus. At the same time environmental and ecological aspects of the changes in the energy system have not been recognized to the same degree. Keeping in mind that many of the planned energy technologies involve coal processing, one may foresee a future reaction to this imbalance.

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