A Professional Platform for Cooperation in Energy Planning

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1. SYNOPSIS

This paper presents a general methodological approach to the technological and economic engineering of sustainable energy systems at the local and regional level of energy planning.

2. ABSTRACT

We are faced with the challenge of design and implementation of sustainable energy systems as integral parts of sustainable ecosystems dominated by the activities of human beings and the many products and processes created by them. Within a limited span of time we have to carry out the transition to efficient energy systems, structurally very different from those which have, so far, been developed by the energy-market forces.

The common search for appropriate ways and means of accomplishing this transition should be based on a general energy systems concept which captures all essential physical properties of present and prospective future energy systems in operation in the different European communities. The adoption of a common, general systems concepts is a precondition for the establishing of a common energy planning methodology and the development of the databases and computer programs needed for practical applications in local and regional communities.

The Sustainable Energy Systems Analysis Model: SESAM, presented in this paper, has been designed to provide a general method and a practical tool for the comprehensive description and computational analysis of energy systems belonging to regional and local communities. In each particular case, a SESAM model consists of a database containing the description of the present state as well as possible future states of the energy system. The database contains technical, structural, operational, and economic data for the energy system as a whole. The SESAM programs attached to the database provides computational facilities for the analysis and documentation of a multitude of scenarios, which may cover a wide space of possible transition strategies.

3. INTRODUCTION

If the local communities, regions, and countries of Europe are to succeed in accomplishing the transition to sustainable energy systems in a well-informed democratic manner, planning authorities, people and their politicians must gain insight into the technological opportunities and the societal conditions for the achievement of well-reasoned environmental goals, to be set as first milestones to be reached within a limited period of time in a continued progression towards the post-fossil-fuel era.

Energy planning for sustainable development is a matter too important and too comprehensive to be left to those involved in energy business. It has to be recognized that the future development of the energy systems, which have become fundamental technological infrastructures of the ecosystems of human habitats, is a basic issue for democratic decision processes. Concerns about environmental risks and other implications of nuclear power have made the building of nuclear power stations a major political issue in some democracies. Concerns about global climate change and regional environmental deterioration caused by continued mining, extraction, transportation and combustion of vast amounts of fossil fuels have been expressed in international conventions and national energy policy statements. However, coherent documentation of technological innovation opportunities and societal conditions for change is needed in order to spell out the practical implications of these concerns in the context of political decision making on a well-informed democratic basis.

The "Sustainable Energy Systems Analysis Model" (SESAM, Illum 1995) was built to provide coherent documentation of technological and socio-economic opportunities for the achievement of substantial reductions of CO_2-emissions in Danish regional energy systems (the Storstrøm and North Jutland counties) under certain conditions as regards the development in energy consuming activities in the society (Illum, 1992). It was further developed to facilitate the modelling of regional energy systems in the Czech Republic (Illum, 1993), and Poland1. The general applicability of the model has thus been established by its use in a number of projects in different countries.

The SESAM model demonstrates that with respect to energy flows, the activities and processes taking place in the communities situated in the temperate climatic zones of Europe can be described with reference to a general energy systems concept which also captures the representation of future changes of components and structures. Within the systematic frame of reference thereby established, energy planning may be conducted as a methodologically based, professional discipline concerning the system of basic community infrastructures as whole. This comprehensive systems approach is a precondition for the achievement of socio-economic least-cost solution under given environmental constraints.

The SESAM model is, however, not made to be a tool for professional consultants only. Indeed, it should be used by regional and local planning authorities to organize the data needed for comprehensive energy planning in databases structured in accordance with the general energy system concept underlying the model. Once the basic database for a municipality or a region has been established, possibly with the assistance of consultants, energy planning officials can examine a wide range of different scenarios (or investment programmes) for the future development: the information embedded in the database and in the assumptions made in the different scenarios is unfolded and completely documented at different level of detail by means of the SESAM programs for the computation and documentation of energy flows.

This means that regarding the assessment of technological opportunities and socio-economic costs, the costs involved in public energy planning can be limited to the costs of data acquisition and the costs of analysis of computational results. The comprehensive and sometimes quite complex computations involved in the derivation and documentation of environmental and economic consequences of alternative long-term investment programmes can be left to the computer.

It also means that the general public, represented by individuals and interest groups, can be given assess to the information upon which political energy planning decisions may be based: complete documentation of the alternative programmes considered may be handed out to those interested in gaining insight into the opportunities for future development. Thereby, energy planning can be made a truly public activity.

As a general method and basic computer tool, the SESAM could become the carrier of collaboration in a European network of local and regional energy planners, working together through the exchange of experiences, data, programs and results, with the common objective to provide coherent information upon which energy policy decision aimed at sustainable development can be based.

4. THE CASE FOR REGIONAL ENERGY PLANNING

Sustainable energy systems have to be integrated into the ecosystems of local communities. Fuel cycles will have to be interconnected with the biological life-cycles so as to utilize energy potentials in local biomass turn-over in rural and urban ecosystems. The conversion of fuels (chemical energy) to electric power and heat will have to take place in conversion units (engines, fuel cells, heat pumps, etc.) located where the efficient use of their energy outputs can be obtained at the least economic costs, e.g. in industries or individual buildings. Industrial and agricultural production processes may thus have to be adapted to the local energy system or vice versa. Buildings may become partly self-supporting energy systems making use of solar radiation through windows and by means of photovoltaic cells and solar absorbers. Electricity generation from renewable sources such as windmills and photovoltaic cells may require elaborate power regulation facilities and storage capacities, e.g. in the form of electrolytic converters. The powering of vehicles in transportation systems will have to become integrated into the energy flows of the system as a whole.

Like natural ecosystems, sustainable communities will thus have to comprise energy systems meticulously designed to make efficient use of the potential energy sources available. The design of such systems is a structural design problem involving the industries, the farmers, the households, and the public utilities. The planning as well as the implementation process thus calls for the common appraisal of the objectives to be achieved and the cooperation of the citizen in the achievement of these objectives.

The transition to sustainable energy systems has, therefore, to be planned and accomplished within local communities where the details of the design of efficient systems can be properly considered.
Local communities like towns or villages are, however, not independent entities regarding energy demand and supply. They are interconnected via the electric grid and they will depend on renewable resources such as windpower and biomass fuels which are not a priori dedicated to particular local communities.

Local communities within a certain region should, therefore, collaborate in the design of an efficient regional energy system in which exchange of energy between local systems may take place when appropriate for the efficient functioning of the regional system as a whole.

In Europe an administrative district (county, province) of about half a million inhabitants could be a suitable region with respect to energy planning.

This technological approach to energy planning as a regional activity does, of course, not diminish the political responsibility of national governments to provide the overall economic and institutional framework for the development of sustainable energy systems. First of all, it is a national political responsibility to provide the administrative framework at the regional and local levels within which energy planning can be carried out. Secondly, economic regulators concerning the pricing of energy and the financing of investments, the setting of technical standards such as building codes and standards for the efficiency of electrical appliances, and environmental regulations such as emission standards have to be established by the national governments.

5. THE MODELLING OF REGIONAL ENERGY SYSTEMS

The precondition for the construction of a generic energy systems model is, of course, that energy systems can be identified and adequately described and specified in generic terms referring to a general energy systems concept. Indeed, this is a precondition not only for the generic modelling but also for the establishing of an energy planning methodology.

To describe the energy systems of human habitats is to describe one very essential aspect of their functioning. While the communities of today almost exclusively depend on external sources for their energy supply, the communities of tomorrow will have to balance their energy accounts by integrating to a much higher degree the control of energy flows into all the technologies that make up the antropogenic ecosystems.

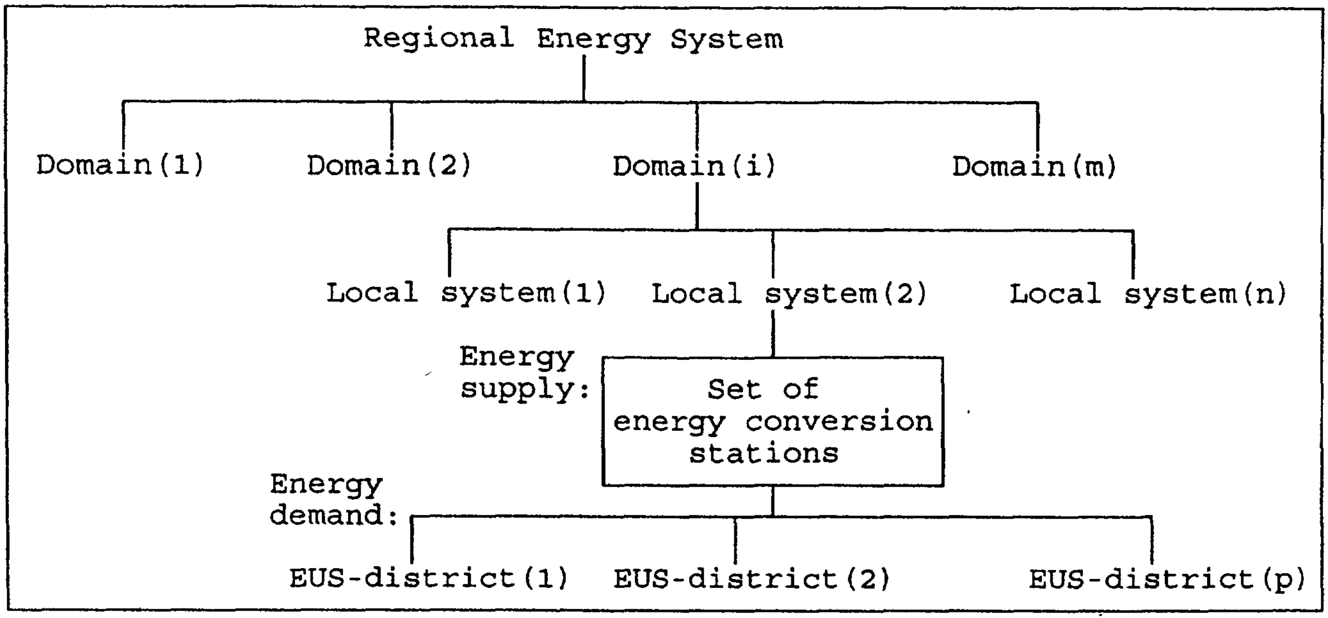
The description of energy systems in transition from their present state to future sustainable states is, therefore, the description of changes in the technologies upon which communities depend for survival, comfort and pleasure. Their buildings, their tools and appliances, their workshops and industrial work, their means of transportation, and, not the least, their agricultural production systems.

5.1 The Geographical Structuring of Regional Energy Systems

A regional energy system should thus be seen as a system of human habitats, described from the technological point of view with particular regard to its energy flow properties. This means that the technological mapping of a regional energy system, i.e. the demarcation of its subsystems, should, generally, reflect the topographical mapping of its habitats.

As schematically shown in Figure 1, a regional energy system may be divided into a number of domains, each domain comprising a number of local energy systems.

Figure 1. *The general paradigm for the geographical structuring of a SESAM model of a regional energy system.*



A domain may, for example, comprise the villages in the region, the smaller towns, or a larger city area.

A local energy system is an elementary subsystem in the sense that it is the smallest entity for which particular scenarios for future development may be specified and for which complete documentation of the computational results may be printed out or inspected on the screen. With respect to the description of present an future heat supply structures, a local system may be further divided into so-called End-Use System districts (EUS-district).

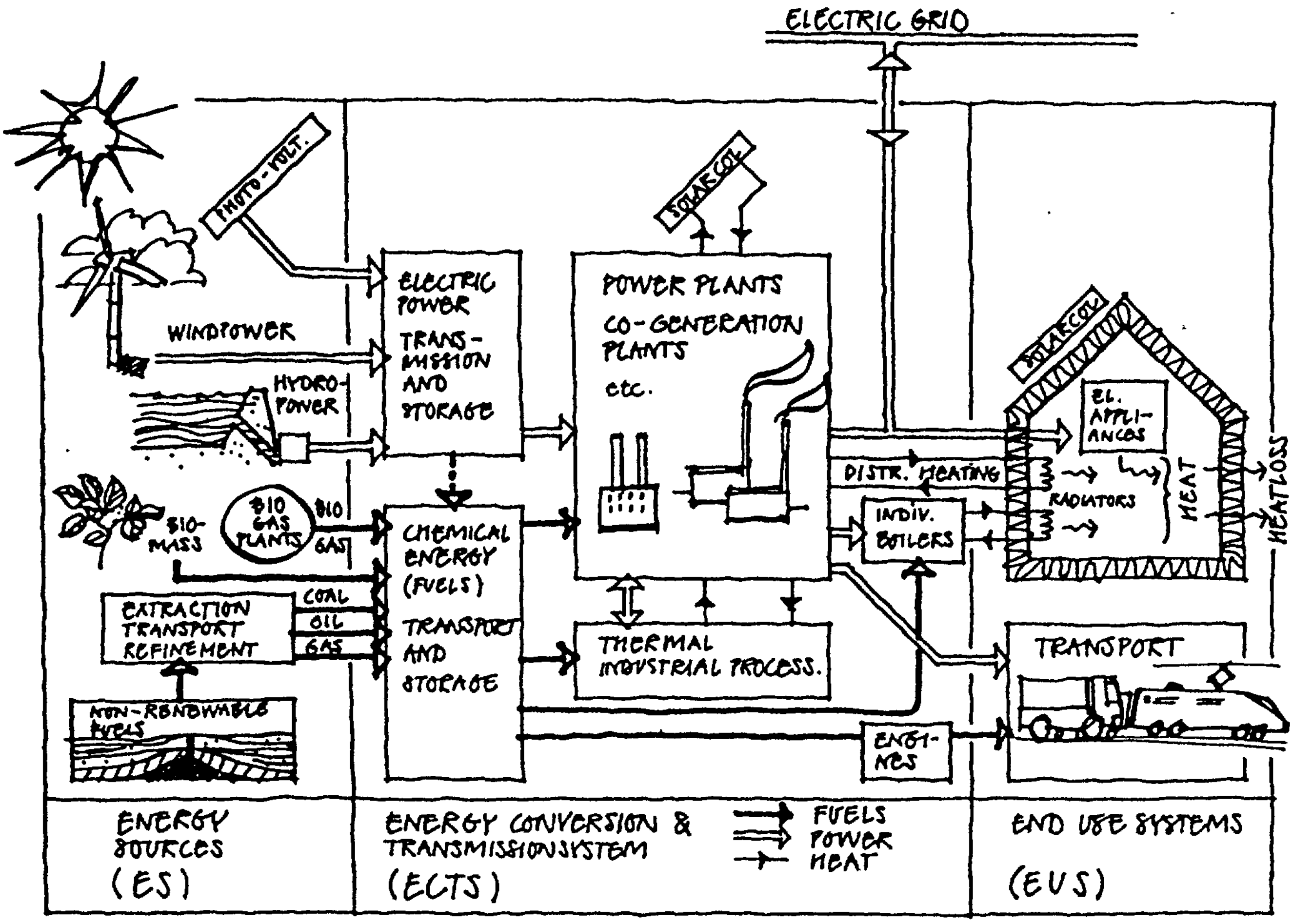
It is entirely left to the user of the SESAM model to decide how a particular region should be divided into domains, local systems, and EUS-district in order to make the model useful for the regional planning to be accomplished.

5.2 Local Energy Systems

A local energy system may represent a certain geographical area: a town, a township or an agricultural area with its farms and villages. In some cases a group of towns or townships with similar properties as to energy demand and supply may be modelled as one local system2.

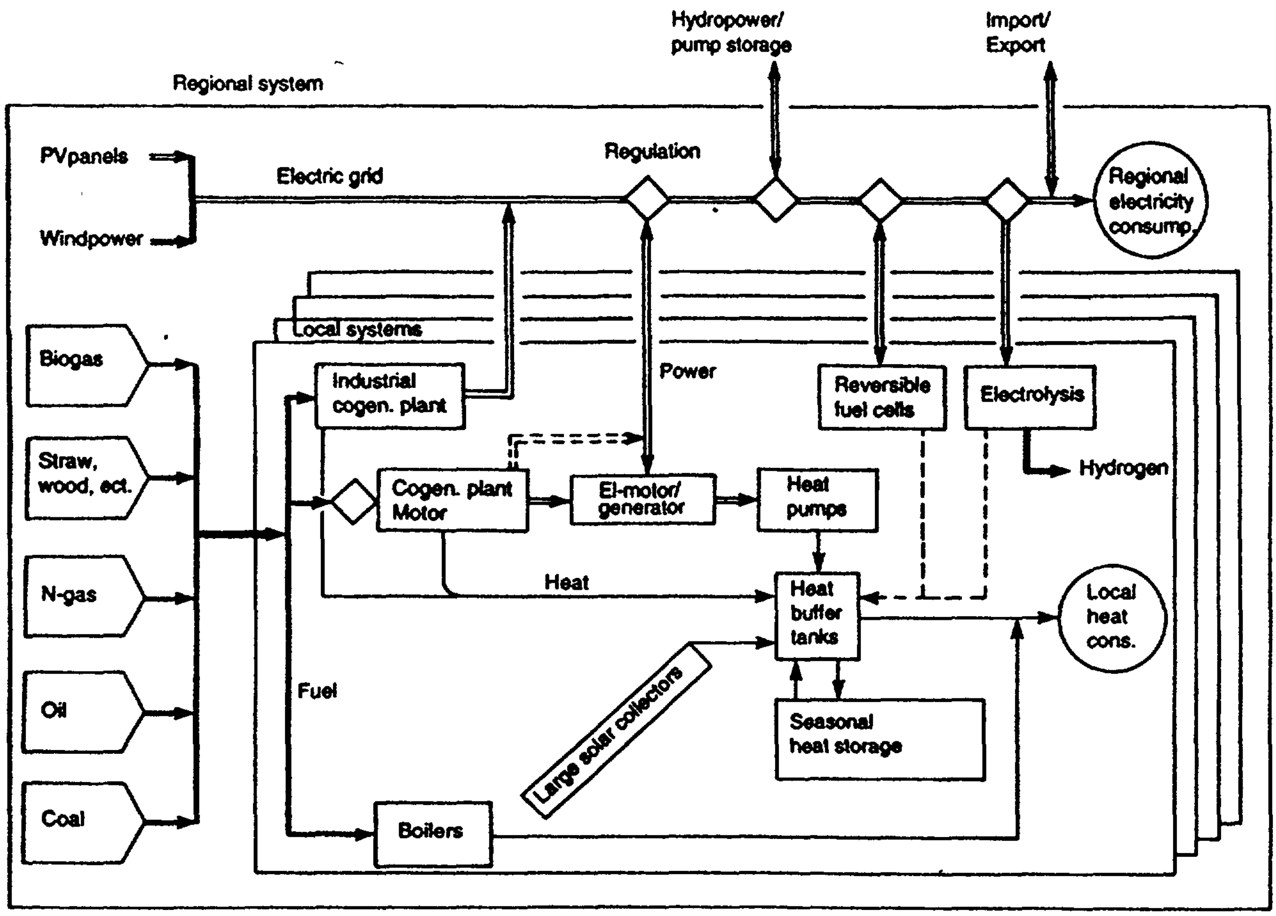
A local system consists of three subsystems: the End-Use System (EUS), the Energy Conversion and Transmission System (ECTS), and the system of Energy Sources (ES) utilized by the local system, see Figure 2. In scenarios for the future development of the energy system changes may take place concurrently in the EUS, the ECTS, and the ES of the different local systems.

Figure 2 *The three subsystems of a local energy system.*



3. The different kinds of energy conversion units which may be included in a local system's ECTS are shown in Figure

Figure 3 Energy sources, energy conversion and storage units, and energy flows in a regional energy system comprising several local systems.



A local energy system's *End-Use System* comprises the buildings used for dwellings, offices, institutions, workshops, industries etc. as well as the electrical appliances and machinery used in the buildings. It also comprises the vehicles used for the transportation of people and goods.

The net heat consumption - i.e. heat transmitted from the ECTS to the EUS - for room heating in different types of buildings at different times of the year is determined by the difference between the indoor and the outdoor temperature, the thermal insulation of the buildings, the ventilation, the amount of solar radiation transmitted through windows, and the amount of heat released from electrical appliances and persons. Heat from solar absorbers connected to the buildings' heating installations may reduce the net heat consumption for hot water and possibly for room heating.

The electricity consumption in buildings is determined by the number of electrically driven appliances and machines in use, the quality (i.e. the efficiency) of these appliances and machines, and the frequency with which they are used. The SESAM model includes a particular program which facilitates the modelling of the development of the quantitative and qualitative composition of the stock of electrical appliances and machines at any level of detail. By means of this program different scenarios for the development of electricity consumption can be generated.

A local energy system's *Energy Conversion and Transmission System* comprises all the energy conversion units and plants which serve to convert fuels (chemical energy) to heat (thermal energy) and electric power: boilers and stoves in individual buildings, district heating stations, power and cogeneration plants. Also heat pumps, which convert electrically or mechanically transmitted power to thermal energy at a temperature above the ambient, may be included in the ECTS. In addition, the ECTS comprises installations for the transmission and storage of power and chemical energy from the ES as well as the power lines and district heating networks, which transfer energy from the ECTS to the EUS, see Figures 2 and 3.

The ECTS also includes thermal industrial processes which, from a thermodynamical point of view, are of the same nature as power and cogeneration stations. These are processes which require substantial amounts of heat, such as those taking place in chemical works, paper mills, ceramic works, dairies and other food industries, etc. The efficient operation of such processes has, in many cases, to be achieved by the integration of the process into a cogeneration system in which the fuel is used to generate electricity as well as process heat at the required temperature level. The heat released from the process at lower temperature levels may be utilized in a neighbouring district heating system. Thereby, further improvement of the efficiency of the ECTS as a whole may be achieved. Thermal industrial processes may thus become integral parts of the ECTS.

The *Energy Sources* utilized by a local energy system may comprise several sources of chemical energy in the form of renewable and non-renewable fuels as well as sources of electrically transmitted energy: windmills, hydropower stations and possibly photovoltaic cells, see Figures 2 and 3. Which fuel sources are actually being utilized by a particular local system at a given time does, of course, depend on the types of energy conversion units in operation in the system at that time.

Electrically transmitted energy from the ES may either be transferred directly to the EUS or converted to heat by means of heat pumps or to hydrogen by means of electrolytic converters.

When referring to the regional energy system as a whole, the EUS should be understood as the set of all the End-Use Systems belonging to the different local energy systems. Similarly, the ECTS means the set of Energy Conversion and Transmission Systems, and the ES means the set of Energy Source systems.

All the local systems within a regional energy system are assumed to be interconnected through the regional electric grid. The regional system may exchange electric power with its environment, at times importing power from external power stations, at other times exporting power from the regions own power stations, windmills, or photovoltaic cells to cover demands outside the region, see Figure 3.

6. THE SESAM MODEL'S DATABASE

The setting up of a SESAM model of a regional energy system involves the establishing of a database comprising the multitude of data which specify the system in its present state as well as the changes of system components, structures, and operational strategies taking place in the system in different scenarios for future development.

The degree of detail to which the different system components are specified in the database may depend on the data available or on the specific purpose of the analyses to be carried out. As a general rule, it is recommended to make the database as detailed as the data and time available allow. The SESAM program can automatically produce documentation of aggregate as well as detailed results at any level of detail, only restricted by the degree of detail of the specifications in the database.

The database comprises

- qualitative technical data, which specify the technological development of existing types of system components, as well as data for new types of component being introduced in the system in the scenarios considered.

- quantitative data, which specify the development of the building stock, the stocks of electrical appliances, industrial production quantities, etc.

- data specifying *structural changes* of the system, such as shifts to new structural compositions of the ECTS (e.g. more widespread cogeneration of power and heat) andchanges caused by the introduction of new energy sources, in particular renewable energy sources.

- *annual energy flow variation data*, specifying the annual variations of the average monthly values of: outdoor temperature; solar radiation; wind velocity; electricity consumption for different types of electrical appliances; forward and return temperatures for district heating networks; thermal reservoirs for heat pumps; biogas production.

- *diurnal energy flow rate variation data*, specifying month by month the diurnal variations of: outdoor temperature; solar radiation; wind velocity; electricity consumption for different types of appliances.

- *operational data*, which specify present and future strategies for the operation of energy conversion units on an annual and diurnal basis. These strategies should be set up in such a manner that performance requirements are met at any time with the least possible conversion unit capacities (measured in MW output capacities of power and heat generating units).

- an *economic cost database*, which contains estimated present and future investment and reinvestment costs and costs of operation and maintenance for each type of system omponent (e.g. cogeneration plants of different types, biogas plants, district heating networks, etc.etc.). Different scenarios for the development of fuel costs are also to be included in the this database.

Several possible values of the variables which specify future qualitative, quantitative or structural changes of the system may be entered in each register or table. The database may thus contain a *multitude of different scenarios*, each specified by a certain combination of values selected for the different variables. Once the database has been established with appropriate sets of relevant alternative values for each variable, the SESAM model may thus be used to search for feasible least-cost solutions by examining a wide range of different scenarios.

7. REGULATION AND CONTROL OF ENERGY FLOWS

The energy flows in a regional energy system comprising a number of local energy systems are shown in Figure 3. The system of energy sources may include windmills and photovoltaic cells, biogas plants, biomass fuels, and large solar collector plants as potential future energy inputs. In the energy conversion and transmission system electrolytic conversion of electric power to chemical energy in the form of hydrogen and vice versa (by means of reversible fuel cells) is included as future options.

The SESAM model provides computational means of assessing the energy conversion and transmission capacities (in MW) required in future conversion units and transmission lines in order regulate and control the energy flow rates in accordance with the demand rates in the end-use system. These technical capacity requirements are, of course, of primary importance for the economic assessment of alternative compositions of future energy systems.

In the following the regulation and control task and the roles to be played by the different types of conversion units in the accomplishing of this task are briefly described:

The heat released from motors3 and electrolytic processes belonging to a local system may be sufficient to cover the local demand for low-temperature heat, especially if seasonal heat storage reservoirs are used to level out the monthly differences in the demand/production ratios. When required, additional heat may be supplied from solar collectors and heat pumps. It is imperative for the thermodynamic efficiency of the energy system that the use of boilers is restricted to short peak load periods.

In regional systems with access to hydropower reservoirs, these reservoirs may be used as sources of energy supply and/or as energy flow regulation units (pump storage).

The regulation and control task consists in ensuring that the energy conversion units installed in the different local systems at a given time are operated in such a manner that

a) *heat is supplied to the buildings of each local system* at the rates demanded at different times each day.

b) *electricity* is supplied *to the regional grid* at rates determined by the varying demands in the regional system as a whole, making use of available hydropower resources and power transmission to and from other regions in such a manner that the efficient performance of the system as a whole is obtained at the lowest possible costs.

c) the regional system as a whole *utilizes the local energy sources* available at different times *in a thermodynamically and economically efficient manner.*

This task is relatively simple as long as the main energy sources are fossil fuels and hydropower, which are readily delivered to the conversion units at the rates demanded. In future energy systems, which will have to rely on renewable energy sources, the task may, however, become quite complex. Energy flow rates from these sources are out of phase with demand rates, annually as well as diurnally. This is the case not only for wind power, power from photovoltaic cells and heat from solar collectors but also for biomass fuels such as biogas. Furthermore, it is expensive to provide energy storage capacities - such as reversible fuel cells and seasonal heat storage reservoirs - sufficient to compensate for these differences in time.

Heat pumps provide a relatively inexpensive means of regulating the ratio between electricity production and heat production in the system, in particular when connected to heat buffer tanks for the diurnal regulation of heat output. Furthermore, heat pumps may be used to extract low-temperature heat from seasonal heat storage tanks with sufficient capacities for storing surplus heat from solar collectors, motors and electrolysis plants in the summer season for use in the winter season.

When the *transportation system* becomes interconnected with the stationary energy conversion units by the use of hydrogen as a propellant in vehicles, electrolysis plants may also serve to adjust power supply to end-use demand on a diurnal, weekly or monthly basis, depending on the hydrogen storage capacity. Indeed, if hydrogen in future becomes more widely used as an energy carrier, electrolysis plants and fuel cells and/or reversible fuel cells may come to play an important role as conversion units with a substantial regulation capacity. Small scale reversible fuel cells may be installed in individual buildings.

In the European energy system the capacities of the available hydropower reservoirs - which are presently the only major renewable energy sources - should be efficiently utilized for the regulation of power supply. Highly valuable hydropower should not be squandered in electric radiators and boilers - as it is the case today in many countries because prices paid for hydropower are much lower than the real value of hydropower in future sustainable energy systems.

8. ENERGY PLANNING INFORMATION FROM THE SESAM MODEL

When the database for the regional energy system in question has been properly set up, the SESAM model provides readily accessible information about the development of energy consumption, emission rates, and economic costs to be expected in different scenarios for the future development. In search for least-cost investment programmes, energy planners may thus easily examine a large number of different scenarios and produce complete documentation of the results at any level of detail.

A well-documented basis for political decision making may thus be provided.

For each scenario the SESAM computer program computes all *energy flow rates* in the system year by year and month by month, making sure that energy balance requirements are satisfied for each system component in each local system and that electricity production in the regional system as a whole equals consumption plus/minus power export/import. These computations include *electricity and heat consumption* in the EUS as well as *primary energy consumption*: fossil fuel consumption, production and consumption of biomass fuels, power from windmills, photovoltaic cells, and hydropower plants. Furthermore, the resulting *emission rates* are computed.

In order to assess the *conversion unit capacities* (i.e. capacities, in MW, of power and cogeneration units, district heating stations, heat pump installations etc.) required to meet the diurnally varying rates of electricity and heat consumption, the program simulates (in time steps of, for example, 15 minutes) the operation of the system of conversion units in accordance with the operational data specified in the database for the scenario in question. If *flue gas purification plants* are to be installed, the program also computes the required capacities (kg/hour) of these plants.

If it appears that *heat storage tanks* used as heat buffers in the diurnal production cycle of cogeneration plants are needed, the program computes the required capacities of these tanks. In cases where *seasonal heat storage reservoirs* are included for storage of heat from solar collector plants and cogeneration plants (in particular biogas fueled plants), the computations include the required capacities of these reservoirs.

If necessary for the balancing of power and heat generation against demands, *heat pumps* may be introduced in the system. If this is the case, the SESAM program ensures that heat pumps are put into operation in an optimal manner and computes the required heat pump capacities accordingly.

The required capacities of *electrolysis plants for hydrogen production* are computed under the assumption that these plants serve to regulate the power supply to the EUS in accordance with demand, hour by hour and month by month.

Furthermore, available *hydro-electric power and pump storage reservoirs* may be used to regulate power supply. The regulatory capacities of hydro-power and pump storage reservoirs are to be specified month by month as a maximum net power supply (MWh per month) and a maximum transmission rate (MW).

The *economic costs*, comprising investments costs and the costs of operation and maintenance, are computed year by year for each local energy system and for the regional system as a whole. For each system component the costs are computed on the basis of the specific *investment, reinvestment and maintenance costs* given in the database. For each fuel the *fuel costs* are computed as the product of fuel consumption and fuel price at the time. The costs are presented as time series of annual costs as well as present value totals, computed by using a specified discount rate.

9. LANGUAGE

The SESAM model can be run in any language using the Latin alphabet and print out documentation in any of these languages. Adding a new language option only requires the translation of text strings in the models text string library from English or any other language already included in the library.

10. REFERENCES

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11. ENDNOTES

1. A SESAM model of regional energy system comprising 15 towns rural areas in south -eastern Poland hasbeen set up by the engineering consultans Brunn & Sörensen, Energiteknik A/S, Aarhaus Denmark.

2. In the system description language the term 'local system' refers to what is being modelled as a local system. This need not in all cases referm to a geographical location. In some cases a local system may represent a number of geographically dispersed locations with similar properties regarding energy systems modelling.

3. In the present context the term 'motor' means any thermodynamic unit which converts chemical energy (fuel) to mechanically or electrically transmitted power, i.e. steam turbine plants, piston engines, gas turbines, fuel cells etc.

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