A SESAM Model of the

Nordic Energy System

Methodology
and the Modelling of the Nordic Energy System

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Contents

Note:
In the data and the result filenames given in the different sections of this paper:
reg stands for the region (country), reg = NOR, SWE, FIN, DEN, and
sc stands for the scenario identifier, see Appendix 2.
txt is the default file extension

References are made to the SESAM manual:
Klaus Illum: *SESAM - the Sustainable Energy Systems Analysis Model.* Aalborg University Press, 1995.

1. Introduction

The study presented in the paper *A Viable Energy Strategy for the Nordic Countries 2006 - 2030*, Greenpeace Nordic January 2006, is based on a SESAM model of the Nordic energy system. This report describes the SESAM methodology and the contents of the multi-scenario SESAM database which in that study represents the Nordic energy system. Moreover, the result file names and the documentation program names given in the different chapters and sections and in Appendix 5 provide a guide to the documentation files available from the result database.

The database contains 25 registers in which data specifying the present and possible future structural and physical properties of the system as well as data specifying alternative quantitative development factors are registered. Moreover, the specific economic investment and maintenance costs assigned to each particular type of system component are registered in the database.

Each particular structural and physical property is represented as time-series data. A time-series contains the present value of the property in question followed by a series of alternative future values. Thus, the database represents a myriad of alternative scenarios for the future change of the system, each scenario being specified by the selection of a particular time-series among the alternatives given in each of the data registers.

The SESAM programs compute the energy flows in the system on a diurnal and monthly basis. The computations are performed for the present state of the system and for a number of years during which the system undergoes changes as specified in the database time-series. The SESAM program execution manager allows the selection at run-time of the time-series values to be used among the alternatives given in each database register. Thus, a wide spectrum of alternative scenarios can readily be computed. Subsequently, the SESAM documentation and comparative analysis programs facilitate the comparative analysis of the physical and economic results obtained for each scenario.

Regarding the degree of detail and accuracy of the system specification in the database, a distinction should be made between, on the one hand, the technical and economic information needed for the long-term strategical decision-making and, on the other, the data required as a basis for the many specific investments decisions to be made in order to implement an a chosen strategy. Regarding the information provided for long-term strategical decision-making, the efforts made to obtain accuracy in the database representing the energy system in its present state should be balanced against the uncertainties of the assumptions made as regards the many factors which strongly influence the future development. When it comes to the implementation of a chosen strategy, a more accurate and detailed representation of the energy system is needed. However, as a general rule, whenever accurate and detailed data are available they should be entered into the database. SESAM can easily aggregate detailed data.

The report contains two parts. In Part One, the general SESAM methodology of multi-scenario energy systems analysis is introduced. This methodology is based on a general, comprehendible energy systems concept, appropriate for the description and analysis of regional, national or local energy systems. It provides a well-structured conceptual framework and a rational terminology for the formulation and discussion of alternative future investment policies.

Part Two gives a concise description of the SESAM representations of the geographical, technical and quantitative properties of the Nordic energy system. References are made to the files and records which contain the formal specifications of the structural properties of the system as well as to those which specify the properties of the different system components. Also references to the result files appertaining to particular scenario computations are made.

Part One. Methodology.

2. The Multi-scenario Analysis Method

SESAM is a generic systems analysis model. The precondition for the construction of such a model is, of course, that the class of energy systems in question can be identified and adequately described and specified in generic terms referring to a general energy systems concept. The energy systems concept upon which the SESAM method is based is shown in figs. 1, 2, and 3.

SESAM analyses concern fuel consumption in alternative prospective energy systems and environmental impacts of the combustion of fuels as well as the economic costs directly related the construction and operation of the systems. Series of different scenarios for the future development of the energy system in question can be examined and the SESAM documentation programs facilitate the comparative analysis of of alternative scenarios. Scenarios differ because of different assumptions as to

- the *technical properties* of the structures and components (incl. transportation infrastructures and vehicles) of future systems,

and/or

- the *quantitative properties*, i.e. the development in the quantities of energy consuming buildings and hardware (heated floor area; number of electrical appliances in use; number of cars; etc.) and the development in industrial production quantities,

and/or

- the *behavioural properties* such as the indoor temperatures in rooms of different use; the frequencies of use of electrical appliances and lamps; and transportation volumes by different means of transportation.

2.1 The multi-scenario database

The data which specify the physical properties of the energy system components are entered into a comprehensive database, structured in accordance with the physical description of the energy system as a whole (see fig. 1). The database also contains specifications of the geographical and technical structuring of the system, the climatic conditions in the countries' different climatic zones (temperature, wind, solar radiation), and the behavioural parameters which influence energy consumption.

For each type of component the specifications are entered as time-series data. The first value in a series represents the present value of the property in question. For the future values of the property, a number of alternative values may be entered into the time-series. This also goes for the specifications of structural properties and behavioural parameters. Thus the database represents the system in its present state as well as a multitude of scenarios for future changes in the state of the system: For each type of component, the time-series of future property values can be chosen among several alternatives, independently of the values chosen for other component types.

In this manner, a SESAM model facilitates the specification of series of different scenarios in which future changes in the different systems properties are varied in a systematic manner. When a multi-scenario database has been set up, scenarios which represent different strategies for the development of the energy system as well as scenario modifications made for sensitivity analysis purposes can easily be specified.

2.2 Energy flow computations

At any time, the energy flows in the system are determined by

- the demands for electric power, heat, and motive power in the end-use system
- the electric power generation in windmills and photovoltaic panels
- the technical properties of the energy conversion and transmission units
- the available hydropower capacity

and

- the strategy applied for the regulation of the energy conversion system and the use of hydropower, i.e. the rules applying to the regulation of the operation of the different energy conversion and storage units.

On the basis of the system specifications contained in the database, a system of computer programs computes the energy flows taking place month by month and year by year in a particular scenario (i.e. the integrated flows by month and by year). Moreover, in order to assess the required capacities of the different energy conversion and storage units used in the scenario in question, electric power and heat flows are computed at short time intervals (normally 15 - 30 minutes) for a number of typically different diurnal variation patterns regarding wind, solar radiation, heat demand, and electricity demand.

2.3 Documentation

For each scenario, the computer programs enter the results computed into a result-database. From this database various, more or less detailed result tables can be displayed: Aggregate energy balance results for the system as a whole or for particular regions; particular results for one or more energy conversion stations or units; heat and electricity consumption and production accounts; etc. etc. Thus the user may inspect the results at any level of detail and thus verify that the results are consistent with the specifications given in the database. In particular, it can be verified that the energy balance requirements are fulfilled for the system as a whole as well as for any subsystem and component for any period of time.

The documentation programs also comprise programs for the print-out of economic costs results for the system as the whole as well as for particular regions, subsystems, and system components.

2.4 Comparative scenario analyses

For the comparison of results for different scenarios, documentation programs are available for the print-out of tables in which main results for a number of different scenarios are displayed in parallel columns or rows.

Moreover, comparative analyses of results for a number (max. 40) of different scenarios can be carried out by means of the SESAM comparative analysis programs. These programs perform sensitivity analyses with respect to fuel consumption, CO_2 emission, and economic costs so as to assess marginal effects of investments in energy savings, efficiency improvements in the energy conversion and transmission system, and renewable energy sources in relation to marginal costs.

2.5 Systems too complex for mathematical description and optimization

Generally, the results regarding fuel consumption and emissions obtained by a particular type of investments (e.g. investments in additional thermal insulation of buildings or additional windpower) is a systems property, i.e. they depend on all the other properties of the system at the time when the investments are made and the future changes in these properties. This is one reason why “optimal development scenarios” cannot be computed using linear optimization procedures. Generally, the relations between the system’s variables are not linear and the dynamic properties of the system as a whole are, generally, too complicated to render their description in mathematical notation feasible.

3. Energy Accounting and Efficiency Analysis

Conventional energy statistics account for energy quantities as quantities measured by the calorimetric method. No quantitative distinction is made between energy transmitted by an electric current between a high voltage and a low voltage node and energy transmitted as heat between two bodies of different temperatures. Also the so-called heat of combustion of a particular fuel, which is due to a difference in chemical potential between the fuel and the atmosphere, is measured by its calorimetric value.

However, it should be obvious to anyone that for all practical purposes there is a categorical difference between electric power and low-temperature heat. For example, electric power from a photovoltaic panel is a phenomenon of a another category than warm water from a solar collector. The sum of the two quantities is of no relevance whatsoever. The two quantities are incompatible. Likewise, the sum of a certain quantity of electric power transmitted through a cable from a power station or a windmill and the heat of combustion of a certain amount of straw or oil is of no relevance whatsoever. Neither does it make sense to add the electric power output and the heat output from a cogeneration station so as to calculate the “efficiency” of the station. (Calculated in that manner, the “efficiency” of a cogeneration station equals that of a simple boiler station).

It follows that for any analytical purpose, the sums of mutually incompatible “energy” quantities, e.g. “total primary energy consumption”, including fuels of different kinds, hydropower, windpower ,etc., which appear in conventional energy statistics are irrelevant. Generally, nothing of analytical relevance can be derived from such sums.

3.1 Energy balance accounts and sensitivity analyses

In order to provide documentation of the energy balance, SESAM computes monthly and annual energy balance accounts for electricity consumption and production as well as for heat production and consumption. The balance accounts can be displayed for the system as whole as well as for any regional or local subsystem.

Moreover, the development in the systems properties can be inspected in more or less detail in various tables showing: electricity consumption; heat consumption for room heating and hot water; process heat consumption; fossil fuel consumption; non-fossil fuel consumption; capacity requirements in energy conversion units of different types; etc; etc; In these tables no incompatible quantities are added.

Because of the complex, non-linear relations between the many variables of the system, the relationships between changes in particular systems properties and changes in fuel consumption and emissions cannot be figured out from the energy balance accounts, except in cases where the development in one particular property only is changed. Therefore, to perform sensitivity analyses regarding the effects caused by changes in particular properties, a series of scenarios in which only one property is changed in any one scenario must be computed. Thereupon, the comparative analysis programs mentioned in section 2.4 above can carry out the sensitivity analyses.

3.2 Thermodynamic efficiency and loss analysis

To improve the efficiency of an energy system means to reduce the losses which occur within the system or at the system boundaries. Therefore, what is relevant as regards the analysis of potential improvements of the systems efficiency is the identification of the losses which occur in the system in its present state. Moreover, when new energy sources are installed, new energy conversion units which enable the efficient utilization of these sources - i.e. units which keep the losses as low as practically possible - will, generally, be needed.

The biggest losses occur

- in combustion chambers (ovens, furnaces, piston engine cylinders) where air of a lower temperature is mixed with the very hot air in the flame and radiation from the flame is absorbed in the furnace or cylinder walls. The losses in electrochemical conversion processes in fuel cells are, generally, smaller than in internal combustion engines.
- in heat exchangers, in which heat is transmitted between fluids or air currents at high temperature differences.
- in electric radiators where electric power is converted to low-temperature heat. Regarding thermodynamic efficiency this heating method is equal to the generation of heat by the rotation of a propeller in a barrel of water.
- wherever fluids with different temperatures or different pressures are mixed. For instance when a hot exhaust gas mixes with the ambient air.

When any of these losses are reduced or eliminated, e.g. when oil- or gas-boilers or electric radiators are replaced by low-temperature district heating from an efficient cogeneration station, the efficiency of the system is improved, meaning that less fuel or less electric power from the energy sources is needed to meet the demands in the end-use system.

For each scenario, SESAM computes year by year the thermodynamic efficiency of the system as a whole. Generally, the efficiency is improved when individual boilers are replaced by district heating from cogeneration stations, electric radiators are replaced by thermodynamically more efficient means of heat supply, and the power rates of power and cogeneration stations (i.e. the ratio of electric power output to fuel input) are increased. However, as the power input to the system from fluctuating power sources (such as windmills and photovoltaic panels) increases, the efficiency tends to decrease. This is because new energy conversion and storage unit such as heat pumps and electrolytic converters for hydrogen production are needed for the regulation of power and heat supply to the end-use system in accordance with current demands. Each such conversion and storage unit introduces additional losses.

3.3 Cogeneration - a somewhat misleading word

Internal combustion engines and condensers in steam turbine plants must be cooled and considerable thermal potentials are available in the exhaust gas from engines and steam-boilers as well as from gas turbines. Hence, whenever electric power is generated by such machines there is a thermal potential available in the cooling circuits and the exhaust gases.

Cogeneration - which is a somewhat misleading word - simply means that the radiators in buildings are used to provide the necessary cooling of the engines and steam turbine circuits in power stations and that the thermal potentials in exhaust gases from power stations is utilised for additional heating of the radiator circuits - instead of cooling the machines by the ambient air, rivers or seawater.

In steam turbine circuits, the condenser temperature must be increased from about 15 to about 80 ºC. Thereby, the power rate, i.e. the ratio of power output to fuel input, is reduced by 10-20 percent. However, this reduction is amply compensated for by the replacement of district heating boilers and individual boilers in which the thermodynamic losses are excessive.

Naturally, if radiators in buildings are to be used for the cooling of power station circuits, power stations must be placed in the vicinity of built-up areas. This is why the decentralisation of power generation serves to improve the thermodynamic efficiency of the energy conversion and transmission system (see fig. 1 and 2). In areas with natural gas supply and rural areas where biomass fuels are available, the decentralisation may go as far as to the individual buildings (mini-cogeneration installations) and farms (e.g. woodchip fired Sterling engines).

4. Accuracy and Verification

A SESAM model of an energy system can be specified to any degree of accuracy and detail. It a question of the data available. Generally, the data entered into the database should be as detailed as the available statistical or measured data warrant. The reason for this is that if a high degree of detail is not required in the model in question, the SESAM programs can easily aggregate data. However, if aggregated data are entered into the database, new, more detailed data will have to be entered if more detailed specifications of the system as whole or particular subsystems are required at later stage.

For the purpose of examining alternative strategies for the future development of a national or regional energy system, the specification of the system to a high degree of detail and accuracy is not required. What is required is that the model represents the significant features and functional characteristics of the different parts of the system and that the computed results for the system in its present state correspond to the 'real' statistical values. Thus, for the present state of the system it should be verified that the computed values of the following quantities correspond to the 'real' statistical quantities recorded for each country, region, and particular local systems for which data are available:

- Total consumption of the different types of fuels used in stationary energy conversion units:
  - power stations
  - cogeneration stations
  - district heating boiler stations
  - individual boilers
  - industrial processes

- Total consumption of fuels used for transportation:
  - in cars
  - in buses
  - in lorries and trucks
  - in trains
  - in ships
  - in aeroplanes

- Total electricity production in
  - power stations
  - cogeneration stations
  - hydropower stations
  - windmills

- Total heat production in
  - cogeneration stations
  - district heating boiler stations

- Total electricity consumption in:
  - households, public buildings, shops, office buildings, etc.
  - electric radiators

- electric heat pumps
- industrial manufacturing
- transportation

The quantities mentioned above are measurable and they are to some degree of accuracy recorded in properly kept national statistics. Although the statistical values may deviate from the real values, they constitute the only basis for the assessment of the degree to which the computed results for the present state of the system correspond to the 'real' values.

However, the values computed by SESAM are inherently consistent with the specified technical properties of the energy conversion units, and the model ensures that the energy balance requirements for the system as a whole as well as for every subsystem and plant are fulfilled month by month. As the statistical values do not necessarily comply with these consistency requirements, deviations of the computed values from the statistical values may reveal inconsistencies in the statistical values rather than in the computed values.

If the data entered into the database represent the real energy system in its present state to a sufficient degree of accuracy, then the computed results can be verified by the inspection of the energy balance tables produced by SESAM.

Part Two. The Modelling of the Nordic Energy System

5. The Geographical Structuring of the Energy System

In order to take differences in climate, rural and urban geography, buildings, and means of heat supply into account, the model of the Nordic energy system has been divided into nine domains (see GEOSTRU.nrd and DOMAINSU.nrd[1]):

South Norway	South Sweden	South Finland	Denmark
Mid-Norway	Mid-Sweden	North Finland	
North Norway	North Sweden		

As long as there are no building registers available for Norway, Sweden and Finland, neither for the each country as a whole nor for each town or municipality, this division into domains can only be done in an ad hoc manner, namely simply by allocating a certain part of the population and a certain parts of the buildings (i.e. the floor area of buildings of different categories and with different types of heat supply) to each domain. Under the present circumstances regarding data availability, this is the only way to take into account the differences in the monthly average temperatures, the physical characteristics of the rural and urban buildings, the predominating means of heat supply, and the available fuels, such as natural gas and wood.

If data for the building stock (i.e. numbers and heated floor areas of buildings with different types of heat supply) are made available for the different cities, towns and rural areas, these data can be entered into the database and the domains can thereby be demarcated in accordance with the geographical data for each country and subdivided into local systems representing the particular cities, towns and rural areas.

Moreover, if the domains are geographically demarcated in this manner and subdivided into local systems, the particular power stations, cogeneration stations, district heating stations and the major industrial process plants can be allocated to the local systems where they belong. Also the so-called geophysical energy sources (hydropower, windmills, photovoltaic panels, see Energy Sources, section 10) can be allocated to particular local energy systems so as to facilitate the simulation of the energy-efficient local regulation of the utilization of available energy sources.

The geographical structure of the present model should, therefore, be considered a preliminary structure which should be amended when more accurate and detailed data for the building stock and its geographical allocations become available.

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[1] Here and in the following identifiers in capital letters with the extension .nrd (for Nordic) are names of files in the SESAM database for the Nordic energy system.

6. The End-use System. Buildings

The heat balance of buildings is computed on a monthly basis. The heat transmission to the surroundings due to the difference between the indoor and the outdoor temperature plus heat loss by ventilation is balanced against solar radiations through windows, heat from electrical appliances, heat from persons, and heat from radiators (thermal or electrical), stoves and fireplaces. The *net heat consumption* for room heating is defined as the heat from radiators, stoves and fireplaces, i.e. the residual when heat from the other sources has been subtracted from the heat transmitted to the surroundings.

Hence, in buildings wholly or partly heated by electric radiators, the total electricity consumption is divided into consumption in electrical appliances, which is determined by the appliances in use, and the residual consumption in radiators.

For each consumer category (see below), hot water consumption is computed on the basis of the number of persons occupying the buildings (number of square metres per person), the daily hot water consumption per person (litres/person per day), and the hot water and cold water temperatures.

6.1 Building categories

In a SESAM model, the building stock can be divided in to any number of different building categories, each category representing buildings with specific physical and architectural characteristics(see SESSETUP.nrd section 5 and EUSSETUP.reg). However, in the present Nordic model, because of the lack of data for buildings in Norway, Sweden and Finland, the building stock has been divided into only four building categories for each country:

	Code	Identifier
• existing detached houses	Dx	DETACH.reg
• existing multi-storey buildings	Mx	MULTIS.reg
• future detached houses	FD	FUTDET.reg
• future multi-storey buildings	FM	FUTMUL.reg

in Norway (x=N, reg= NOR), Sweden (x=S, reg= SWE), Finland (x=F, reg= FIN) and Denmark (x=D, reg= DEN) respectively:

Each of these building categories is specified by the following data (see SHBALANC.nrd):

- specific heat transmission through walls, windows, and ceilings per m^2 of floor area (W/m2*K).
- ventilation m^3/hour (monthly average values)
- solar influx per m^2 of floor area (monthly average values)

The thermal insulation of future buildings is assumed to be improved as compared with existing buildings.

6.2 Consumer categories

In a SESAM model, the consumers who occupy the buildings of different categories (or rather, the activities of persons at home or at work, which influence energy consumption) can be divided into any number of consumer categories. In the present model of the Nordic energy system, the consumers are divided into only four categories (see SESSETUP.nrd section 4 and EUSSETUP.nrd):

	Code	Identifier
Households	DW	DWELLINGS
Commerce, service and public institutions	CS	COM+SER+PU
Industry	IN	INDUSTRY
Other		

The data assigned to a consumer category comprise:

- Present electricity consumption (including electric heating), see GCDFACTO.nrd
- The present mix of electrical appliances, lamps and machinery in use (see Chapter 7 below)
- Hot water consumption (litres/per person per day), see SHBALANC.nrd section GENERAL
- Buildings occupied by the consumer category (see section 6.5 below)
- Future growth in the building stock occupied by the consumer category, see GCDFACTO.nrd and FUBLDSTK.nrd

6.3 Types of heat supply

In the present model of the Nordic energy system the following types of heat supply installations in buildings are specified (see SESSETUP.nrd section 10):

Already existing types:

Code	Type	Identifier	Text
DH	1	DH	'District heating'
NG	2	NGAS.BOIL	'Natural gas boiler'
OB	4	OIL.BOIL	'Oil boiler'
BB	4	BIOM.BOIL	'Biomass fired boiler'
EL	6	EL.HEAT	'Electric heating'
HP	7	HEATPUMP	'Individual heat pump'
NH	0	NO.HEATING	'No heating'

Future types:

Type	Identifier	Text
10	MINICG.GAS	'Mini cogeneration., gas fired'
10	MINICG.BIO	'Mini cogeneration., biomass fired'

In 'Electric heating' supplementary boilers are included. Mini-cogeneration units may be equipped with heat pumps for the regulation of ratio of power output to heat output.

The cogeneration or boiler stations which supply district heating to buildings in a particular area are specified in the District Heat Supply data file (DHSUPPLY.nrd).

6.4 The building register

The building register (BUILDIN.reg) contains the data which specify the composition of the present building stock by geographical location, building category, present means of heat supply, and consumer category. The register consists of a list of records each of which specify a particular group of existing buildings. The record format is:

EUS-district		Building Category	Floor area	Number of buildings	Present heat supply	Consumer category	Others, not used in the present model
<No.>	<Name>	<Code>	<Integer>	<Integer>	<Code>	<Code>	

In cases where the data are available, additional fields may be filled in, for instance the number of condemned buildings, the owner category (private, public), and a code referring to planned changes in heat supply. Moreover, floor area and number of buildings may be subdivided into two age-groups.

In the present model of the Nordic energy system, the end-use districts (EUS-districts) are identical to the geographical domains (see Chapter 5 above). If more detailed geographical data become available, these domains can be subdivided into specific urban or rural areas.

6.5 Heat consumption

For each building register record, the net heat consumption for room heating in a certain month in the buildings specified in the record is computed as

Net heat consumption for room heating =
\+ (1) heat transmission and ventilation losses through walls, windows and ceilings
\- (2) heat from solar influx through windows
\- (3) heat from persons
\- (4) Net heat contribution from electrical appliances, lamps and machinery

[Data for (1), (2), (3) and (4) in SHBALANC.nrd.. Data for electricity consumption in GCDFACTO.nrd and ELDATA.reg]

(1) is computed using
- the specific physical heat loss data for the building category in question (W/m2*K)
- the monthly data for
  - the outdoor temperature for the geographical domain in question
  - the indoor temperature specified for the building category (see section 6.1).

(2) the monthly values (W/m^2 of floor area) are given for each building category.

(3) the average number of square metres per person in the building category in question is computed on the basis of the total population and relative distribution numbers given for each building category.

(4) is computed as a specified percentage of the monthly electricity consumption in electrical appliances, lamps and machinery (see SHBALANC.nrd section GENERAL) allocated to the consumer category (as by square metre of floor area). See section 7 below.

The present net heat consumption for room heating is assigned to the type of heat supply installation given in the building register record (Present heat supply). In future the means of heat supply may change, see section 6.7 below.

Heat consumption for hot water may be partly covered by solar absorbers (see section 6.6 below) and, for the consumer category in question, a certain portion of the heat consumption for hot water (litres/person per day at the given hot water and cold water temperatures) may be specified to be heated in electric hot water tanks (see GCDFACTO.nrd). The remainder is assigned to the type of heat supply installation specified in the building register record. In buildings heated by electric radiators, all the hot water is assumed to be heated in electric hot water tanks.

In this manner the heat consumption for room heating and hot water to be covered by the type of heat supply installation given in a building register record is computed. Adding up the results for all records with the same type heat supply installation, the total monthly heat demand to be covered by that type is found for each EUS-district and for the system as a whole.

6.6 Solar absorbers

Within a certain geographical domain a certain part of the monthly heat supply for hot water in buildings with different types of heat supply installations can be covered by solar absorbers.

For example, in the allocation specifications in the ALLOCAT.nrd file it may be specified that 10% of the heat supply for hot water in July in buildings in South Sweden heated by natural gas boilers is to be covered by solar absorbers. In the other months of year, the heat supplied from solar absorbers is then computed in proportion to the average insolation in relation to the average insolation in July.

For each geographical domain the different types of solar absorbers used (if any) must be declared in the DOMAINSU.nrd file by unit type and a reference to an allocation table.

6.7 Future development

Alternative scenarios for future changes in heat supply installations are specified in the *Heat Supply Transition* tables (HSTRANSI). In each of these tables alternative future changes for one or more geographical domains, one or more local systems within the domains, and one or more consumer categories are specified as sets of alternative time-series data.

Likewise, alternative scenarios for future changes in the physical properties of buildings (specific heat loss by transmission and ventilation, solar influx) as well as changes in indoor temperatures are specified as time-series data in the specific heat balance records for the different building categories (SHBALANC.nrd).

Alternative scenarios for the overall future growth in the building stock are specified by consumer category in the *General-Consumption-Development-Factors* file (GCDFACTO.nrd). The distributions by geographical location and building category are specified in the *Future-Building-Stock* file (FUBLDSTK.nrd). The heat consumption in future buildings is computed in the same manner as for existing buildings. Alternative scenarios for the means of heat supply in future buildings are specified in the HSTRANSI.nrd file.

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Results: ALLreg.sc &

	ALLDOMAI.sc	Heat consumption and hot water consumption by consumer category
	HEATBALA.sc	Monthly heat balances for the different building categories
	HEATSUPP.sc	Heat supply by heating installations
	FLOORARE.sc	Floor areas by consumer category and building category

Programs for additional documentation:

SESAM52	Monthly energy balance tables
MAINTABS:	MAIN1reg.txt, MAIN2reg.txt, MAIN3reg.txt (for each country: reg), MAIN1TAB.txt, MAIN2TAB.txt, MAIN3TAB (for the Nordic system as a whole): Total thermal and electric heat supply. Relative changes in heated floor areas and net heat consumption per square metre of floor area. Values for several scenarios in parallel for comparison.

7. The End-use System. Electrical Appliances, Lamps and Machinery

For each consumer category, the electricity consumption in electrical appliances, lamps and electrical machinery (except specific industrial processes, see Chapter 11) in the first year in the scenario period is computed by subtracting electricity consumption in electric radiators for room heating from the total electricity consumption given in the *General-Consumption-Development-Factors* file (GCDFACTO.nrd).

Generally, only data for the total electricity consumption by a certain consumer category are available. Therefore, for each month electricity consumption for room heating W_{heat} has to be computed from the equations:

$$W_{total} = W_{heat} + W_{appl}$$

$$Q_o = W_{heat} + \alpha W_{appl}$$

or

$$W_{heat} = (Q_o - \alpha W_{total}) / (1 - \alpha)$$

where

W_{total} is the total electricity consumption

W_{appl} is the consumption in appliances, lamps and machinery

Q_o is the heat loss from the buildings belonging to the consumer category minus heat from solar influx and persons

α is the percentage of W_{appl} which effectively contributes to room heating.

7.1 Types of appliances, lamps and machinery

The different types of units (refrigerators, kitchen stoves, washing machines, TV sets, etc.) are specified in the ELAPPLIA.nrd file.

The units in use in the first year in the scenario period are specified by:

- average specific electricity consumption (kWh/year) by year of purchase.
- average technical life-time and standard life-time deviation, assuming a Gaussian distribution of the life-time of the type of unit in question.

In the different scenarios more energy-efficient units are assumed to penetrate the market at a quicker or slower rate (see section 7.4). Hence, regarding the units purchased in future, three models of different qualities as regards energy efficiency are specified for each type of unit:

MODEL0 represents the average efficiency of units purchased in the first year of the scenario period.
MODEL1 represents units which are more energy efficient than MODEL0
MODEL2 represents units which are more energy efficient than MODEL1

Thus, MODEL1 and MODEL2 represent successive future efficiency enhancements. The specific annual consumption for these models is given as a percentage of the MODEL0 consumption.

As for the existing units, the average technical life-time and the standard deviation in life-time is specified for MODEL0, MODEL1 and MODEL2 units.

For a certain type of unit, the electricity consumption depends on the frequency of use. Therefore, alternative values of a *“behavioral consumption factor”* can be specified. For example, a factor of 0.85 means that the average specific electricity consumption in the type of unit in question is reduced by 15% through to the end of the scenario period. Different factors may be chosen in the different scenarios considered (three alternative values).

7.2 The ‘mix’ of appliances, lamps and machinery in use

For each consumer category, the ‘mix’ of units of different types installed in the first year of the scenario period, i.e. the average number of units of a certain type and age per consumer unit (household, office building, etc.), is specified in the ELINSTAL.nrd file. Moreover, the annual variation in electricity consumption is specified for the different types of units (by references to record numbers in the *Annual-Variations* file ANNUVARI.nrd).

For each type of unit, the age distribution in the first year, i.e. the average number of remaining units purchased in the earlier years, is computed on the basis of the technical life-time distribution specified in the ELAPPLIA.nrd file.

For each consumer category, the electricity consumption in the first year of the scenario period W_{appl} (see above) is in this manner distributed by type and age of the units in use.

7.4 Future development

For each consumer category, the future development in electricity consumption is determined by

- the growth in the number of consumer units (households, shops, etc.) The growth is assumed to be proportional to the growth in the building stock as specified in the *General-Consumption-Development-Factor* file GCDFACTO.nrd.
- the changes in the number of units of different types per consumer unit and thus the changes in the ‘mix’ of appliances by types and age of the different types of units as existing units are replaced by new MODEL0, MODEL1 or MODEL2 units and additional new units of these models are purchased.

The rates of replacements of existing and future units and the rates at which future models (MODEL1 and MODEL2) penetrate the market may vary in the different scenarios. The specifications of these rates are found in the ELDATGEN.nrd file

(Electricity Data, General). For a description of the meaning of the tables contained in this file, see the SESAM manual, Chapter 8.

Results: ALLreg.sc &

ALLDOMAI.sc	Total electricity consumption in buildings by consumer category, in industrial processes, etc.
SUMMARY.sc	Total electricity consumption and production

Programs for additional documentation:

SESAM52	Monthly energy balance tables
MAINTABS:	MAIN1reg.txt, MAIN2reg.txt, MAIN3reg.txt (for each country: reg), MAIN1TAB.txt, MAIN2TAB.txt, MAIN3TAB (for the Nordic system as a whole): Total electricity consumption for transportation, in industrial processes, for electric heating, stand-alone heat pumps, and other consumption. Relative changes in total stocks of electrical appliances, electricity consumption, and the average efficiency of electrical appliances. Values for several scenarios in parallel for comparison.
EL1	Appliances. Stock development, energy-efficiency mix and specific consumption for the different types of appliances. Plot-display.
EL2	Total electricity consumption development by country. Year by year for each consumer category.
EL3	Changes in the energy-efficiency mix of appliances. Time-series of replacements of existing appliances by MODEL0, MODEL1 and MODEL2 appliances

8. The End-use System. Transport

In a SESAM model transportation is an integral part of the end-use system(see fig. 1). The transportation subsystem represents the different types of motorized vehicles (cars, buses, trains, trams, ships, aeroplanes, etc.) as by:

- the technical properties of the different types of vehicles
- the transportation volumes by type of vehicle (person-kilometres or ton-kilometres per year).

The motive power to the vehicle shafts is generated in liquid-fuel or gas driven internal combustion engines, fuel cells, or electric motors.

8.1 Types of vehicles

The names and type-identifiers of present and future the vehicles included in the model are declared at the bottom of the *Domain-Supply* file DOMAINSU.nrd. In the present model of the Nordic energy system, the following types of vehicles are declared:
CAR BUS PTRAIN (P for Person) GTRAIN (G for Goods)
VAN LORRY AIRPLANE CARGOSHIP
FERRY

The technical properties and the utilization of these vehicles and alternative scenarios for the future development of these properties are specified in the VEHICLES.nrd file. The motor specifications are found in the *Conversion-Unit* file CONVUNIT.nrd.

The future changes in the technical properties of vehicles concern:

- Changes in the percentages of vehicles powered by different types of liquid-fuel or gas driven internal combustion engines or fuel cells.
- Changes in the percentages of vehicles powered by electric motors and the specific power conversion loss (electric to mechanical) in the motors (in battery powered vehicles including charging and discharging losses in batteries).

Moreover, for each type of vehicle, future reductions in the shaft power per unit of transportation (personkilometre or ton-kilometre) are specified in the VEHICLES.nrd file. These reductions can be obtained by

- vehicle weight reductions,
- reductions of air and/or wheel-road-surface resistance,
- an increase in the average number of persons transported in each vehicle,
- fewer half-loaded or unloaded lorry-kilometres,

8.2 Transportation volumes by type of vehicle

Transportation volumes are the quantitative multipliers which are applied to the qualitative technical vehicle specifications to obtain the fuel and electricity consumption in vehicles: For each month the fuel and electricity consumption in a certain type of vehicle is proportional to the transportation volume specified for that type for the year in question.

For each of the four Nordic countries, the present transportation volumes and alternative scenarios for the future development in the volumes are given in the TRANSPVO.nrd file.

Monthly variations in transportation volumes can be specified in the CONSRATE.nrd file.

8.3 Future development

Future changes in fuel and electricity consumption in vehicles are determined by

- Changes in transportation volumes by type of vehicle
- Changes in the technical properties, the means of propulsion, and the utilization of the different types of vehicles

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Results:

SUMMARY.sc	Electricity consumption for transport and fuel consumption by type of vehicle.
TRANSPOR.sc	Changes in transportation volumes and specific technical parameters for each type of vehicle.

Programs for additional documentation:

SESAM52	Monthly energy balance tables. Electricity consumption for transport
MAINTABS:	MAIN1reg.txt, MAIN2reg.txt, MAIN3reg.txt (for each country: reg), MAIN1TAB.txt, MAIN2TAB.txt, MAIN3TAB (for the Nordic system as a whole):. Total electricity consumption for transportation. Relative changes in the distribution of transport volumes by means of transportation. Values for several scenarios in parallel for comparison.

9. Energy Sources

The climate and the life on this planet is conditioned by the solar radiation. The sun is the source of life on Earth. Our economy is solar, but for a short period of time - a short anomaly in the history of this planet - it has become distorted by technologies which have made fossil fuels easily recoverable.

The minute portion of the energy radiated by the sun which is absorbed by this planet is enormous as compared to the energy flows in its anthropogenic energy systems. Even the small portion of the insolation which propels the ocean currents, sets the atmosphere in motion, and nourishes the biological photosynthesis surpasses the energy flows in anthropogenic energy systems by an order of magnitude.

However, although abundant solar radiation and wind is around us for free, it takes soil with green plants to convert solar energy to food, livestock and fuel wood; it takes sail-masts and windmills to convert wind energy to motive power; and it takes dams and hydro-turbines to make use of the rain- and snowfall in the highlands and mountains. Hence, while sunshine, wind and precipitation constitute the basic environmental conditions for life on Earth, the energy sources for the life in human settlements are cultivated fields, forests, the fish in the seas, lakes and rivers, and human artefacts as windmills, photovoltaic panels, and hydropower stations. And, alas, in our time, fossil fuels and nuclear power.

With respect to the technological properties of relevance to energy systems analysis, the energy sources available for the operation of the energy systems of the present human habitats are classified as

- Fuels, i.e chemical energy sources in the form of solid, liquid or gaseous substances with a chemical potential with respect to the atmosphere
- Fissionable material for nuclear reactors
- Geo-physical electric power sources: Windmills, photovoltaic panels, hydropower stations, and, possibly, wave machines, which serve to sustain the electric potential in the grid.

In contrast to these chemical and electric energy sources, which are available to the energy system as a whole, solar absorbers provide low-temperature thermal potentials, which contribute to the sustaining of a temperature difference in hot water supply circuits or central heating circuits. Thus, like solar radiation through windows, individual solar absorbers serve to sustain thermal potentials between buildings and the environment. An individual solar absorber is therefore considered to be an integral part of a building. It is not an energy source available to the energy system as a whole. (See section 6.7)

Likewise, a collective solar absorber plants for district heating is considered to be an integral part of the district heating network. It is not an energy source available for any other purpose.

The same is the case for geothermal reservoirs, which at certain locations in the Nordic countries can be utilised as heat reservoirs for heat pumps or, if the reservoir temperature is high enough, directly for low-temperature district heating.

9.1 Chemical potentials: Fossil fuels, peat, waste, and biomass fuels

The different types of fuels available as energy sources in the model are declared in the SESSETUP.nrd file, section 3.

In the present model of the Nordic energy system the following types of fuels are declared:

Fossil fuels: COAL,
ORIMULSION, FUELOIL, GASOIL, PETROL, DIESEL,
NATUR.GAS
Peat: PEAT
Waste: WASTE
Biomass fuels: STRAW+WOOD
BIOGAS

While no restrictions are imposed on the amounts of fossil fuels used in the different scenarios, the amounts of peat, waste, and biomass fuels available presently and in the future are specified in the FUELS.nrd file.

For fuels of the types peat, waste, and biomass, the actual amount used in a certain year in the scenario period is determined by the production of electricity and/or heat in the energy conversion units using the fuel in question (as specified in the CONVUNIT.nrd file). The actual amount cannot exceed the total amount available. If the total amount available does not suffice to produce the electricity and/or heat to be delivered from these units, the available amount is distributed among the units using the fuel in proportion to the units' production or in accordance with priority specifications given in the FUELS.nrd file. For each conversion unit, the remaining fuel consumption is covered by one or more types of fossil fuels as specified in the CONVUNIT.nrd file.

The heat of combustion (MJ/kg) and the specific emission data (CO_2, SO_2, ash, slag and particles) assigned to the different fuels are found in the FUELS.nrd file.

SO_2: In particular combustion processes, e.g. fluidised bed combustion, the SO_2 emission can be lower than the standard value for the fuel in question. Therefore, in the specifications of an energy conversion units with a combustion chamber (in CONVUNIT.nrd), the specific SO_2 emission is specified as a percentage of the standard value.

Particles: Likewise, for the particular conversion units, the actual emission of particles, which can be reduced by means of filters, is specified in the CONVUNIT.nrd file as a percentage of the standard value.

NO_x: The specific NO_x emission is, generally, determined by the combustion process as well as by the fuel combusted. Therefore, for each combustion process (in CONVUNIT.nrd), the specific NO_x emission is specified as g/GJ.

9.2 Fissionable material for nuclear reactors

Neither the amounts of fissionable material used in nuclear reactors nor the amounts of radioactive waste to be deposited is accounted for in the model. A nuclear power station is simply treated as an electricity generating unit - like an energy source.

9.3 Geo-physical power sources: Hydropower, windpower, photovoltaic panels

The geo-physical power sources available in the different domains of the Nordic energy systems model are declared in the DOMAINSU.nrd file by

- type of energy source. The source types (here HYDRO, WIND and PVP) are declared in the SESSETUP.nrd file, section 1.
- type of unit. The different energy source units are specified in the GEOSOURC.nrd file.
- a reference to an allocation table. In a SESAM model, the power from a geo-physical power source or the aggregate representation of several such power sources must be allocated to one or more energy conversion stations declared in the DOMAINSU.nrd file and specified in the CONVSTAT.nrd file. The reason is that the regulation of power and heat production with respect to the power input from these energy sources may be assigned to the conversion stations to which they are allocated. The allocations are specified in allocation tables in the ALLOCAT.nrd file.

In the present model all the Norwegian hydropower stations are represented by one aggregate station HYDRO.NOR, allocated to the domain Mid-Norway (MID.NOR). Likewise, Swedish hydropower is represented by one aggregate station HYDRO.SWE, allocated to the domain Mid-Sweden (MID.SWE) and Finnish hydropower is represented by HYDRO.FIN allocated to North Finland (NORTH.FIN). (See DOMAINSU.nrd.)

In the present model also the windmills and the photovoltaic panels are represented by one aggregate unit for each country: WIND.M.NOR, WIND.M.SWE, WIND.N.FIN, WIND.DEN and PVP.S.NOR, PVP.S.SWE, PVP.S.FIN, PVP.DEN (M for Mid, S for South).

In a more detailed model, several hydropower stations, windmill parks or groups of windmills and photovoltaic installations allocated to different domains can be specified.

The specifications of the different types of geo-physical energy source units are found in the GEOSOURC.nrd file:

- *Hydropower units*: One unit is one station or the aggregated representation of several stations. A unit is specified by the annual distribution of its electricity production, i.e. the average production month by month (GW average). Moreover, a maximum power transmission rate from the station (GW, higher than or equal to the average production) is specified. If for a certain month the maximum transmission rate is higher than the average production, the production may vary from time to time during the month.

  For hydropower, production data are specified for years with normal, low and high precipitation, respectively.

- *Windpower units*: One unit is 1 MW of installed capacity of a certain type of windmills at a certain geographical location or an aggregate of several types at different locations. A windpower unit is specified by its specific average monthly electricity production (MW average per MW of installed capacity).
- *Photovoltaic panel units*: One unit is 1000 m^2 of panel. A photovoltaic unit is specified by its specific average monthly electricity production (kW average per 1000 m^2).

The total number of energy source units of different types allocated to different energy conversion stations at different times are given in the ALLOCAT.nrd file. In the present model the conversion stations named HYDRO.M.NOR, HYDRO.M.SWE, HYDRO.N.FIN are dummy stations with no electricity or heat production. This means that the power from the energy source units is transferred directly to the electric transmission grid. In Denmark windpower is allocated to a coal-fired backup station COALBCKDEN, which serves as the backup power station for the whole Nordic energy system.

9.4 Wave machines

Electricity production in wave machines can be specified in the same manner as production in windmills.

9.5 Future development

The future development in the consumption of fossil fuels is determined by the power and/or heat production in the different types of fossil fuel fired stationary energy units and the shaft power generated in the different types of vehicles, ships and aeroplanes furnished with different types of fossil fuel-driven motors.

Likewise, the future development in the consumption of waste and the different types of biomass fuels is determined by the production in energy conversion units fuelled by these types of fuels. However, the consumption of biomass fuel of a certain type cannot exceed the maximum available amount given in the FUELS.nrd file (see section 9.1 above).

Alternative scenarios for the future development in the capacities of windmills of different types and the installed areas of photovoltaic panels are specified in the ALLOCAT.nrd file, while future changes in hydropower capacities are specified in the GEOSOURC.nrd file.

Results:

SUMMARY.sc	Total fuel consumption by type of fuel in stationary units. Total fuel consumption for transportation and fuel consumption for transportation by type of vehicle and by type of fuel. Total electricity generation in windmills and photovoltaic panels

EMISSreg.sc and
EMISSION.sc Fuel consumption and emissions for the conversion station groups specified in the CSGROUPS.reg and the CSGROUPS.nrd files.

ALLreg.sc and
ALLDOMAI.sc Windpower, hydropower and photovoltaic panels

Programs for additional documentation:

SESAM52 Monthly energy balance tables.

MAINTABS: MAIN1reg.txt, MAIN2reg.txt, MAIN3reg.txt (for each country: reg), MAIN1TAB.txt, MAIN2TAB.txt, MAIN3TAB (for the Nordic system as a whole):
Fuel consumption by kind of fuel. Power generation in windmills, hydropower stations and photovoltaic panels.
Values for several scenarios in parallel for comparison.

10. The Energy Conversion and Transmission System (ECTS)

The energy conversion system comprises the different types of energy conversion processes (see fig. 4) in which

- chemical potentials (fuels) are converted into electrically or mechanically transmitted power and/or thermal potentials (heat),
- an electric potential is converted into a thermal potential (in a heat pump or an electric resistance coil),
- an electric potential is converted into mechanically transmitted power for the propulsion of vehicles, or
- an electric potential is converted into a chemical potential in the form of hydrogen or a chemical compound.

The transmission system comprises district heating networks and the electric grid.

Large solar absorbers connected to specific district heating stations or, on the small scale, solar absorbers connected to central heating installations in individual buildings, are components dedicated to particular plants or installations.

Also fermentation processes in which biomass is converted into biogas are considered to be parts of the energy conversion system.

Heat buffer tanks for the diurnal regulation of heat supply to district heating networks are integral parts of cogeneration stations and seasonal storage tanks are parts of large solar absorber installations (see fig. 2).

10.1 Conversion stations and conversion units

A conversion station represents a plant (a power plant, cogeneration plant, or a district heating station) or, on the small scale, an individual installation (a mini-cogeneration or a boiler installation for central heating). The existing conversion stations or types of stations as well as the types of stations which may be built in future are specified in the CONVSTAT.nrd file.

A conversion station comprises one or more energy conversion units of the following categories (see fig. 2 and 4):

- *Motors*. "Motor" is the general term used for units which convert a chemical potential (fuel) to an electric potential or to mechanically transmitted power: Steam and gas turbine units and piston engines driving electric generators and engines in vehicles. Fuel cells in which a chemical potential is directly converted into an electric potential also belong to this category.
- *Heat pumps*. A heat pump is the general term for units which convert an electric potential or mechanically transmitted power to a thermal potential (heat). Such heat pumps are driven by compressors. Absorption heat pumps, which are driven by thermal potentials, may be parts of conversion stations, in which case they increase low-temperature heat production by the utilization of the high-temperature thermal potential in exhaust gasses.
- *Boilers*. "Boiler" is the general term for units which converts a chemical potential (fuel) into a thermal potential.
- *Solar absorber plants*. In cogeneration or boiler stations for district heating the

return water in the district heating network may be pre-heated by heat from solar absorber plants with seasonal storage reservoirs.

- *Biogas plants*. In a biogas plant fermentable biomass and/or organic waste is converted into biogas.
- *Electrolytic converters*. In an electrolytic converter an electric potential is converted into a chemical potential in the form of hydrogen.

In the conversion station records in the CONVSTAT.nrd file, the types of energy conversion units used in a particular station are named by identifiers (e.g. GAS.ENGINE, OIL.BOILER, INDIV.HP). The identifiers refer to records in the CONVUNIT.nrd file, in which the technical data for the different types of units are given.

For conversion stations connected to district heating networks, the CONVSTAT-records contain a reference by identifier to a network specification record in the DHNETS.nrd file.

For conversion stations with a biogas plant attached, the CONVSTAT-record contains specifications of the biomass used in the plant and a reference by identifier to a record in the BIOGASPR.nrd file in which the technical specifications of the biogas plant is given.

10.2 Individual installations

Individual energy conversion stations are

- boilers for central heating, wood fired ovens and stoves, etc. and
- mini-cogeneration installations

The different types of individual installations are declared by identifier in section 10 of the SESSETUP.nrd file (see section 6.4 above). The identifiers refer to records in the CONVSTAT.nrd file. The types of installations used in the different geographical domains are declared in the DOMAINSU.nrd file.

10.3 Power stations

A power station is a conversion station consisting of one or more motors, for example a steam turbine plant with a low-temperature condenser, a gas engine, a stack of SOFC fuel cells, or a nuclear power station.

10.4 Cogeneration stations

A cogeneration station is a power station which is cooled by the water flowing in a district heating network or a central heating circuit, i.e. by heat radiation and convection from radiators for room heating. Also the hot exhaust gas or flue gas from motors may by means of heat exchangers be cooled down by the district heating or central heating flows and thus contribute to room heating.

A cogeneration station may be equipped with a heat pump for the regulation of the ratio of power output to heat output in accordance with the electricity and heat demand, see figs.2 and 4.

Normally a cogeneration station is equipped with one or more boilers for backup and additional heat output in peak heat demand hours.

Also, solar absorber panels connected to a station's district heating circuit for additional heat supply may be specified in the CONVSTAT:nrd record as belonging to the conversion station.

A cogeneration station may be wholly or partly fuelled by a biogas plant. The mix of fermentable biomass substances used in a particular type of cogeneration plant is specified in the CONVSTAT.nrd record for the type of plant in question. The CONVSTAT.nrd record must also contain a reference to a record in the BIOGASPL.nrd file, in which the technical parameters for the type of biogas plant used are specified.

10.5 District heating stations

A district heating station consists of one or more boilers connected to a district heating network. The different types of district heating stations are specified in the CONVSTAT.nrd records. A record specifying a district heating station may contain the same units as a record specifying a cogeneration station, except motors.

10.6 Conversion of electric power to chemical or electrochemical potentials for vehicles

As oil supply becomes restricted because of a decline in global oil production, an increasing number of vehicles must directly or indirectly be powered by electricity. Electric trains, trams, and trolley buses are directly powered by electricity from overhead wires or power rails while battery powered vehicles are linked to the power grid only when the batteries are being charged (see section 10.9 below). Electric power can, however, also be transferred to vehicles as chemical potentials in the form of hydrogen, methanol, magnesium hydrate, and others, produced in electrolytic converters or other electrochemical processes. By oxidisation in combustion engines or fuel cells such chemicals can generate mechanical or electric motive power in vehicles. Another possible option is to use electric power to reduce zinc oxide to zinc and subsequently generate electric power in a galvanic fuel cell where the oxidisation of zinc is accompanied by an electric current.

Conversion of electric power to chemical or electrochemical potentials should take place only at times when the power delivered to the grid from windmills, photovoltaic panels, and cogeneration stations plus the available power from hydropower stations exceeds electricity demand - available power from hydropower stations being the power which can be produced a the time without compromising the production capacity needed at other times, see section 10.1 below. Otherwise, one chemical potential, e.g. natural gas, will be used to generate electric power in power or cogeneration stations at the same time as electric power is converted to another chemical potential. This is clearly a wasteful manner of operating the energy system. Natural gas can be used directly in vehicles. The SESAM program procedures which emulate the regulation of power generation and the use of power in heat pumps and electrolytic or electrochemical converters minimize the occurrences of a such wasteful operational coincident.

In a SESAM model the transfer of electric power to vehicles as chemical potentials is represented by the generation of hydrogen in electrolytic converters even though the transfer may take place by means of another chemical substance which are easier to store and transport.

In electrolytic converters an electric potential between the anode (+) and the cathode (-) is converted into a chemical potential as the water molecules are split into hydrogen and oxygen, hydrogen being released at the cathode, oxygen at the anode. In a fuel cell the process is reversed, the chemical potential between free hydrogen and free oxygen being converted into an electric potential.

Electrolytic converter units are specified by their conversion efficiency, i.e. the ratio of electricity input to the available chemical potential of the hydrogen produced. Also the heat from cooling circuits available for district heating or central heating is specified relatively to the electricity input.

The conversion of a chemical potential to mechanical power to the wheels of vehicles taking place in “motors”, which are either combustion engines or fuel cells+electric motors, is specified only by the conversion efficiency, i.e. the ratio of power output to the chemical input potential (measured as exergy).

The specifications of electrolytic converters and “motors” are found in the CONVUNIT.nrd file.

If electric power supplied to the grid in excess of electricity demand should at all times be utilised in electrolytic converters - also when short-lasting peaks in excess production occur - then the required total capacity of electrolytic converters would become excessive. Therefore, a minimum utilization of electrolytic converters (hours per year) is specified in the LOADPRIO.nrd file.

No specifications of a future infrastructure for hydrogen production and distribution exists. Therefore, in the SESAM model it is assumed that electrolytic converters are located at cogeneration stations where the heat from the converter’s cooling circuits can be utilised for district heating. Thus, the SESAM programs distribute electrolytic convertion capacities among cogeneration stations in proportion to the stations’ annual district heating production.

It should be noted, that chemical potentials (fuels) and electrochemical potentials (e.g. in the form of zinc) produced by means of electric power should be used in vehicles - not recycled into power or cogeneration stations. The recycling entails additional losses

10.7 District heating networks

In the CONVSTAT.nrd file, each record specifying a cogeneration or district heating station must contain a reference (by an integer number or a name) to the record in the DHNETS.nrd file, in which the properties of the district heating network connected to the station is specified.

A district heating network is specified by
- the monthly variations of the forward and the return temperatures and the temperature in the soil or the air surrounding the pipes
- a heat loss factor which specifies the relative heat loss in the month where the highest heat loss occurs (relative to the heat transmitted)
- the power consumption in pumps (kW per kW heat transmitted)

On the basis of these data, the relative heat loss in the different months of the year is computed.

When a district heating network is extended and buildings outside the range of the existing network are connected, the heat loss is increased in proportion to the number of additional buildings connected. In the GEOSTRU.nrd file it may be specified that only a certain percentage of the buildings within the range of a district heating network are presently connected to the network. When more buildings are connected in future, it is assumed that the network is not extended before all buildings within the range of the existing network are connected.

A district heating network may be divided into a primary transmission network and secondary connection networks to individual buildings or groups of buildings. For the different local energy systems, end-use districts and building categories, references to the specifications of secondary district heating networks (in DHNETS.nrd records) may be entered into the GEOSTRU.nrd file.

10.8 Electric grids and power transmission lines

A SESAM model does not comprise the representation of electric grids and transmission lines. However, the power loss in the electric grids and transmission lines is computed using loss factors given for each conversion station in the CONVSTAT.nrd file records.

10.9 Propulsion engines and electric motors for transportation

For the different types of vehicles declared in the TRANSP.reg sections at the bottom of the DOMAINSU.nrd file, the distribution of shaft power by types of engines and electric motors is specified in the VEHICLES.nrd file. The engine specifications are given in the CONVUNIT.nrd file.

10.10 The allocation of power generation

For each month (m) electricity consumption CON(m) in the end-use system (including consumption in electric radiators, individual heat pumps, and industrial consumption) must be balanced against production in:

- POW(m): power stations
- COG(m): cogeneration stations (possibly with heat pumps for the regulation of the ratio of power to heat output)
- WPh(m): windmills and photovoltaic panels (as specified in the GEOSOURC.nrd and the ALLOCAT.nrd files)
- HYD(m): hydropower stations (as specified in the GEOSOURC.nrd file)
- IMP(m): plus/minus electricity import (+)/export (-). In the Nordic energy systems model no import i specified.

Let COG_O (m) denote the so-called heat-bound electricity production in cogeneration stations, i.e. the electricity production determined by the required heat production when no heat pumps are running.

Then, if consumption exceeds minimum production:
$CON(m) > COG_O(m) + Wph(m) + HYD(m)$

additional power ADD(m) must be produced (assuming that IMP(m) = 0):

$$ADD(m) = CON(m) - COG_O(m) - Wph(m) - HYD(m)$$

The additional power generation is allocated to the different power and cogeneration stations in accordance with relative priority numbers specified in the ELPRIO.nrd file. For cogeneration stations, the priority numbers are multiplied by the stations' relative heat production (i.e. the station's heat production divided by the total heat production in the area) so as to avoid the allocation of large portions of the additional electricity production to small stations.

If, on the other hand, consumption is less than minimum production:
$CON(m) < COG_O(m) + Wph(m) + HYD(m)$

i.e. ADD(m) < 0, then the available heat pumps are used to reduce the electricity production in cogeneration stations. If production still exceeds consumption when the heat pumps installed in the different conversion stations produce as much heat as they possibly can (as restricted by heat demand and maximum condenser temperatures), then the excess production is used in electrolytic or electrochemical converters or exported out of the system.

Electric power to be used in heat pumps is allocated to the heat pumps in the different energy conversion stations as specified in the ELPRIO.nrd file (in the same manner as for power generation).

10.11 Required energy conversion unit capacity estimates

For economic cost computations - but not for the monthly energy balance accounts - the energy conversion unit capacities (in MW) required for the operation of the energy system must be estimated.

A monthly energy balance accounts is the results of the integration over the month of the many fluctuating energy flows in the system as functions of time. Assuming that the system is in the same state at the beginning and at the end of the month, the integral values (in MWhours) equal the average monthly values (in MW) multiplied by the number of hours in the month. Hence, given the monthly average values for the exogenous parameters, the average monthly values of the energy flows in the system can be computed.

Thus, for given technical and structural properties of the energy system, the monthly energy balance accounts depend on the monthly average values of the exogenous parameters only. However, for these average values to materialise as integrals of the many fluctuating energy flows, the capacities of the energy conversion units must be sufficient to handle the flow variations occurring in the course of time, i.e. to handle the many different combinations of energy flows which occur because of diurnal climatic variations (outdoor temperature, wind, solar influx) and diurnal variations in electricity and heat demand at the different times of the year.

In order to assess the energy conversion unit capacities, heat storage capacities, and the capacities of flue gas purification plants which are required in a certain year in order to handle these variations, the diurnal energy system flow variations are simulated at short time-steps under different load variations, i.e. different combinations of the diurnal variations in

- electricity generation in windmills
- solar radiation reaching photovoltaic panels
- electricity demand in the end-use system
- heat demand in the end-use system

For each year in the scenario period, SESAM simulates the diurnal energy flows at short time steps (e.g. 15 or 30 minutes) under 36 characteristically different *load variations*, i.e. different combinations of the different diurnal average values and the different diurnal variations and of the four variables, namely:

- twelve different combinations of
  - average values and diurnal variations of electricity demand and heat demand and
  - diurnal variations in electricity production in windmills and photovoltaic panels,

  namely one combination for each month of the year
- three different combinations of average electricity production in windmills and photovoltaic panels (weak, medium and strong wind and sun).

The diurnal variations entered into the capacity computations are specified in the DIURVAR.nrd file. The annual and diurnal variations can be displayed by running the

SESAM203 program (see the program menu).

Combined with the different average values of the variables, the diurnal variations specified for the computations represent should cover a wide spectrum of different load variations. Provided that this is the case, an energy conversion system whose units have sufficient capacities to handle the 36 different load variations in an efficient manner will have sufficient capacities to handle most of the load variations occurring during the year in an efficient manner. Should the capacities be insufficient for the handling of some extraordinary, short-lasting load variations, backup facilities are assumed to be available as specified in the CONVSTAT.nrd records.

That the load variations are handled in an efficient manner means that the different types of energy conversion stations are utilised in such a manner that the rate of power generation (in MW) is kept as low as possible (i.e as constant as possible) without unduly compromising the thermodynamic efficiency of the system. If cogeneration stations with heat pumps are installed in the system, this can to some extent be achieved by the regulation of the ratio of power to heat output from these stations, using the heat pumps at times when excess power is available. In the same manner electrolytic or electrochemical converters are used to utilise excess power, see section 10.10 above..

Results of these very complicated simulation procedures can been found in the POWERRAT.sc and ELBALANC.sc result files. Diurnal production variations in the different power and cogeneration stations can be displayed by means of the SESAM62 program (see the program menu).

Note: It should be kept in mind that the results of these computations of required energy conversion unit capacities are used primarily as estimates of the magnitudes of the future investments to be made in the different types of energy conversion stations and units. These investment costs are parts of the total costs to be estimated in order to compare of the future economic costs to be expected in the different scenarios. These total cost estimates are, naturally, very uncertain, not the least because of the uncertainties regarding future fossil fuel prices.

In actual practice, the capacities to be installed in the different energy conversion stations will, of course, be decided on the basis of specific technical and economic assessments for each particular plant.

However, the capacity estimates also serve to depict the technical and economic characteristics of the different scenarios considered and, thereby, the trade-off of, for instance, investments in energy savings in the end-use system as against investment costs in the energy conversion and transmission system and fuel costs.

10.12 Future development

Future changes in the types of units in operation in the different types of conversion stations are specified by the time-series data in the records of the CONVSTAT.nrd file, while future technical changes in the different types of unit are specified in the records of the CONVUNIT.nrd file.

Future changes in heat supply from individual heating installations and heat supply from district heating networks are specified in the heat-supply-transition tables in the HSTRANSI.nrd file.

For each local energy system (in the present version of Nordic energy systems model: each domain), the total district heat supply is year by year apportioned to the types of cogeneration and district heating stations in operation as specified in the DHSUPPLY.nrd file (the stations must be declared in the DOMAINSU.nrd file).

Thus, the heat production allocated to a certain type of cogeneration or district heating station changes as specified in the time-series data in the DHSUPPLY.nrd file.

Concurrently, changes in the electric power generation allocated to the different types of power and cogeneration stations may change because of changes in the power generation priorities specified in the ELPRIO.nrd file (see section 10.10).

Regarding motive power for vehicles, future changes are specified in the transportation volumes file TRANSPVO.nrd, the vehicle specification file VEHICLES.nrd, and in the CONVUNIT.nrd file, where future changes in the technical parameters of the different types of motors are specified.

Results:

- SUMMAreg.sc and SUMMARY.sc:
  Heat and electricity production in the different energy conversion stations, grouped according to the groupings specified in the CSGROUPS.reg files.
- EMISSreg.sc and EMISSION.sc:
  Fuel consumption and emissions. Stations grouped as in SUMMARY files.
- ALLreg.sc Production, fuel consumption, average district heating temperatures and losses, and average efficiencies for power and cogeneration stations, district heating plants, industrial plants and individual installations.
- POWERGEN.sc Capacities and utilization of power and cogeneration stations.
- CAPSPECI.sc Detailed specifications of capacities and utilization of conversion station units.

Programs for additional documentation:

SESAM80 Select program module 7 for generation of the files COGENPLA.sc, DHPLANTS.sc and INDIVHEA.sc in which production and fuel consumption is recorded (Totals for types of stations and results for each particular station of each type).

MAINTABS:	MAIN1reg.txt, MAIN2reg.txt, MAIN3reg.txt (for each country: reg), MAIN1TAB.txt, MAIN2TAB.txt, MAIN3TAB (for the Nordic system as a whole): Fuel based power generation, heat generation, power conversion the energy conversion and transmission system. Values for several scenarios in parallel for comparison.
SESAM56	Technical parameters for the particular energy conversion stations

11. Industrial Processes

Thermal industrial processes, i.e. processes in which considerable heat exchanges take place, are considered to be subsystems within the energy conversion and transmission system (ECTS), see fig. 1. This is because in many cases such processes can function as integral parts of the ECTS. In some cases high-temperature process heat can be supplied by the exhaust from gas turbines or gas engines, and low-temperature heat down-stream in the process cycle can be utilised in district heating networks. In other cases, low-temperature processes can be driven by heat from steam turbines or gas engines belonging to the industries or cogeneration stations outside the industrial plants. The use of power generating machines ("motors") for the supply of electricity and heat to industrial processes and/or to networks outside the industrial plants is called industrial cogeneration.

Like other conversion stations, the present and future industrial processes belonging to the different domains must be declared by name and type in the DOMAINSU.nrd file and the power and heat supply units in use in the different types of process plants (motors, heat pumps, boilers, etc.) must be specified in the CONVSTAT.nrd file with references to records in the CONVUNIT.nrd file.

The specific electricity and heat consumption and production data pertaining to a particular process plants or an aggregate of plants are found in the SPECPROC.nrd file.

In the present model of the Nordic energy system, the industrial processes are represented by one aggregated process for each region (South Norway, Mid-Norway ,..., North Finland, Denmark). When data for specific major industrial plants are acquired, records specifying these processes can be entered into the SPECPROC.nrd file.

Results:

ALLreg.sc: Section "Specific major consumer enterprises": consumption and production, electricity and heat.
Section "Industrial plants": Specifications of electricity and heat production, technical parameters and fuel consumption.

EMISSreg.sc and
EMISSION.sc : Fuel consumption and emissions for industrial plants (according to groupings specified in the CSGROUPS.nrd file)

12. Economic Cost Assessments

The ECONCOST.nrd file contains economic cost records for the different types of units in the system of energy sources and the energy conversion and transmission system as well as for heat supply installations and heat saving investments in the end-use system. Also records specifying specific costs of fuel of different types and the prices assigned to electricity import and export across the system boundary are found in this file (see table 12.1). On the basis of these cost specifications, the SESAM economic cost program computes the costs of investments, operation and maintenance, and the costs of fuel consumption for the system as a whole as well as for each of the system's regions and local systems.

In this context, costs should in principle be understood as social opportunity costs, i.e. the values of material resources and labour resources used to develop, maintain and operate the energy system expressed in monetary terms. Market prices - without VAT, other taxes, and customs - do not necessarily represent these costs, in particular not the real costs of non-renewable resources[2]. However, generally there is no other way to assess these values than using the market prices. Moreover, the biggest costs are the costs of oil and natural gas supplies, and future oil and gas price forecasts are most uncertain. For these reasons, cost assessments based on current market prices need not represent the real social opportunity costs.

Nevertheless, the results of total cost computations based on present and estimated future market prices may indicate whether one development strategy, as represented by a particular scenario, is likely to be considerably more (or less) costly for the society as a whole than another scenario. Such assessments are relevant for the political decision process because the more material resources and labour the society spends on energy needs, the less is available for other purposes.

It should be noted that in an integrated energy system where electricity is produced in power stations, cogeneration stations, windmills, and photovoltaic panels there is no way to assess the cost of electricity production in EUR/MWh other than to compute the marginal change in total costs for the system as a whole caused by a marginal change in electricity consumption. The same is the case for the cost of heat production from a particular cogeneration station. By means of the SESAM ANALYSIS program such marginal costs can be computed. While these computed marginal costs may indicate short-term opportunity costs of electricity or heat production, they do not reflect the prices of electricity and heat paid by the consumers.

12.1 Cost assignments

The different types of items to which specific costs are assigned are shown in table 12.1. Examples showingthe formats of cost assignment records are shown in table 12.2.

---

[2] It should be noted that, for example, the market price of windmills depends on subsidies as well as the expected future price of electricity from windmills and that, for example, the price of biomass fuels are related to the prices of fossil fuels, which fluctuate as the global market conditions change. Moreover, low fossil fuel prices in the shorter run may result in more steeply rising prices in the longer run.

Type no. Identifier	Type of item	Prices to be specified as per:
101 CENTR.HEAT	Central heating installations (piping, radiators, etc.)	Sq.metre of floor area
102 DH.CONNECT	District heating connections in the individual buildings (meters, heat exchangers, hot water tanks, etc.)	Building connected
103 GAS.CONNEC	Gas connections in the individual buildings (meters, valves,etc)	Building connected
104 DH.MAINP.	District heating main pipes (in streets)	Building connected to new main pipes
105 DH.CON.PIP	District heating connection pipes (from mains to buildings)	Building connected
106 GAS.CONN.P	Gas connection pipes (from mains to building)	Building connected
201 MOTOR	Motors, i.e. engines, steam turbine plants, fuel cells, etc.	MW max. power rate
202 HEATPUMP	Heat pumps	MW max. heat rate
203 IND.BOILER	Individual boilers	Boiler installation
204 COL.BOILER	Boilers in collective district heating stations	MW max. heat rate
205 HEATSTORE	Heat storage tanks	1000 cubic metres
206 SO2.PURIF	SO2 purification	kg/hour of SO2 absorbed
207 Nox.PURIF	Nox purification	kg/hour of Nox absorbed
208 ELECTROLYS	Electrolytic converters (Electric power to hydrogen)	MW power input
209 BIOGASPL.	Biogas plant	tons of wet biomass treated per day
210 WINDMILLS	Windmills	MW max power rate
211 IND.SOLARC	Individual solar collectors	MWh of heat per year
212 DH.SOLARC	Solar collectors connected to district heating stations	MWh of heat per year
213 PHOTOVOLT.	Photovoltaic panels	1000 sq. metres
300	Fossil fuels, local fuels, and electricity import/export	MWh
400	Heat saving measures in buildings	sq. metres of floor area
500	Electricity savings (more energy-efficient appliances)	Appliance

Table 12.1 Types of economic cost items in the ECONCOST.nrd file.

By means of the COSTS program (no. 100 on the program MENU) a cost record (a 'price tag') from the set of records in the ECONCOST file is attached to each item in the energy system. This is done manually because the user must specify which cost record is to be assigned to a particular type of item.

```
{Result in (currency): } EUR
{Conversion factor: 1 EUR = } 7.50 {Dkr}

102 DH.install<200.m2   1000 Dkr/build
                            1996   2000   2015   2030    ;
{Investment             :}   10 ;
                             10    9.5    9.0    8.5 ;
                             10    9.0    8.5    8.0 ;;
{Lifetime (years)       :}   30 ;;
{Reinvestments (percent):}   30 ;;
{          after: years:}   15 ;;
{Maintenance (percent)  :}    1 ;;

104 DH.distr.pipes.NOR   1000 Dkr/connected.build
[District heat distribution pipes, Norway]
                            1996   2000   2015   2030 ;
{Investment             :}  25 ;
                            25     24.3   20  ;;
{Lifetime (years)       :}   30 ;;
{Reinvestments (percent):}   10 ;;
{          after: years:}   15 ;;
{Maintenance (percent)  :}   0.7 ;;

201 N.gas.comb.cycle.15 1000000 Dkr/MWel : 15 {MW min.cap./unit}
[ N.gas-fired combined cycle power plant, 15-75 MW ]
                             1993   2005   2015 ;
{Investment             :}   7.2 ;
                             7.2    8.0    9.0 ;;
{Lifetime (years)       :}   30 ;;
{Reinvestments (percent):}   30 ;;
{          after: years:}   15 ;;
{Maintenance (percent)  :}   2.5 ;;

400 Thermal.insul.build  Dkr/m2.floor.area
                                   1996 ;
    {Specific heat loss
     reduction factor  :}   0.80   144 ;;
                            0.75   187 ;;
                            0.70   250 ;;
                            0.65   345 ;;
                            0.25  1400 ;;
                {End of list: } ;

300  Diesel.iea 129.2*0.01  Dkr/MWh
                            1996    1999  2010   2020 ;
```

Table 12.2 The ECONCOST file. Examples of cost record formats.
In each record three alternative cost development time series may be entered: Higher, medium and lower future costs, see for example DH.install.
When a factor appears after the record identifier, the cost figures given in the record are multiplied by this factor.
In this case the costs are given in Danish crowns (Dkr) but the results are printed in EUR using the conversion factor given above.

12.2 Economic cost computations and comparative analyses

When cost records (‘price tags’) have been assigned to all items in the system, economic cost computations for a particular scenario can be carried out by the COSTS program. The results are found in two files the names of which are chosen at run-time: The program suggests filenames which indicate the future hardware and fuel cost alternative selected (1, 2 or 3, see table 12.2) and the discount rate chosen for the present value computations. The one file contains a year-by-year summary of costs. The other contains more detailed cost specifications by categories of costs for each region.

For the comparative analysis of sets of different scenarios and the sensitivity analysis with respect to changes in particular macro-variables (see appendix 2 and 3) the ANALYSIS program (no. 92 on the program MENU) provides a tool. From a set of up to 40 different scenarios the program automatically selects pairs of scenarios which differ by a change in one macro-variable only and are thus comparable with respect to the effects of changes in the set of variables represented by that macro-variable. Results are found in the ANALYSIS.ext result file. Moreover, the program produces tables (in the TOTALS.ext file) containing fuel consumption, emissions and economic costs for the set of scenarios chosen. Other tables for the comparison of the different scenarios are found in the SCENVIEW.ext result file.

Appendix 1: Database files

The names of files which are used in all scenario computations are given in section 1 of the SESSETUP.nrd file. If any of these filenames or the contents of any of these files are changed, all completed scenario computations must be re-run.

The following filenames are found in the MACROVAR.nrd file, which is included in the SCENSPEC.nrd file. I one of these filenames or the contents of the file is changed, the programs which use the file in question must be re-run.

Using the SESAM run-command, the re-runs required because of changes in one or more database files will be executed automatically.

```
$ FILENAMES $
{ 1. Geographical structure file (geostru):   } geostru.nrd
{ 2. Specific heat-balance file (shbalanc):   } shbalanc.nrd
{ 3. District heat supply file (dhsupply):    } dhsupply.nrd
{ 4. Domain-supply file. (domainsu):          } domainsu.nrd
{ 5. Conversion stations: Heat, cogeneration,
    and power stations (convstat):            } convstat.nrd
{ 6. Specific industrial processes (specproc):} specproc.nrd
{ 7. Vehicles (vehicles):                     } vehicles.nrd
{ 8. Heat supply transition (hstransi):       } hstransi.nrd
{ 9. Geophysical energy sources, production
    data (geosourc):                          } geosourc.nrd
{10. Allocation of geophysical energy sources
    to conversion stations: (allocat):        } allocat.nrd
{11. Energy conversion units (convunits):     } convunit.nrd
{12. District heating networks (dhnets):      } dhnets.nrd
{13. Biogas production, specific production
    data (biogaspr):                          } biogaspr.nrd
{14. Electricity generation priorities on a
    diurnal basis (elprio):                   } elprio.nrd
{15. Load priorities for power and cogeneration
    stations and industrial power generators,
    MW hour by hour (loadprio):               } loadprio.nrd
{16. General consumption development factors.
                          (gcdfacto):  } gcdfacto.nrd
{17. Transportation volumes     (transpvo):  } transpvo.nrd
{18. Fuels. Specific fuel data and available
    local fuels (fuels):                      } fuels.nrd
{19. Flue gas purification plants (fluepuri): } fluepuri.nrd
{20. Annual consumption rate variations:
    hot water, process heat and transportation.
                          (consrate): } consrate.nrd
{21. Diurnal variations (diurvar):            } diurvari.nrd
{22. File in which existing conversion unit
    capacities/volumes are specified. This file
    may be omitted.            (exicap):  } exikap.nrd
{End of FILENAMES: } ;
```

Running the UPDATE program (UPD in the program menu), these database files are checked for completeness and syntactic correctness and cross-reference identifiers are inserted in the database records.

Appendix 2: Scenario specifications

A scenario is identified by a 2-character identifier: A letter indicating the set of quantitative development factors which apply to the scenario in question followed by a letter or a digit. In the example below the letter H has been chosen for "High" growth in the building stock, the stocks of electrical appliances, industrial production, and transportation.

The choice of time-series values from the alternative time-series given in the different database files is indicated by the values of the 9 so-called macro-variables shown in the example below. A macro-variable value is a letter followed by a digit. Two dots (..) indicate that the value is the same as in the line above. For mnemotechnic reasons, the rule *that the higher the digit the higher are the fossil-fuel-saving investments made* has been applied in this example. For instance, W1, W2, W3 indicates progressively higher investments in windpower.

The meaning of the different macro-variable values is specified in Appendix 3. The number of different values of a macro-variable is not restricted to three. Up to 9 different values may be specified in the macro-variable tables.

```
$ SCENARIOS $

{ Quantitative development factors
  .    0: Functional determinants
  .    . 1: Heat consumption, room heat and hot water
  .    . . 2: Industrial process heat consumption
  .    . . . 3: Electricity consumption, appliances and machinery
  .    . . . . 4: Local fuels, available quantities
  .    . . . . . 5: Windpower
  .    . . . . . . 6: Photovoltaic panels
  .    . . . . . . . 7: Solar collector panels
  .    . . . . . . . . 8: Hydropower
  .    . . . . . . . . . 9: Vehicles
  .    . . . . . . . . .          }
  H0: F0H0I0E0L0W0P0S0h0V0 {No changes in any variables
                            except the QUANTA variables and in
                            electricity consumption as old
                            appliances are gradually replaced
                            by newer models}
  HA: F1H1I1E1L1W1P1S1h2V1
  HB: F2..................
  HC: F3..................
  HD: F1H2..E2..W2......V2
  HE: F2..................
  HF: F3..................
  HG: F1H3..E3..W3......V3
  HH: F2..................
  HI: F3..................
  HJ: ..H1................
  HK: ..H3..E1............
  HL: ......E3..W2........
  HM: ..........W1........
  HN: ..........W3........
  HO: ..H1................
  HP: ......E1............
  HQ: ..........W2........
  {End of scenario table: } ;
```

Appendix 3: Macro-variable specifications

The macro-variable values - H, M, L for quantitative variables; a letter followed by a digit for technical and structural variables, see Appendix 2 - are defined in the tables in the MACVARS.nrd file. Examples of the three first sections of this file are shown below.

For each macro-variable the numerical values chosen in the different database files (see appendix 1) or file sections are specified:
1 for the first of the alternative time-series values, 2 for the second, and so on.

For example, in H-scenarios the first of the alternative values in the files and file sections in the QUANTA list are chosen. In L-scenarios the third of the alternative values are chosen.

In the other tables in this example, most of the digits in the macro-variable valuables correspond in this case to the index of the numeric values chosen in the different files or file sections. Exceptions are the macro-variable value F4 in the table MACROVAR.0, which indicates that the first of the alternative values in the HSTRANSI file and the second values in the DHSUPPLY file are chosen. In section 5.2 of the MACROVAR.0 table it is indicated that the first of the alternative values of the variable "Boilers' share of heat production" is chosen for all the F macro-variable values.

```
$ QUANTA Quantitative development factors $

{ Table 1:  }
    {Scenario identifier character: }      H  M  L ;
{1. gcdfactors. General Consumption
                Development Factors}
{   1.1 Number of consumer units
        (dwellings, shops, offices, etc.)
        by consumer category: }            1  2  3 ;
{   1.2 Industrial production
        volumes: }                         1  2  3 ;
{   1.3 Process energy consumption
        factors, electricity/heat:}        1  ;
                                   VAR     1  ;
{2. shbalance  Specific Heat Balance
               data}
{   2.1 Population: }                      1 ;
{   2.2 Hot water consumption: }           1  2  3 ;
{   2.3 Number of square metres per
        person (floor area in different
        building categories: }             1 ;
{3. eldata. Electricity consumption
            data. GENERAL section:
            Stocks of electrical
            appliances and machinery
            by consumer category: }        H  M  L ;
{4. transpvol. Transportation volumes
               by transport category: }    1  2  3 ;
{5. consrate. Annual consumption
              variations}
{   5.1 Hot water consumption:        }    1 ;
{   5.2 Proces heat consumption:      }    1 ;
{   5.3 Transportation:               }    1 ;
{End of table 1: } ;
```

```
$ MACROVAR.0 Functional determinants, stationary ECTS units.
             Vehicles: see MACROVAR.9 $
   {Time-series index 0 (zero) indicates that the variable values are kept
    constant equal to the value given for the first year in the time-series.
    The same applies to the tables MACROVAR.1 - MACROVAR.9 below.
   Thus, when the macro-variable value F0 is selected in this table, all the
    specific ECTS properties are kept unchanged.
    VAR values refer to the alternative values for named variables given in
    the VARIABLE.nrd file, see Appendix 4 }


   {Macro-variable identifier: }           F0 F1 F2 F3 F4 ;
{1. hstransi.  Heat Supply Transition.
               Means of heat supply
               from the ECTS to the EUS:}   0  1  2  3  1 ;
{2. dhsupply.  District Heat Supply.
               Stations supplying district
               heating to district heating
               networks in local systems:}  0  1  2  3  2 ;
{3. specproc.  Specific industrial
               processes and conversion
               stations with fixed annual
               production (incinerators
               etc.) }
{   3.1 District heat production: }         0  1  2  3 ;
{   3.2 District heat production
        in excess of waste heat: }          0  1  2  3 ;
                                   VAR      1  1  2  3 ;
{   3.3 Electricity production: }           0  1  2  3 ;
                                   VAR      1  1  2  3 ;
{4. domainsu.  Domain Supply.
               Capacities and generation
               priorities for heat supply
               stations: }                  1 ;
{5. convstat.  Conversion Stations }
{   5.1 Motors, heatpumps, boilers: }       0  1  2  3 ;
{   5.2 Boilers' share of heat prod.: }     0  3 ;
{   5.3 Electric heating: }                 1 ;
{   5.4 Losses in grids: }                  1 ;
   {Macro-variable identifier:             F0 F1 F2 F3;}
{6. convunits. Conversion Units
               Technical parameters for
               stationary units: motors,
               boilers, and heat pumps: }   0  1  2  3 ;
{7. dhnets.    District Heating
               Networks, primary: }         0  1  2  3 ;
              {Secondary: see MACROVAR.1}
{8. biogaspr.  Biogas production.
               Biogasplants, specific
               production data: }           0  1  2  3 ;
{9. elprio.    Electricity generation
               priorities and use of
               electrolytic converters }
{   9.1 Use of electrolytic converters: }   1  1  2  3 ;
{   9.2 Electricity generation priorities
        on a diurnal basis
        (MWhours/24 hours): }               1  1  2  3 ;
{10. loadprio. Load Priorities }
{  10.1 Utilization of electrolytic
         converters (hours per year):}      1 ;
{  10.2 Electricity generation rate
         priorities (base load
         priorities, MW hour by hour):}     1  1  2  3 ;
{11. diurvar.  Diurnal variations }
{  11.1  Electricity import }
{              Table no.: }                 3 ;
{  11.2  Electricity export }
{              Table no.: }                 3 ;
```

```
{12. fluepuri. Flue gas Purification
               plants: }                    0  1  2  3 ;
{End of MACROVAR.0 table 1: } ;


$ MACROVAR.1  Heat consumption, room heating and hot water.
              Technical and behavioral parameters $
{Table 1: }
   {Macro-variable identifier: }          H0 H1 H2 H3 ;
{1. shbalanc. Specific Heat Balance
              data }
{   1.1 Specific transmission heat
        loss (W/(m2*K): }                  0  1  2  3 ;
{   1.2 Heat contribution factors for
        electrical appliances: }           0  1  2  3 ;
{   1.3 Solar radiation: }                 0  1  2  3 ;
{   1.4 Ventilation (1/hour): }            0  1  2  3 ;
{   1.5 Indoor temperature (K): }          0  1  2  3 ;
                                   VAR     1  1  2  3 ;
{   1.6 Specific heat loss modification
        factors: }                         0  1 ;
{2. dhnets.   Secondary district heating
              networks: }                  0  1 ;
             {Primary: see MACROVAR.0}
{3. diurvar.  Diurnal variations in heat
              consumption }
{             Table no.: }                 4 ;
{End of MACROVAR.1 table 1: } ;

........
........

$ MACROVAR.9  Vehicles.
              (Transportation volumes by type of vehicle: see QUANTA) $
 { Table 1: }
   {Macro-variable identifier: }               V0  V1  V2  V3 ;
{1. vehicles. Specifications of types of
              vehicles }
{   1.1 Shaft power per unit
        of transportation: }                    0   1   2   3 ;
{   1.2 Types of fuel-powered motors
        used: }                                 0   1   2   3 ;
{   1.3 Electrically powered portion
        of vehicles and
        electric conversion losses: }           0   1   3   4 ;
                                          {ETR: 0   1   2   3 ; }
{2. convunits. Conversion units.
               Technical specifications
               of motors in vehicles: }         0   1   2   3 ;
{3. transpvol. Transport volume distributions
               by type of vehicle:  }           0   1   2   3 ;
{End of MACROVAR.9 table 1: } ;
```

Appendix 4: Named variables

In the database files, a numeric value can be replaced by a named variable (an asterix '*' followed by an identifier). Alternative values of named variables are given in the VARIABLE.nrd file. In the example below alternative values of variables named in the SHBALANC.nrd file are given.

For the different macro-variable values, the index of variable values chosen in the VARIABLE.nrd file is given in the MACROVAR tables, see VAR entries in the tables in Appendix 3 above.

```
 $ VARIABLES $
        {Value set index:}  1         2     3    ;
  shbalanc.nrd   detach.den  0.001  0.0011 0.0012 ;
  shbalanc.nrd   detach.nor  0.0015 0.0017 0.0019 ;
  shbalanc.nrd   detach.swe  0.001  ;
  shbalanc.nrd   detach.fin  0.001  ;
  shbalanc.nrd   multist.de  0.001  ;
  shbalanc.nrd   multist.no  0.0015 ;
  shbalanc.nrd   multist.sw  0.001  ;
  shbalanc.nrd   multist.fi  0.001  ;
{End of VARIABLES : } ;
```

Appendix 5: Result filename notations

The names of the standard result files written by the SESAM programs for each scenario are found in the SESSETUP.nrd file section 12, see below. These names are the names of files containing results for the Nordic energy system as a whole.

The names of files containing results for a region or country are construed by replacing the last three letters of the standard filenames by the three letters denoting the region or country in question (in the Nordic system: NOR, SWE, FIN, DEN).

Thus, in the result filenames given in the different sections of this paper:

reg stands for the region (country), reg = NOR, SWE, FIN, DEN, and
sc stands for the scenario identifier, see Appendix 2 above.
txt is the default file extension

```
$ SECTION.12  Print-out Filename Heads. $
             {For the standard print-out files automatically generated
              by the program the filename extension is identical to the
              2-character scenario identifier.
              For particular print-out files generated at the user's choice,
              the filename extension is to chosen by the user. By default the
              extension is txt

              The standard print-out files are those marked with an * }

 {1*} FLOORAREa    {Floor areas by consumer categories}
 {2*} HEATBALAnce  {Detailed heat balance accounts by building categories}
 {3*} HEATSUMmary  {Summaries of heat consumption accounts by building
                    categories. Total consumption at the bottom of the file}
 {4*} SUMMARY      {Heat and electricity production distributed on conversion
                    stations. Total summaries of production, consumption,
                    and emissions}
 {5*} ALLDOMAIns   {Comprehensive consumption, production, and emission
                    tables for the entire regional system (all domains)}
 {6}  DOMAINS      {Comprehensive consumption, production, and emission
                    tables for one or more domains. Generated by the
                    SESAM80 program}
 {7}  CONVSTATions {Production and consumption data for individual energy
                    conversion stations. Generated by the SESAM80 program}
 {8}  LOCALSYStems {Comprehensive consumption, production, and emission
                    tables for one or more local systems. Generated by the
                    SESAM80 program}
 {9*} HEATSUPPly   {Number of buildings heat from different types of
                    conversion stations and units. Heat produced by
                    different types of conversion stations and units.
                    For each domain and total for all domains}
{10*} EFFICIENcy   {Thermodynamic efficiency account for the regional
                    Energy Conversion and Transmission System (ECTS) as
                    a whole}
{11*} PLANTSURvey  {A survey of the types of plants in operation in the
                    different local systems}
{12*} INDIVHEAt    {Production and consumption data for individual heating
                    installations}
{13*} DHPLANTS     {Production and consumption data for district heating
                    plants}
```

```
{14*} COGENPLAnts  {Production and consumption data for cogeneration
                   plants}
{15*} POWERGEN     {A survey of all power generating stations and
                   units. Production and capacities}
{16*} CAPSPECI     {Capacity specifications. Detailed accounts of the
                   computed generating capacities of all energy
                   conversion units belonging to the different conversion
                   stations}
{17*} ELBALANCe    {Electricity production/consumption balances}
{18*} POWERRATe    {Electric power consumption and production rates at
                   30 minutes intervals}
{19*} MARGINAL     {Marginal changes in fuel consumption and emissions as
                   a result of marginal changes in heat consumption,
                   electricity consumption, windpower generation, and
                   heat production from solar collectors}
{20} ECORES        {Results from economic cost computations.
                   Only the first 6 characters of this filename are used.
                   Two digits indicating the cost development scenario and
                   the discount interest rate chosen are added by the
                   program}
```

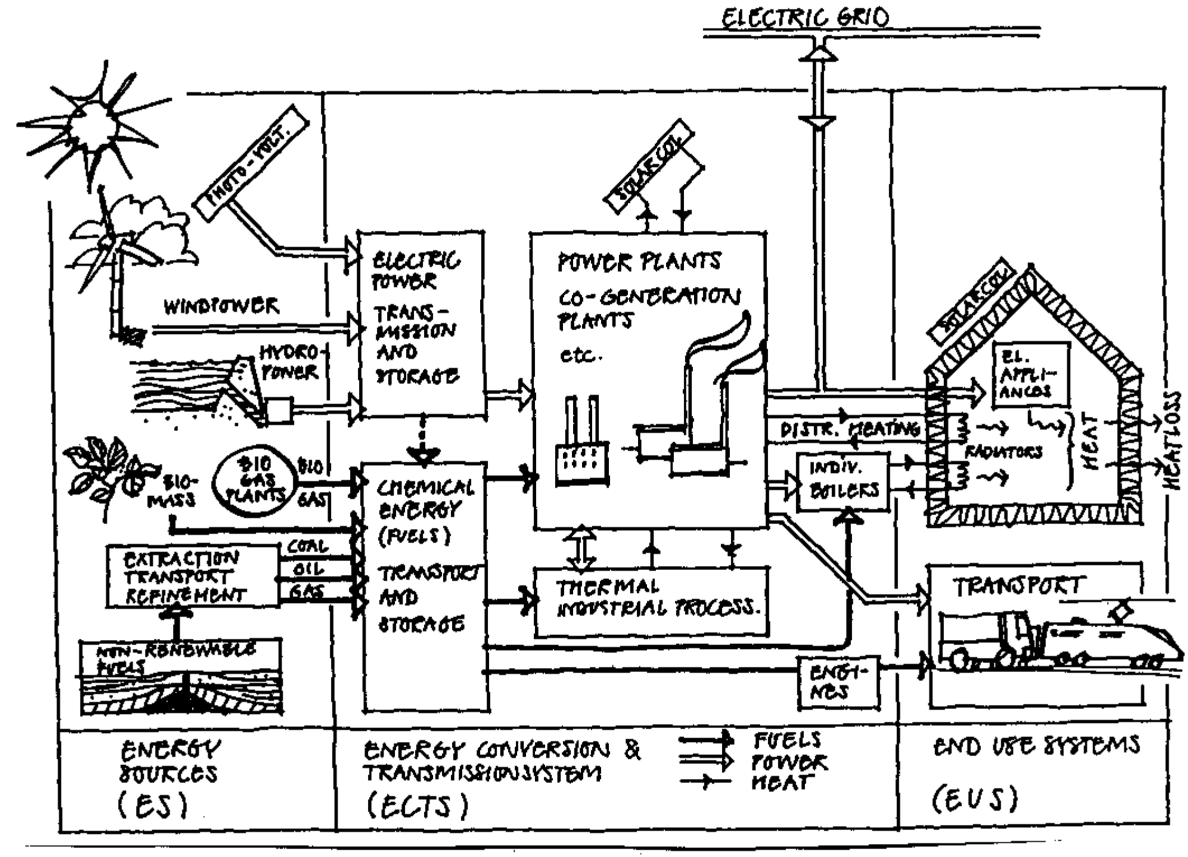

Figure 1. The three subsystems of an energy system.

For analytical purposes the energy system is divided into three subsystems.

The *Energy Conversion and Transmission System* (ECTS)comprises the energy conversion processes, storage facilities and transmission networks which serve to convert and transmit the chemical potentials (fuels) and the electric potentials gained from the system of *Energy Sources* (ES) to the thermal potentials (heat), electric potentials, and the mechanical power transmission (in vehicles) needed in the *End-use System* (EUS).

Thermal industrial processes driven by cogeneration units can be integrated into the energy conversion and transmission system and low-temperature heat from these processes can be utilized for district heating.

The thermodynamic efficiency of the energy conversion and transmission system is measured as the ratio of the thermodynamic potentials gained in the end-use system to the chemical and electric potentials gained from the system of energy sources.

The energy conversion processes and the procedures for the regulation of the interactive processes under the incessant variations of demands on the one hand and inputs from the energy sources on the other should be designed so as to avoid unnecessary thermodynamic losses in the system.

Hence, boilers and electric resistance coils in which high-temperature thermal potentials are converted into low-temperature potentials should be replaced by cooling circuits in engines, condensers in steam turbine power stations, and heat pumps in cogeneration stations. Moreover, district heating and central heating temperatures should be kept as low as possible.

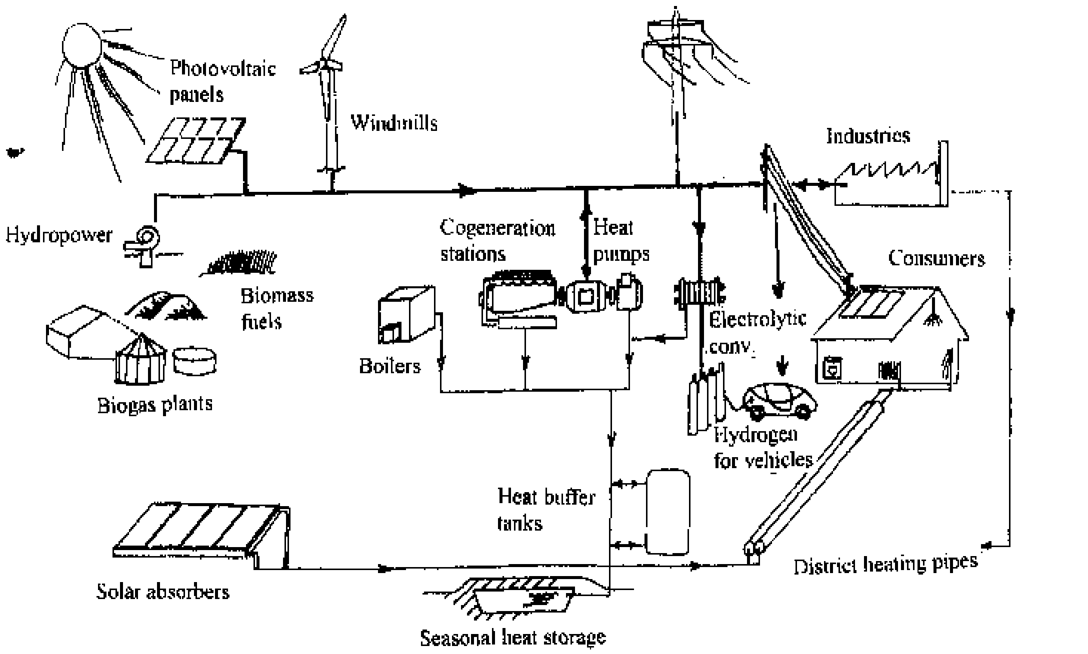

Figure 2. Future local energy systems.

In future local energy systems, e.g. in towns or urban areas with their rural surroundings, there will be an incessant interplay between electricity generation, heat generation and, possibly, electrolytic or electrochemical power conversion (e.g. hydrogen production) in order to meet current heat and power demands by the efficient utilization of the varying electric potentials generated in windmills and photovoltaic panels, the available hydropower capacity, and the available biomass fuels.

Heat pumps in cogeneration stations serve to regulate the power to heat production ratio in accordance with the demand variations on the one hand and the power input from windmills and photovoltaic panels on the other.

Thermal industrial processes driven by industrial cogeneration units can be integrated into the system and low-temperature heat from the processes can be utilized for district heating.

By means of electrolytic or electrochemical power conversion, power generated in windmills, photovoltaic panels and cogeneration stations in excess of the current electricity demand can be converted to chemical energy for use in vehicles.

Collective solar absorbers with seasonal heat storage reservoirs connected to district heating networks serve to reduce the heat generation in cogeneration stations while heat buffer tanks serve to level out heat production against the varying demand on a diurnal basis. Naturally, seasonal heat storage reservoirs can also be used to store excess heat production in cogeneration stations in the seasons where heat demand is low.

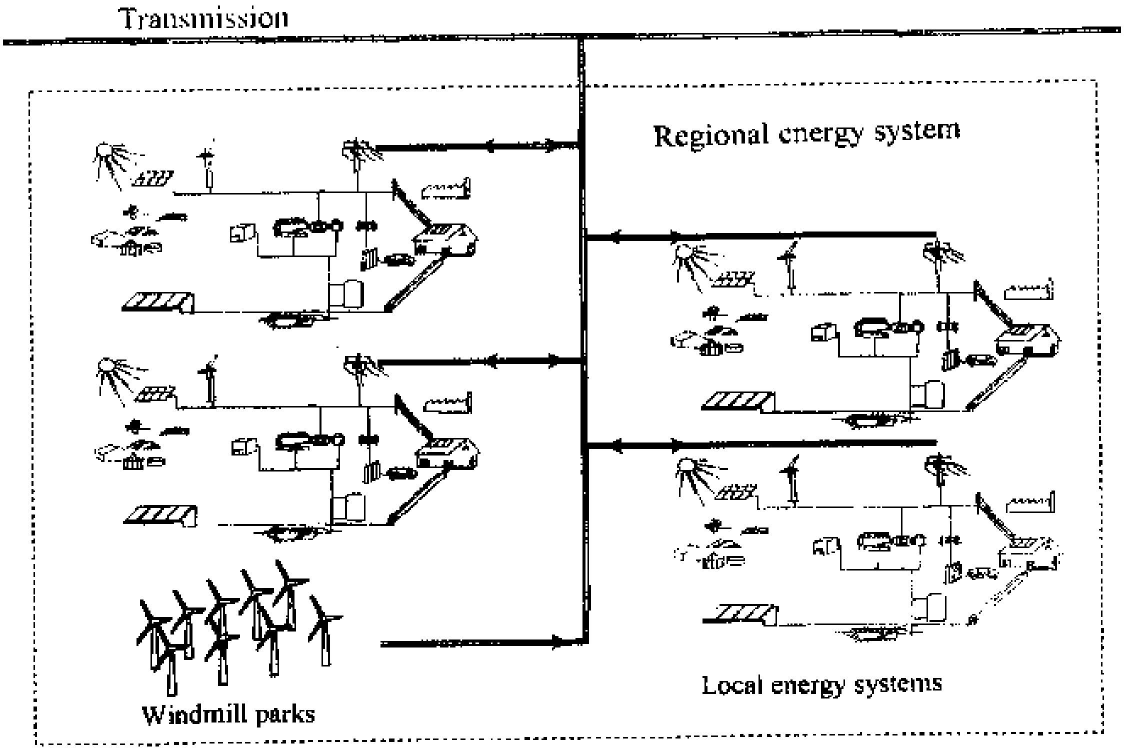

Figure 3. Local systems integrated into regional systems.

When the local energy systems within a regional energy system are built in accordance with the principles illustrated in fig. 2, each local system has a capacity for the regulation of the electric power input/output across it boundaries. Thus, the available energy resources can be efficiently utilized within each local system and long-distance power transmission can be reduced.

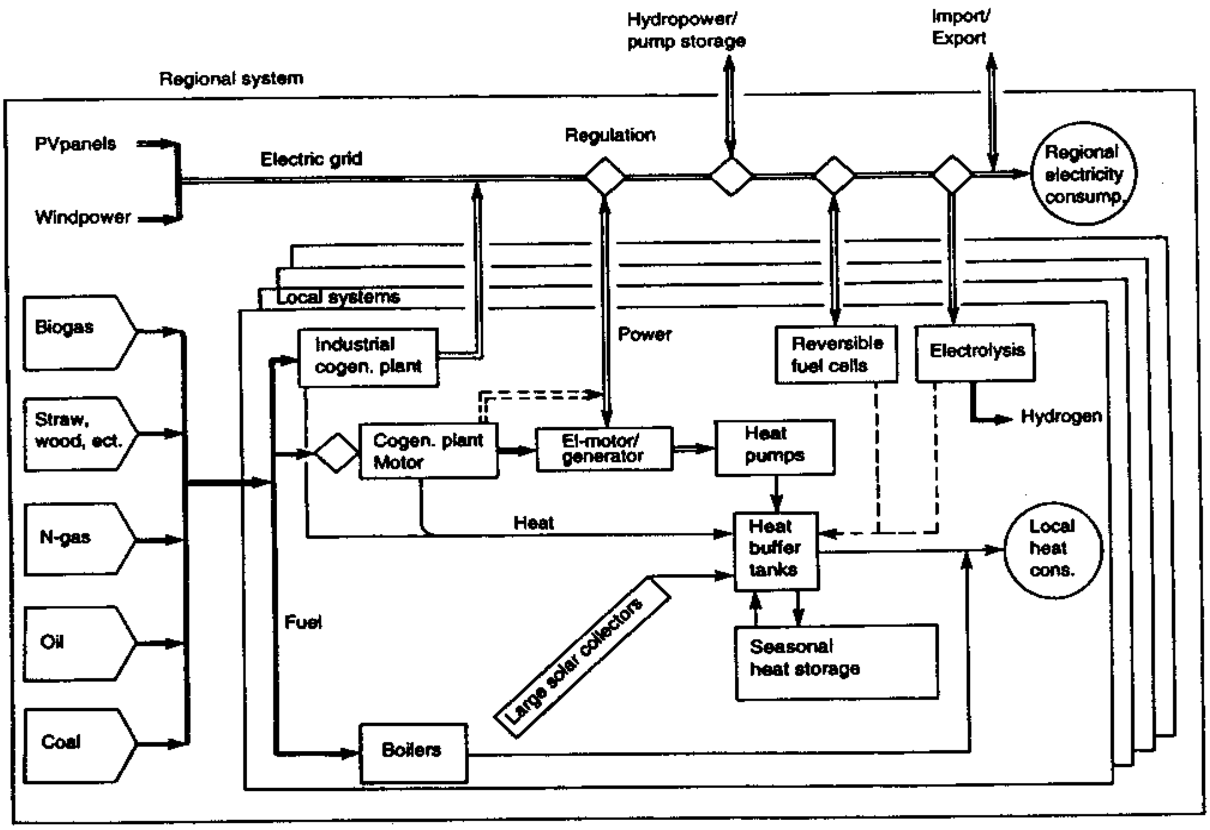

Figure 4. Fuel, power and heat flows in future local energy systems.
The rhombs show the main points of power regulation. Several local systems exchange electric power with the transmission grid, see fig. 3.
Because of the additional losses involved, the regulation of the electric power flow by means of reversible fuel cells shown as far as possible be avoided.
Here, “Electrolysis” and “Hydrogen” stands for any type of electrolytic or electrochemical conversion process and its chemical output.