The Swedish Energy Agency's methodology for long-term energy projections

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Foreword

The Swedish Energy Agency is responsible for producing projections of the trends in energy supply and energy consumption in Sweden in both the short and the long term. These projections are used for a range of different purposes, but in recent years, work on climate change has led to an increased interest in projections of the emission of greenhouse gases from, among others, the energy sector. An important component in these emission projections is the projections of energy supply and energy consumption.

The work of producing long-term projections is a resource-intensive process, and the Swedish Energy Agency is constantly striving to improve this process through evaluating and developing the methods and models used.

This report presents the step-by-step process and the models used in producing long-term projections of energy supply and energy consumption at the Swedish Energy Agency.

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Eskilstuna, 30 August 2005

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Contents

1 Introduction

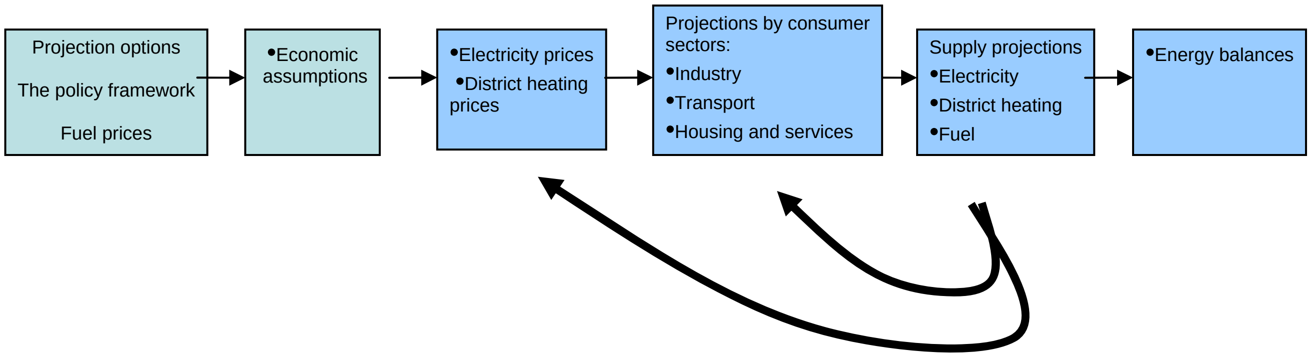
The Swedish Energy Agency’s long-term energy projections describe the trend in the Swedish energy system over a period of ten to twenty years. The methodology is based on a combination of a systems analysis perspective and a macroeconomic perspective. The Swedish Energy Agency uses a number of methods and models in its projections.

A fundamental starting point in the Swedish Energy Agency’s projection work is that total energy consumption and the mutual apportionment of forms of energy are adjusted for anticipated energy prices, the level of activity in the economy and technological developments. The composition of the Swedish energy system is also affected, among other things, by trends in the Nordic electricity market and by Swedish energy and environmental policy. The Swedish Energy Agency bases its projection work on the Swedish Parliament’s decisions in the energy and environmental areas. This constitutes the “business as usual” projection.

The majority of the methods and models used in the Swedish Energy Agency’s long-term projections start from a bottom-up perspective. This means that projections for individual sub-sectors within the energy system are made on the basis of a highly-detailed analysis of the energy system. The reason the Agency adopted this method is the importance of the level of detail in describing various sub-sectors in developing the energy system. An iterative (repetitive) process is used, in which the model results for different sub-sectors are checked against each other to produce an overall projection for the whole energy system. Expert assessments are an important element of each stage of the projection process.

The Swedish Energy Agency’s projections are produced in collaboration with a number of other agencies. One important component in the Swedish Energy Agency’s projection of the trend in the energy system is the Swedish National Institute of Economic Research’s projection of economic trends. The projection of energy consumption in the transport sector is produced jointly with the Swedish Institute for Transport and Communications Analysis, SIKA, which projects transport use. For estimates of emissions, the Swedish Energy Agency cooperates with the Swedish Environmental Protection Agency and the Swedish Methodology for Environmental Data consortium, SMED.

Diagram 1. The Swedish Energy Agency's projection procedure.



To show how the development of the energy system changes when any of the assumptions underlying the projection change, a number of sensitivity analyses are carried out in parallel with the "business as usual" projection. The procedure for sensitivity analyses is frequently the same as for the "business as usual" projection, but, on occasion, simpler model calculations are carried out using one or more of the models and methods adopted by the Agency.

Assessments of how the energy system will develop in the future are based on a number of more or less uncertain assumptions. It is safe to assume that many of the assumptions on which a projection is based will change over time, which is one reason why it is likely that the projection will, to a greater or lesser extent, differ from the actual outcome. For that reason, projections should not be regarded as cast-iron statements of the detailed development of the energy system. The primary aim of the Swedish Energy Agency's projections is to provide indications of the probable development of the energy system as a whole in the light of the assumptions on which the projection is based.

The Swedish Energy Agency works continuously to refine its projection methodology. The current projection methodology includes a number of components. Considerable efforts are being made, for example, to improve consistency between the projection of economic trends and the projection of the trend in the energy system. In addition, the Agency aims to improve the energy statistics underlying the energy projections.

General assumptions

The fundamental framework for the projections is current energy and environmental policy. For the reference projection, the “business as usual” projection, it is assumed that the decisions made by the Swedish Parliament will not be amended during the projection years.

In addition to the reference projection, sensitivity analyses are carried out, in which the underlying assumptions are changed. This is done to provide an estimate of how sensitive the results of the projection are to changes in these underlying assumptions. In the sensitivity analysis, it can be assumed, for example, that new control measures are introduced or that the price of an energy carrier changes. Which sensitivity analyses are made varies from case to case depending on the nature of the assignment.

In the text below, the general assumptions on which the long-term projections are based are described, along with the appropriate energy and environmental policies.

1.1 Economic trends

The trend in energy consumption is very much dependent on the performance of the national economy. Until now, increased economic activity has led to an increase in energy requirements. To what extent this connection will continue to apply in future primarily depends on any structural changes which may arise as the economy develops.

An important starting point, therefore, in predicting the long-term trend in the energy system is the development of the Swedish and international economies. The variables included in the energy projection are largely estimates of GDP, private and public sector consumption, disposable income and the performance of manufacturing industry and the rest of the business sector. For manufacturing industry, estimates of performance are made at sector level.

The assumptions on economic growth are taken from the Swedish National Institute of Economic Research’s Environmental Medium term Economic Model, EMEC. [1] These are themselves based on the latest estimate by the Long-Term Planning Commission[2] of future productivity trends etc. As far as energy-intensive industries are concerned, the Swedish Energy Agency also carries on a

[1] For more information on EMEC see Östblom G, “EMEC, An environmental medium term economic model” Working paper 69, 1999, The Swedish National Institute of Economic Research
[2] For more information on the Long-Term Planning Commission, Långtidsutredningarna, see www.regeringen .se

dialogue with sector organisations and energy-intensive companies to establish the reasonableness of the estimates used in the models.

To avoid any inconsistency between the projection of trends in the Swedish energy system and the projection of economic trends, the Swedish Energy Agency and the Swedish National Institute of Economic Research cooperate in the development of models to increase the degree of harmonisation in the assumptions in each organisation's models.

1.2 Fuel prices

Fuel prices are a crucial assumption in the projections, directly affecting which fuel the various user sectors are expected to use in the future, as well as how electricity and district heating will be produced.

1.2.1 Oil and coal

Price trends for crude oil and coal in the projection are based on estimates of future trends in the oil and coal markets. The assumptions for the fuel price projection are based on the 10, 20 and 30-year projections produced by the IEA in *World Energy Outlook*.

A model is then used for converting from international fossil fuel prices for crude oil and coal to domestic user prices to end customers. This is partly due to the necessity of refining crude oil into vehicle fuel and heating fuel before it can be used in the Swedish market. The calculation model uses a base year and known historical values for crude oil prices, coal prices, the USD exchange rate and annual changes in the RPI. The Swedish National Institute of Economic Research's EMEC model is used to generate data on the USD exchange rate and changes in the RPI. Calculation coefficients, conversion factors and price increments produced through regression analysis are also used.

The following domestic future fuel prices are generated by the model: fuel oil 1 (light fuel oil, domestic heating oil), fuel oil 5 (heavy fuel oil), coal, LPG, petrol and diesel. Fuel prices are determined for the following user-categories:

- Electricity-generating companies at harbours
- Major industrial companies at harbours
- Major district heating plants at harbours
- Small industrial companies
- Large buildings
- Single-family houses
- Transport

The appropriate taxes and VAT are then added for each fuel and customer category. These are based on the energy and environmental policy adopted by the Swedish Parliament. Bills, motions etc. which have not yet been debated in parliament are not taken into account in the calculations unless they are covered by the directive setting the assignment as a sensitivity alternative (or otherwise requested by the principal).

1.2.2 Natural gas

The estimates of future natural gas prices are based on the IEA's projection of the European import price for natural gas in *World Energy Outlook*. To this is added the cost of transmission, the supplier's margin and any taxes on different user categories.

1.2.3 Biofuels

The starting point for the trend in biofuel prices is *Prisbladet for biobränslen, torv m.m.* [the Price Bulletin for Biofuels, Peat etc.]. This is a quarterly survey carried out by the Swedish Energy Agency and Statistics Sweden. Historical time series have been used to produce historical price trends in real terms for each category of fuel. Taking account of qualitative analyses of future biofuel use, partly based on the assumptions in the EU Renewable Energy Directive, international trade in biofuels and government energy and environmental policy, price trends are then developed.

1.3 Electricity and district heating prices

In producing energy projections, preliminary electricity and district heating prices are first calculated, and these are used for an initial preliminary projection of energy consumption in industry and in the housing and service sector.[3] These preliminary user projections are used as input data in the MARKAL-NORDIC model (the MARKet ALlocation-NORDIC model) and PoMo (Power Model), which give a revised energy supply and through that a revised electricity price. The MARKAL-NORDIC also gives a revised district heating price. The final electricity price is determined by making a combined assessment of the results of both models. The following section explains how the initial preliminary price estimate for electricity and district heating is made for a long-term projection.

1.3.1 Preliminary electricity price

In a properly-functioning electricity market, the price of electricity will be determined by the marginal cost of electricity generation. The short-term marginal cost of electrical energy at a given date is determined by the marginal cost of the most expensive power source used at that date, and so it varies over the year. The long-term marginal cost is determined by total production costs, i.e. both fixed and variable costs. Given that electricity consumption is increasing, it follows that more expensive production sources will have to be used more frequently, which will cause the short-term marginal cost to rise. When the short and long-term

[3] Since the price of electricity has only a very marginal impact on energy use in the transport sector, no initial preliminary forecast is made for this sector.

marginal costs in the system are on a par with each other, it becomes profitable to construct new electricity generating capacity.

In the preliminary determination of the electricity price, the estimate is based partly on future economic trends and on the historical development of electricity consumption in Scandinavia. This provides an estimate of how much new capacity may be required. Using expected future fuel prices, and taking account of taxes and control measures adopted, the generating costs for new and existing electricity generation is calculated. Finally, it is determined what generating method will be marginal in the long term, and this establishes the price of electricity.

1.3.2 Preliminary district heating price

District heating markets are local markets, in which the customer is usually assigned to one supplier. Accordingly, prices are not set in competition with other district heating suppliers. Estimates of future district heating prices are based on price trends for the fuels used and on production costs for competing methods of heating.

1.4 Price of emission rights for carbon dioxide

The market price for emission rights depends on the supply of and demand for emission rights. Ideally, the price will be equivalent to the marginal cost of emission reductions within the trading system. The need for action to reduce emission is determined by each member state's allocation plan (the distribution of emission rights to companies) and a reference scenario of emissions without the trading system.

The Swedish Energy Agency is currently involved in developing methods to determine future price levels for emission rights. Up to now, the Swedish Energy Agency has based its price projections on reviews of existing estimates and the literature on the subject.

2 Energy consumption

On the basis of the overall assumptions and estimates of future fuel, district heating and electricity prices, as well as assumptions on economic trends and sector-specific assumptions, a revised calculation is made on demand trends for fuels, district heating and electricity. The factors which are included in the estimate of future energy consumption in the industrial, transport, housing and service sectors etc. are described below.

2.1 The industrial sector

Industry’s energy consumption is strongly linked to the level of economic activity in the various sub-sectors. This connection is especially marked for the energy-intensive sectors. The trend in energy consumptions is based on assumptions of growth in the various sub-sectors, the trend in energy prices and developments in technology. In the short term, volume of output is the most important determining factor in industry’s energy consumption. In the longer term, demand is subject to changes in the sector and product composition of manufacturing industry, and to developments in technology. Taxes and the trend in energy prices influence the choice of energy carrier, and to some extent also the growth potential of the various sectors. The ability to adapt to changes in energy prices and cost relationships are greater in the longer term. Higher energy prices normally lead to an increase in substitution between energy carriers and investment in new, energy-saving technology. The incentive to reduce energy costs increases with rising energy prices, and varies between sectors depending on the energy costs in each sector. The ability of a specific sector to substitute one energy carrier with another depends on the cost of substitution.

For long-term projections, the energy statistics from Statistics Sweden’s “Annual Energy Balances”[4], divided over 16 energy carriers, are used. The energy statistics relate to 14 sub-sectors, as well as to small-scale industry and other industries. In addition, a projection of sector-specific economic growth is obtained from the Swedish National Institute of Economic Research’s EMEC model. The Swedish National Institute of Economic Research’s model provides sector-specific growth figures for the seven sub-sectors within industry[5]. Since the Swedish National Institute of Economic Research works with larger sector aggregates, this means that the Swedish Energy Agency breaks this data down further into fourteen sub-sectors. The growth estimates for the sub-sectors must, however, stay within the framework of the Swedish National Institute of Economic Research’s estimates of the larger sector aggregates. The assumed

[4] Statistics Sweden’s annual energy balances may be downloaded from www.scb.se
[5] The Swedish National Institute of Economic Research is currently involved in breaking down the EMEC model into smaller segments. This is being done for both the transport sector and the industrial sector. The work is expected to be completed during 2006.

growth rate for the smaller sector aggregates is based on a combination of historical data and contacts with sector representatives.

The projection of industrial energy consumption is based on a sector-specific model. More specifically, the model starts from energy consumption in the base year and information on the specific energy consumption of different energy carriers in the various sectors. Specific consumption is defined here as the ratio between consumption and output value (energy consumption/output value). Specific consumption can be regarded as a measure of how energy-intensive a certain production process is. Historically, specific consumption has declined for industry as a whole. This does not necessarily apply to all sectors, however.

In the model, the actual base and projection years, along with the annual trend figures for specific energy consumption are specified. Implicit in these trend figures is an assumption about technological and structural effects as well as economic cycle factors. Relative price trends and possible substitutions between different energy carriers, as well as the absolute price level, are also taken into account. To sum up, demand for a certain type of fuel for a certain sector consists of the output value multiplied by specific consumption.

Energy consumption per fuel =
specific consumption by energy carrier*trend figure*projected output value

Energy policy, in the form of control measures, affects the relative price between different energy carriers and thereby the composition of energy consumption.

The result is checked by extensive contacts with energy-intensive companies and trade organisations. In addition, the DoS model[6] (Demand and Supply model), which models demand for manufacturing industry, giving special emphasis to electricity-intensive industry. The results from the MARKAL-NORDIC energy systems model are also taken into account, which use the projection of industrial energy consumption as input.

2.2 The residential and service sector

The residential and service sector consists of housing, non residential premises excluding industrial premises, holiday homes, land use and other service, including primary industries, the construction sector, street and road lighting, sewage and purification works, electricity works and water works. Other service also includes the residual items in the energy statistics, which consist of changes in stocks and the statistical difference between supply and consumption. Residual items represent a very small part of the sector’s energy consumption.

[6] See Appendix 1 for more information on the DoS model.

The most important statistical source for the residential and service sector is the official energy statistics.

2.2.1 Energy consumption for heating purposes

Approximately 60 percent of the energy consumption in the residential and service sector is for heating residential and other properties. Economic growth and population growth have an impact on how extensive new construction, refurbishment and extensions of residential and other properties will be. This is in turn crucial to the requirement for heating. Projections for new housing construction are provided by the National Board of Housing, Building and Planning. The trend in new construction of non-residential premises is linked to economic growth, and to expert assessments of the trend in the immediate future.

The amount of energy used for heating depends on temperature conditions. To compare energy consumption between different years without taking account of the differences resulting from temperature variations between the years, a correction is made to the figures to eliminate the difference in the energy consumption that depends on temperature. The temperature corrected energy consumption indicates how much energy would have been used in a specific year if it had been average as far as temperature is concerned. It is assumed that the projection years are standard in respect of temperature. Standard-year corrections are based on degree day statistics from SMHI, the Swedish Meteorological and Hydrological Institute. As from 1 January 2003, the period 1970-2000 is used as the reference period for a standard year.

The Swedish Energy Agency uses the DoS model to project the heating requirements of the residential and service sector. The DoS model was developed in 1999, and initially provided a combined supply and demand model for the Nordic countries, excluding Iceland. The DoS model has since been developed into a purely demand model.[7] For the residential and service sector, the model provides, in addition to demand for electricity, demand for energy carriers other than electricity for heating.

The DoS model is a bottom-up model, which includes a detailed analysis of energy consumption for heating. The following input data is required for the DoS model to generate a projection for the heating sector:

- Energy consumption divided by heating system and type of property (single-family dwelling or multiple-unit dwelling house/non-residential premises)
- Projection of new construction and demolitions
- The proportion of heating systems assumed to require replacement during the projection period

[7] See Appendix 1 for an explanation of the DoS model

- Investment costs for different heating systems, cost of capital and depreciation period
- Energy prices, taxes and charges
- Efficiency of the various heating systems and the estimated development of these
- Maximum potential for changing to different heating systems. Since the model is based on the assumption that consumers choose the most economical replacement option, those using the model must set limits. Where a wood-pellet boiler would be the most economical choice, a household may, for example, decide not to go down that route for the sake of convenience or for lack of space to store pellets.

Given this information, the model calculates energy consumption by energy type at different electricity prices. The model also optimises the operation of oil/electricity combi-boilers in single-family dwellings.

The results from the DoS model are checked against the results generated for the residential and service sector by MARKAL-NORDIC. Another important aspect in the production of the projections is the discussions carried out with sector experts on the trends in energy demand.

2.2.2 Energy consumption for non-heating purposes

Over and above energy for heating and water heating, electricity is used for running properties and for electrical appliances in multiple-unit dwelling houses, non-residential premises and other service, as well as household electricity in the household. This electricity consumption is affected, among other things, by economic growth, private consumption growth in non-residential and residential area and developments in technology.

For projecting the trend in electricity for non-heating purposes in non-residential premises, the trend is linked to the trend in the economy, and also to trends in the areas of non-residential premises and assumptions on specific consumption per square metre independent of the trend in GDP. Household electricity consumption is linked to the trend in private consumption, the trend in area and an assumption on continuous improvements in efficiency.

Energy consumption in primary industries and other service etc. is linked to a certain extent to economic growth, and also to growth in population. These estimates are supplemented by sector experts' estimates of the trends for individual sectors and sub-sectors.

2.3 The transport sector

The transport sector is usually divided into four sub-sectors: road traffic, aviation, rail and shipping. The projection of energy consumption for road traffic is calculated using two parallel methods, one based on daily transport usage, and the other on daily energy consumption. The Swedish Institute for Transport and Communications Analysis, SIKA, is responsible for the transport projection, while the Swedish Energy Agency is responsible for the projection of energy consumption. Projections for aviation, rail and shipping have been calculated on the basis of daily energy consumption.

Important statistical sources for the projection are the official energy statistics, the Swedish National Institute of Economic Research’s projections of economic growth, sector reports and statistical data from each sector government agency, Bilismen i Sverige (Bil Sweden) [the Swedish trade association for the automotive industry] and statistics from the Swedish Gas Association.

Another important aspect in the production of the projections is the discussions carried out with experts at each traffic sector government agency and at other industry organisations on the trends in the various sectors.

2.3.1 Energy consumption of road traffic

The Swedish Energy Agency’s petrol projection is calculated using a top-down model, which models demand for petrol on the basis of macroeconomic functions. The main effects on demand are expected to be the price of petrol, household incomes and technological developments. The effect of price and income on energy consumption is calculated using elasticities.

The model function is as follows:

$$B_{t+1} = B_t * ((dP_t * \varepsilon p + dY_t * \varepsilon y - T)/100+1)$$

B_{t+1} = petrol consumption in the projection year
B_t = petrol consumption in the base year
dP_t = percentage real change in the price of petrol
εp = price elasticity
dY_t = percentage change in household incomes
εy = income elasticity
T = trend variable, e.g. reduced fuel consumption due to technological developments and changes in driving behaviour.

The model calculates annual changes in demand for petrol based on annual changes in the price and income variables as well as estimated elasticities. Which elasticities are used depends on whether the calculations are made for the short or long term.

The assumptions on technological development include improving the efficiency of average fuel consumption and an increase in the number of flexible fuel vehicles (FFV). Taxation on future average fuel consumption is calculated by the Swedish Road Administration using the EMV model[8].

The diesel projection is also estimated on the basis of a top-down demand model. The model includes assumptions on the price of diesel, the trend in different industrial sectors and technological developments. The sectors which have proved to have the greatest influence on diesel consumption are the pulp and paper industry, the petrochemical industry and the engineering industry. One weakness in the model is that it does not take account of structural changes in the vehicle pool. For that reason, the calculations in the model are supplemented by an assumption on an increased proportion of diesel-powered light commercial vehicles.

Diesel consumption is calculated using the following function:

$$D_{t+1} = D_t * ((dM\&P_t * \varepsilon m\&p + dPk_t * \varepsilon p + dV_t * \varepsilon v + dP_t * \varepsilon p - T)/100+1)$$

Where
D_{t+1} = diesel consumption for the projection year
D_t = diesel consumption for the base year
$dM\&P_t$ = percentage change in pulp and paper production
$\varepsilon m\&p$ = elasticity in respect of pulp and paper production
dPk_t = percentage change in petrochemical production
εp = elasticity of petrochemical production
dV_t = percentage change in engineering production
εv = elasticity in respect of engineering production
dP_t = percentage real change in the price of diesel
εp = price elasticity
T = trend variable, e.g. improved fuel efficiency or increased capacity utilisation

This model is limited in the same was as the top-down model for petrol above, i.e. there is no adaptation mechanism built into the model.

The projection of natural gas consumption and the consumption of renewable fuels is calculated on the basis of assessments of the future technological development of the different fuels. Future energy consumption of renewable fuels is primarily dependent on production costs, the construction of a distribution system, access to vehicles and the construction of filling and service stations.

[8] For more information on the EMV model, see Hammarström, Ulf Karlsson, Bo O, "EMV - ett PC-program för beräkning av vägtrafikens avgasemissioner : programbeskrivningar och användarhandledning", [EMV – a PC program for calculating exhaust emissions from road traffic; program description and user guidance] The Swedish National Road and Transport Research Institute,. VTI report 849.

Reconciliation of figures between the Swedish Energy Agency and SIKA

SIKA calculates petrol and diesel consumption on the basis of transport projections which are produced in the SAMPERS and SAMGODS models, which are bottom-up models.[9] Fuel consumption is calculated by multiplying total transport traffic by average fuel consumption. Transport measures the movement of loads, and is calculated by multiplying traffic by the average capacity utilisation (passenger transport) and average load weight (freight transport).

Comparisons are made on the basis of the Swedish Energy Agency's and SIKA's model calculations. Certain differences may arise due to the formulation of the models and the various assumptions. Through a careful analysis of the results, the results are reconciled with each other, which leads to a joint final projection of energy consumption in the road traffic sector.

2.3.2 Energy consumption of aviation

Calculations of consumption of aviation fuel are based on the Swedish Civil Aviation Authority projections of the number of landings at Swedish government airports. It is supplemented with a passenger projection which is produced using a demand function, in which the connection between demand for air journeys and economic trends are utilised along with price trends for air journeys. The passenger projections are also produced by the Swedish Civil Aviation Authority. Since the Swedish Civil Aviation Authority projections of the number of landings refer only to government-owned airports, certain adjustments are made to take account of municipal and private airports.

In the long-term energy projections, there is also an assessment of expected technological development, which affects the average fuel consumption of the aviation sector. This assessment is made on the basis of discussions with FOI [The Swedish Defence Research Agency].

2.3.3 Energy consumption of rail traffic

The projection of electricity consumption is based largely on Banverket's [the Swedish National Rail Administration] projection of the sector's energy consumption. The energy consumption of passenger traffic is not affected to any great extent by economic conditions but rather by infrastructural changes. Freight traffic is affected by GDP and exports, as well as by the future expansion of the infrastructure. Corrections are made to the projections of electricity consumption to take account of those parts of rail traffic which are not included in Banverket's projection (e.g. Stockholm's underground system).

2.3.4 Energy consumption of maritime traffic

Energy consumption for domestic shipping is largely set by changes in the passenger traffic between the island of Gotland and the mainland. As a result of this, the projection is based on planned changes in supply and vessel structure on

[9] For more information on these models see www.sika-institute.se

this route. These assessments are made on the basis of discussions with the Swedish Maritime Administration and the Swedish Institute of Shipping Analysis.

Bunkering for international shipping is estimated by the Swedish Energy Agency partly through a model based on changes in exports, and partly through discussions with representatives of major companies in the oil sector.

3 Energy supply

The total energy supply in Sweden over one year consists of net imports (i.e. the difference between imports and exports) of energy carriers such as oil, natural gas, coal and electricity, domestic supply of biofuels, hydroelectric power and fuel inputs for nuclear power generation, as well as changes in stocks. Total energy supply is the quantity of energy utilised in the Swedish energy system to meet the needs of end-users.

Part of the energy provided, in the form of different fuels, is used for conversion to, and the distribution of, electricity and district heating. The electricity and district heating supplied to consumers, as well as other fuel supplies, are consumed in the user sectors, i.e. the industrial sector, the transport sector and the residential and service sector.

The projection of energy consumption excluding consumption for conversion and distribution losses, i.e. the energy supply to cover consumption in the user sectors, is produced by each sector in accordance with the preceding section 2 Energy Consumption. The projection of energy supply for conversion to, and distribution of, electricity and district heating production is produced separately. The energy supply for energy conversion includes refineries.

To produce the projection of trends in the electricity and district heating systems, a number of crucial assumptions must be made. These include:

Assumptions on

- demand trends
- fuel prices
- current control measures
- production costs for existing plants
- standard year's output for hydroelectricity and nuclear power
- service life of existing plants
- investment costs and production costs for new plants
- technological development (effects on efficiency)
- limitations in the potential of different production technologies not covered by the MARKAL-NORDIC model, such as inertia in the permit process etc.
- energy systems of neighbouring countries
- capacity of transmission lines
- potential for the extension of infrastructure such as the electricity grid, the district heating network and natural gas pipelines.

Assumptions on the trends in demand for both electricity and district heating are made by the user sectors (see Chapter 2). Other assumptions are based on various reports, historical data and, as far as possible, on interviews with electricity and district heating organisations and companies (sector experts).

The projected energy consumption of the industrial sector and the residential and service etc. sector are used as input data for the MARKAL-NORDIC model. For the residential and service sector, net demand[10] for electricity for purposes other than heating, and the total number of TWh net energy demanded for heating purposes are used as input data for the model. For the industrial sector, the projected consumption of electricity and district heating is used along with a total of all other energy consumption. This means that the MARKAL-NORDIC model provides an optimisation of all energy which is substitutable for the residential sector and the industrial sector, which may differ from the projections made by each sector using other models.

All the above-mentioned assumptions are entered in the MARKAL-NORDIC model, which optimises the whole Nordic energy system to minimise the total cost of meeting energy demand. The model permits trading in electricity between the Nordic countries excluding Iceland, which means that production takes place where it is most cost-effective. MARKAL-NORDIC is a dynamic model which means that it can be used to model investment in new production plant to cover future energy needs in the event that the existing energy system, which is the starting point for the projections, is not sufficient. The assumptions on the trend in investment costs over time are based on the theoretical structure of experience curves, i.e. the assumption that the cost of investment falls by a certain percentage for every doubling of accumulated capacity. MARKAL-NORDIC does not itself incorporate experience curves but includes assumptions on reduced investment costs for wind power, solar power etc., derived from research on experience curves[11]. The transport sector is not represented in MARKAL-NORDIC other than through its electricity consumption, which is a very small part of total energy consumption in the transport sector.

The Swedish Energy Agency uses the following results from the MARKAL-NORDIC model:

- Electricity and district heating production from every type of plant
- Import/export of electricity from Norway, Finland and Denmark
- Electricity and district heating prices
- Input fuel for electricity and district heating production
- Energy consumption in the industrial sector and the residential and service sector per energy carrier, which is reconciled against the Swedish Energy Agency's user-only projections.

For the projection of electricity supply, the PoMo model is used in addition to the MARKAL-NORDIC model. This is also a bottom-up model, but, unlike MARKAL-NORDIC, PoMo is a static model. The model cannot be used to model

[10] Net demand is the energy demanded excluding all distribution and conversion losses.
[11] For more information on the MARKAL model, see Appendix 2.

future investments in energy production. It optimises the production resources which already exist without creating new resources. It is possible to input assumptions on additional production capacity for the projection years manually into the model. An advantage with PoMo is that electricity demand can be flexible. The most widely used result from PoMo is the price of electricity, which is compared with the price of electricity from MARKAL-NORDIC[12].

The projection of electricity and district heating production is produced using data from the results generated by MARKAL-NORDIC, PoMo and expert assessments. Changes in the results from MARKAL-NORDIC are entered in an Excel-based calculation tool, which takes account of links between electricity and district heating production, such as electricity for heat pumps, electric central heating boilers and production in district heating power plants.

[12] For more information on the PoMo model, see Appendix 3.

4 The energy balance

The energy balance is a summation of energy consumption and energy supply broken down by energy carrier, which expresses the total of all energy flows in Sweden’s energy system. The total of the energy balance is zero, i.e. the quantity of energy supplied is equivalent to the quantity of energy consumed. Going from the results of MARKAL-NORDIC requires the Swedish Energy Agency to break down the figures for certain fuels, since the breakdown of fuels in the balance is not quite the same as in the model. The breakdown of fuels is based on the official statistics for the base year. One example of this is fuel oil, which is the only fuel in MARKAL-NORDIC, while the Swedish Energy Agency’s energy balance is reported as two different fuels, Fuel Oil 1 and Fuel Oil 2-5.

When the projections of energy consumption in all sectors, industry, residential and service, transport, electricity and district heating production, as well as refineries, energy consumption for non-energy purposes and international transport, along with projections of conversion and transmission losses are complete, they are entered in a balance file, which is an Excel-based calculation tool. This file checks that the energy system is in balance with the projection trend, i.e. the supply of energy is equivalent to total energy consumption. When the balance is ready the projection is complete.

5 Appendix 1. The DoS model

The swedish consulting firm EME-Analys has, with support from the Swedish Energy Agency, developed a projection model for the Nordic electricity market, the Demand and Supply model, DoS.

In the Nordic countries we have a large share of electricity intensive industry and a high use of electricity for heating purposes. A model that describes the willingness to pay for electricity is therefore desirable. The DoS model does this both for long term and short term, although the model is first and foremost made to be used for projections describing the Nordic electricity market 10-20 years ahead.

As is the case for all models, the model results depend on what input data you feed into the model. The DoS model is made in Microsoft Excel, and uses VBA-technique (Visual Basics for Applications) to get reliability and flexibility when running the model.

Output from the DoS model

The DoS model mirrors the total electricity demand in the Nordic countries excl. Island. The model calculates demand for electricity given different prices of electricity. This includes the calculation of the demand for substitutes to electric heating in the residential and services sector and substitutes to electricity use in industry. It is also possible to get a picture of the total electricity demand in a specific country. In this case the DoS model also calculates the losses, as is not the case in the sector specific calculations.

The basis for the electricity prices are the 12 month future prices in the Nordic power exchange, Nord pool. The model also calculate carbon dioxide emissions in each country and for the Nordic countries as a whole, for substitutes to electric heating that gives rise to carbon dioxide emissions and for industry where electricity and other energy carriers are assumed to be complements.

The DoS model has to be complemented with a power balancing model to model the supply side in a correct way, and by this mean simulate electricity price levels for different electricity demand. An equilibrium situation occurs when demand equals supply in the DoS model and in the balancing model.

Model structure

The DoS model consists of four different excel-files:

Kraft-	Here most indata is put and most of the calculations are made. The model calculates

modell.xls	demand for electricity in the electricity intensive industry, demand for electric heating in new production of buildings, electricity demand for household purposes and all other electricity use except for electric heating in the existing residential and tertiary buildings. These demand estimations are made for Sweden, Finland and Norway. The use of electricity in Denmark is also calculated but only in the form of general development and elasticity calculations, as the use of electricity for heating and the electricity intensive industry is negligable in Denmark.
Kraftunder-modell.xls	Here assessments are made of how the heating systems are developed in the buildings that are existing in the base year. The main assumption is that the owners of the buildings mainly will change their heating system when the existing heating system needs to be changed. It is assumed that when changing heating system, the owner knows the total cost of investing in a new system and the cost of reinvesting in the existing heating system.
DoS.xls	Here electricity demand given different electricity prices is shown for each subsector, for each country and for the Nordic countries as a whole. Electricity demand curves are also shown for each subsector, each country and for the Nordic countries as a whole. A rough calculation of electricity supply (on a yearly basis) is made to estimate an approximate equilibrium electricity price.
CO2-kod.xls	This is a file for macros, input data and control parameters.

Input data

Most of the general input data is in the Kraftmodell.xls, but input data regarding the heating systems is in the Kraftundermodell.xls. Most of the input data regards electricity intensive industry and electric heating. Other electricity use is treated in more general terms in the form of assumptions about growth rates, efficiency, and elasticities of electricity use and a cross price elasticity of the use of oil and electricity, In the table below the overall input data structure in the DoS model is given:

Excell-file	*Sheets in the Excel-file*	*Input data*
Kraft-modell.xls	Förutsättn	Overall input data that is general for all countries. Fuel prices, prices of transmission of electricity, additional charges on the electricity price, exchange rates, elasticities, growth in the building stocks, parameters for heating such as energy efficiency improvement in existing buildings and the share of heating systems that will have to be changed until the projection year. Here also economic parameters such as GDP and the growth in private consumption are put, which for example affects the use of electricity for common purposes in commercial and public buildings, electricity for household purposes as well as interest charges and depreciation rates. Finally in this file is also the name definitions and data concerning the CO2 content in different energy carriers.
Kraft-	Pris och MC	Here are marginal costs of different electricity production in the

modell.xls		Nordic countries. Calculations of how the electricity price is divided over the summer and winter for weekdays at daytime and for nights and weekends as well as profiles over how different categories of customers electricity use is divided on the above mentioned periods of time. This altogether gives different electricity prices for different user categories, given the same 12-months future price.
Kraft-modell.xls	Konv kostn	In this sheet investment costs are given for different heating systems in new construction The investment costs are allocated over the years with an annuity calculation.
Kraft-modell.xls	Föruts S	Here the prerequisites that are assumed to be country specific are presented, in this case for Sweden. Total electricity use and total electricity losses for the base year, district heating prices for the projection year, energy- and environmental taxes and electricity certificate prices. Here you also have the projections of new construction of dwellings, specific energy use for heating in new construction as well as the relationship between economic growth and the growth in the stock of non residential premises. To calculate electricity use for household purposes and common purposes in commercial and public buildings assumptions are made about changes in specific electricity use.
Kraft-modell.xls	Elvärme S	Here the max. potentials for how much of each type of heating system that is allowed to enter into new construction. Even if the model at certain energy prices finds it profitable to invest in direct-acting electricity you might not want the model to choose 100% direct-acting electricity as considerations other than the investment and operating costs also has to be regarded, as for example comfort and flexibility. In this sheet the short run price elasticity for households with a combined heating system is also calculated, i.e. optimal use given different electricity price levels is calculated. For this no new input data is needed.
Kraft-modell.xls	S Övr	In this sheet the projection of the electricity use in the residential and sevices sector other than electricity use for heating is calculated. The input data used is time series of the different user categories. The development is assumed to be driven by the growth in GDP and private consumption and by assumptions about energy efficiency improvments (see Föruts S). The purpose of this sheet is also to guarantee that no electricity is ”forgotten”. Therefore also electricity use in the transport sector is included.
Kraft-modell.xls	Ind S	Here you put input data for the yearly change in industry production and energy efficiency. This is made for each industry branch. Here you also put statistics for the different industry branches of energy use, electricity costs, value added, profits and investments. Regarding profits and investments EME-Analys has used statistics covering many years, as profits and investments strongly fluctuate over business cycles etc. There is always a possibility to put your own data and assumptions instead of what the model proposes.
Kraft-	DK	Here the Danish demand for electricity is calculated using

modell.xls		assumptions about growth in electricity use, own price elasticities of electricity and a cross price elasticity for electricity and oil.
Kraftunder - modell.xls	Konv kostn	Total costs for different heating systems in the existing building stock. Investment costs are allocated for each year using annuity calculations. (Default values for the interest rates and depriciation rates are given in ”Kraftmodell förutsättn”). Investment costs are different depending on what heating system you have in the base year. It is for example more expensive to change from direct acting electricity (no water borne system) to district heating, than to change from an electric boiler to district heating.
Kraftunder - modell.xls	Elvärme S	Here gross energy use for heating in the base year is given for about ten different heating systems, as well as mean annual efficiencies in the base year and in the projection year. In this sheet max. potentials for how much of each heating system that is allowed in the model due to conversion. As in new construction some alternatives have to be limited as it is not realistic that 100% of the building owners will invest in the same system even if the economic calculation in the model shows that it is the most profitable alternative. Here is also summary tables that shows the results for a chosen price level.

Running the DoS model

With the CO2-kod.xls the user can use the DoS model with the help of different macros. The macros can be adjusted according to the wishes of the user, so that they for example are run for one country only, or for chosen heating systems.

Electricity intensive industry

From the input data electricity use and costs of the electricity use are given. By comparing this with the profits of some years it is possible to make a calculation of how high electricity prices an industry branch can take in short term before the profit is all gone.

In longer term the companies must make investments to be able to keep on operating. EME-Analys has therefore also collected several years of statistics of the investments in different industry branches.

It is important to point out that it is always possible for the user to take into account other judgement and to modify the proposals in the model regarding for example what is the highest electricity price different industry branches can take.

In all long term projections assessments have to be made regarding growth rates in different industry branches. These figures normally are taken from computable general eguilibrium models or from the lastest long-term planning commission. Assumptions are also made about how the specific electricity use can be expected to develop in each industry branch.

Non electricity intensive industry

Demand for electricity from the non electricity intensive industry is in the DoS model calculated on the basis of assumptions about growth rates, energy efficiency improvements and assumptions about elasticities.

Electricity for heating purposes

Also for electricity for heating purposes DoS generates demand curves, calculated as price levels for 12 months futures.

The long term electricity use for heating purposes is determined by how the stock of buildings is expected to develop, how flexible heating systems are used and how much heated space that is added and taken away by extension and demolitions as well as how the energy efficiency in the buildings improves through better insulation etc.

In ”Kraftundermodell.xls” it is calculated how the stock of heating systems can be expected to develop given different electricity price levels. (In the model it is assumed that the investors can predict future electricity price levels when they do the investments.) Those calculations are used for the long term electricity demand for heating. Normally it is assumed that a change of heating system only occurs when the old system needs to be changed. The model puts the costs of alternative heating systems against the reinvestment cost for the existing system and chooses the cheapest alternative.

Given the stock of heating systems that is calculated for the projection year ”Kraftmodell.xls” is used to calculate how the stock of oil/electricity combi-boilers in single-family dwellings are operated.

Other electricity use

In the sheet “övrig elanvändning” the projection of the electricity that is used for other purposes than by industry and electricity for heating purposes is made. An additional purpose with this sheet is also to guarantee that no electricity is “forgotten”.

Other electricity use is divided into the following groups:
Electricity for household purposes including holiday homes
Electricity for common purposes in commercial premises and public buildings,
Electricity for land use applications
Electricity for other service
Electricity used in the energy supply sector and
Electricity for transports

The development in electricity used for household purposes is related to the development in private consumption and an assumption about the rate of energy efficiency improvement. The development in use of electricity for common purposes in commercial premises and public buildings is related to the economic development and an assumption about the rate of improvement in energy efficiency. For the other user groups within the residential and services sector the development is related to economic growth. The energy supply sector and the transport sector has so far been assumed to have a relatively stable electricity use.

For all user groups a simple elasticity calculation is used to estimate the dependency of the electricity price.

Carbon dioxide taxes

The DoS model also gives the possibility to calculate how electricity demand is affected by different carbon dioxide taxes and prices on emissions rights. When it comes to the non-emissions trading industry these taxes can be put in different levels in different countries , but when it comes to the trading sectors they are equal in all the countries.

An equilibrium solution with a power balancing model

The DoS model calculates electricity demand, with different demand for different electricity prices. A power balancing model, as PoMo[13], gives the short run marginal costs (SRMC) of electricity production given the prerequisites that have been put into the model as input data. With an increased electricity production the SRMC gets higher. In this way a supply curve for electricity is calculated. Where the demand curve intersects the supply curve the market equilibrium demand and supply for the projection year is given.

[13] See the description of the PoMo-model in appendix 3.

6 Appendix 2: the MARKAL methodology and the MARKAL-NORDIC model

This summary describes the MARKAL methodology in general, and MARKAL-NORDIC in particular.

MARKAL – An overview

Brief history

MARKAL (MARKet Allocation) was developed at the beginning of the 1980s jointly by Brookhaven National Laboratory in the USA and Kernforschungszentrum Jühlich in Germany. The original formulation of the model is described by Fishbone et al and Fishbone and Abilock[14]. The MARKAL model has achieved a unique currency throughout the world, which means that a great deal of combined experience of the application of MARKAL is available. A crucial strength of MARKAL is the international organisation ETSAP (Energy Technology Systems Analysis Programme), which has been responsible for the model and its development since 1977.[15] ETSAP in turn is the result of an implementing agreement within the IEA.

MARKAL and the energy system

The "traditional" application of MARKAL is related to studies of the *technical* energy system. The technical energy system relates to its environment as shown in Figure 1. At the far right of the diagram is the actual energy requirement, which is itself linked to trends in the rest of the macro economy. Energy consumption is itself a result of the real requirements we have, i.e. homes, goods, services etc. In addition to the energy requirement, factors such as technological progress, international fuel markets and environmental policy are dealt with exogenously in

[14] a) Fishbone L G, Giesen G, Goldstein G, Hymnen H A, Stocks K J, Vos H, Wilde D, Zölcher R, Balzer C and Abilock H (1983), "User's Guide for MARKAL (BNL/KFA Version 2.0), Report BNL-51701, Department of Applied Science, Brookhaven National Laboratory, Upton, NY
b) Fishbone L G and Abilock H (1981), "MARKAL – A Linear Programming Model for Energy System Analysis : Technical Description of the BNL Version", *International Journal of Energy Research 5, 353-375*

[15] On ETSAP's website (www.etsap.org) there is more information on the organisation itself and the MARKAL model.

the “traditional” application of MARKAL.[16] Handling the factors in the model’s environment is best done using *scenarios* in which the scenarios are based on assumptions about the exogenous factors.

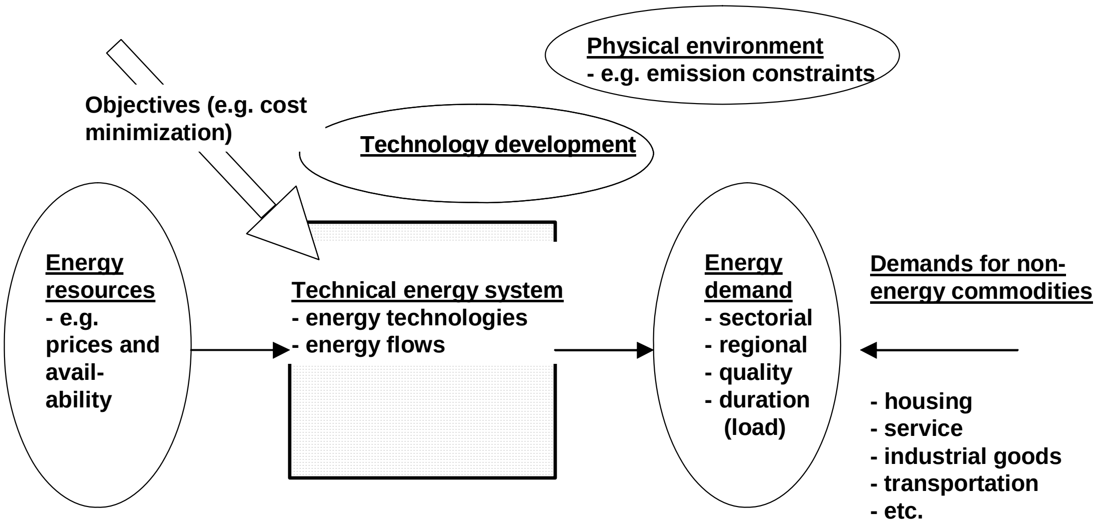


Figure 1 The technical energy system and its environment

The energy system in the MARKAL model (i.e. within the limits of the technical energy system) is described using the reference energy system concept (RES)[17]. This illustrates energy flows from the extraction of fuels and raw materials, via conversion for power and district heating generation to the end use of the fuel, electricity and district heating in a number of different sectors, such as households and industry (see Figure 2).

[16] Some of these exogenous factors have been internalised, i.e. have become endogenous, in certain versions of the MARKAL package. For more on this, see the section on “Model development and enlargement”

[17] For a more detailed description of the RES concept, see: Marcuse W, Bodin L, Cherniavsky E and Sanborn Y (1976), “A Dynamic Time Dependent Model for the Analysis of Alternate Energy Policies”, K B Haley (Ed.), *Operational Research ’75*, 647-667, North Holland Publishing Company, Amsterdam

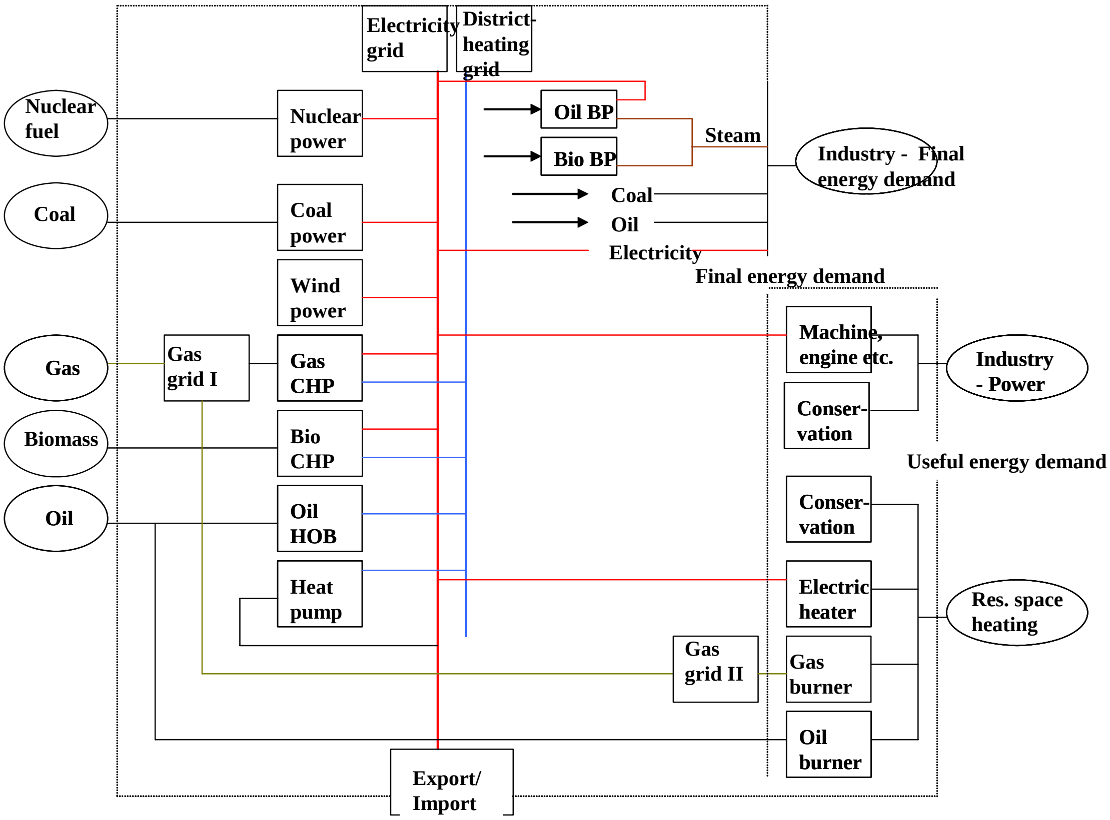


Figure 2 Example of a reference energy system

The geographical limits to the system depend on how the problem is presented, and may involve everything from individual municipalities in Sweden to the whole world.

The architecture of the MARKAL model

A modelling procedure in MARKAL consists of three main parts (see Figure 3):

- A database with all calculation assumptions (input data)
- An equation generator, i.e. input data expressed in a very large number of equations. These equations are "sent" to a problem solver in which the actual optimisation takes place. The solver package used in MARKAL is GAMS.
- Result report with the calculation results presented in tables and diagrams

In addition, the MARKAL package utilises a user-interface, such as MUSS or ANSWER, so that both input data and output data can be handled effectively. The user-interface and the solver are commercial software, while the actual "MARKAL core" is free of charge.

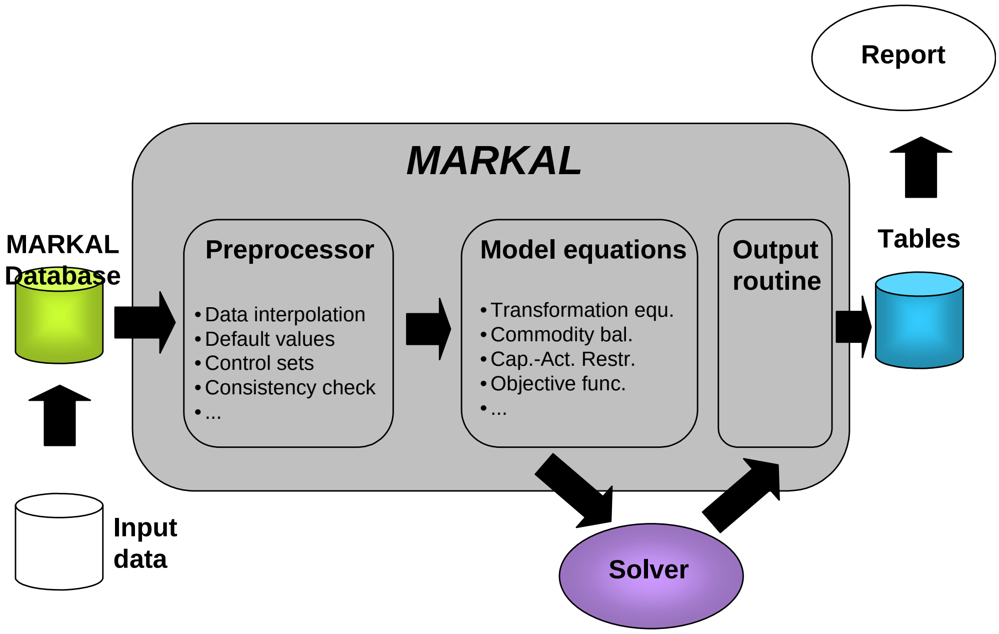


Figure 3 The architecture of the Markal system

The database and input data

For large parts of the input data in MARKAL, the level of detail may be selected when a database/model is being constructed. This provides, of course, some degree of flexibility in the description of energy demand, energy technologies and energy supply, but it also means that it is possible to construct databases with different problem focus and for different large geographical areas.

The driving force of the whole model, so to speak, is the requirement for energy in different sectors. This energy requirement can be expressed either as a requirement for useful energy or a requirement for final energy. Useful energy is defined as the energy service itself, e.g. an indoor temperature of 20°C. In the model, however, these 20°C are expressed as an amount of energy, for example, in MWh, based on information on the output requirement in W/m^2 to obtain precisely 20°C. An indoor temperature of 20°C may be effected using an oil-fired boiler, electric heating or a combination of energy supply and energy saving. In the last-mentioned case, the final energy is reduced as a result of the energy saving. Final energy is defined as the actual use of the energy carrier. In the model, for example, the preferred expression of household electricity is as a final energy requirement, since it is not as meaningful to talk of useful energy in this context.

The technologies in the model are described using investment costs, operating and maintenance costs, service life, efficiency, availability and emission data (e.g. carbon dioxide, sulphur oxides and nitrogen oxides).

MARKAL contains a load curve for electricity and district heating, which describes the annual variation. For this, electricity consumption is broken down into six annual time stages, while district heating consumption is represented by three.

The model is dynamic in the sense that up to nine individual but mutually-dependent time stages (model years) can be analysed. In general, the time horizon is 20–50 years into the future.

More information on input data is contained below in the section on MARKAL-NORDIC.

Mathematical formulation

The model is based on linear programming, i.e. a mathematical algorithm for solving optimisation problems in which the target function (the one to be optimised) and boundary conditions are expressed as linear equations. The target function is generally the discounted total system cost, and this is to be minimised. An alternative target function could, for example, be emissions. Boundary conditions may include the efficiency of a certain type of plant, environmental standards, power transmission connections between countries, energy consumption in a certain sector etc.

A linear programming problem is generally formulated as follows:

$$\text{min or max } \sum_i c_i x_i$$

$$\text{boundary conditions: } \sum_i a_{ji} x_i \geq b_j \text{ , } j = 1,...,m$$

$$\text{and } x_i \geq 0 \text{ , } i=1,..,n$$

where c_i, b_j and a_{ji} are coefficients which are given as input data and x_i is activities obtained in the solution.

The solution of a MARKAL calculation is, in other words, the combination of technologies throughout the chain from fuel extraction or import via conversion, such as to electricity and district heating, to end use (c.f. Figure 2), which meet the lowest total cost expressed as net present value.

The benefits of MARKAL

The main advantage of MARKAL modelling is in its holistic approach to the energy system, limited only by the modeller's ambition. All important parts of an energy system are represented, which makes it possible to make direct comparisons of the cost-effectiveness of individual measures, for example to reduce carbon dioxide emissions, and to weigh them against other measures. An optimal system is obtained, which can be compared with, and used as a standard or bench-mark for, an actual system in which various degrees of sub-optimisation are included for explicable reasons.

Changing individual parameters or assumptions in a MARKAL calculation gives a very good picture of the importance of the precise parameter or assumption, given that all other things remain unchanged. This effectively isolates the cause-effect connection. In this way, it is possible to assess the value, for example, of common energy markets instead of separate national markets, the costs of excluding a certain type of energy or a certain technology, and the effects of changes in the control framework.

The model provides a picture of a complex reality related to energy and environment. Both through the actual modelling process/model formulation and the result of the calculations, we learn more about the real system and win new insights. It is also important to link the theoretical formulation and the explanatory models to the model results to legitimise them. Close collaboration during the modelling phase with consumers and other experts in the problem area is, therefore, important.

Given the sometimes large uncertainties surrounding certain assumptions (such as trends in energy demand and fuel prices), it is important to remember to use the results of the calculations with some degree of caution. Calculation results relating to the future expressed in TWh or SEK are often illuminating, but the assumptions underlying them should always be borne in mind. The greatest value of these figures is the qualitative knowledge they give. MARKAL can, however, also be used as an *aid* in projection work, preferably in connection with sensitivity analyses. This is an excellent aid in assessing the significance of uncertainties in the key assumptions made.

The brief discussion on the benefits of MARKAL modelling in this section is partly linked to the distinction between a *normative* and a *descriptive* model tool. MARKAL is first and foremost a normative tool constructed around a specific target function, system cost minimisation to *understand* reality, but it is also a tool for *simulating/describing* actual events.

MARKAL-NORDIC

MARKAL-NORDIC is a MARKAL model in which the database contains a comprehensive description of the whole Nordic (Sweden, Norway, Finland and Denmark) stationary the energy system, i.e. excluding transport. Input data for the Nordic database, MARKAL-NORDIC, has been compiled in collaboration with IFE (the Energy Technology Institute in Kjeller, Norway), Risø in Denmark and VTT in Finland. At present, MARKAL-NORDIC is administered and updated by the consulting firm, Profu, and Chalmers University of Technology.

Fuels

The stationary energy sector in the model includes the import of fossil energy carriers such as coal, heavy and light fuel oil and natural gas. A simplified description of the Norwegian off-shore sector is included. Import prices for the fossil energy carriers are determined exogenously, which also applies to nuclear fuel. For biofuels, each country has a domestic supply curve with fuel cost and the associated potential in TWh. The domestic supply curve can, however, be complemented with a given ceiling price at which imports are regarded as infinite.

Technical description

Nuclear power, both in Sweden and in Finland, has an assumed life of around 40 years. To achieve this, however, a major reinvestment will have to be made after 25 years operating time of the same order of magnitude as was, for example, carried out at Oskarshamn 1. No new capacity will be permitted to be built in Sweden. The potential for gas power along the west coast of Norway is regarded, however, as independent of a Trans-Nordic gas pipeline. Coal and oil-based power have no limitations other than the requirements for electricity and/or district heating.

Carbon dioxide separation is available as an option limited to gas and coal-fired condensing power plants, as well as gas and coal-fired heating. In total, the Nordic database contains investment and operating costs for over 200 power and district heating generating technologies. The plants are described using a long list of input data, which is specified for every plant and – if required – for every time period (year, season, day/night). The list below gives some important input data:

- investment cost and service life
- fixed and variable operating and maintenance costs
- fuel mix
- efficiency (and electricity ratio for district heating power plants/back pressure)
- availability and audit
- emissions coefficients for carbon dioxide emissions

For existing plants, the following is also specified

- existing capacity
- current production

A number of small-scale technologies in the user-stage are also included in the description of the model. This may, for example, involve electric central heating boilers, direct electricity, heat pumps, wood-pellet boilers, oil-fired boilers, district heating heat exchangers, solar heating etc for heating single-family dwellings, multiple-unit dwellings or in the service sector.

The power generating system in the four countries is linked through the existing transmission capacities. There are also options to extend the transmission connections. Other than the ability to import from Russia to Finland , there are no other connections with other non-Nordic countries.

Energy consumption

The demand side in the model databases includes over 70 different sectors, such as household electricity in Sweden and end-use of fuel in the Finnish chemical industry. Demand for heating can be met using electricity, oil, wood-pellets or district heating. As was discussed earlier, final energy consumption can be reduced through investment in energy-saving measures and/or converting to other, more efficient forms of energy. Useful energy consumption is, however, the same (but changes, naturally, over time in line with projection requirements).

Environmental effects

Of the environmental effects arising in connection with energy supply and energy consumption, at present only carbon dioxide emissions are given by MARKAL-NORDIC.

Control measures

A long list of control measures is included in MARKAL-NORDIC. In principle, the majority of energy and carbon dioxide related control measures in each Nordic country are included.

- Energy and electricity taxes, carbon dioxide taxes in the residential and service sector, as well as the industrial sector in Sweden and the district heating sector
- A Swedish system of electricity certificates is taken into account through an assumption that the ratio set for the renewable quota will be achieved
- Support for renewables. Investment support is described in the model as a reduced investment cost in SEK/kW for electricity or heating.
- Trading in emission rights for carbon dioxide: The system has been described by an exogenous assumption on the price of emission rights.

7 Appendix 3: the PoMo model

PoMo is a model of a combined thermal power and hydro power system that predicts future spot prices. The model takes account of the unpredictable variations in precipitation and inflow of water to the water reservoirs. It is an optimisation model based on the assumption that power producers try to maximise their future profit from power sales in a competitive market.

It is typically to be used at the start of each week to predict spot prices for the coming weeks based on the latest information about the present water reservoir level and other data. It can also be used for long-term forecasting.
User-friendliness and rapid interactivity between the user and the model are main features.

Result

The main result of the model is the expected future average weekly spot prices as illustrated in the diagram.

The model

The model determines the optimum production of hydro power with the aim of minimising the present value of the cost of the future power production. It simulates an electricity market where there are many competing power producers, each trying to maximise future profits.

The choice for hydro power producers is to determine how much of the water in the reservoirs is to be used today and how much is to be used later when the price maybe is higher. The model determines the optimum hydro power production the coming week based on information about thermal power marginal cost, hydro power capacity, present water reservoir level and statistical data on average and standard deviation for demand, water inflow and base load production. It then makes a forecast of the prices up to several years ahead. The basic unit of time in the model is one week.

In its present version the model is implemented for the Nordic electricity market. But it is constructed in a way that makes it easy to implement the model for any combined thermal and hydro power system.
PoMo has been developed by the Swedish companies EME Analys och Tentum.

Thermal power

Thermal power is represented through data on the operating cost and available capacity for each week of the year. In the present implementation for the Nordic market data on around 200 thermal power plants are tabulated. The model links the operating costs to fuel prices. In this way changes in world market fuel prices are automatically transmitted to the operating cost of the individual power plants.

Fuel taxes are treated in the same way, making it easy to simulate how energy tax changes affect electricity prices.

Snow sub-model

PoMo includes a sub-model for snow melting where snow is treated as an intermediate water reservoir. The sub-model predicts the rate at which the present of snow reservoir melts in the following spring period. By using available information about the snow reservoirs some of the uncertainty of future water inflow is reduced. Predictions are thus improved.

Price-sensitive demand

The model also takes account of price-sensitive electricity demand, for instance in electric kilns that constitute a substantial part of demand in the Nordic market.

Price distribution functions

One unique feature of PoMo is that it treats water inflow, demand and some base-load production plants such as nuclear and CHP as statistical functions rather than as samples of discrete historic records. This makes it possible to compute statistical distribution functions for the future spot prices for a mathematical representation of the volatility.

User friendly

User-friendliness has been an important goal in designing the model. The user has good overview of the parameters put into the model. By using the best available programming techniques the run-time of the model is only 1 minute on a modern desk-top computer when optimising 8 years or 400 weeks ahead.

Learning tool

The simplicity and user-friendliness makes the model suitable for learning how a combined thermal-hydro power market works. The user can easily experiment by changing for instance water reservoir capacity, thermal capacity, fuel prices and fuel taxes and monitor the effect on prices.

Simple

PoMo is similar in structure to other commercially available models of the Nordic electricity market used by the big power producers. Compared to these, PoMo is simplified. All water reservoirs are representing by one large reservoir. There are no transmission constraints within the market area

Despite these simplifications the predictive power of the model is good when applied to the Nordic market.