Balmorel:

A Model for Analyses of the Electricity and CHP Markets in the Baltic Sea Region

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Balmorel Project
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This report describes the motivations behind the development of the Balmorel model as well as the model itself.

The purpose of the Balmorel project is to develop a model for analyses of the power and CHP sectors in the Baltic Sea Region. The model is directed towards the analysis of relevant policy questions to the extent that they contain substantial international aspects.

The model is developed in response to the trend towards internationalisation in the electricity sector. This trend is seen in increased international trade of electricity, in investment strategies among producers and otherwise. Also environmental considerations and policies are to an increasing extent gaining an international perspective in relation to the greenhouse gasses. Further, the ongoing process of deregulation of the energy sector highlights this and contributes to the need for overview and analysis.

A guiding principle behind the construction of the model has been that it may serve as a means of communication in relation to the policy issues that already are or that may become important for the region. Therefore, emphasis has been put on documentation, transparency and flexibility of the model. This is achieved in part by formulating the model in a high level modelling language, and by making the model, including data, available at the internet.

Potential users of the Balmorel model include research institutions, consulting companies, energy authorities, transmission system operators and energy companies.

Cover: The Baltic Sea Region from satellite at night.
Source: Microsoft Encarta World Atlas '97.

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Preface

The present report provides an introduction to the Balmorel model, emphasising a description of the Baltic Sea Region, the challenges met there and the possible applications of the model for enhancing the analyses, understandings and actions in relation to this. The report has been kept non-technical.

The Balmorel model was developed during 1999 and 2000 in co-operation between various organisations in the countries around the Baltic Sea.

The background for the project is the trend towards internationalisation in the electricity sector. This trend is seen in increased international trade of electricity, in investment strategies among producers and otherwise. The development is in part due to the deregulation of the energy sector. Further, environmental considerations and policies are to an increasing extent gaining an international perspective in relation to the greenhouse gasses.

The purpose of the Balmorel project is to develop a model for the analysis of the power and CHP (combined heat and power) sectors in the Baltic Sea region. The model shall be directed towards the analysis of relevant policy questions to the extent that these contain substantial international aspects.

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Units and abbreviations

CHP	combined heat and power
cif	Cost, insurance and freight
CO_2	carbon dioxide
DH	district heating
ECU	European Currency Unit (until 1998)
ECE	United Nations Economic Commission for Europe
EFOM	Energy Flow Optimisation Model
EU	European Union
GJ	Gigajoule
GW	gigawatt
GWh	gigawatt hours
HVAC	high voltage alternate current
HVDC	high voltage direct current
IEA	International Energy Agency
kW	kilowatt
kWh	kilowatt hours
Mtoe	million ton of oil equivalent
MW	megawatt
MWe	megawatt, electric
MWh	megawatt hours
NEA	Nuclear Energy Agency
NO_x	nitrogen oxides
OECD	Organistion for Economic Co-operation and Development
PJ	petajoule
RES	renewable energy sources
SO_2	sulphur dioxide
TJ	terajoule
toe	ton of oil equivalent
UN	United Nations
TWh	terawatt hours
Conversion factors	
1 GWh	3600 GJ
1 toe	41.86 GJ
Unit prefixes	
k	kilo, 10^3
M	Mega, 10^6
G	Giga, 10^9
T	Tera, 10^{12}
P	Peta, 10^{15}
E	Exa, 10^{18}

1 Introduction

1.1 The Baltic Sea Region

The Baltic Sea Region is in this project understood as consisting of Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, (parts of) Russia and Sweden. These countries are widely different with respect to natural resources endowments, economic conditions, institutional and political traditions, international relations and also with respect to the energy sector.

Moreover, rapid changes are taking place in the countries, and the past ten years has witnessed a political interest to engage in co-operation between the countries, not least with respect to energy and environment.

In coping with the challenges met in relation to the environmental conditions, in particular those related to greenhouse gases, the opportunities given by the interest in co-operation should be exploited. In order to do this in fruitful ways, it is necessary to have on overview of the challenges and the means to deal with them. Modelling and model applications for analysis is one possibility to attain this.

1.2 Modelling the energy sector

Modelling has a long tradition within the energy sector. Thus, the electricity companies has been using models and algorithms for many years as decision support to control room activities, e.g. in the form of economic load dispatch, unit commitment decisions and network analysis. Also in relation to activities with long-term perspectives such as expansion planning, simulations have been a standard activity.

Also national energy administrations have to an increasing extent been applying modelling as part of the activities used in the administration and decision making. This includes analyses of the interplay between economic development and demand, analysis of emission related questions, the cost of restructuring of the energy sector and others.

Research institutions obviously also have a long tradition for modelling in relation to most of the aspects in relation to the energy sector previously mentioned, and a good deal in addition.

Traditionally, modelling activities were focussing on more limited geographical areas. However, with the gradual increase of interdependencies, models have been developed that reflect inter company and international relations.

In relation to the models of interest here, at least two general classes of models may be identified. One has its root in a macroeconomic tradition, but has been supplemented with details on the supply system to a certain level. The interest is on the understanding of the energy system as part of the larger economy of the country, with emphasis on e.g. development of consumption and prices. The other has its root in the optimisation of the operation of the electricity system, as performed in the electricity companies. Models within this tradition emphasise the description of the generation units, the electricity network and other technical elements of relevance for the short-term economic operation while e.g. demand side and general economic development are typically assumed given. The two modelling traditions are sometimes referred to as the top-down and the bottom-up approaches, respectively.

1.3 Specific position of Balmorel

A description of the challenges and activities in relation to the electricity and CHP sector in the Baltic Sea Region was outlined above, and it was pointed out that modelling has a role in relation to further activities in the region. In order to address properly the policy questions, a model should represent the supply system at a certain level of detail, including characterisation of the main electricity and heat generation types with associated technical, economic and emissions related properties and electrical transmission. The demand side description should include specification of the seasonal and diurnal variation of typical demand and the relationship between prices and demand. Geographically, the model should cover the Baltic Sea Region, and the time perspective should be long-term, e.g. up to 2030. The model contains both top-down and bottom-up elements

A quite different type of consideration is that the model should serve the purpose of regional overview and communication. Therefore a requirement is that the model should be transparent, fully documented and suitable for application in many contexts.

For these reasons it was decided that a new model should be developed. Hence, the Balmorel project was initiated. The present report outlines the results of that project.

1.4 Overview of report

The intention of the present report is to introduce the Balmorel model, and the context in which it is intended to serve. Thus, Chapter 2 gives an overview of the energy sector in the Baltic Sea Region. On this background the challenges to the energy and environment aspects in the region will be described.

In Chapter 3 a set of requirement for modelling in relation to these aspects will be outlined.

In Chapter 4 and Chapter 5 the implementation chosen for the Balmorel will be described. Chapter 4 describes how the characteristics of the region, as outlined in Chapter 2, have been represented in the Balmorel model. Thus, the principles of the modelling, the level of detail and the computer implementation will be described.

In Chapter 5 the data needs and principles are dealt with. Thus, main sources used, and the methods used in data extraction and construction will be described.

In Chapter 6 a number of illustrations will be briefly presented. The purpose of the chapter is to indicate typical application areas of the model, along with some characteristics.

Finally, in Chapter 7 the perspectives for the future application of development of the Balmorel model are discussed.

2 Description of Baltic Sea Region

This chapter gives an overview of the energy sector in the Baltic Sea Region considered. The intention is to give some background for interpreting the model results presented in subsequent sections of the report.

Some information about the Baltic area is given in the Baltic 21 Energy report, cf. www.ee/baltic21/[no. 3/98], which includes a regional energy overview as well as individual country profiles. However, supplementary to the general overview of the energy sector given in the Baltic 21 Energy report this section will concentrate on the electricity and heat market characteristics of the countries in the Baltic region.

The Baltic Sea Region covered in this study includes the following countries: Estonia, Latvia, Lithuania, the western part of Russia including the Kaliningrad Region, Poland, Germany, Denmark, Norway, Sweden and Finland. The Baltic 21 Energy study covered the same group of countries, but only the northern part of Germany was included.

Forces for interaction between the countries in the region exist at various dimension:

- First, there is a political will to improve further integration and cooperation between the countries in the Baltic area. At present some of the countries are EU members, whereas other countries have applied for membership. However, in 1992 the Council of the Baltic Sea States was established based on the joint attitude to improve political coordination in the area. On the second Baltic Sea Summit in Riga, 1998, energy was on the agenda. The Heads of Government took note of an initiative of the Nordic Heads of Government to develop the potential for further cooperation on sustainable energy supplies and networking (www.ee/baltic21/[no.3/98]), and further activities follow up on this.
- Second, there is a substantial physical potential for electricity exchange. Further, a multi-national electricity exchange, Nord Pool, already exists including some of the countries in the area - Norway, Sweden, Finland and Denmark. Nord Pool has developed from a market place for excess power within Norway – from 1971 – to a Nordic power exchange, which is being copied elsewhere in the world. From 1992 it became a spot market for all generators and consumers of electricity in Norway, under the name Nord Pool it was extended to Sweden from 1996 and later to Finland. The two Danish regions followed in 1999 and 2000.

2.1 General description of the countries

The countries in the region are very different with regard to economic wealth. In 1998 GNP per capita was 23.7 USD in Norway compared to 3.8 in Lithuania, which are the countries having the highest and lowest figures. In general GNP per capita is much lower in the Baltic countries, Russia and Poland as compared to the Nordic countries and Germany, cf. Table 2.1. In the latter group of countries GDP per capita rose between 7 % and 25 %, while countries like Russia, Latvia and Lithuania were characterised by severe economic recession, which appears as negative growth rates. Poland, however, having the lowest GNP per capita in 1991, rose by 14 % during the period.

Norway and Lithuania are also having the highest and lowest electricity demand per capita respectively. In 1998 a Norwegian citizen used more than ten times the amount of electricity consumed by a Lithuanian citizen. This is in part due to the fact that electric heating is wide spread in Norway. Besides Norway, also Sweden and Finland have very high electricity demand per capita. Despite the growth in GNP in the Baltic region per capita electricity demand decreased slightly from 1991 to 1998.

Table 2.1. GNP, electricity demand and CO_2 per capita.

	GNP per capita (1000 USD (1990))		Electricity demand per capita (MWh)		CO_2 (tonnes per capita)	
Country	1991	1998	1991	1998	1991	1998
Denmark	18.6	22.2	5.8	6.1	12.3	11.3
Estonia	7.8	7.4	4.6	3.8	23.6	13.3
Finland	15.3	18.0	11.9	14.3	12.0	12.4
Germany	16.6	18.1	6.0	6.0	12.2	10.8
Latvia	6.7	4.7	3.1	2.1	7.3	3.4
Lithuania	5.1	3.8	3.4	2.1	6.9	4.5
Norway	19.0	23.7	23.5	24.9	7.9	9.4
Poland	4.7	6.7	2.7	2.8	9.6	8.7
Russia W+K	7.4	4.5	6.0	4.5	14.4	9.0
Sweden	17.4	18.6	15.4	15.0	6.4	6.4
Total	12.8	14.2	6.3	6.2	23.6	17.3

Source: Enerdata and www.ee/baltic21/

Emissions of CO_2 from the Baltic region have decreased by 27 % in the period considered. Not only general recession in some of the countries but also the introduction of national CO_2 targets had an impact on national CO_2 emssions. In all countries but Finland, Norway and Sweden CO_2 emissions have decreased in the period.

The following description of the individual countries focuses on current issues for the electricity and heat markets and their background in the development during the last decades. It starts with Norway, where large hydro reservoirs offers large-scale opportunities for trade with the neighbouring countries, follows the route clockwise around the Baltic Sea ending with Denmark, where thermal generators have the role of ‘swing producers’ for both the annual variations in precipitation and the very short-term fluctuations of wind power.

2.1.1 Norway

Nearly all electricity generated in Norway is hydro, which has been developed over many decades. There is practically no thermal generation and thus very little CHP, and very few district heating systems. Thus, electricity prices are low, which has been the basis for a large electricity-intensive industry. The low prices also led to large electricity consumption in households and widespread use of electric heating.

Norway is the largest gas producer in Europe, but has no domestic use of gas. A proposal on the use of gas for the increased demand for electricity and electricity export has become very controversial, because the CO_2 emissions from gas-fired electricity generation is considerable in a country dominated by hydro power.

Norway has become the first country in Europe that liberalised its electricity supply industry including the retail market with full third party access for all customers. After liberalisation, nearly all generators and distributors have remained in public ownership, and the new grid company Statnett became a state monopoly.

The industry has become very competitive with a large number of generators, suppliers, traders and brokers. Individual customers are able to shift supplier on short notice with competitive price offers on the Internet.

Although Norway is not a member of the European Union. most of the internal market regulation also applies to Norway as a member of the European Economic Area.

2.1.2 Sweden and Finland

Electricity generation in both Sweden and Finland is a mixture of hydro, nuclear and conventional thermal generation. District heating is very important in both countries, but the share of CHP is much larger in Finland than in Sweden.

The development of electricity generation in *Sweden* was first based on hydro power, mainly in the North with long transmission lines to the markets in the South. The further expansion of the electricity generating capacity in the 1970s and 1980s was dominated by nuclear. After a referendum in 1980 the total number of nuclear units was limited to twelve, and a long-term phase-out of nuclear power was decided, which has led to a continuous controversy over energy policy.

The first trials with district heating in Sweden date back to the 19th century, but it was after the Second World War that district heating developed rapidly in Sweden. A few large-scale CHP plants based on coal and oil were built during the 1980s. In the 1990s the availability of efficient CHP units in a much smaller scale has led to investment in this technology to serve existing district heating grids, mainly for using biomass and peat. The traditional availability of cheap electricity has made electricity driven heat pumps an important generator for heat for district heating. Some Swedish cities have also begun investing in district cooling systems – partly using absorption heat pumps – which will further expand the market for cogeneration based on the existing infrastructure for district heating. The large generators in Sweden, Vattenfall and Sydkraft, have taken over the operation of several municipal district heating network in Sweden, and they are expanding elsewhere.

District heating in *Finland* started late, but the development has been rapid. The country's first district heating power plant came on stream in 1952 in Helsinki. Now, there is more than 200 district heating stations or power plants covering 46 % of the heat market. In Helsinki the market share of district heating is over 90 %. The fuels used for district heating depend on the location of the plant, coal is used in coastal regions, natural gas is used in areas covered by the gas grid, and peat is used in inland locations. Oil is used in smaller units or in areas without access to peat or gas. A large quantity of new combined heat and power capacity was added during the 1980s either by new plants or converting existing condensing (electricity-only) facilities. In addition to utility cogeneration, most district heating plants buy the base portion of heat from industry-run back-pressure facilities.

In contrast to Norway and Sweden most of the development in Finland has been market driven, mainly by local initiative from municipalities and local industries.

In both Sweden and Finland natural gas supply is based on import from a single neighbouring country. A large amount of natural gas is imported from Russia to southern Finland mainly for industrial use. A smaller amount is imported to the grid in western Sweden from Denmark.

2.1.3 Western Russia

Before the collapse of the Soviet Union in 1991, the power system in the area from Kaliningrad to the Kola Peninsula was integrated into the North-Western United System with a dispatch centre in Riga, Latvia. The Russian part of this electricity region is included in the Balmorel project.

The population of this region is about 10 million or about 7 % of the total population in the Russian Federation. About half of this population live in Saint Petersburg and about one million in the Kaliningrad Oblast – separated from the rest of Russia between Lithuania, Poland and the Baltic Sea.

The mix of electricity generating technologies in the region consists of nuclear power stations, e.g. four 1 GW units at Sosveny Bor near Saint Petersburg, and fossil thermal generation.

District heating is widespread in Russia, and the district heating system in Saint Petersburg is the largest in the world.

The demands for both electricity and district heating have decreased significantly since 1991, because of the economic crises and a declining industry production.

2.1.4 Estonia, Latvia and Lithuania

The three Baltic countries, Estonia, Latvia and Lithuania are relatively small in size and population (Estonia 1.5, Latvia 2.5 and Lithuania 3.7 million inhabitants in 1995). Although their recent history is similar, they are very different in culture and past history.

The electricity generation in *Estonia* is dominated by the availability of oil shale, which is used in large power stations in the northeast of the country. Traditionally, part of the electricity generated from these stations has been exported to the neighbouring regions. Thus, the capacity for electricity generation by CHP to the largest district heating market in Tallinn is limited.

In contrast, *Latvia* is an importer of electricity from the neighbouring countries. The national generating capacity consists mainly of some hydro capacity on the river Daugava and two coal fired CHP stations in Riga. There are large-scale district heating systems on both sides of river Daugava with no interconnection between them. There are also large-scale district heating systems in the two major cities Liepaja and Daugavpils

Before *Lithuania* re-established its independence, Lithuania was a net exporter of electricity. The Lithuanian Thermal Power Plant at Elektrenai, built in the sixties and seventies, and the Ignalina NPP, built in the eighties, were designed to satisfy regional rather than domestic needs for electricity. The total installed capacity of the Lithuanian power plants is 6150 MW, including Ignalina NPP with 2600 MW installed capacity and the Lithuanian TPP with 1800 MW. The Kruonis Hydro Pumped Storage Power Plant was build in 1992-1998 and comprises four units of 200 MW each. The fourth unit was constructed in 1998. The plant serves to supply peak and semi-peak loads of the Lithuanian power sector. The pumped storage is meant to take up peak loads and compensate for the night drops in connected load. Further, it allows Ignalina to operate at a higher power load factor. There is no natural flow of water to the storage. There are three large CHP plants in Lithuania (Vilnius, Kaunas and Mazeikiai). There are also several small and old public CHP's and industrial cogeneration plants. Most of these plants are dual fired from oil or gas. The recent development of fuel prices and electricity demand has made electricity production at CHP less competitive. At present, the CHP plants are used inefficiently, mostly to produce heat only, because their electrical capacity is not needed in the system.

A common Baltic electricity market is under development. There is a common dispatch centre for electricity covering the three Baltic states, named DC Baltija. Estonia and Latvia have already adopted their legislation according minimal EU requirements, and Lithuania is ready mo make more radical changes towards a competitive market (Vilemas and Krakauskas, 2000).

One of the largest gas storages in Europe is the Inchukalns underground gas storage situated in Latvia. It serves the whole region with a capacity of 2 billion cubic metres, and much further expansion is possible (Davis et al. 1999).

2.1.5 Poland

Nearly all electricity in Poland is generated from coal or lignite. There is a notable hydro capacity – equal to about 10 % of the total installed capacity, which generates less than 3 % of the electricity, and, thus, mainly used for peak shaving.

Next to Russia, the district heating market in Poland is the largest in Europe, covering between one-third and half of the market for space heating.

The liberalisation of the electricity market in Poland follows a time schedule for a gradual opening of the electricity market similar to several of the existing Member States of the European Union. The time schedule for opening the Polish electricity market started in September 1998 opening the grid for customers over 500 GWh per year, ending by December 2005 for customers below 1 GWh per year. District heat consumers will also achieve access rights to transmission services.

A Polish electricity exchange, Gielda Egergii SA, started in June 2000 (www.polpx.pl).

2.1.6 Germany

Electricity generation is dominated by thermal production, primarily on coal fired power plants. For years the development of domestic coal resources has been supported by the government by huge subsidies to the coal industry. Subsidies were based on revenues from an energy tax on electricity use. However, the political attitude to the coal industry has changed, so that subsidies will be phased out within some years ahead. Nuclear power also plays a significant role in German power generation amounting for some 30 % total electricity production. Lignite also has a strong position in electricity production, because lignite is competitive to hard coal, and there is a large industry both in North Rhein Westphalia and in the new federal states in east Germany, where refurbishment of the lignite fields and construction of modern lignite power stations were given high priority after the unification.

In these years wind power is developing very fast, in particular in the coastal regions in the north. Currently, Germany is the country in Europe showing the highest growth in wind power capacity per year.

CHP for district heating has a very long tradition in Germany. Some municipal utilities, *'Stadtwerke'* claim that CHP was started about a hundred years ago.

By the unification in 1990, the penetration of district heating to the market for space heating was 23 % in the new federal states in the East but only 9 % in the old Federal Republic in the West. The development in the West was based on local initiatives with some federal incentives, while an important objective of the development in the former GDR was the use of indigenous lignite.

There are large-scale interconnected district heating systems in Berlin, Hamburg, Munich and other major cities. There were much activity to promote CHP for district heating in Western Germany in the late 1970s and the early

1980s with subsidies from the Federal Government, but the lower fuel prices from 1986 discouraged much of the proposed development. However, some of the opportunities for heat supply from industrial waste heat and CHP were developed by the construction of transmission lines for long-distance heat supply in the Ruhr area, Saarland and Mannheim-Heidelberg.

Smaller district heating systems are found in numerous cities, and many centralised heating systems in blocks of flats and large institutions are existing and potential markets for small-scale CHP *(Blockheizkraftwerke)*. The share of CHP is about 11 %, of which two-thirds are industrial co-generation and one-third is for district heating (1996, see Olsen and Bjørndalen 1999).

By 1997 about 90 % of the electricity in Germany came from public utilities with local or regional monopolies. These monopolies were abolished by the new electricity act from April 1998, which opened the market and started a process of restructuring of the industry. The Amsterdam Power Exchange (www.apx.nl), which began trade in 1999, was also aimed at the German market, and in 2000 two competing power exchanges were started in Leipzig (Leipzig Power Exchange, www.lpx.de) and Frankfurt (European Energy Exchange, www.eex.de).

2.1.7 Denmark

The main characteristics of the development in Danish electricity generation during the last two decades are the increase in the use of renewables (wind and biomass), the promotion of CHP mainly for existing district heating systems, leading to a steady increase in generation from large-scale and small-scale CHP, and the introduction of natural gas for CHP production.

Electricity generation is fluctuating from year to year due to fluctuations in international electricity trade. These fluctuations are reactions to the natural variations in precipitation – and, thus, hydro power generation in Norway and Sweden. For years Denmark has cooperated with Sweden and Norway on joint load management in the Nordel-cooperation. The role of Denmark has been to act as the swing producer in the market.

In contrast to the other Nordic countries, who are protected from competition by their geographical position and the existing infrastructure, the Danish electricity market is more open for international competition than most other European countries. On the other hand, the liberalisation of the national market came much later than in Norway and Sweden.

The very significant variations in the electricity price on the Norwegian or Nordic electricity exchange, Nord Pool during the recent years is reflected in the variation in electricity export.

About one-third of the total electricity demand in Denmark is supplied by CHP, and district heating from all sources covers about half of the market for space heating and hot water.

The interconnected district heating grid in the Copenhagen Area is one of the largest in Western Europe. The Copenhagen grid covers also the suburban 'fingers' and satellite towns to the west and south within a distance of about 35 kilometres from the centre of the city. There are similar grids in the city regions of Odense, Aarhus, Aalborg, Esbjerg, and an industrial region with four towns around the Little Belt bridges. These transmission grids are supplied from different heat generating sources. Totally, there are about 300 distributors of district heating, either with independent supply systems covering a town or village, or connected to the large transmission grids.

2.2 Electricity market characteristics

In this section a closer look at the characteristics of the electricity generation and electricity demand is given, i.e. how much electricity is produced and what is the portfolio of generation technologies and fuels actually used. Further a description of electricity demand in the region is given.

2.2.1 Electricity generation, efficiency and export

Electricity generation varies significantly between the countries in the area: From 550 TWh in Germany to 4 TWh in Latvia, cf. Table 2.2. Looking at the period from 1990 to 1998 electricity generation has increased by only 1 % in the Baltic Sea area (cf. www.ee/baltic21/). However, development has been much different in the countries in the area. In the Baltic countries and Russia, electricity generation has decreased by up to 50 % (Estonia). Opposite to this electricity generation has increased in Denmark, Finland, Sweden and Poland. In the largest electricity generating country, Germany, development has been rather stable. Development in the Baltic countries and Russia indicate that idle generating capacity exists which can be used for increasing electricity export in the years ahead.

Table 2.2. Electricity generation, export and efficiency, 1995.

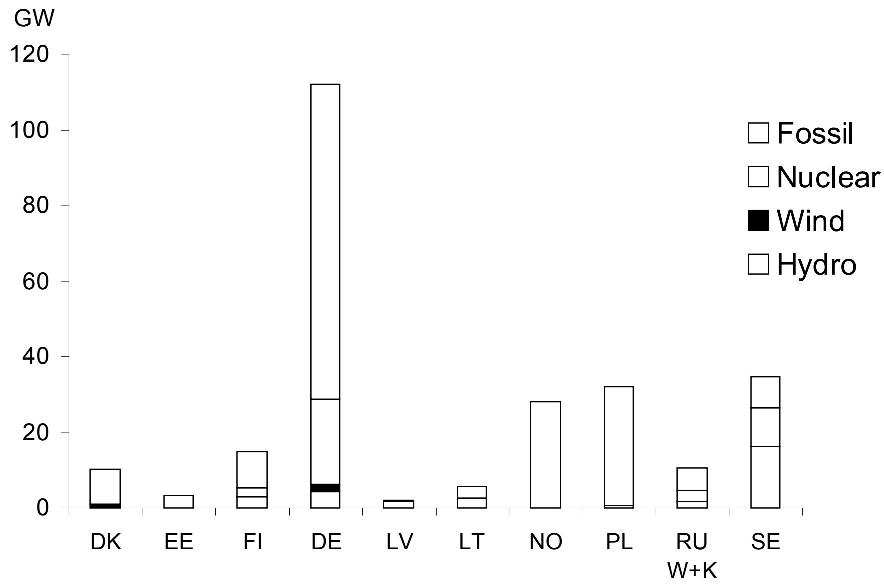
Country	Electricity generation (TWh)	Electricity generation (% of total generation)	Electricity export (TWh)
Denmark	35	3	1.4
Estonia	9	1	2.9
Finland	61	5	-7.3
Germany	550	49	-2.0
Latvia	4	0.4	-1.6
Lithuania	14	1	3.2
Norway	123	11	8.2
Poland	131	12	26.7
Russia W+K	52	5	4.4
Sweden	144	13	2.9
Total	1123	100	38.8

Source: www.ee/baltic21/[no. 3/98]

A lot of electricity is exported from the countries in the region. In 1995 Poland was the largest trader in the area having a net export of 26.7 TWh, cf. Table 2.2. Large traders were also Norway (exporting 8.2 TWh) and Finland (importing 7.3 TWh). As hydro generation is dominating Norwegian electricity production annual production figures are very sensitive to variations in precipitation. Consequently, Norwegian electricity generation and export is fluctuating much from year to year.

2.2.2 Generation capacities

Total generation capacity in the Baltic region amounted to 253 GW in 1997. About 45 % of the capacity is situated in Germany. Thereby Germany is the largest electricity producer in the area. Large generation capacities are also situated in Sweden (13 %), Poland (13 %) and Norway (11 %). Minor countries are the Baltic countries each accounting for 1-2 % of total capacity.



Source: Enerdata and own estimates.

Figure 2.1. Electricity generating capacities 1997.

Figure 2.1 illustrates the composition of generation capacities for each country. Four aggregates representing 11 specific technologies are used: Fossil based technologies (coal, oil, gas, lignite, oil shale and peat), renewables (biomass, waste and wind), hydro and nuclear. Section 5.2 contains the detailed information on the specific technologies used in the region.)

From an environmental as well as an economic point of view it is interesting to look at what kind of fuels are actually used in the electricity market. About one-third of the electricity capacity is coal fired electricity plants. Large coal using countries are Germany and Poland. Next to coal hydro electricity is the most widespread technology accounting for 21 % of total capacity of which a major part is situated in Norway and Sweden.

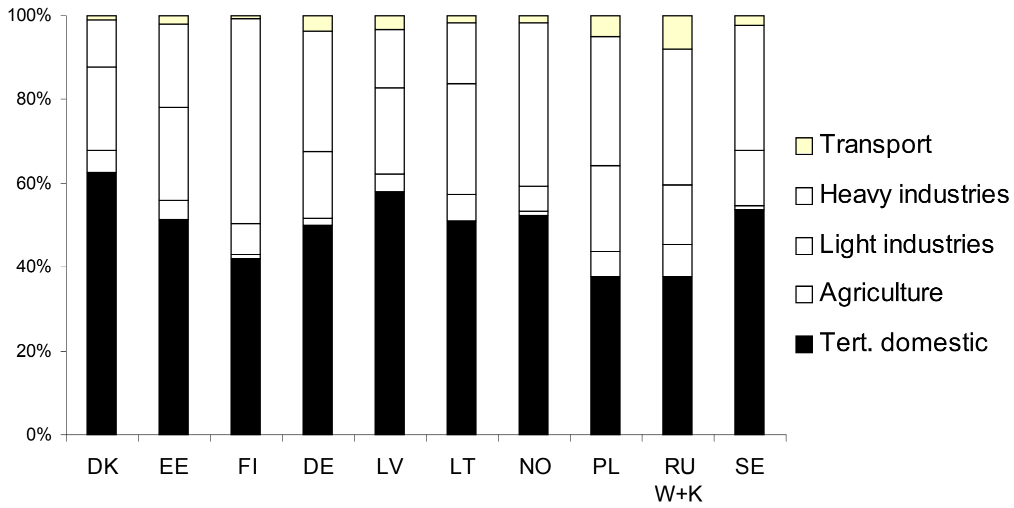
The total amount of electricity technologies based on renewables and hydro is 24 % whereas nuclear makes up 16 %.

In descending order nuclear, gas, lignite, oil and biomass are also used in the Baltic electricity system. Only very small generation capacities are devoted for wind power and electricity based on waste, oil shale and peat. However, oil shale is the dominating technology in Estonia and peat is playing a major role in Finland.

2.2.3 Electricity consumption

In 1995 total electricity consumption in the Baltic Region was 956 TWh. As was seen with generation capacities demand is highest in Germany, Sweden, Poland and Norway. Contrary to this demand, the lowest is in Estonia, Latvia and Lithuania.

As is shown in Figure 2.2 the structure of national electricity demand differs very much in the Baltic region. Residential use and use in the service sector is of major importance in Denmark. More than 60 % of total electricity supply is used in these sectors, whereas in Poland and Russia less than 40 % is used in these sectors. Contrary to this the share of industrial use in Denmark is very low – only making up about 30 % of total electricity supply. In Finland and Poland industrial use plays a more important role accounting for 50-55 % of total electricity demand. Use of electricity for transport is most developed in Russia (about 8 % of total electricity demand).



Source: Enerdata.

Figure 2.2. Composition of national electricity demand in 1997.

In Table 2.3 the demand for electricity is shown. From 1991 to 1995 total demand in the region decreased with 27.3 TWh. From 1995 to 1998, however, the situation changes and the demand increased with 43 TWh. Total increase has been 16 TWh from 1991 to 1998. The largest increase has occured in Finland where demand has been raised by 26 %. At the other end of the scale are the Baltic countries in which electricity demand has decreased. In Latvia demand has decreased about 40 %. Demand has however been stabilized since 1995.

Table 2.3. Demand for electricity 1991-1998, TWh.

Country	1991	1995	1998
Denmark	30.0	31.6	32.4
Estonia	7.2	5.1	5.0
Finland	59.6	66.0	75.0
Germany	482.4	474.0	495.1
Latvia	8.3	4.8	4.9
Lithuania	12.7	6.8	7.4
Norway	100.1	103.4	110.6
Poland	103.6	100.8	109.5
Russia W+K	62.4	49.2	47.4
Sweden	132.5	129.8	127.5
Baltic Sea Region	998.8	971.5	1014.8

Source: www.ee/baltic21/

2.2.4 Economics of generation

There are economic reasons for considering further integration of the Baltic area. Overall costs might be reduced through more proper use of excess capacity. Cheap national resources might be utilized more efficient, e.g. by substituting more expensive energy products in other countries. Finally, increased competition as well might force the national electricity industries to be more competitive thereby giving an incentive to reduce actual generation costs. The existence of Nord Pool shows that international market institutions already have evolved making a background for further developing the electricity market by including more countries.

Generation of heat and electricity in the Baltic Sea Region is based on a portfolio of specific generation technologies. These technologies are having (very) different cost figures. As minimizing total generation costs become a main aim in an integrated and liberalised power market generation technologies having low generation costs will be preferred to technologies having high generation costs. In a short term perspective facing existing generation capacities priority in generation will be based on short run marginal costs. In a long term perspective facing the need for investments in new generation capacity priority will be based on long run marginal costs, which take into consideration investment costs.

The costs of electricity generation are determined by economic variables and by some technical parameters as well. The following economic variables are relevant: Fuel prices, investment costs and operation and maintenance costs. The technical parameters of relevance are: Efficiency in generation and lifetime of technology.

Fuel prices are playing an important role in the short run perspective, as fuel costs are accounting for the major part of short run marginal costs. Consequently, differences in fuel prices will have a lot of influence on generating technologies actually used as most technologies are specific to the kind of fuel used for electricity generation. Not only differences between fuel types are interesting but also differences in fuel prices between the countries in the region. Cheap fuels available for CHP generation give a producer a good opportunity to be competitive in the market.

To give a simple mnemonics for electricity generating costs, the following costs levels could be applied:

- *10 € per MWh* is about the short-term marginal cost of electricity from gas-fired CHP. The cost of nuclear power, hydro power and coal-fired CHP is lower.
- *20 € per MWh* is about the short-term marginal cost of electricity from modern efficient condensing (electricity-only) gas-fired power plants. The cost of efficient coal-fired plants is lower.
- *30 € per MWh* is about the long-term marginal costs of new gas-fired stations generating electricity-only. The long-term marginal costs of new coal or oil fired stations
- *40 € per MWh* is about the long-term marginal costs of new wind turbines at good locations. The long-term marginal cost of new nuclear power units is probably higher.

2.3 Heat market characteristics

The heat market is interesting in this context in which electricity market integration is considered as the possibility of CHP-generation exists, i.e. the joint generation of heat and electricity. As compared to separate production of heat and electricity cogeneration is a cost effective way of production.

2.3.1 Heat generation

In the whole Baltic Sea Region, district heating generation has been reduced by more than 20 % in the period 1990-98 (cf. www.ee/baltic21/). As was seen for electricity generation Estonia has faced the largest reduction by nearly 70 %. In Lithuania and Poland reductions have been about 50 %. Heating generation has also been reduced in Russia and Germany. Contrary to this district heating has increased significantly in Latvia, Denmark, Finland, Norway and not at least Sweden, in which generation has been more than doubled. In 1998 district heating generation is most developed in Russia, Poland and Germany (in the range of 400 PJ per year in each country).

Compared to other European countries CHP generation is much more developed in the Baltic Sea Region. Among others this is due to the cold climate in the region. In EU less than 10 % of the electricity generation in 1994 was combined production (cf. Grohnheit, 1999) as compared to 19 % for the Baltic Region in 1995 www.ee/baltic21/[no. 3/98]. About two-thirds of all district heating in the Baltic Sea countries were based on CHP generation in 1998 (cf. www.ee/baltic21/). In Finland and Denmark district heating based on CHP have a very strong position. However, there has been a negative trend in the development of CHP penetration. In 1990 CHP accounted for about 75 % of all district heating generation in the Baltic Sea Region. This negative trend is due to a reduction in CHP generation in Russia, Lithuania and Latvia. Contrary to this CHP has increased significantly in Denmark and Sweden.

2.3.2 Heat demand

In Table 2.4 total heat demand in each of the countries are shown for 1991, 1995 and 1998. Like the demand for electricity, there has been a decline in heat demand from 1991 to 1995. But contrary to electricity demand the decline in heat demand continues through the period from 1991 to 1998. Except from the Nordic countries all other countries had a lower demand in 1998 compared to 1991. Even though the Nordic countries had a 43 % increase total decrease in the Baltic Sea Region was 25 %.

Table 2.4. Heat demand in PJ.

Country	1991	1995	1998
Denmark	102.7	120.0	126.0
Estonia	91.5	30.6	32.6
Finland	91.8	97.7	117.8
Germany	430.3	416.6	386.4
Latvia	85.2	42.6	46.5
Lithuania	148.0	81.5	76.7
Norway	6.0	6.5	7.1
Poland	734.2	420.8	391.6
Russia	604.7	559.7	419.7
Sweden	91.0	163.1	167.3
Baltic sea region	2385.4	1939.1	1771.7

Source: Enerdata

2.4 International transmission capacities

A precondition for integrating national electricity markets is the interconnection of these markets by international transmission lines having sufficient capacity. The Baltic region is interconnected by a transmission grid having high capacities in between most countries.

Strong interconnections exist between the Nordic countries as these countries for years have been co-operating on load management in Nordel. Also Latvia and Lithuania are interconnected by high capacity transmissions lines, whereas connections between East and West still need to be enlarged.

The electricity market in the Baltic Sea Region can be considered as composed of three segments having different characteristics:

- a hydro based Nordic electricity system (e.g. Norway, Sweden and Finland)
- a Central European electricity system (e.g. Denmark, Germany and Poland) characterised by thermal electricity based on coal
- a Baltic electricity system based on old inefficient thermal electricity plants.

Most strongly connected is the Nordic electricity market and the Central European market as there exist connections between Denmark and Sweden, Denmark and Norway, and Germany and Sweden. A 1060 MW connection between Finland and Russia is linking the Nordic market to the Baltic market. Contrary to that no connections are present between the Central European market and the Baltic market.

The countries in the Baltic Sea Region belong to three different synchronised systems: The Nordic synchronised system consists of Norway, Sweden, Finland and east Denmark, while west Denmark, Germany and Poland belong to the western European system. The Baltic states, Kaliningrad and west Russia are synchronised with the rest of Russia. The three systems are connected with high voltage direct current (HVDC) interconnections. HVDC transmission lines are more expensive than the alternate current lines within the synchronised systems. The two parts of Denmark are not directly connected. However, the two electricity regions are very similar in supply and demand structure, so a HVDC connection between them would not be profitable.

Table 2.5 shows that Sweden, Denmark and Norway are the countries in the area most strongly interconnected to neighbouring electricity systems. The table shows *inter*national transmission capacities on country-to-country basis not taking into account *intra*national transmission capacities. It is also worth noticing that transmission capacities to third countries (i.e. countries outside the Baltic Sea Region) are not taken into account. Also observe that the stated capacities are nominal values that may give misleading indications (viz., too high) with respect to actual operational use.

Looking at the ratio between total international transmission capacity and electricity generation capacity Table 2.5 illustrates that some of the minor countries (e.g. Latvia, Lithuania, Denmark and Estonia) are relatively strongly connected to the international electricity system.

Table 2.5.Total transmission capacities on country-to-country basis.

Country	Transmission capacity (MW)	Transmission. capacity. / Generation capacity.
Denmark	5040	0.51
Estonia	2700	0.82
Finland	2595	0.18
Germany	5388	0.05
Latvia	2700	1.35
Lithuania	3000	0.55
Norway	4740	0.17
Poland	3388	0.11
Russia W+K	3210	0.30
Sweden	8185	0.24

Note: Double counting exist, i.e. every interconnection is accounted twice.

Total transmission capacity from Sweden to neighbour countries is 8185 MW of which 3550 MW is transmission capacity to Norway. Other bilateral connections of significance is a 2000 MW connection between Latvia and Lithuania and four connections in the range of 1400 MW (Denmark (West)-Germany, Denmark (East)-Sweden, Estonia-Russia and Finland-Sweden). The connections between Germany and third countries (e.g. France) are not taken into account in Table 2.5 as only the Baltic Sea Region is considered.

2.5 National energy resources

The Baltic Sea Region is rich in resources for energy generation. Fossil fuels and renewables as well are present in huge amounts. Some of the largest natural gas resources in the world are located in the region. Russia and Norway are net exporters of natural gas, e.g. to Germany. Also large oil resources are located in these countries. On a smaller scale Denmark and Germany as well have oil and gas resources at disposal.

The countries in the area are rich in energy resources. Self sufficiency is high in most of the countries, cf. Table 2.6. In Norway, Russia and Poland self sufficiency is more than 100 %, i.e. energy production more than satisfy energy needs of the citizens. The area is also rich in renewable resources like hydro, wind and biomass. Total renewable energy production in the Baltic region amounts to 1919 PJ (1995-figure), which is 39 % of the potential renewable production. In most of the countries there exist a large potential for further increasing renewable production.

Table 2.6. Self sufficiency and renewable potential and renewable production, 1995.

Country	Self-sufficiency in pct	Renewable potential (PJ)	Renewable energy production (PJ)
Denmark	78	407	62
Estonia	64	66	14
Finland	44	549	246
Germany	46	n.a.	231
Latvia	16	95	22
Lithuania	41	192	12
Norway	879	1100	485
Poland	102	861	206
Russia W+K	133	471	94
Sweden	66	1096	547

Source: www.ee/baltic21/ and www.ee/baltic21/[no. 3/98]
Self-sufficiency is ratio of energy production to total primary energy supply

Huge amount of coal resources are located in Germany, Russia and Poland. Moreover, Russia and Poland are large coal exporters.

All countries in the region, except Denmark, Norway and Sweden, also have large resources of lignite at disposal.

Besides abundant fossil fuel resources large resources of biomass, wind and hydro are available for further developing electricity and heat generation. However, these resources are limited depending on the specific country considered.

In all countries there exist a large potential for further developing wind power and biomass. At present wind power is most developed in Denmark and Germany. However, there is a huge potential for developing wind power in Norway as wind conditions along the West coast are among the best in the region. Huge biomass resources are available in Sweden, Poland, Finland and Russia.

Hydro power is dominating the Norwegian electricity sector and is also playing a major role in the Swedish and Finish electricity sector. There is a technical potential for further developing Norwegian hydro power, however there is some reluctance to initiate future hydro power projects due to environmental considerations. Significant potentials for increased hydro power also exist in Lithuania and Latvia. Minor potentials exist in Finland, Russia and Poland.

Resources of oil shale are very large in Estonia. However, Estonia is the only country in the region having this kind of energy resource. Some potential for further developing peat based technologies is existing in Finland and Russia.

Urban solid waste becomes a resource, when there is a market for heat from waste incineration. Widespread district heating systems in most of the countries in the region offer this opportunity.

Nuclear power contributes significantly to electricity generation in Lithuania, Sweden, Finland, Germany and Russia. The phase-out of the total nuclear capacity is on the political agenda in some countries, and some of the existing capacity is scheduled for decommissioning within a few years.

2.6 Environmental policy aims and means

All countries of the Baltic Sea Region have signed the UN Framework Convention on Climate Change from 1992, committing themselves to limit greenhouse gas emissions, including CO_2 emissions, in the future. As the countries in the region have different potentials for reducing national greenhouse gas emissions (e.g. due to different growth rates in future energy consumption and different potentials for developing renewable resources) possibilities for coordinating emission reduction policies exist.

Table 2.7. CO_2 emissions and national Kyoto targets (with EU Burden Sharing).

	1990 (Mtonnes)	1995 (Mtonnes)	1998 (Mtonnes)	Kyoto reduction target (pct. of 1990)
Denmark	52.9	60.3	60.1	-21
Estonia	37.8	20.9	19.2	-8
Finland	60.8	62.2	63.9	0
Germany	1014.5	902.9	886.2	-21
Latvia	24.8	12.0	8.3	-8
Lithuania	39.5	15.2	16.7	-8
Norway	35.1	38.2	41.7	1
Poland	380.7	348.2	337.5	-6
Russian	164.9	110.5	92	0
Sweden	55.4	58.1	57	4
Total	1866.4	1628.5	1582.6	

Source: Munksgaard et al. (2000) and www.ee/baltic21/

As is indicated by the figures in Table 2.7 national greenhouse gas emissions are fluctuating from one year to another. Variations in precipitation and wind resources lead to variations in electricity generation, and import and export of electricity may have significant influence on national emissions. One example is Denmark in which greenhouse gas emissions in 1990 were reduced significantly due to a large electricity import from Norway. As 1990 has been chosen as a general reference period for the Kyoto targets, however, this raises the question if foreign trade imbalances should be considered when negotiating fair emission targets, cf. Munksgaard and Pedersen (2001).

3 Requirement to the model

The previous chapter outlined the current situation in relation to the electricity sector in Baltic Sea Region, and identified a number of common policy issues in relation to this. In the present chapter a set of requirement for modelling in relation to this will be outlined.

3.1 Types of problems and instruments to be analysed

The description of the Baltic Sea Region given in the previous chapter implicitly points to the types of problems that are to be analysed. In general terms they relate to the restructuring process in relation to energy – in the present project understood as the electricity and CHP sector – and the associated changes in environment and economy.

The focus shall be on those aspects that have substantial international components. This obviously includes electricity exchange. But also the environmental aspects have important international dimensions, in particular in relation to greenhouse gases. In addition to addressing the problems it is similarly important to be able to analyse possible means to solve them.

As witnessed by the development in the Baltic Sea Region over the last ten years, it is difficult to foresee the policy issues that will be relevant at any time interval or in any one country. This in particular holds true for the energy sector. Although some themes may be identified from the description in the previous chapter, the details will invariably differ with time and space.

It is therefore a requirement to a model for policy issues analysis in the region that it should be adaptable in order to the able to answer those questions may become relevant also in the future – even in the not-so-distant future – in the countries in the region.

3.2 Elements and relations to be modelled

A model should include those elements and their relations that are of most importance to the analysis. A brief specification will be given here.

The representation of the supply system must embrace the generation units and the distribution and transmission systems. The generation units must be represented at a level of detail that permits identification of the most important types of units. In the region in question this means that fossil fuelled thermal units, nuclear units and hydro units must be represented. In order to represent the interplay between heat and electricity generation and markets there should be a representation of the CHP units in a detail that permits this. In relation to the long-term perspective, also representations of renewable energy types like wind power should be represented.

The distribution systems have to be represented in order to account for losses and costs. However, it seems not necessary to represent distribution constraints.

The electricity transmission should be represented by losses, costs and constraints, since further integration between the countries of the electricity system seems to be taking place. Heat consumption supplied from district heating systems is local in the sense that heat can only be transported a limited distance in such systems, therefore a transmission system for heat need not be represented.

Demands for electricity and heat are characterised by clearly distinguishable variations over the day and over the year. This has influences on the operation of the supply system, and therefore a suitable subdivision of the year must be possible. Moreover, as the restructuring of the energy systems may imply significant price changes of electricity and heat, the dependence of consumption on the price should be represented. Also due to the capacities in the supply system it is necessary to have a representation of the peak loads.

The long-time perspective could be represented by e.g. covering the period up to 2030.

Since environmental consideration are among the driving forces in restructuring of the energy systems, the relevant environmental effects of electricity and CHP generation should be represented. This at least includes those effects that are relevant for a regional scale, viz., emission of CO_2 and SO_2

Finally, the model should represent various policy instruments. This includes energy taxes, and taxes and quota on emission, and may extend to include systems of emissions trading permits, joint implementation, renewable energy certificates trading and others.

3.3 Availability and distribution of data

The level of sophistication of the modelling should maintain the intricate balance between what is desirable as seen from the model analysts' and users' point of view, and what is possible seen from the point of view of model developers. In this, the availability of data will often have a decisive role.

This is a general issue. However, what makes the acquisition of data specific in the present project is that the model is international. Since the main data sources will obviously be nationally based, this has the implication, among others, that availability, methods of collection and definition of data etc. will differ between the countries.

In addition, for some of the data it must be recognised that even if they are available then the credibility will be limited. This for instance holds true for economic and behavioural data, e.g. energy demands. In the new democracies the economic development has over the last ten years been subject to drastic changes and therefore characteristics derived from analysis of historical data here has particularly limited validity for the future situation.

A principal requirement to the modelling is that a balanced representation of the various elements of importance for the proper applicability of the Balmorel model should be achieved. By this is meant that the different types of phenomena represented (e.g., generation differentiated by technology and fuel use, demand, prices, taxes) should be represented in a level of detail that reflects their importance for the results. Further it is demanded that the level of detail is the same in all countries. It is anticipated that otherwise the simulation results may be biased.

Another perspective on the data side relates to the sources available. A basic principle behind the Balmorel model is that it should be fully transparent, cf. below. Since this includes data it follows that confidential data sources can not be used, and the data acquisition is based mainly on publicly available sources.

By and large, these considerations relative to the data availability tends to lower the level of detail.

On the other hand it is foreseen that the model can be updated and supplemented with respect to data. In order to facilitate this, the model structure has to be prepared to permit a more detailed representation of data than what is presently available.

3.4 A model as a means of communication

In a process of restructuring as that one which is taking place in the Baltic Sea Region a further characteristic is the lack of overview among the parties involved in the process. The parties in this context include energy authorities, transmission system operators, energy companies and others. They all have to redefine their roles, and some of them even have been allocated a new role, not existing under the older regime.

In such turbulent situation one important thing is that the parties can maintain a high level of information about their operations environment. This includes information of a statistical nature (economics, energy, environment, etc.), analytical results, and also information about the motivations and acts of the other parties in the regions. Lack of information, irrelevant information, or lack of understanding of the other parties may be detrimental.

One of the main purposes that a modelling effort could serve in such situation is that of enhancing communication between the parties. A model may give material for this at different levels. First, it provides a set of relevant data, such that any disagreement that originated in differences about this basic issue may be disputed directly here. The full data set should be available.

Second a model provides an interpretation of the working mechanisms of the subject in question, in this case the electricity sector. This includes understanding of the formation of costs and prices, incentive structures and other fundamental issues related to the conditions of the acting of (at least some of) the parties. Also this should be transparent and available to all parties.

Third the model may serve the purpose of identifying and formalising relevant questions for discussion. This may be in the form of asking "What if..." questions and making them more specific within the formalism of a model. Often part of this is done in the form of scenarios, which are consistent paths into the future for some of the key determinants. Based on this the model may be used to specify responses to these scenarios, and the consequences may be analysed, communicated and debated among the parties involved.

The point in the above description of the use of models is not that the results of model simulations – in the form of prices, energy quantities, or otherwise – are in themselves the major goals. Rather, what is important is that the model application may serve as a means of communication between the parties and that it may enhance a better mutual understanding.

3.5 Summary of requirements

The requirements to the model may be summarised as follows:

- There should be a representation of the energy supply system at a level of detail that permits identification of essential characteristics.
- In particular there should be a representation of the electricity transmission system in sufficient detail to permit analyses of international electricity exchange.
- The demand system should be elastic to identify the responsiveness of demand to changes in supply prices.
- The environmental effect of the energy supply should be represented.

- The long term perspectives should be represented.
- Policy instruments should be represented.

In addition these requirements the following aspects must also be given high priority in order to enhance the possibility of using the model as a means of communication:

- The model should be fully documented and the data should be public.
- The model should be easily accessible for new potential users.
- The model should be flexible such that new problems may be addressed.

The next chapter describes how this is achieved.

4 Model implementation

In the previous chapter a number of important characteristics and mechanism in relation to the electricity and CHP sectors were described, and also a number of key policy issues were identified. Moreover, requirements to the model have been outlined.

This chapter describes how this has been dealt with in the Balmorel model. Thus, the principles of the modelling, the level of detail and the computer implementation will be described.

4.1 Model structure

In this section the model structure will be briefly presented. The purpose is to describe the level of detail in the modelling by describing the various dimensions along which input data may be distinguished.

By model structure is meant the parameters and variables that are represented in the model, plus the relations that exist between. This may be though of as an abstract representation in the sense that it holds true irrespective of the actual numerical values of the input data. By data is meant the actual numerical values that the parameters take, i.e. the input data originating e.g. from measurements, statistical databases, or assumptions regarding future developments. The present chapter describes the model structure while data are dealt with in the next chapter.

4.1.1 Geography

The model permits specification of geographically distinct entities. On the supply side the primary reasons for this are related to possibilities of application of and restrictions on generation technologies and resources, to transmission and distribution constraints and costs, and to different national characteristics.

On the demand side the reason is the need for specifying different trajectories and elasticities according to consumers' geographically distinct characteristics.

The three basic types of geographical units are areas, regions and countries, with areas further subdivided into urban and rural areas, cf. Figure 4.1. The relations between the geographical entities are such that a region contains areas, and a country contains regions. The characteristics of each type of geographical entity will be specified below.

As a consequence of this, most exogenous variables will be specified individually, according to the geographical entity to which they refer. In particular this concerns demand, generation technologies (specified for each area), electricity transmission (between regions) and distribution (such that electricity distribution is specified by region and heat distribution is specified by area).

Further, the endogenous variables will be specified relative to the geographical entities. In particular this concerns consumption, generation, and transmission.

In the present version most countries are represented by one region, the exceptions being Denmark and Russia because these countries are electrically divided such that transmission between the two halves can only take place via other countries.

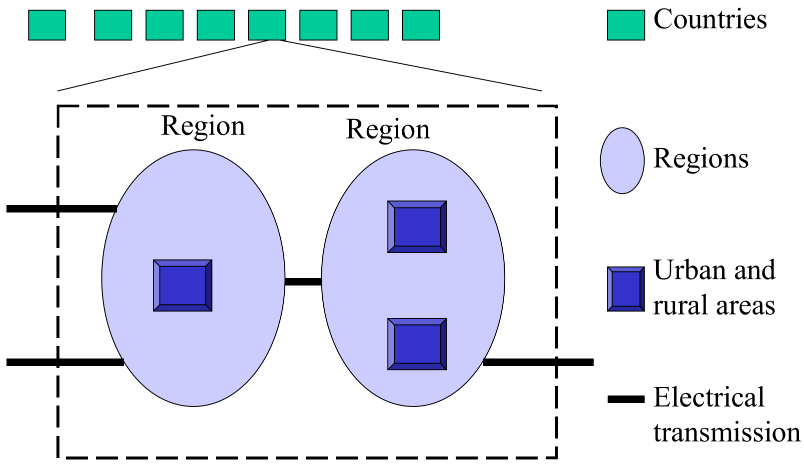


Figure 4.1. Illustration of the geographical entities and the transmission possibilities in the model.

The data given at the level of countries describe overall economic aspects. This includes assumptions on interest rates and economic life time of investments, taxes, environmental policy instruments and availability of certain fuels (including assumptions of a political nature, e.g. in relation to nuclear power).

The regions are introduced in the model in order to represent electricity transmission aspects. A country may consist of one or more regions. The data specified at regional level include entities related to electricity demand (annual nominal electricity demand, variation within the year of the nominal electricity demand, demand elasticities, historical consumer prices for electricity and others). The data also include those related to electricity transmission and distribution (losses and costs, electricity export to countries not otherwise modelled, initial capacity on electrical transmission, investment cost for new electrical transmission capacity and others) and further include specification of aspects of renewable energy (water availability for hydro generation, wind and solar power generation, availability of certain fuels).

The areas are the smallest geographical entities. The date given at the level of areas include those related to heat demand (annual nominal heat consumption, variation within the year of the nominal heat demand, demand elasticities), and data related to heat distribution (losses and costs) .

At the area level also information about the generation technologies are found. The data include operation and maintenance cost, capacities and investment cost for new technologies. Also information about fuel prices is given at the areas level, and for some fuels (e.g. waste) a potential is specified.

4.1.2 Time structure

The model operates with several time periods. We may distinguish between time periods within the year (i.e., a subdivision of the year) and between the individual years.

Time within the year

The subdivision of the year permits derivation of important characteristics of the energy system, including variations in demand patterns and renewable energy generation (e.g., hydro or wind), the interplay between base and peak generation units and the associated differences in costs, fuel use etc.

As concerns the time periods within the year, this is handled by a two level subdivision. First, the year is divided into seasons, e.g. two (representing winter and summer), four (winter, spring, summer, autumn) or twelve.

Second, each season is subdivided into a number of time periods, e.g. two (representing day and night), four (representing e.g. night, day, peak, weekend) or 24.

Time between the years

The data structure has a representation of the years 1995 to 2030. During the simulation of one year, all time sub periods described above are considered interdependently, through a simultaneous optimisation. The exogenous parameters relative to this are among others installed generation and transmission capacities at the beginning of the year.

The result of the simulation is a number of physical quantities, including new capacities for generation and transmission installed during the year.

This new capacity is transferred to the beginning of the following year, and this, together with exogenously specified changes in capacities (due to already planned constructions or due to foreseen decommissioning because of e.g. outdating) constitute the initial conditions when that year is simulated.

The entities specified or found within a subdivision of the year include generation (exogenous and endogenous), availability of hydro, demands for electricity and heat.

Some entities are the same throughout each year, but may be different from one year to the next one e.g. generation capacities, fuel prices and emission limitations and taxes.

4.1.3 Generation of electricity and heat

The model includes the definition of a large number of generation technologies. These may be classified into nine types, viz., condensing, back pressure, extraction (see Figure 4.2), heat-only boilers, electric heaters/heat pumps, hydro power with storage, hydro power without storage, wind power and solar power.

Within each type as many specific technologies as desired may be defined; presently the model contains about 50 different generation technologies.

Technologies of similar type are distinguished by a number of physical and economic parameter values, describing the fuel types, efficiency, environmental characteristics, economic parameters (operation and maintenance cost, and investment costs for new units).

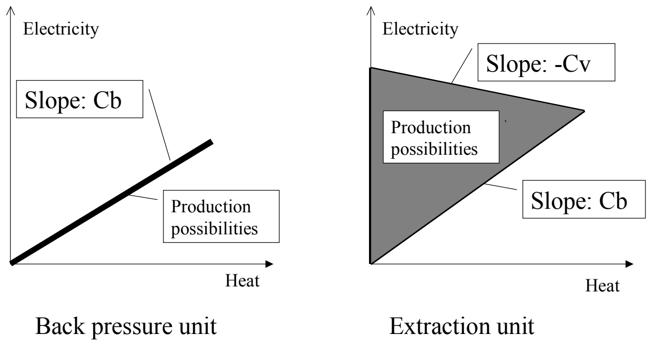


Figure 4.2. Operation area (i.e., feasible combinations of electricity and heat generation) for back-pressure and extraction type CHP units.

4.1.4 Investment decisions

In the model decisions are made relative to increases in capacities for generation and for electricity transmission. For the calculation of the cost of such increase the following approach is taken. The investment is assumed to have a life time of e.g. 20 years and with an assumption of e.g. 8 % interest rate the annual cost may be assessed to be equal to that annuity (i.e., annual payment) which precisely matches this. An investment is made in the year simulated if this will decrease the sum of fuel cost, operation and maintenance cost and the annuity related to investments (however, this is balanced against demands, see below). Hence, the annuity represents the difference between long term and short term marginal costs.

4.1.5 Fuels

The model specifies a number of different fuels. Each fuel is characterised by its physical properties in relation to emissions, viz., constants indicating the emission of CO_2 and SO_2. In addition, the fuel has a price, specified according to geographical entity. Each generation technology uses a specific fuel type.

The use of a specific fuel may be limited within a geographical entity. In practice, this is implemented as an upper limit on the generation capacity related to that fuel. The type of geographical entity to which the limit refers depends on the fuel. Thus, nuclear, lignite, oil shale and peat may be restricted at a country level, wind, solar, hydro and biomass may be restricted at a regional level, and natural gas and waste may be restricted at an area level. Use of a specific fuel may also be left unrestricted, like e.g. coal or oil.

4.1.6 Transmission and distribution

Transmission and distribution characteristics relate to each of the two products, electricity and heat. These products are handled differently, essentially because for a model covering a large geographical region like the one in focus here, transmission of electricity may be seen as being possible while transmission of heat may not.

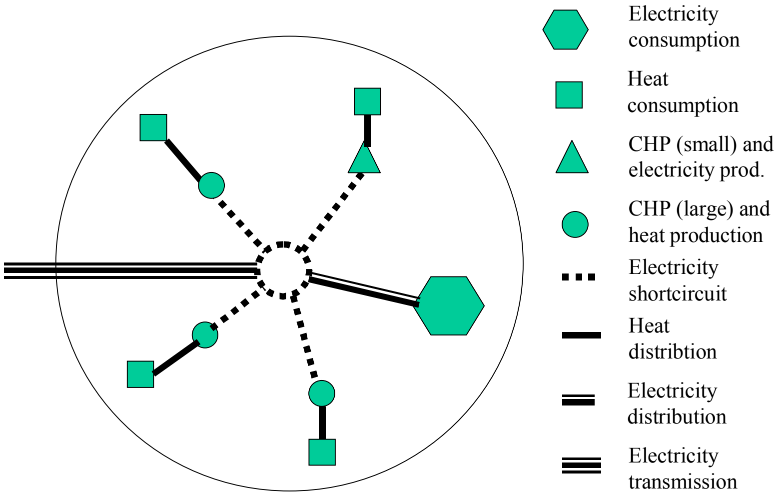


Figure 4.3. The entities within a region with one electricity transmission line.

Electricity transmission

The electricity transmission characteristics are related to pairs of regions. Electricity may be transmitted between regions subject to a loss, proportional to the amount of electricity transmitted. Transmission also implies a cost proportional to the amount of electricity transmitted.

Transmission is only possible within the limits specified by the transmission capacities. This capacity may be increased every year, according to economic criteria, as described above.

Electricity distribution

Within each region electricity is distributed to end consumers without constraints. However, there is a loss due to the distribution of electricity from generators (including import from other regions) to consumers. This loss is proportional to the electricity entering the distribution network. Distribution also implies a cost proportional to the amount of electricity transmitted.

Heat distribution

Heat demand and heat generation is specified individually for each area. Heat transmission between areas is not possible in the model.

Heat distribution in district heating network is possible within urban area. This is not subject to any constraints, similar to the assumptions taken in relation to the electricity distribution. There is a loss and a cost, proportional to the heat distributed.

The difference between urban and rural areas is mainly with respect to the possibility of making a heat dispatch, i.e., to distribute the heat generation over different units, according to economic criteria.

4.1.7 Demands

Demand for electricity is specified for each region and demand for heat is specified for each area.

The specification may be considered to consist of three components for each geographical entity:

- A nominal value, specified for each year in the simulation period as an annual quantity.
- A nominal profile, i.e., a distribution of the annual quantity over the time periods within the year, according to the time profiles discussed above.
- An elasticity function which specifies the relationship between quantity and price for deviations from the nominal profile.

In the above, demand specified is to be understood as the sum of demand for all consumer groups in the particular geographical entity. As seen the model operates with what is know as own price elasticities.

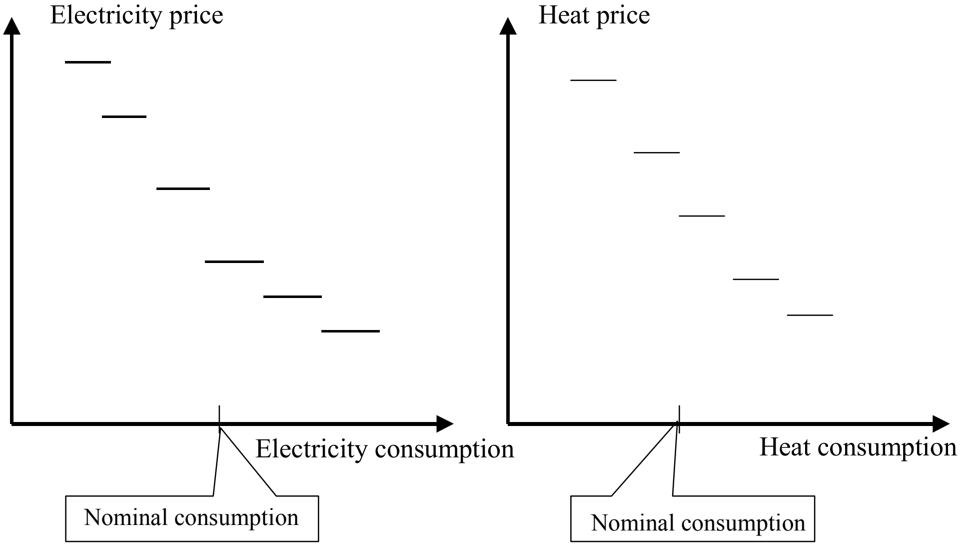


Figure 4.4. Demand versus price functions for electricity and heat.

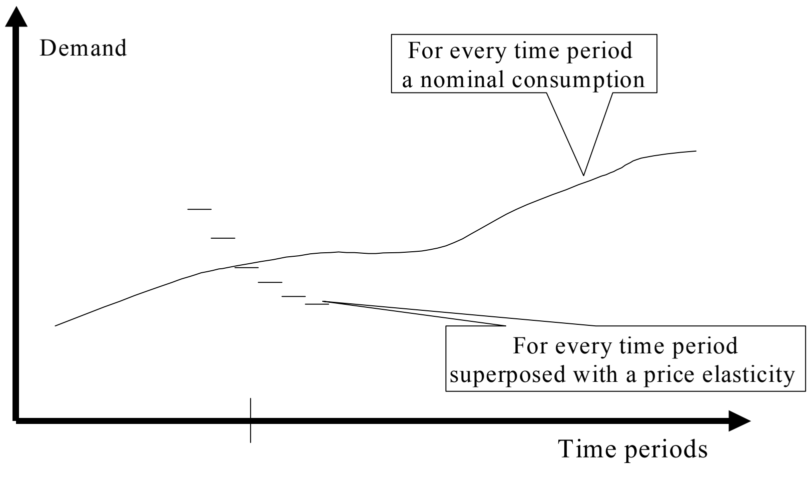


Figure 4.5. Demand versus price functions for electricity and heat.

4.1.8 Taxes

Taxes may be included in various ways, individually for each country in the model. The following types are implemented:

- Fuel taxes, for each fuel proportional to the amount consumed in heat and electricity generation
- Consumer taxes, proportional to the consumed amount of energy (electricity and heat, respectively). Each tax is specified as the weighted average of tax of all consumer groups in the particular geographical entity.
- Emission taxes, for each emission type proportional to the amount emitted

4.1.9 Emissions policies

Environmental considerations are central, and therefore emissions are accounted for in the model, and policy instruments aiming at emission reductions are implemented. The emission types are CO_2, SO_2 and NO_x. For each type, a national limit may be specified, and similarly for each type a tax may be specified. In addition there may be emission taxes as described above.

4.1.10 Linear model formulation

As follows from the previous description, Balmorel is implemented as a linear model.

The advantages of this are that it provides easy and efficient solution of the model. Moreover, most of the data is not available with an accuracy that justifies non-linear relations. Finally, the equilibrium conditions may be elegantly expressed as equivalent conditions in a linear programming.

The linear modelling guarantees most of the essential characteristics of theoretical models usually found and also some empirical observations. Thus, e.g., the supply cost function displays increasing marginal costs.

4.2 Solving the model

The values of the endogenous (free) variables in the Balmorel model are determined such that physical and economic principles are satisfied. The physical constraints include generation possibilities on the different technologies according to e.g. installed capacities and fuel availability. Also transmission and distribution constraints are satisfied, along with balance between supply and demand, appropriately taking into account losses and limitations.

In particular, the following physical constraints are respected:

- Consistency between demand and supply in each sub period and each geographical entity, taking into account distribution losses
- Consistency between distinct regions according to transmission constraints and losses in each sub period
- Consistency between time periods according to storage possibilities
- Availability of generation capacities
- Fuel availability
- Emission limitations

Within the freedoms that are left, the variables are determined according to economic criteria, including:

- Equilibrium between electricity and heat consumers' marginal utilities and producers' marginal costs in each sub period and each geographical entity; this is also known as maximising the sum of consumers' and producers' surplus
- Equilibrium in each sub period between distinct regions' marginal cost of electricity, taking into account transmission losses, storage possibilities, costs and constraints
- Equilibrium between short and long term marginal generation costs in each geographical entity such that long-term marginal costs prevail in periods in which capacity is extended and short-term marginal costs otherwise

The model determines the following entities:

- Generation of electricity and heat, distinguished by technology and fuel
- Consumption of electricity and heat
- Electricity transmission
- Emissions
- Investments in generation and transmission capacities
- Prices of electricity and heat.

All these entities are specified with respect to time period and geographical entity.

The solution of the model is done by solving a linear programming optimisation problem.

4.3 Transparency and accessibility

A guiding idea behind the Balmorel project is that the model should be fully documented and fully available to anyone interested.

There are several reasons for this. One is that in this way a detailed documentation of the project's research results is possible.

Another is that it may increase the application of the model. Potential users may inspect the details of the model and thereby decide for themselves whether to use it or not.

A final perspective, not the least important, is that having more users of the model increases the probability that the model will be updated, both with respect to data and with respect to model structure, as new application issues arise.

Obviously, in relation to the last perspective it will be important that a co-ordination of such efforts takes place.

The objectives of openness and documentation are achieved by providing full information of model structure and of data. This is obtained by making the model itself available in electronic form at the internet along with a number of documents that describe various features of the model, including the theoretical background, the user manual, data documentation and application examples.

Finally, the model is implemented in a modelling language that enhances transparency, documentation and flexibility, see the next section.

4.4 Flexibility

The implementation of the model in a modelling language also served the objective of flexibility. Provided that a user has the necessary software (see next section) the model can be taken from the internet, and run on a personal computer. Further, due to the provided documentation and the flexibility of the modelling language, users may modify the model and adopt it to their own specific purposes.

Obviously, some modifications are easy while others are more complicated. The following systematisation may be suggested, where the first modifications are very simple, and the last one more complicated.

- Limit the scope of the model, while maintaining basic structure. Thus for instance with respect to geography, the model represents ten countries. It is easy to delete some of the countries (and the associated regions and areas) from the model.
- Change the values of the data entered. It is easy to change the values of input parameters.
- Enlarge the model with elements similar to those that are already there. E.g., the model contains a number of energy transformation technologies, and more may be added by copying the ideas in the representations already there. If the new technology is similar to an existing one this is fairly simply done by copying the ideas of the existing technology and then filling in the required parameter values.
- Change the model structure. The model structure consists of the parameters and variables in the model and the relations between them. In relation to this item it is not possible to indicate the efforts involved as they depend heavily on the specific requirements.

In relation to the last item, a number of variants of the model are described in the detailed documentation. It should be emphasised that since the model is formulated in a general modelling system, the kind of changes that can be made is limited only by the capability of the modelling system, which in turn is quite powerful.

4.5 Computer implementation

The Balmorel model exists in the form of a number of transparent computer files (ascii format) that together constitute the model. The model is written in the GAMS modelling language, and is intended for execution within the GAMS modelling system. Accordingly, the files contain the model structure (variable declarations, relations, equations, etc.) as well as the data. Data and model structure may be changed by changing the ascii files. The GAMS modelling system includes features for providing various output from the simulations. For further information, see www.gams.com.

Any potential user of the model can take the model, run it and modify it, provided he has the GAMS modelling systems and an associated linear programming optimisation program (solver).

In addition to this basic model and operation method a number of additional features are supplied, aimed at facilitating input and output handling.

Relative to the input side, spreadsheets have been constructed that permit manipulation of the input. For instance, it may be convenient in many cases to construct time series of fuel prices in a spreadsheet. Therefore a spread sheet is provided that does this, and which in addition has a macro command that permits the resulting time series to be printed to a file in the required format, so that it may be included directly into the GAMS model. The user may use these spreadsheets, modify them as needed, or take the inspiration to make others according to specific needs.

Relative to the output side a number of facilities are provided to present various selections of simulation output in convenient ways, ranging from providing tables in ascii files to making graphs in a spreadsheet. Again, the user may use these facilities or modify them as needed.

5 Data and calibration

The data that are use to implement the model as described in the previous chapter have been selected on the basis of experience from multinational modelling studies focusing on long-term forecasts of energy demand and energy conversion technologies. National specific data have been based on existing internationally comparable data that are regularly updated. Additional data have been provided by the partners from Poland, Russia and the Baltic countries.

Further details on the data used in the first version of the Balmorel model (March 2001) are found in the appendix “Balmorel – Data and Calibration.”

5.1 Types of data for Balmorel

Different types of data are used for the Balmorel model

- Technology data
- Structural data
- Macroeconomic data
- Global data

Technology data are techno-economic parameters that characterise the various technologies for electricity and heat generation, transmission and distribution. These data are fuel efficiencies, emissions and cost. For a given technology the physical properties are independent of location. Cost data may vary from country to country dependent on model assumptions

Structural data are used to describe the electricity and heat systems in the various countries, regions and urban areas. Most important are initial capacities of the various technologies and demands for electricity and heat in the start year. Also the assumptions on decommissioning of the existing generating capacities are site specific, because the ageing of these capacities depends on the vintages of the initial capacities.

Macroeconomic data such as growth rates and elasticities are assumptions necessary for determining the future demand for electricity and heat. Reference demand forecasts for electricity and heat are exogenous in the Balmorel model, but future demand is elastic. Thus price elasticities for the various consumer groups are input parameters in the model. The impact of consumer price elasticities on the wholesale demand for electricity and heat is highly dependent on taxes and the market structure. National fuel price forecasts are calculated adding transport costs and national taxes to cif prices (cost, insurance and freight) to a national harbour or border station. Fuel price forecasts for indigenous fuels are based on national forecasts.

Global data are mainly price forecasts for internationally traded fuels. The forecasts are the same for all countries.

The data sources are different for the various groups of data.

5.1.1 Sources for technology data

There exists a range of technology catalogues that contains techno-economic data that are suitable for bottom-up modelling in the details that are appropriate for Balmorel. Similar data are published with other technology-based models (including the Baltic 21 Energy study). Relevant technologies from these data sources has been collected in a spreadsheet database, which enables the most important parameters for Balmorel and similar models to be compared from different sources. Further data for specific technologies have been submitted by the participants in the Balmorel project.

As a part of the Balmorel project a systematic set of technology data has been developed. A few reference technologies were chosen (conventional fossil fuelled steam turbines for electricity generation, combined cycle gas turbines, nuclear power stations, hydro power, wind turbines, electric heat pumps for district heating, and heat-only boilers). Based on these reference the techno-economic data for a wide range of technologies has been determined by a systematic variation of parameters, such as fuel use, output (electricity and/or heat), scale, technology vintage, and end-of-pipe facilities for emission abatement.

Table 5.1 shows the main sources for technology data.

Table 5.1. Sources for technology data.

Catalogue	Name	Developer	Country	Contents	Update
IKARUS	Instrumente für Klimagas-Reduktionsstrategien	Many German Institutes for the Federal Ministry of Education and Research	Germany	Electricity and heat, households, industry, transport. Structural data for Germany	1995
Baltic 21	Baltic 21-Energy	An Agenda 21 for the Baltic Sea Region for the Council of the Baltic Sea States	Baltic region	Production of electricity and heat	1998
OECD-NEA	Projected Costs of Generating Electricity. Update 1998	OECD Nuclear Energy Agency/International Energy Agency	IEA	Projected cost of generating electricity. Country comparison	1998
Energi 21	Danmarks Energifremtider	Danish Energy Agency	Denmark	Energy Savings in buildings, industry and the public sector; electricity and district heating; renewables; biomass	1995
PRIMES	PRIMES model	National Technical University of Athens for the European Commission	EU	Simplified techno-economic data for an equilibrium model	1999
VE2	Fluktuerende vedvarende energi i el- og varmeforsyningen - det mellemlange sigt	Risø National Laboratory for Danish Energy Agency	Denmark	Renewable energy.	1998

5.1.2 Sources for structural and economic data

The electricity demand is well described in official statistics and available in details that are sufficient for the model. Data for heat demand are much more uncertain. The definitions are unclear, there are significant differences between different statistical publications, and the data are available in sufficient details only for few countries.

Official data for electricity generating capacities are too aggregate for the model. Other sources, such as national energy planning data or qualified guesses will be necessary to obtain initial capacities in reasonable details. The data for heat generating capacities are even more weak.

The most important source for statistical data for initial capacities and electricity demand is the IEA (International Energy Agency) energy balances. These data are published annually for nearly all countries in the world. The sources for these data are national official statistics, ministerial annual reports, UN ECE Questionnaire and direct communications to the IEA Secretariat from national ministries. Most data are available with two years delay. The 2000 Edition cover the years 1997 and 1998. There is an ongoing activity to increase data quality. In some countries information may be limited due to confidentiality.

The Enerdata energy statistics (developed by Enerdata s.a., Grenoble, France) is an important additional source for national energy end economic time-series. The Enerdata statistics is based mainly on the OECD/IEA statistics. It may be purchased on a CD-ROM, which is updated twice a year. In addition to energy data, economic time-series from 1970 are included, e.g. value added in eight branches or aggregates.

In Balmorel electricity and heat demand forecasts are based on official national forecasts if available, or the assumptions of the Baltic 21 Energy study are used. Demand elasticities are assumed for five consumer groups (heavy industries, light industries, transport, agriculture, ands residential and services) on the basis of international studies on energy price elasticities. The numerical values of these elasticities are highly uncertain. Initially the same direct price elasticities are assumed for each consumer group in all countries. However, given these assumed elasticities the wholesale price elasticity for elasticity will be very different among the countries, because taxes and the demand structures are very different.

The international fuel price forecasts are from the Shared Analysis Project and calculated by the POLES model for the global energy market. The forecasts are supplemented by own calculations and submission from the participants for indigenous fuels.

5.1.3 Model delimitation

The choice of technologies and data sources are significant for the delimitation of the model. The initial version of the model describes the electricity and heat markets in the Baltic Sea Region. The model covers practically all electricity that is generated and consumed, but only part of the markets for space heating and industrial steam.

The electricity market is very well described by national and international statistics, and the various statistical sources are using the same definitions and figures.

However, the definition of “district heating” is unclear. The term normally refers to public networks that are combining many property sites, while a similar heat distribution network for several buildings within the same site may not be considered as district heating. Thus, water-based heat distribution systems for blocks of flats or large institutions may be transferred to district heating systems without much additional investment in piping.

Outside the district heating systems there are large markets for CHP for industrial processes.

The focus of the Balmorel model is the part of the heat market that is suitable for CHP. This includes parts of the markets for both space heating and industrial processes. The delimitation chosen for the first version of the Balmorel model is “Heat production in the transformation sector” according to the IEA Statistics. This includes both district heating and industrial autoproducers.

When this definition is used the heat market does not include a potential market for micro-scale CHP in the form of very small gas motors or – in the future – fuel cells. In some countries there is a very developed natural gas grid that supply gas boilers for space heating. If micro-scale CHP becomes available the heat market suitable for CHP become much larger. These technologies are not considered in the first version of the model.

5.2 Technology data with systematic parameter variations

A set of technology data for electricity generating units and other identifiable technologies has been developed within a series of studies. The basic idea is that the techno-economic parameters shall vary systematically with various characteristics (fuels, generator type, scale, technology vintage, etc.). The sources of these data are available technology catalogues. These data are used in the bottom-up elements of Balmorel with common data for all the countries in the region

5.2.1 Reference technologies

The technology data with parameter variations are constructed by selecting a number of representative technologies as references for classes of technologies for which it is assumed that the techno-economic parameters such as efficiencies will vary in a systematic way depending fuel use, technology vintage, size, etc. parameter variations. Table 5.2 shows the selected reference technologies with their most important techno-economic data.

Table 5.2. Reference technologies for parameter variations.

	Scale	Vintage	Electric efficiency	Total efficiency	Elec.-heat ratio	NOx	SO_2	Inv. cost	O&M cost
	MW	year	p.u.	p.u.	p.u.	kg/GJ	kg/GJ	€ /kW	€/MWh
Electricity output									
Coal condensing	500	1980	0.380			0.400	0.655	850	5.000
Combined cycle gas turbine	500	1990	0.500			0.070	0.000	400	1.700
Nuclear	1000	1990	0.350			0.000	0.000	1375	4.400
Hydro	1000		1.000					1000	4.444
Wind	0.5	1995	1.000			0.000	0.000	794	9.000
Heat output									
Electric heat pump	20	1980	1.000	2.700	0.370	0.000	0.000	245	1.729
Boiler	>1	1980		0.850		0.150	0.000	40	0.400
Electric heat	0.001		1.000	0.950	-1.053	0.000	0.000	13	0.007

For the largest technology group, conventional fossil fuelled power generating units, some 60 technology variations are calculated. For the other reference technologies the number of variants ranges from 4 to 18.

These reference technologies are used as the basis for parameter variations for the various types of electricity and heat generating technologies. The numerical variations of efficiency and cost variables are constructed to meet some logical requirement: New equipment is more efficient than old, or the construction cost for coal-fired units is larger than for gas.

In practice the parameter variations are shown as sensitivity factors compared to the reference technologies for investment and operation cost, fuel efficiency and emissions reduction,

5.2.2 Parameter variations for conventional technologies

Table 5.3 shows the variations in electric efficiency for conventional fossil fuelled units as dependent of types of units, fuel input, sized of units, and technology vintages. The table shows that newer units are significantly more efficient than old ones, and larger units are slightly more efficient than small units. It is also shown that gas-fired units are more efficient than coal or oil fired units.

The fuel prices and efficiencies are those parameters that are most significant for the economic dispatch among existing units in an interconnected electricity system. The units having the lowest variable costs will gain the highest utilisation time. With no further constraints the fuel use will be determined largely by these parameters.

Table 5.3. Conventional fossil fuelled units. Variations in electric efficiency for types of units, fuel input, scales and vintages.

Type/Fuel	Scale	Vintage				
		Old	1980	1990	2000	2010
Condensing/Extraction						
Coal	Large	0.304	0.380	0.418	0.456	0.494
Oil Shale	Large	0.274				
Lignite				0.376	0.410	0.445
Peat	Large	0.274			0.410	0.445
Oil	Large	0.304	0.380	0.418	0.456	0.494
Gas	Large	0.319	0.399	0.439	0.479	0.519
Waste				0.376	0.410	
Biomass					0.410	
Back pressure						
Coal	50 MW		0.380	0.418		
Oil	50 MW			0.418		
Gas	50 MW			0.439	0.479	0.519
Gas	5 MW					0.493
Waste	50 MW				0.410	
Biomass	5 MW				0.390	
Peak						
Oil	Large		0.304			

For the long-term technology choice the investment cost will be another very significant parameter. This parameter is shown in Table 5.4. In particular, larger units are cheaper than smaller ones, and gas-fired units are cheaper than coal fired units. The extra investment costs for extraction-condensing units for CHP compared to condensing units for electricity-only are relatively small.

Table 5.4. Conventional fossil fuelled units. Variations in investment cost for types of units, fuel input, scales and vintages. €$_{90}$/kW.

Type/Fuel	Scale	Vintage				
		Old	1980	1990	2000	2010
Condensing/Extraction						
Coal	Large	1275	850	937	797	750
Oil Shale	Large	1275				
Lignite				937	797	750
Peat	Large	1275		937	797	750
Oil	Large	1148	765	843	717	675
Gas	Large	1020	680	714	607	571
Waste				1530	1301	
Biomass					1366	
Back-pressure						
Coal	50 MW		1148	1148		
Oil	50 MW			1033		
Gas	50 MW			918	780	771
Gas	5 MW					1028
Waste	50 MW				1756	
Biomass	5 MW				2341	
Peak						
Oil	Large		383			

Obviously, the optimisation model will not select obsolete technologies for future investment. Thus, the investment cost for these technologies has little meaning for the model. They are used only under very special assumptions, e.g. for the optimisation of the past, or assuming that some newer vintages were not available.

5.2.3 Parameter variations for new electricity generating technologies

The technology data for combined cycle gas turbines (CCGT) are treated separately from conventional fossil fuelled units, because this technology has shown a significant progress over the last decade, and there is still a potential for efficiency gains. Table 5.5 shows that new vintages that may be available from 2010 will be much more efficient with no increase (or reduction) in investment cost. It is also assumed that coal gasification will be available from 2010 at thermal efficiency similar to modern coal-fired units, but higher investment cost.

Table 5.5. Combined cycle gas turbines and coal gasification. Variations in electric efficiency and investment cost.

Technology	Scale	Electric efficiency			Investment cost, €/kW	
	MW	1990	2000	2010	<2000	2010
Combined cycle gas turbines (CCGT)						
Condensing	500	0.50	0.55	0.63	400	400
Extraction	500	0.50	0.55	0.63	480	480
Back-pressure	50	0.50	0.55	0.63	576	576
Back-pressure	5		0.52	0.59	792	792
Coal gasification						
Condensing	500			0.48		1020
Extraction	500			0.48		1224

The parameter variations of nuclear units are limited, and, thus, no distinction is made between the different types of existing nuclear units in the region. Extraction facilities for CHP are assumed to add 3 % to investment cost, and new vintages from 2010 may increase the thermal efficiency for electricity-only from 0.35 to 0.36.

The parameter variations and potential technological progress for wind power are significant, but uncertain and complicated. There are significant regional differences in wind resources, and the constraints and requirement for a large-scale introduction of wind power cannot be addressed satisfactory with this type of model. Thus, the dataset contains only few parameter variations for wind power as shown in Table 5.6.

Table 5.6. Wind turbines. Variations in load factor and investment cost.

Type	Scale	Load factor	Investment. Cost, €/kW		
	KW		1995	2005	2010
Land	500	0.22	750		
Land	1000	0.22	675		
Sea	500	0.33	1500		
Sea	1000	0.33		1215	
Sea	2000	0.33			1020

Although hydro power is very important in the region, it is not reasonable to assume detailed techno-economic data for this technology. The investment cost for large-scale hydro power is very site specific, and few investment data are available for small-scale hydro power facilities in technology catalogues. The investment cost shown in Table 5.2 is 1000 $€_{90}$ per installed kW, which is the same order of magnitude as nuclear and wind.

5.2.4 Parameter variations for heat generating technologies

Heat-only generating technologies are mainly boilers fired by various fuels. The potential for efficiency improvements and cost reductions are limited, except for biomass fuelled boilers. The technology data also contains data for electrically driven heat pumps, which traditionally have been used in regions with low electricity prices. There is some potential for efficiency improvements and cost reduction for heat pumps, see Table 5.7.

Table 5.7. Heat generating technologies. Variations in totalefficiency and investment cost.

	Total efficiency					Investment. Cost, €/kW			
	Old	1980	1990	2000	2010	<1980	1990	2000	2010
Heat pumps, 20 MW thermal output									
Electricity driven		2.70	3.00	3.25	3.50	250	237.5	225	212.5
Boilers, >1 MW thermal output									
Gas	0.75	0.85	0.85	0.95		40	40	40	
Oil	0.75	0.85				60			
Oil Shale	0.67	0.76				120			
Coal	0.67	0.76				120			
Lignite	0.67	0.76				120			
Peat	0.67	0.76				120			
Waste	0.67	0.76				240			
Biomass	0.67	0.76	0.76	0.76	0.85	240	240	240	192

5.2.5 Environmental parameters

Table 5.8 shows emission factors for CO_2 and SO_2 . These emission factors are fuel specific, while the NO_x emission factor depends on the combustion technology.

Table 5.8. Fuel specific emission factors.

	CO_2 kg/GJ	SO_2 kg/GJ
Biomass	0	0.21
Waste	55	0.50
Natural gas	57	0.00
Fuel oil	78	0.49
Peat	85	2.00
Coal	95	1.00
Lignite	101	2.67
Oil Shale	109	2.67

Source: Baltic 21 Energy.

Biomass is defined as a renewable energy source. Although CO_2 will be emitted during the combustion, the same amount of CO_2 had been absorbed in the photosynthesis during a limited number of years in the past. This is in contrast to peat, which may be burned using the same combustion technology. However, peat is a young fossil fuel that was created only few thousand years ago.

The CO_2 emission factor for urban waste must be based on convention, taking into account the composition of typical urban waste. The remaining emission factors are also based on conventions with much less uncertainty. The SO_2 emission factors represent conventional averages of low and high sulphur fuels.

5.3 Structural data

The structural data are used to describe the electricity and heat systems in the various countries, regions and urban areas. Most important are initial capacities of the various technologies and demands for electricity and heat in the start year.

5.3.1 Generation capacities

The initial and planned generating capacities for electricity and heat for the various countries are divided into electricity regions and district heating areas on the basis of available statistics or estimates. The initial generation capacities are summarised in Figure 2.1, above.

Urban areas consist of large-scale interconnected district heating networks and electricity generating technologies that supply these networks with heat or steam.

Rural areas contain all electricity-only technologies and small-scale CHP technologies that are designed for a local heat market.

These capacities are reduced exogenous for future years following the assumptions on decommissioning of the existing capacities, which depends on the ageing of the different vintages of the existing capacities.

Figure 5.1 shows the assumptions on the existing and planned generation capacities over time in the various countries. As seen, there are three main distinct time periods:

- The first period extends up to 2010, and essentially maintains the installed capacities at 1998 level.
- At the beginning of the second period, 2011-2020, a substantial part of the existing capacity is assumed decommissioned,
- At the beginning of the last period, after 2020, further decommissioning has taken place. The generation capacities that remain throughout the whole period up to 2030 are only hydro power.

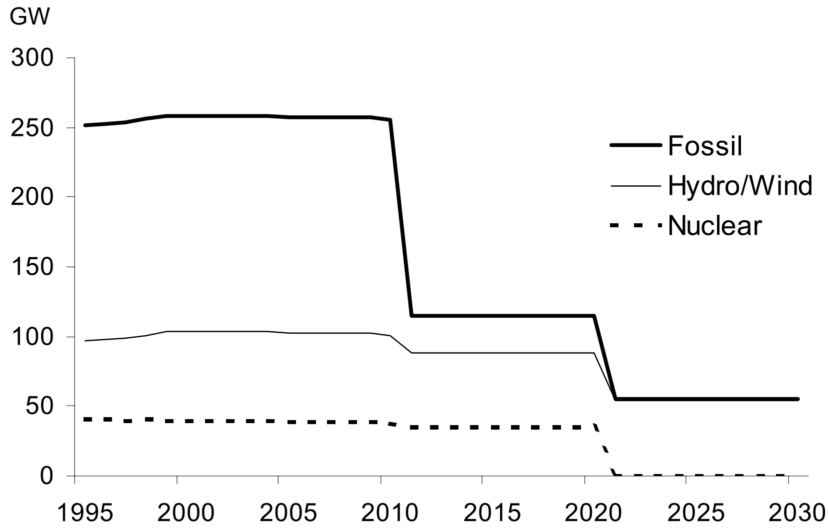


Figure 5.1. Existing and planned electricity generating capacities in the Baltic Sea Region 1995-2030.

New generating capacity is either exogenous – in particular planned capacities in the beginning of the period – or determined by the model optimisation.

5.3.2 Transmission capacities

Existing and new transmission capacities between electricity regions are treated similar to generation capacities. The initial capacities in 1995 are summarised in Table 2.5.

5.4 Reference demand forecasts

Reference demand forecasts for electricity and heat are exogenous in the Balmorel model, but future demand is elastic. Thus price elasticities for the various consumer groups are input parameters in the model.

5.4.1 Market structure and distribution losses

The demand forecast to the model is specified as the total demand for all final consumers in each electricity region and heat area. The electricity required for the national market to be fed into the transmission network or the required heat generation is the final demand plus the distribution losses.

Obviously, distribution losses are much smaller for large consumers than for small, and the losses may vary through time with the changes in demand structure and technology changes in transmission and distribution technology, but these variations are not addressed in the first version of the model, which focus on interregional and international electricity trade. Thus, the demand structure and distribution technology is fixed, and the losses are represented by parameters for electricity and heat in each electricity region and heat area. These parameters are calculated from data for 1997 as shown in Table 5.9. As shown in the table these 'distribution losses' are very different among the countries. Further, there are significant variations in the period 1991-1994, in particular for the transition economies. These differences only partly reflect differences in demand structure, distribution technology and efficiency. They may also reflect differences in statistical definition and practice.

The composition of consumer groups in the final demand for electricity is shown in Figure 2.2, above.

Table 5.9. Electricity and heat available for distribution, final demand and calculated distribution losses, 1997.

	Electricity			Heat		
	Available for distribution	Total final demand	Distribution losses	Heat generation	Total final demand	Distribution losses
	TWh	TWh	p.u.	PJ	PJ	p.u.
Denmark	37.06	31.85	0.1406	125.03	95.04	0.2399
Estonia	8.24	5.05	0.3871	32.59	27.00	0.1715
Finland	76.83	70.36	0.0842	125.70	113.02	0.1009
Germany	549.19	461.73	0.1593	381.58	344.01	0.0984
Latvia	6.32	4.30	0.3196	46.54	38.22	0.1787
Lithuania	11.34	6.74	0.4058	76.68	55.52	0.2759
Norway	115.47	103.49	0.1037	6.87	4.76	0.3073
Poland	140.61	94.61	0.3272	422.97	366.11	0.1344
Russia W+K	56.60	39.47	0.3027	419.67	374.77	0.1070
Sweden	146.70	124.27	0.3027	162.44	150.75	0.1070

Source. Enerdata, CD-ROM 2000

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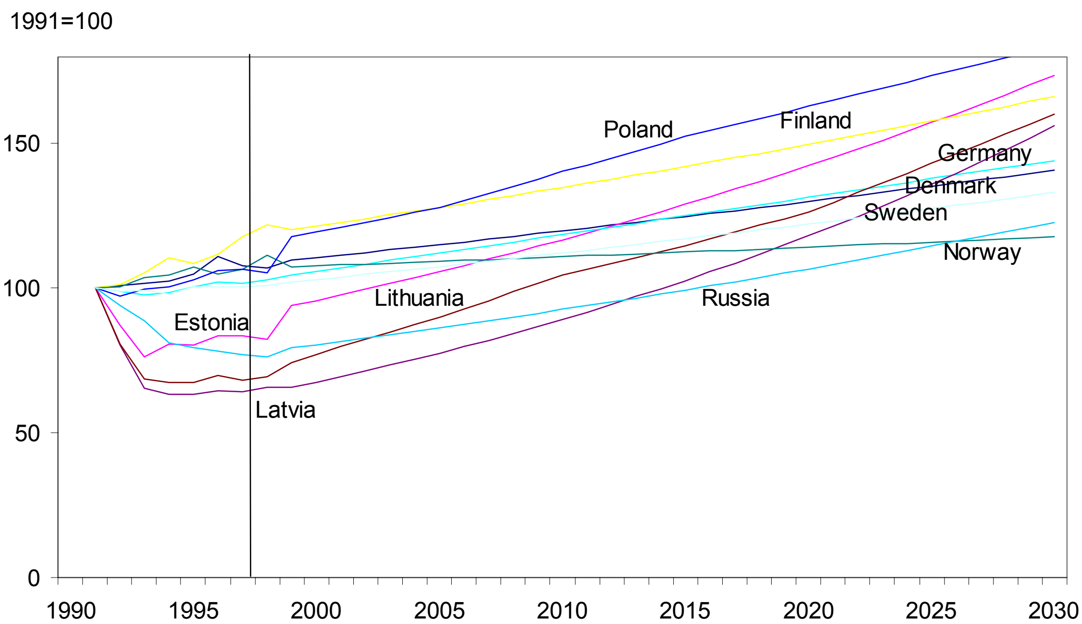

Figure 5.2. Electricity demand 1991-2030.

5.4.2 Electricity demand

The electricity demand in the 1990s is well described in official statistics and subdivided into consumer groups that can be assumed to react differently to price variations.

The electricity demands for the various consumer groups are aggregated for each region outside the model itself. Distribution losses and costs are added as weighted averages that are calculated for each region, using the percentage of each consumer group, see Figure 2.2. Thus, the model will represent the electricity demand and electricity cost as final energy delivered to the final consumers.

The demand forecast, as illustrated in Figure 5.2, must be seen on the background of the very different development in the countries in the first half of the 1990s. The reference demand forecasts used in the first version of Balmorel (March 2001) are taken from Baltic 21 Energy or submitted by the participants on the basis of more detailed or recent national studies.

5.4.3 Heat demand

The quality of data for heat demand in urban and rural areas is widely different among the countries. The reference demand forecasts are taken from Baltic 21 Energy or submitted by the participants. The subdivisions in urban and rural areas are either based on aggregation of more detailed data (Denmark) or set by distribution parameters.

The heat demand is aggregated for all types of heat uses in each 'urban' or 'rural' area outside the model itself. Distribution losses and costs are added as weighted averages for each area. Thus, the model will represent the heat demand and cost of heat as final energy delivered to the final consumers. The heat demand forecasts for the different countries is shown in Figure 5.3. Like electricity the development has been very different among the countries in the first half of the 1990s with drastic reductions in the heat demand in the transition economies.

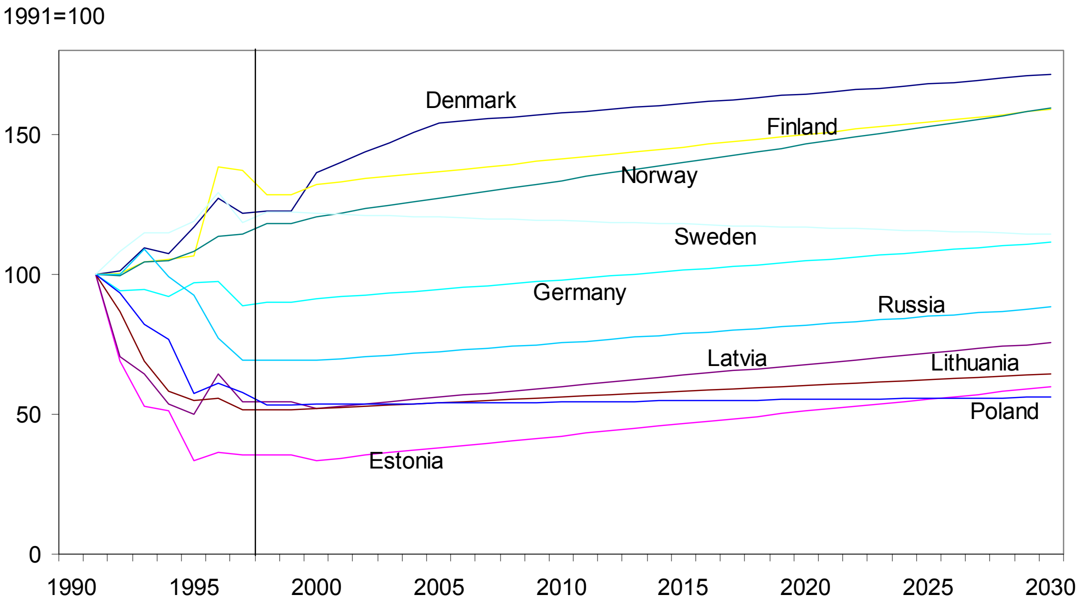

Figure 5.3. Heat demand 1991-2030.

5.5 Own price elasticities in Balmorel

The impact of consumer price elasticities on the wholesale demand for electricity and heat is highly dependent on taxes and the market structure.

Table 5.10 shows the own price elasticities for electricity in the demand segments used to calculate the aggregate wholesale demands. At the consumer level the same elasticities are assumed for all countries.

Table 5.10. Own price elasticities of electricity demand.

Sector	Own price elasticity
Heavy industry	-0.5
Light industry	-0.2
Transport	0.0
Agriculture	-0.2
Residential and services	-0.3

The impact of consumer price elasticities on the wholesale demand for electricity and heat is highly dependent on taxes and the market structure. Table 5.11 shows the calculation of aggregate wholesale elasticities on the basis of the different structures of demand in the countries or regions in the Balmorel model. The very low price elasticities for Denmark for wholesale electricity is explained by high taxes on electricity sold to private consumers.

Table 5.11. Electricity structure demand 1997 and calculated aggregate demand elasticities.

	Aggregate wholesale price elasticity
Denmark	-0.06
Estonia	-0.18
Finland	-0.20
Germany	-0.14
Latvia	-0.17
Lithuania	-0.17
Norway	-0.20
Poland	-0.19
Russia W+K	-0.20
Sweden	-0.19

While assumptions on demand elasticities can be based on the results econometric studies from of numerous sources, such studies are virtually non-existent for the heat demand from district heating systems. Thus, in the first version of Balmorel the heat demand is assumed inelastic.

5.6 Global and national fuel prices

National fuel price forecasts are calculated adding transport costs and national taxes to cif prices (cost, insurance and freight) to a national harbour or border station. Fuel price forecasts for indigenous fuels are based on national forecasts.

Price forecasts for internationally traded fuels are global data. The forecasts for these prices are the same for all countries. Figure 5.3 shows the fuel price forecasts used in the first version of Balmorel, which are used for all countries.

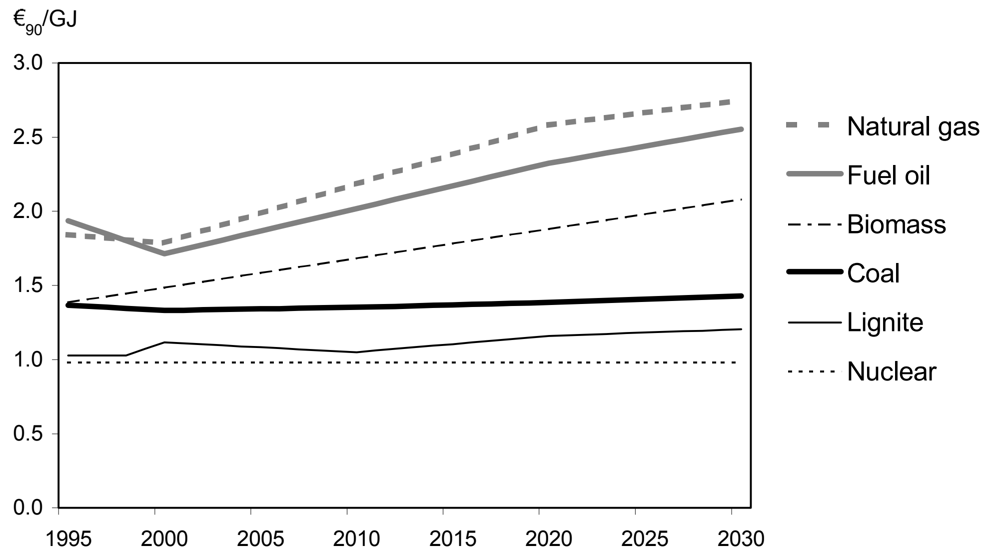

Figure 5.4. Global fuel price forecasts.

The international fuel price forecasts are from the Shared Analysis Project. These are calculated by the POLES model, which simulates the global energy market. The forecasts are supplemented by own calculations and submission from the participants for indigenous fuels. The Polish forecast for lignite is used for lignite, peat and oil shale in all countries. The price of urban waste is set at zero.

5.7 Other economic data

A key parameter is the discount rate, which may greatly influence the future technology choice. In practice the discount rate is implemented as an annuity factor. The annuity factor used in the main presentation in Chapter 6 is 0.16, which represent a 10 % discount rate and 10 years economic lifetime.

Variations in the discount rate are an important parameter for sensitivity analyses. The discount rate is also used to implement assumptions on the degree of competition and regulation. A high discount rate represents a high degree of competition and limited regulation.

Data for prices and costs of investment and operation and maintenance are from different sources and, thus, quoted in different currencies and different price-years. To use these different sources in a model requires conversion to the same currency and price year. All prices in the Balmorel model are shown in $€_{90}$ or more correctly ECU 1990, because the Euro was not introduced until 1999.

This conversion is non-trivial. Adjustment for inflation may be based on different inflators, which may lead to very different results, and the sequence of the conversion of currencies and the inflation/deflation may have significant impact on the result. Data for the conversion factors and further explanation are found in the appendix “Balmorel – Data and calibration”.

5.8 Calibration of Balmorel

The Balmorel model contains the possibility to calibrate various parameters. The purpose of this is to adjust the model results in order to attain better correspondence with historically observed values; it is expected that this will also increase the credibility of the model result for future years.

The first possibility is to adjust basic parameters of the generation units. In particular, each unit is characterised by a fuel efficiency, which may be modified using a calibration parameter. The model estimate of the total fuel consumption for a particular year should be close to the historical figure. If not so, the fuel efficiency may be adjusted. This may be done for a unit individually or for a group of units, as the data material permits. 1998 has been used as base year for a calibration where all thermal units were taken as one group. The IEA statistics was used for fuel use and for heat and electricity generation.

The second basic possibility is to adjust the demand functions so that demand in a base year, as calculated in the model, coincides with the statistical data. The mechanism here is to shift the demand function upwards or downwards, so that the desired consumption results. A particular point is here that historically there has not been much variation of prices of the day or over the year. However, the model operates with prices for each time segment (time of the day and year), this has to be reflected in the calibration. Also here the 1998 IEA statistics have been used as a source for the calibration.

6 Application illustrations

In this chapter a number of illustrations relative to the Balmorel model will be presented. The intentions with this are:

- To illustrate possible problem areas to which the model may be applied.
- To illustrate possible types of output generated by the model.
- More generally, to give the reader a preliminary feeling of the characteristics of the model.

These illustrations are given in relation to potential applications. It should be stressed that it is by no means pretended that any of the illustrations presented here constitute an analysis of a problem. It is obvious that this is not possible within the space allocated here. The key point in the presentation here is that the Balmorel model is capable of supplying certain types of information of relevance to analysis of the electricity and CHP sector.

6.1 Development of electricity prices

In the previous chapters, in particular Chapter 2 and Chapter 5, some key figures describing the Baltic Sea Region have been given. Also some assumptions related to the development over the next thirty years have been indicated, e.g. with respect to demand for electricity and heat, fuel prices and others.

Based on this and the more technical and detailed assumptions made in the model, cf. Chapter 5, a few observations on the development of resulting indicators as calculated by the Balmorel model will be given.

The formation of electricity prices and their role on the development in the region are central for the analysis and understanding of a regional liberalised electricity market. Therefore the present section will illustrate the development of these prices. In particular, the emphasis will be on demonstrating the influence of various central assumptions.

Figure 6.1 indicates the development over time of electricity prices under the same assumptions of fuel price development shown in Figure 5.4. In the Balmorel model, an electricity price is calculated for each region and each time segment of the year. This price represents the electricity producers' marginal cost of generation (including fuel costs, fuel and emission taxes, operation and maintenance costs, and investment costs). The prices shown in Figure 6.1 are the average annual prices, given for each country. As is observable, the development of prices fall into three time segments, in part a reflection of the assumption on the development of generation capacities as described in Chapter 5. In particular, a clear price change may be observed between 2010 and 2011. This is because a restructuring of the supply system takes place in order to replace the capacity decommissioned at the end of 2010.

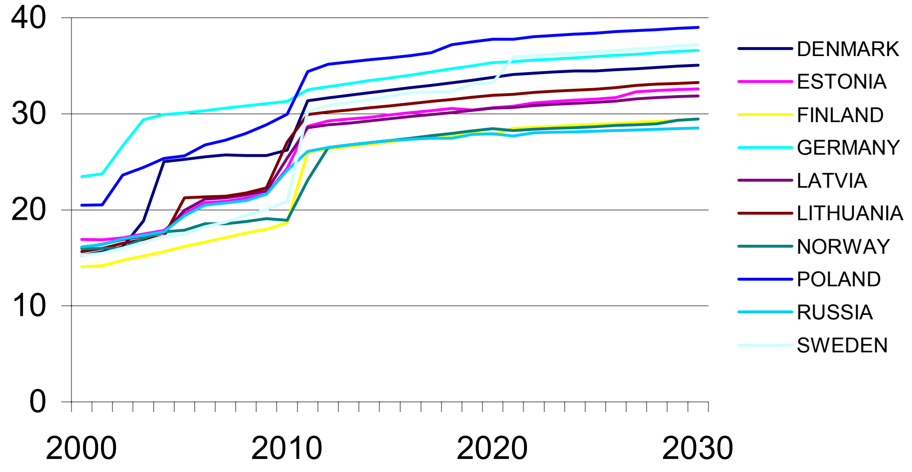

Figure 6.1. Development of electricity prices, €$_{90}$/MWh..

A second explanation for the general increase of electricity prices with time is the increase in fuel prices, cf. Figure 5.4. To illustrate this, two additional illustrations are given. In Figure 6.2 the electricity prices are indicated for "low" fuel prices, corresponding to having the prices fixed at the year 2000 level throughout the period 2000-2030, while in Figure 6.3 "high" fuel prices are assumed, corresponding to having prices fixed at year 2030 level, cf. Figure 5.4. As seen, in the long run the prices will in the former case stabilise in the range 25-35 €$_{90}$, while in the latter case they will be about 5 €$_{90}$ higher. The prices in Figure 6.1 and Figure 6.2 for the year 2000 are identical, and the prices in Figure 6.1 and Figure 6.3 are close for the year 2030.

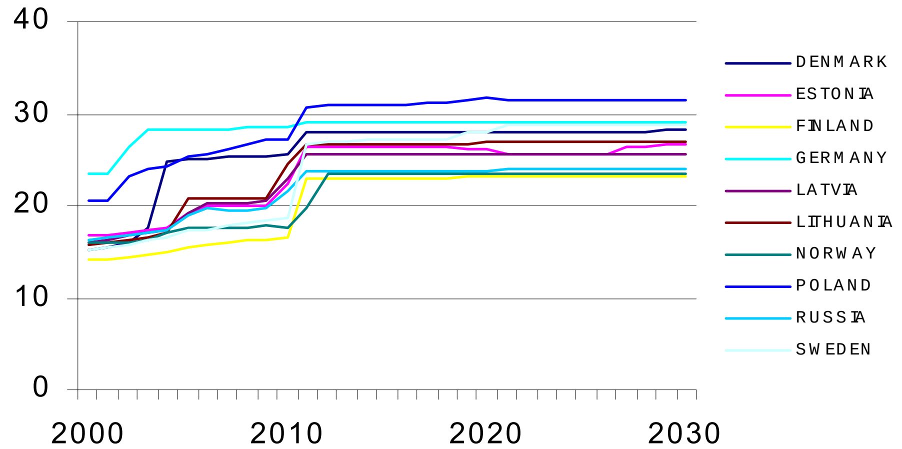

Figure 6.2. Development of electricity prices with low fuel prices, €$_{90}$/MWh.

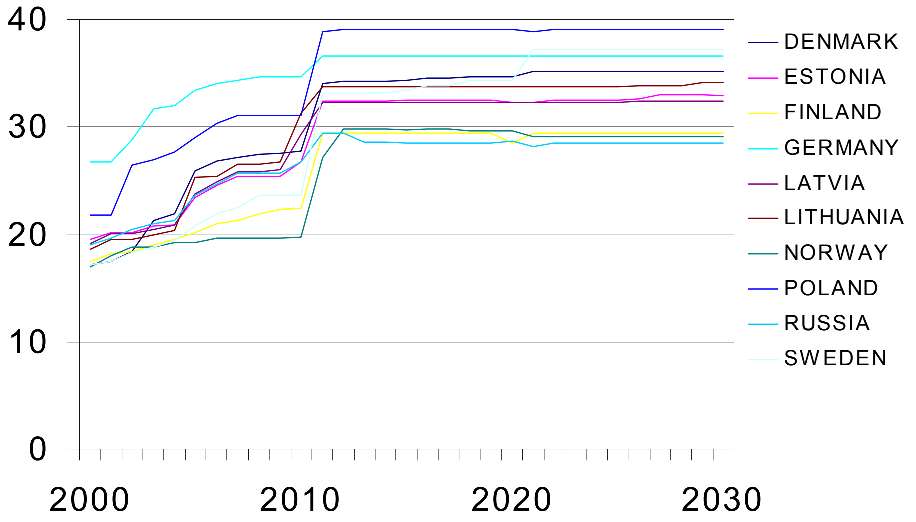

Figure 6.3. Development of electricity prices with high fuel prices, €$_{90}$/MWh.

The shift in the composition of supply structure that is behind the price changes also indicates a shift from dominance of short-term marginal prices to dominance of long-term marginal prices. The difference between the two is due to the fixed cost associated with investments. In the Balmorel model, this is represented by the annual payment on the investment. Thus, for instance, if the assumption is that investment should be paid back in 10 years and that the interest rate (or requirement to profit) is 10 %, then an investment of € 1 will impose an annual cost (the annuity) of € 0.16 . This cost will be reflected as a mark up in relation to the short-term marginal electricity price. Similarly, a pay back period of 20 years and an interest rate of 5 % will impose an annuity of € 0.08.

In Figure 6.4 the development of electricity prices is shown under the 20 years 5 % assumption, while all other figures were made with the 10 years, 10 % assumption. It is seen that the development the electricity prices over time is more smooth in Figure 6.4, indicating that it is easier to invest in new generation capacity. Differences between these two sets of assumptions may be interpreted as the difference between a situation with a protected investment climate and a turbulent situation where expectations of short pay back times and high interest rates prevail.

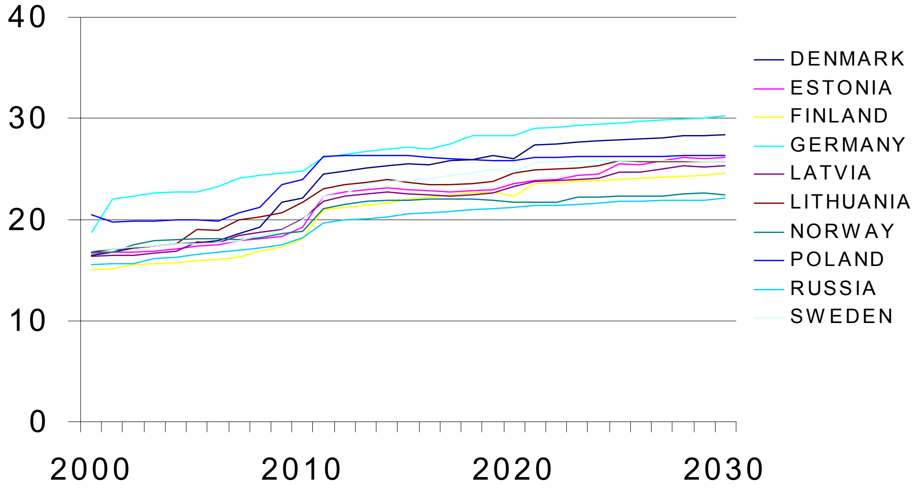

Figure 6.4. Development of electricity prices with low interest rate and long pay back period, €$_{90}$/MWh.

As seen on all the figures presented, there are substantial price differences between the electricity prices in the various countries. Such price differences may only be maintained if there are electricity transmission bottlenecks.

An indication of international electricity transmission capacities was given in Table 2.5. Recall that the figures in that table refer to nominal capacities. However, electricity networks are complex. In particular, the real capacity on the transmission between two regions cannot be stated without knowing the conditions within each of the two regions. Therefore the real capacity may substantially lower than what is indicated by the nominal capacities, and moreover it may depend on the time of the day and the time of the year, reflecting supply and demand variations.

The previous figures were made using the nominal transmission capacities. The results in Figure 6.5 were made assuming substantial increases in the transmission capacities. The figure shows that with increased electricity transmission possibilities the electricity prices in the individual countries will converge.

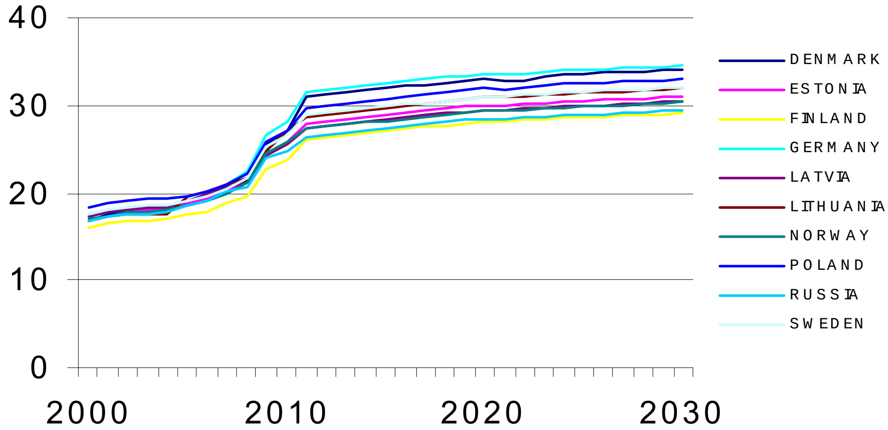

Figure 6.5. Development of electricity prices with increased electricity transmission capacities, €$_{90}$/MWh.

The electricity prices are associated with the supply structure, as already noted. In turn, this is intimately linked with the variation over the day and the year of demand for electricity and heat.

This for instance motivates a differentiated division of generation between the different units, characterised as e.g. base load, medium load and peak load units. Associated with this there is a differentiation in the fuels used.

The calculations reported in this chapter were, unless specifically noted, performed on a data set with a subdivision of the year into four segments, representing a day-night and a winter-summer subdivision. It is obvious that the details of such subdivision of the year will influence the results. To illustrate, Figure 6.6 shows the development of electricity prices when no subdivision of the year is assumed. As seen by comparison with Figure 6.1 even this apparently minor difference implies a difference in prices of around 20 %. The Balmorel model permits application of various subdivisions of the year, see further Section 6.4.

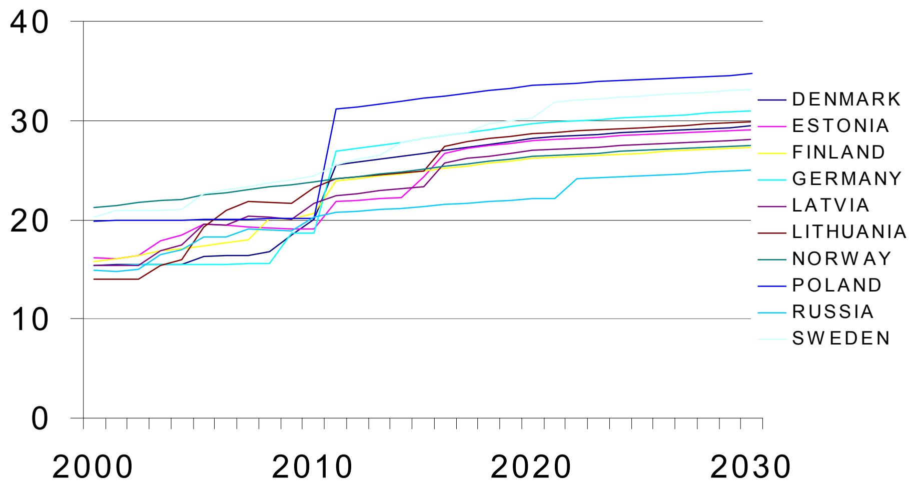

Figure 6.6. Development of electricity prices with no subdivision of the year, €$_{90}$/MWh.

As the present section has illustrated, there are a number of central quantities that have decisive influences on the electricity prices. Behind each combination of choice of such quantities is an associated composition of the energy system, with consequences for technologies, fuels, emissions, transmission, demand and other aspects, nationally as well as internationally.

As the purpose of the present chapter is not to perform analyses in relation to this, the following sections will present aspects of problems that may be analysed using the Balmorel model.

6.2 Emissions permits trading and Joint Implementation: marginal emission reduction costs

The Kyoto protocol from 1997 describes emission reduction targets for greenhouse gases and a number of instruments to achieve such goals. At the Kyoto conference it was agreed that industrialised countries as a group should reduce their emissions of greenhouse gases by at least 5 % relative to the 1990 level, up to the period 2008-2012. Some industrialised countries (the so-called Annex B countries) further agreed to specific reduction goals. See also Table 2.7. The Kyoto protocol has not been ratified.

A number of issues are of importance in relation to the implementation of the emission reductions, e.g.

- Is the number of countries and their individual goals sufficiently high to ensure that the total reduction will be effective in relation to the global warming problem?
- The reduction in the Annex B countries may take place in part by moving those parts of production that have high emission rates to non-Annex B countries (the so-called ‘leakage’). This will reduce the effect.
- Some Annex B countries today have an emission that is less than their 2008-2012 goals (e.g. some countries in Eastern Europe). The agreed reduction in a sense is therefore not real (the so-called ‘hot air’).
- It is difficult to measure the emission. Possibly this is not outspoken for CO_2, but it is for some other greenhouse gases.

- The individual country does not have any motivation to reduce emission unilaterally. Therefore a control system has to be applied.

Further, an important question in relation to emission reductions is how to secure that the reductions are made in a cost efficient way. One prerequisite for this is that the distribution between countries reflects the marginal costs of reduction.

Hence, if the marginal reduction costs differ between two countries then it would be economically sound to redistribute the reduction goal between them, until the marginal costs were equal. For this purpose a number of instruments are described in the Kyoto protocol, including emission trading, clean development mechanism and joint implementation.

In the following the marginal emission reduction costs will be derived for the countries in the Baltic Sea Region. Figure 6.7 summarises the results. The graph shows the marginal reduction cost as a consequence of the percentage reduction in emission. The baseline against which this is calculated is equal to the calculated emissions from each country in 1998 with no transmission between countries. However, observe that countries that are net importers of electricity and that cannot satisfy their domestic demand of electricity, have been allowed a certain import of electricity. Further it has been assumed that there can be no investment in new generation technologies. All calculations are specified to refer to 1998, i.e., they represent a kind of fictive exercises on a past situation. These assumptions illustrate just a few aspects in relation to the question of how to define and set up a baseline scenario.

In Figure 6.7 it can be seen that the marginal emission reduction cost increases in most countries as the limit of CO_2 emissions is tightened. In these calculations investments in new generation technologies were allowed. The graph shows that the marginal emission costs between the countries in the Baltic Sea Region differ substantially. In countries where the marginal emission costs are zero a potential to gain a positive profit by change of technologies is indicated. This again points to a difficulty in relation to definition of a baseline.

In order to comply with the imposed emission limit, electricity and heat are either generated by other existing technologies with less CO_2 emissions or new capacities are established

At the point of departure (no CO_2 emission reduction) coal accounts for approximately 42 % of the fuel used for electricity and heat generation, while this share decreases to 31 % with a CO_2 reduction of 10 %. Similarly the share of natural gas increases from 8 % to 19 %. The shift in fuel consumption is due to new investment in gas fired combined cycle technologies together with a more intensive use of existing gas fired power plants. In relation to the use of existing plants there is a slight shift from condensing plants to CHP.

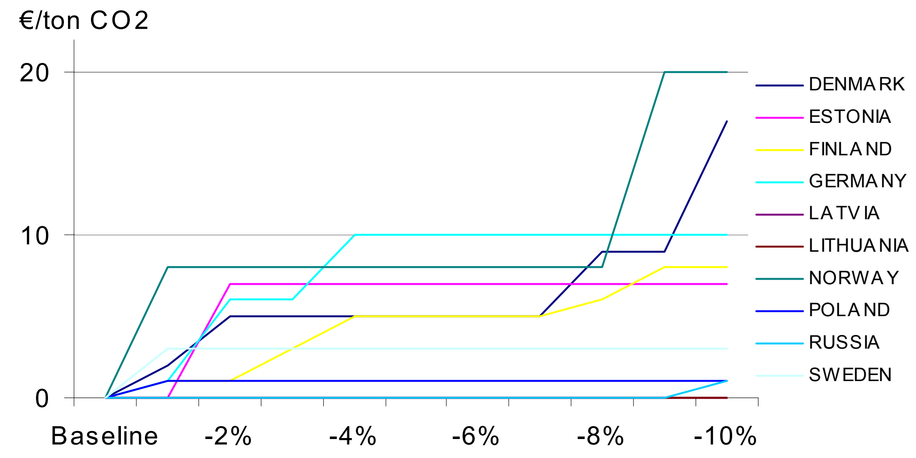

Figure 6.7. Marginal CO_2 emission cost with national CO_2 emission limits.

The illustration in Figure 6.7 deals with emission reduction in each country individually. If the percentage reductions targets for emissions were the same in all countries, then the figure illustrates a potential for economic rationalisation by international co-operation. As indicated above, several ways of doing this are stipulated in the Kyoto protocol.

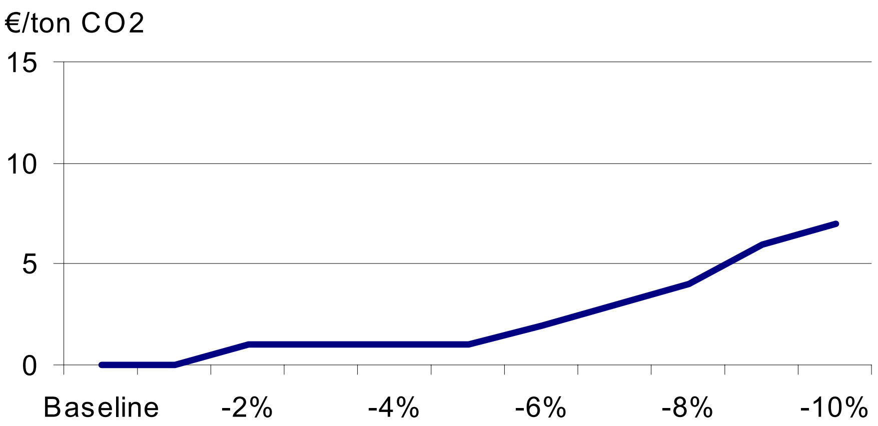

Figure 6.8. Marginal CO_2 emission cost with one common regional CO_2 emission limit.

Figure 6.8 illustrates the consequences of application of one of these, viz. emissions trading. The modelling is done by assuming a perfect marked for emissions trading, such that the identical percentage emissions reduction goals of each individual country is replaced by the same percentage reduction, but not applied to the total emissions of all countries. I.e., the reduction is for the Baltic Sea Region as a whole. As seen, now a 10 % reduction is attained at substantially lower marginal costs than those appearing in Figure 6.7.

6.3 A renewable energy share and market

The use of increased shares of renewable energy in the supply of electricity and heat is specified in many national energy strategies. Various means have been used in order to accomplish such goal, such as support to the development of renewable energy technologies (through research and development), support to the establishment of generation units, and extra payment for the electricity generated from renewable technologies (e.g., feed-in tariffs).

One way of achieving an increased share of renewable energy application in electricity generation is to make it obligatory for the consumers to buy a certain share of their electricity from production based on renewable energy sources. The idea is to separate the market into two parts. On the physical market all electricity is traded in the same way, renewable or not. On the green certificate market the certificates related to renewable energy electricity are traded. Each producer gets such certificates in proportion to the production of electricity based on renewable energy. Each consumer then has to buy such certificates corresponding to the obligatory share of renewable energy consumption. The additional income (over the income from sale at the physical market) to the producers of renewable energy electricity should then be the motivation for producers and investors to ensure that a sufficient amount of renewable electricity will be produced.

Figure 6.9 illustrates a modelling of such construction. A constraint has been added to the basic Balmorel model, ensuring that the obligatory share of the electricity consumption is based on renewable energy. The figure illustrates the case where the share of renewable energy in electricity generation is assumed to increase linearly from 10 % in 2000 to 40 % in 2030.

As seen on the figure, the electricity price (the upper graph), as observed by the consumers, may be seen to be composed of two parts. One part (second from the top in 2020) is the electricity price as represented at what previously was called the physical marked. The other part (lowest in 2020) is the price paid for the certificates, documenting the required share of renewable electricity. The weighted sum of these two prices (dotted graph), with weights reflecting the share of renewable based electricity, corresponds to the total price of electricity.

The figure clearly shows that the prices at the physical market and at the certificates market are highly interdependent. If one goes up, the other goes down, and the sum of the two prices will be almost constant. This sum represents the total payment that the producers of renewable electricity get.

The large shifts around 2011 represent the necessary adjustments in installed capacity when decommissioning takes place, cf. Section 5.3.1, Figure 5.1. As seen, this increases the price of electricity at the physical market, while the price at the certificates market decreases correspondingly. At this time, the obligatory renewable electricity share is around 20 %, and the weighted consumer price therefore experiences an upward jump like the electricity price at the physical market.

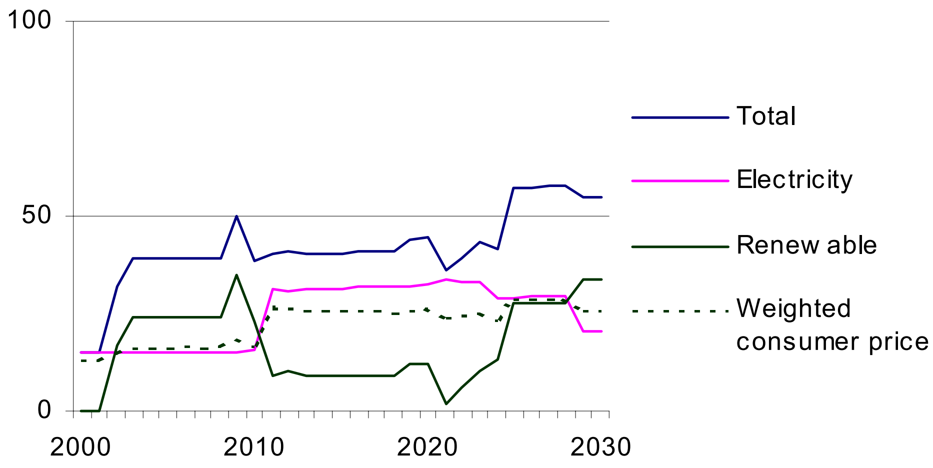

Figure 6.9. Development of prices with an obligatory share of renewable energy in electricity generation.

6.4 Analysis of a hydro pumped storage

The Balmorel model is intended for analysis of the electricity and CHP sector in an international context, covering a large geographical area, but the model design is flexible. This permits analyses that focus more sharply on specific issues. Thus, more detail of particular interest for such an issue may be added, possibly limiting simultaneously the score of the model with respect to other dimensions, e.g. geographical extension, time span, or number of generation technologies of interest. A multi-resolution analysis may be obtained by combining such detailed analysis with a more extensive analysis, where for the latter may be used to derive boundary conditions for the former. These possibilities will be illustrated in relation to the analysis of a pumped hydro storage.

Such energy storage is important for several reasons. Thus, in a system consisting of units with slow power output regulating capacities (e.g. nuclear power plants) or very different marginal costs the balancing of production and demand may become difficult and/or expensive. But energy storage is also important due to the increased application of renewable energy sources, of which several types have a very fluctuating power output (viz., wind turbines and solar power. This section illustrates the analysis of the use of a pumped storage power plant. In the Baltic Sea Region such plant is found in e.g. Lithuania.

The basic optimisation period of the model is one year, which can be divided into a flexible number of sub periods (viz., seasons that are further subdivided into hours) making the model capable of handling seasonal and diurnal variations in the demand of electricity and heat.

In the analyses several different time structures have been tried as listed in Table 6.1. The time structures were made from the hourly load profile of Lithuania in 1999. The 8760-hour time structure was this profile without any modifications. For e.g. the 4-168 and 4-24 subdivisions the year was split into four seasons each of three months' duration, where for each season an average week and an average day were calculated.

Table 6.1. Various subdivision of the year.

Name	Description
8760	All 8760 hours of the year
4-168	4 seasons each of 168 time periods
4-24	4 seasons each of 24 time periods
2-4	2 seasons each of 4 time periods
2-2	2 seasons each of 2 time periods
1-1	No subdivision of the year

The geographical scope of the model was limited so that only Lithuania was included. The export from Lithuania was fixed and also a fixed production profile for the Ignalina nuclear power plant was used (approximating the actual production profile from 1999); thus, economic dispatch of this plant was excluded from the modelling. The model was solved for one year, excluding any investment possibility. The cycle loss on the pumping operation was 28 %. Restrictions on maximum energy level of the storage and the pumping and generating capacity were modelled.

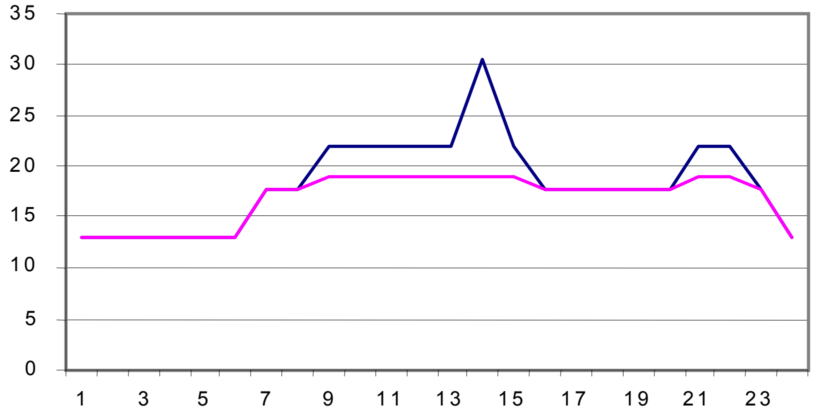

Figure 6.10. Electricity prices without (upper graph) and with (lower graph) the pumped storage facility.

In Figure 6.10 the marginal production costs (electricity prices) for the 4-24 case are shown, both with and without the storage. It is seen that the storage is able to “buy” electricity at night at a price 28 percent lower than the price to which it can sell the generated power during peak hours. It is seen that the storage capacity is not used fully, since the marginal cost difference in that case would have been higher in some hours. Figure 6.10 also indicates that a storage can take over production from typical peak units (often condensing type power plants that are oil or gas fuelled). This will influence fuel usage and thus also emissions (CO_2, SO_2, and others).

From Figure 6.11 it can be seen that the use of different time structures has little influence on the total system costs, viz., they are within the same 3 percent range. So when analysing the overall system the fineness of seasonal and diurnal variations does not need to be that high. This is explained by the fact that the pumped storage plant is only a small part of the whole system.

However, the situation is different when the interest is on a particular detail in the model, in this case the pumped storage plant. The storage is not used in the 2-2 and 1-1 cases and these time subdivisions imply vanishing savings on variable costs compared to a situation without a pumped storage. However, as the number of subdivisions of the year increases, the gain from having a storage becomes more outspoken. This illustrates the importance of adopting the level of detail to the problem being analysed.

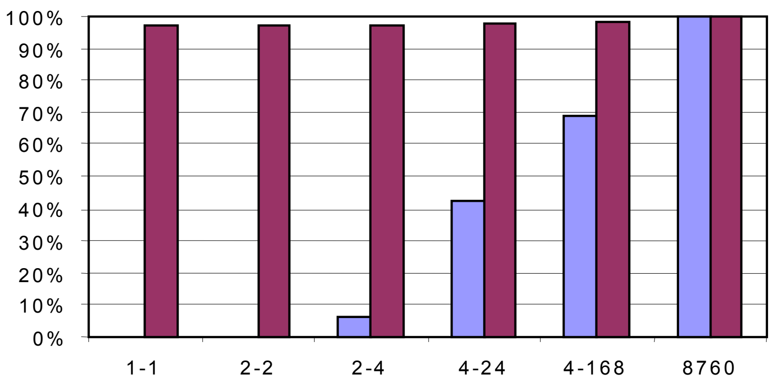

Figure 6.11. Total costs and gains from having a pumped storage, relative to the finest time structure.

7 Conclusions and Perspectives

The report has described the motivations for the development of the Balmorel model, as well as the model itself.

A background for the project is the trend towards internationalisation in the electricity sector. This trend is seen in increased international trade of electricity, in investment strategies among producers and otherwise. Also environmental considerations and policies are to an increasing extent gaining an international perspective. Further, the ongoing process of deregulation of the energy sector highlights this and contributes to the need for overview and analysis.

The purpose of the Balmorel project therefore has been to develop a model for analyses of the power and CHP sectors in the Baltic Sea Region. The model is directed towards the analysis of relevant policy questions to the extent that they contain substantial international aspects.

As described above, the model for analysis of such issues now exists. The model has been briefly presented and a number of illustrations of possible results from the model have been given. The model as presented here makes extensive use of the openly available data and substantial improvements on the data side is not possible without improvements in the international public data bases.

A guiding principle behind the construction of the model has been that it may serve as a means of communication in relation to the policy issues that already are or that may become important for the region. Therefore emphasis has been put on documentation, transparency and flexibility of the model.

As described, this is achieved in part by formulating the model in a high level modelling language, and by making the model available at the internet. Such openness is unusual. Among other things this means that any inexpedient or erroneous element in the model will be exposed to critics. Indeed, this is considered a strength, not least in the perspective of maintaining the model, cf. below.

The model has been constructed for analysis of the long-term perspectives of the development of the electricity sector of the Baltic Sea Region. As for any model, the purpose of the model determines not only the strong sides of it, but also to some degree the weak sides. Thus, the ambition of covering a large geographical area and a large time span invariably implies that the model will lack detail with respect to these dimensions. Questions that are relevant for a shorter time perspective or for a more limited geographical area may therefore not immediately be meaningfully addressed by the model.

However, it should be noted what the specific reason is. Thus, the model structure and implementation are quite flexible. This means that minor modifications and augmentations of the model structure can easily be made, and in this way many problem types may be represented and analysed, as already illustrated. Indeed, for many problem types the work involved in the adjustment of the model structure will be far less than the work involved in acquiring the necessary associated data.

Further, the model can accommodate more model data detail than what is presently represented. It will therefore be possible for instance to adapt the model to a more detailed analysis with one country in focus, as a supplement to the regional overview originally aimed at. Such adoption is actually taking place presently.

The purpose of the Balmorel project was to develop a model, and as documented, this has been achieved. However, implicitly there is the more fundamental goal that the model will be used for strengthening the analysis and communication in relation to the development for the energy sector in the region. It is not part of the project to do so. In fact, only users can achieve the goal by using the model.

Assuming that the present model is indeed a suitable tool, then in a longer perspective the following interlocking issues are of importance for achievement of the goal:

- There must be a number of users of the model.
- The data must updated regularly.
- The model must be maintained and possibly further developed according to the development in the region.

As argued, there may be a number of different categories of potential users, including research institutions, consulting companies, energy authorities, transmission system operators and energy companies.

Some of these may have a legitimate interest in using and maintaining the model by themselves. However, in accordance with the idea of developing an open model for enhancement of analysis and communication, the data and the model could suitably be maintained in co-operation between parties in the region that have a need for mutual communication.

Thus, there are ongoing activities among the energy authorities in the region in relation to data gathering and development of statistics on energy and environment. Part of these activities could benefit from and contribute to the existence of an updated date base for the Balmorel model. Similarly, the energy authorities have an interest in maintaining a tool for analyses and evaluation of various initiatives with in an international perspective.

Also the transmission system operators in the region have a common interest in maintaining an overview of the energy system in their areas. They further have the need to communicate with, among others, the energy authorities and the energy companies in their respective countries.

A vision for the future of the Balmorel model is therefore that the maintenance and use are user driven, supported by the necessary co-ordination and development activities.

Appendices

The aim of the present report is to provide an introduction to the Balmorel model, including a description of the Baltic Sea Region, the challenges met there and the possible applications of the Balmorel model for enhancing the analysis, understanding and actions in relation to this.

The report has for this purpose been kept non-technical. Potential users of the model therefore need further material in order to decide on applications, and if so decided, to actually use the model.

Additional material is given in a number of appendices, see in particular the volume containing:

- The Balmorel Model: Theoretical Background, *Hans F. Ravn.*
- Elasticities – A Theoretical Introduction, *Jesper Munksgaard and Jacob Ramskov.*
- Balmorel Model Structure, *Hans F. Ravn.*
- Balmorel – Data and Calibration, *Poul Erik Grohnheit and Helge V. Larsen.*

The documents may be obtained from the homepage of the project: *www.balmorel.com.*

Further information is available at this homepage. The information will among other things include update information about the model, application examples and information about user support.

Publications from the Balmorel project

Mogens Petersen and Magnus Hindsberger, *The Baltic Sea Region electricity market and the co-existence of markets for CO_2 emission quotas and renewable electricitity certificates,* paper presented at the conference "Multiregional models, energy markets and environmental policies", Helsinki March 9-10, 2000.

Magnus Hindsberger and Hans Ravn, Bottom up modelling of an integrated power market, paper presented at the conference "Multiregional models, energy markets and environmental policies", Helsinki March 9-10,2000.

Poul Erik Grohnheit and Gaidis Klavs, *Elastic electricity and heat demand in the Balmorel model.* In Proceedings, "Second International Conference: Simulation, Gaming, Training and Business Process Reengineering in Operations", Riga, September 8-9, 2000, pp. 80-85.

Poul Erik Grohnheit and Gaidis Klavs, *Introduction of elastic electricity and heat demand into the Balmorel model.* Latvian Journal of Physical and Technical Sciences, 2000 No. 1, pp. 3-12.

Arvydas Galinis, Magnus Hindsberger and Hans Ravn, *Buttom Up Modelling of an Integrated Power Market with Hydro Reservoirs,* In Proceedings, "Second International Conference: Simulation, Gaming, Training and Business Process Reengineering in Operations", Riga, September 8-9, 2000, pp. 75-79.

Magnus Hindsberger and Hans Ravn, *Multiresolution Modeling of Hydro-Thermal Systems*, paper to be presented at PICA 2001, Sidney, May 2001.

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