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**Prospects for a Common,
Deregulated Nordic Electricity
Market**

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Abstract:

Electricity markets have typically been regulated all over the world. In Europe, UK and Norway have begun to deregulate their electricity markets. Several more countries will probably join them in the near future, for example Finland, Sweden and Spain. The objectives are twofold: to increase efficiency and to contribute both locally and globally to environmental improvement. Even larger regions like the European Union, plan to deregulate their internal electricity markets. For the EU this implies introduction of third party access to the transmission grid within and between the Union member countries. In this context, the Scandinavian push towards deregulation is an interesting experiment. We discuss the consequences of an international deregulation of electricity markets on the basis from simulations on an empirical energy market model for the Nordic countries. Deregulation may have severe effects on the location of new power plants within the Nordic area and implies a large impact on the income distribution both among countries and between electricity producers and consumers. The beneficial effects of deregulation are highly dependent upon the Nordic natural gas trade and prices. In our model, international co-ordination of environmental instruments like carbon dioxide taxes has a greater impact on emission level reductions than does deregulation. However, deregulation also contributes.

Keywords: Deregulation, Electricity markets, Natural gas markets, CO₂-taxes

JEL classification: E1, F1, Q4, H3, I3

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1. Introduction

Electricity markets all over the world are still largely regulated. The most common and important regulatory feature in these markets is the regional electricity companies exclusive right to deliver electricity to all customers in their region. Regulation of foreign trade is also common. In addition the price of electricity is often politically decided rather than market based.

In Europe, UK and Norway have begun to deregulate their electricity markets. Several more countries will probably join them in the near future, for example Finland, Sweden and Spain. In UK, a gradual deregulation is chosen. The process will be completed in 1998 when customers with peak demand less than 100 kW will be free to seek supplies from sources other than their regional electricity company. In Norway, all customers were given free access overnight 1. January 1991. However, much remains to be done; for example, long-term power contracts with power-intensive industries (which comprise 30 per cent of the Norwegian electricity demand) have been excluded from the deregulation. In addition, foreign trade is subject to considerable limitations on the possibilities for entering into long-term export/import contracts. However, an important first step in the direction of a more efficient Norwegian electricity market has been taken.¹

Even larger regions, like the European Union, plan to deregulate their internal electricity markets. For the EU, this implies the introduction of third party access to the transmission grid within and among the Union member countries. This requires deregulation within each member state.

In Sweden, the approved deregulation of the electricity market was postponed as of 1 January 1995 pending further studies. If Sweden follows Norway's example², the two largest national electricity markets in the Nordic area will be deregulated. This permits a more efficient utilisation of these countries' energy resources. If Norway and Sweden are gradually to have one electricity market, this will require an arrangement which allows third-party access to the transmission grids. Solutions will also have to be found for the practical problems associated with a joint Norwegian-Swedish exchange of electricity. Finland has announced that it will follow in the footsteps of Norway and deregulate its national electricity market in mid-1995. At the moment it appears that deregulation will not take place in Denmark for a long time.

One factor that is expected to induce a considerable exchange of electricity among the Nordic countries is the difference in cost structures in the national power generation systems. Norway primarily uses hydro power with high fixed costs and low variable costs. Therefore it is not very costly to regulate Norway's electricity production up or down. Sweden has sizeable quantities of hydro power and nuclear power, as well as power generation based on fossil fuels. Denmark has substantial coal-based power production (considerable use of combined heat and power cogeneration) and wind power, while Finland has nuclear power, hydro power and coal-based power generation. Nuclear power generation has high fixed costs, although they are lower than for hydro power. In relative terms, conventional thermal power generation has lower fixed costs and higher variable costs than hydro power generation. Moreover, the short-term regulation of thermal power generation is more costly than for hydro power. In what follows, we will disregard the short-term exchange of electricity and concentrate on long-term trade.³

Modernisation of power stations, higher demand for electricity and more stringent environmental requirements all favour the increased use of natural gas. Gas-based power generation and exports of electricity to the other Nordic countries can take place in the event of surplus capacity in electricity

¹ Jess Olsen (1995) gives a more comprehensive discussion of the different regimes and experiences.

² Sweden has indicated that a deregulation of its electricity market will take place at the beginning of 1996.

³ The consequences of this for our results are commented on below.

transmission lines from Norway. Better utilisation of waste heat from gas-based power generation in other countries⁴ and considerable demand for electricity may, however, justify investment in gas pipelines and could result in power generation through the use of natural gas in the other Nordic countries.

An important basis for profitable trade in electricity is that there are price differentials for electricity among the countries, see Table 1. There are also substantial price differentials for various end uses within each country. The prices are highest in Denmark and lowest in Norway. Some of the differences, especially in the residential sector, are due to different electricity taxes. However, correcting for differences in taxes still leaves price dissimilarities.

In recent years, there has been growing interest in the co-ordination of the Nordic countries measures to combat air pollution. This may be of considerable importance for future electricity trading in the Nordic area. The power generation systems in the various countries are very different with regard to pollution. A co-ordinated climate policy might entail considerable changes in the profitability of thermal power generation in the future. For example, there may be a substantial shift from the use of oil and coal to the use of natural gas in power generation. The export of electricity or natural gas from Norway to the other Nordic countries is thus a relevant issue. The question of when and where possible gas pipelines should be established will be determined by several of the factors mentioned above.

Table 1. Electricity production by technology and some purchaser prices, 1991

	Sweden	Norway	Finland	Denmark
<i>Production (TWh):</i>				
Hydro	62.3	110.5	13.0	
Nuclear	73.5		18.4	
Back-pressure ¹⁾	6.3	0.3	16.7	0.5
Condens incl.heating ¹⁾	0.5	0.2	7.1	32.9
Wind				0.8
<i>Prices (Nkr/kWh excl. VAT):²⁾</i>				
Households	0.54	0.39	0.55	0.90
Industry	0.33	0.18	0.28	0.39

1)Based on coal, oil or biofuels

2) USD=6.48 Nkr in 1991

Norway has considerable natural gas resources in the North Sea and Barents Sea. In 1993, about 25 mtoe of natural gas and 3.5 mtoe of NGL/condensate were produced in Norway. This is equivalent to about 0.8 per cent of the world's natural gas production. Norwegian natural gas production is expected to increase substantially from 1996 (doubling towards the turn of the century).

The export of natural gas to the Nordic countries is a recurring theme in public debates. The discussion revolves around the use of Norwegian gas, both in industrial processes and for gas-based electricity generation. In recent years, gas-based power generation in Norway for the export of electricity to neighbouring countries and possible gas exports for gas-based power generation in import countries have been the focus of discussions.

In order to analyse the Nordic electricity market more closely, Statistics Norway has developed a Nordic energy market model. In section 2, we describe briefly some interesting aspects of this model. In section 3, we present some important features of Nordic natural gas market. The Nordic energy

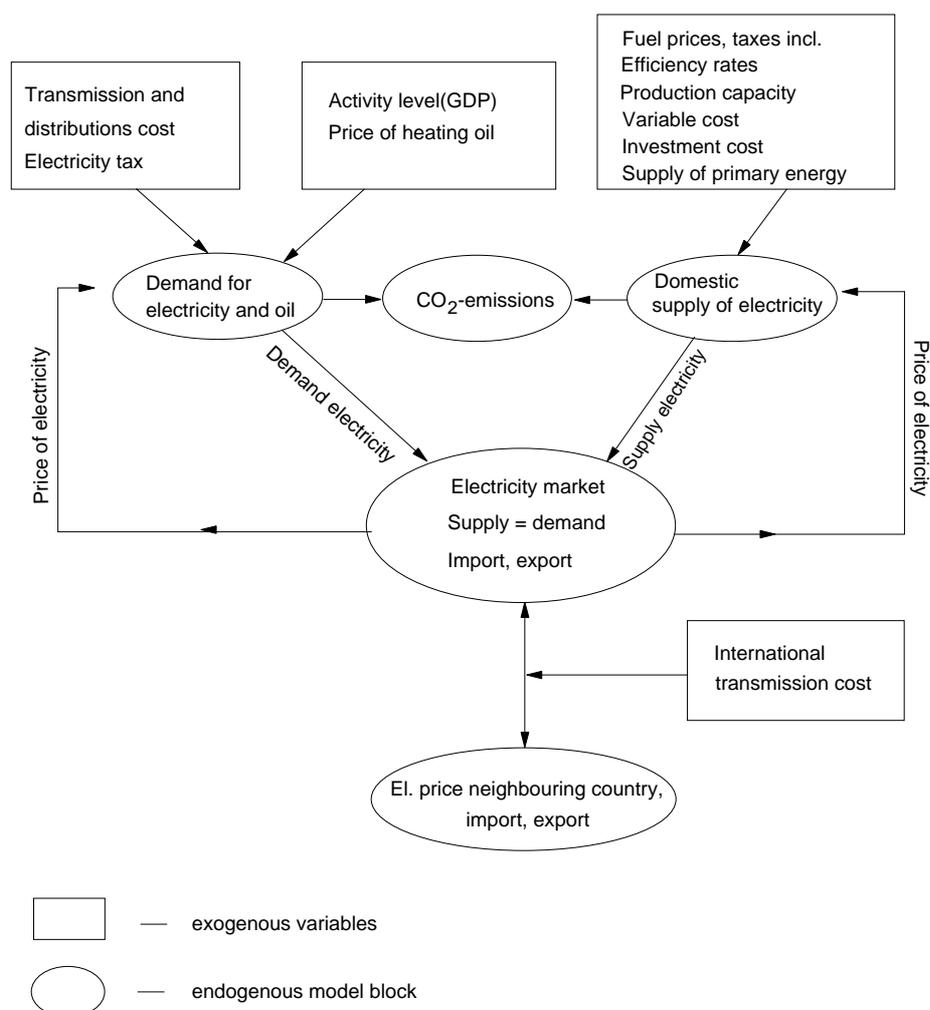
⁴ Both Sweden and Denmark have thermal power plants today and they have also invested in hot water transportation infrastructure for district heating, which is not the case in Norway.

market model can be used for analysis of the electricity market and help us to evaluate the profitability of gas and electricity trade among Nordic countries, section 4.

2. The model

The Nordic energy market model is a partial equilibrium model, see Figure 1. Partial implies that the model only describes the energy market, i.e. the final uses of oil and electricity and the use of the inputs water, oil, gas, coal and biofuels in electricity generation. The model does not encompass the use of energy for transport purposes. Equilibrium implies that the supply and demand for electricity balance. For other goods, world market prices or constant prices apply given certain supply limitations (particularly for natural gas and biofuels). Perfect competition ensures that all prices in the model correspond to the world market price or to the marginal production cost, unless autarky (no trade) is assumed. The model describes the demand for energy in each of the Nordic countries (Norway, Sweden, Denmark and Finland) by five sectors: power-intensive industries, pulp and paper, other manufacturing, services and households.

Figure 1. The Nordic energy market model



2.1 Demand for electricity and oil for final consumption

Electricity demand in the model is based on actual developments in the 5 specified sectors in each country over the last 15 years. The level of activity (changes in production or revenues), the price of heating oil and the price of electricity are the driving forces in the Cobb-Douglas derived demand functions for electricity and oil. Income, scale and price elasticities are estimated for each sector in each country, cf. Table 2.

Table 2. Elasticities in the demand functions for electricity

<i>Direct price elasticities:</i>	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>	<i>Sweden</i>
Power intensive industry	-0.3	-0.5	-0.2	-0.3
Pulp and paper	-0.3	-0.7	-1.5	-0.7
Other manufacturing	-0.2	-0.2	-0.4	-0.3
Services	-0.3	-0.4	-0.3	-0.5
Residential sector	-0.8	-0.8	-0.8	-0.8
<i>Cross price elasticities:</i>	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>	<i>Sweden</i>
Power intensive industry				
Pulp and paper	0.0	0.0	0.8	0.5
Other manufacturing	0.0	0.0	0.1	0.0
Services	0.1	0.2	0.1	0.2
Residential sector	0.4	0.4	0.3	0.4
<i>Scale elasticities</i>	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>	<i>Sweden</i>
Power intensive industry	0.9	0.9	1.0	0.9
Pulp and paper	0.7	0.9	0.9	0.9
Other manufacturing	0.8	0.8	0.9	0.9
Services	0.9	0.9	0.9	0.9
Residential sector	0.7	0.7	0.7	0.7

*) Denmark has no pulp and paper industry. For Denmark the food and beverages producing sector is replacing the pulp and paper sector, i.e. other manufacturing differs from the other countries also.

The estimates are to a large extent similar for the same sectors in different countries. An exception is the pulp and paper industry, which in Norway is estimated to be more flexible than in Finland and Sweden. For a further discussion of the estimates, see Mysen (1994).

2.2 The supply of electricity

Initially (base year 1991), each country has a given stock of electricity generating equipment. The investment costs for these power stations are sunk costs. The plant will operate if the market price of electricity is sufficiently high to cover operating costs. Existing power stations are, on average, assumed to have a remaining life of 15 years, with the exception of hydro power and nuclear plants which are projected to produce beyond the end of the simulation period (2010). Each technology is described by the fuel, an accompanying fuel price, fuel efficiency and variable cost. The thermal power plant technologies in the model are either based on oil, coal, natural gas, uranium or biofuels/peat. World market prices are used as a basis, adjusted for transport and receiving costs for uranium, coal and oil. Biofuels and peat are present in limited quantities in each country, and the prices of these fuels are estimated separately for each country. The price and supply of natural gas are discussed separately in section 3. For existing power stations, a step-like upward sloping supply curve is constructed. In the model, we have assumed equal fuel efficiency and the same variable costs for all power stations within the same technology.

In addition to already existing power stations, each country may choose from a selection of new power generation technologies. A large number of alternative technologies with varying operating and investment costs are specified in the model. Limitations in the supply of fuel exist for some of the technologies. For example, the domestic supply of biofuels and natural gas might be limited by a country's resource base and transport costs making import non-profitable. In the case of hydro power, there are limitations with regard to the availability of suitable waterfalls and the quantity of water that can be led to power stations. Table 3 shows investment and variable costs for the various technologies.

Table 3. Fixed and non fuel dependent variable costs in new power plants, Nkr/kWh

<i>Technology</i>	<i>Fuel</i>	<i>Norway</i>	<i>Sweden</i>	<i>Denmark</i>	<i>Finland</i>
Condens	Coal	-	0.252	-	0.252
Coal dust	Coal	-	0.170	0.17	-
Coal gas	Coal	-	-	0.21	-
Fluid bed	Coal	-	0.210	0.21	-
Condens	Oil	-	0.150	-	0.150
Gas turbin	Oil	-	0.108	-	-
Combined cycle	Gas	0.123	0.123	0.123	0.123
BIG/STIG	Bio	-	0.186	-	0.186
Condens	Peat	-	0.178	-	0.178
Condens	Bio	-	0.216	-	0.216

Source: Norwegian Water and Energy Resources Administration (1993) and own estimates

In the model, generation capacity will be expanded if the market price exceeds variable costs plus fixed costs (measured as annual cost per kWh). The model describes a long-term equilibrium solution which implies that the time delay connected to the increase of capacity in the generation system is of less importance. The importance of uncertainty and/or strategic adaptation to investments in new capacity is disregarded.

2.3 Transport of electric power

The domestic price of transport of electricity for each country is assumed to cover the costs of the grid owner. A total unit cost is applied for domestic electricity transport. Various consumers, however, use electricity at differing voltage levels, and transport prices therefore vary between users. Table 4 shows today's capacities for electricity transmission between pairs of Nordic countries.

Table 4. Existing transmission capacity between the Nordic countries. MW, 1994

	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>
Norway	990	50	
Sweden	1870	1335	2160

Source: NORDEL (1991)

An efficient use of existing transmission capacity is characterised by price equal to short-term marginal costs (losses and variable operating costs). When the capacity limit of the grid is reached, the price will rise. When the price exceeds the cost of developing new grid capacity, new investment will take place. Unit costs for transmission of electricity between the Nordic countries, including investment costs, is reported in Table 5.

Table 5. Total unit cost for transmission of electricity between the Nordic countries, Nkr/kWh

Source: NWE and own estimates

	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>
Finland	0.056		
Norway	0.035	0.046	
Sweden	0.035	0.020	0.025

2.4 Market clearance

The electricity market is characterised by producers maximising their profits and households maximising their utility. In addition, electricity prices equal the marginal production cost (long run or short run depending upon capacity utilization) plus any transport costs and taxes. This implies that the model excludes any type of market power or strategic behavior.

There is a balance between supply (including imports) and use of electricity in each country. Based on the model's solution, consumer and producer surpluses can be calculated for each scenario. The model can also incorporate barriers to trade in electricity. When trade is permitted, the price of electricity, adjusted for the transmission costs, will be the same in the various countries.

3. Natural gas in the Nordic countries

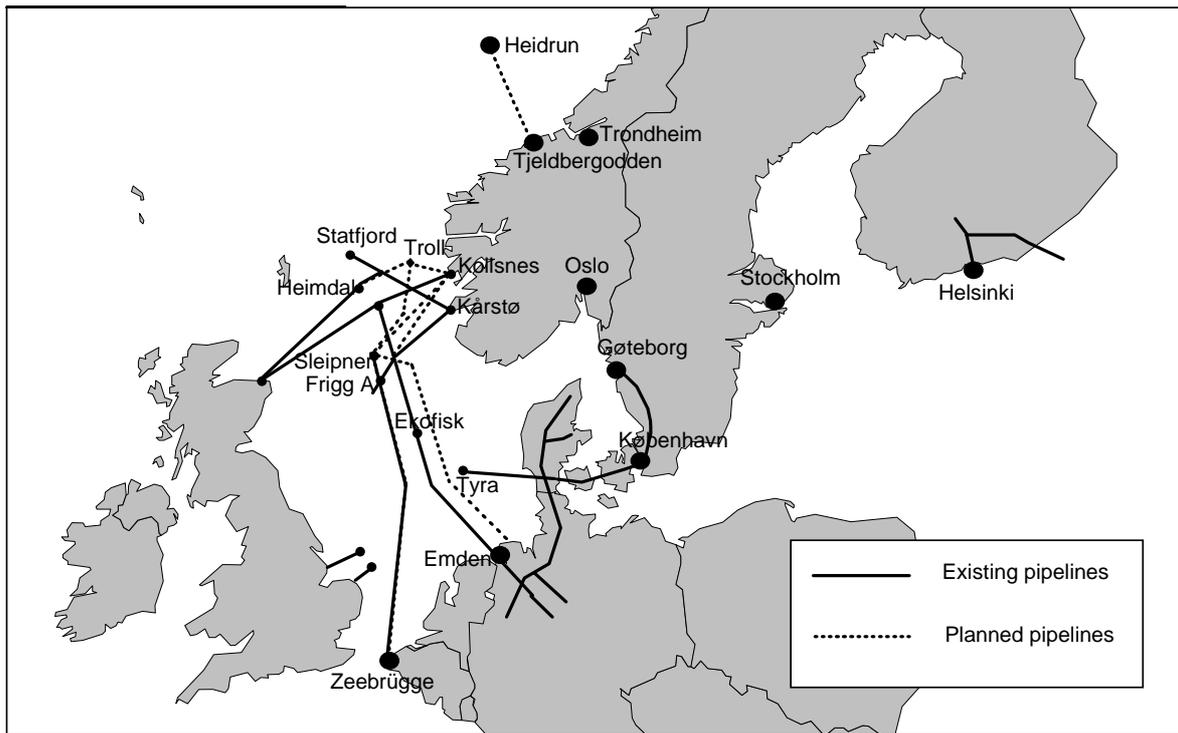
Norway and Denmark extract natural gas from the North Sea. Finland imports natural gas from Russia, while Sweden imports natural gas at the world market. In Denmark, Finland and Sweden, existing transport capacity and terminal capacity limit the quantity of gas that can be used in electricity generation.

Most gas pipelines are located in the North Sea, from which there are pipelines to the UK, Germany and Belgium. Figure 2 shows that there are also pipelines to mainland Denmark which continue on to the Malmø and Gothenburg area in Sweden. Parts of these pipelines are tied up in deliveries for industrial purposes. In the calculations, it is assumed that in Denmark and Sweden the current installations can provide a maximum use of gas in electricity generation of 0.4-0.5 mtoe per year. This corresponds to about 2.5 TWh electric power when gas is utilised in a thermal power plant. In Finland, the transport capacity of the pipeline from Russia sets a limit on imports. This is assumed to be 2.5 mtoe a year (14 TWh). New pipelines must be laid for any quantities exceeding this. In this analysis we have assumed two possible gas pipelines. Both are based on the delivery of natural gas from the North Sea.

One alternative is based on the production of natural gas on the Haltenbanks. We have assumed a maximum annual supply of natural gas from the Haltenbanks of 3.8 billion Sm³ (corresponds to about 20 TWh electricity) and an average cost of 0.75 Nkr/Sm³ for gas delivered from these fields. The Troll field further south in the North Sea is another alternative with a maximum supply of 8 billion Sm³ (45 TWh) per year at a cost of 0.62 Nkr/Sm³.⁵ With a higher extraction of gas from the Troll field or surrounding fields, the maximum supply may reach more than 8 billion Sm³.

⁵ This refers to the supply for gas-based electricity generation in the Nordic countries. In addition, large quantities of Troll gas are sold to the rest of Europe.

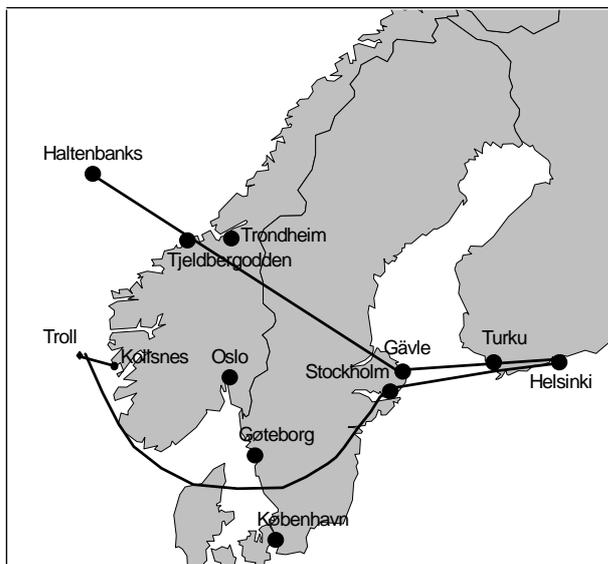
Figure 2. Existing and planned gas pipelines



We analyse two gas pipelines for the transport of gas from the Haltenbanks and Troll to the other Nordic countries, cf. Figure 3. The pipeline from the Haltenbanks goes to Tjeldbergodden where Norwegian methanol production has been established. The pipeline continues further across the mountains and into Sweden. It is brought to Gävle, north of Stockholm, and on to Turku, Finland. The pipeline from the Troll field stretches to Denmark, continues to Sweden (south of Stockholm) and from there across the Baltic Sea to Finland.

Based on cost estimates connected to the transport of gas in underwater or onshore pipelines - including capital cost, transport prices for natural gas are estimated for the various countries. An estimate of USD 2.50 per 100 km per toe is used for all land-based natural gas

Figure 3. Two pipeline alternatives



transport. For the underwater transport of natural gas, an estimate of USD 3.75-7.50 per 100 km per toe is used, depending on the length of the underwater cable. The low estimate is used for the pipeline from Troll to Denmark, while the high estimate is used for the other pipelines.

Our estimates is assuming a transportation volume large enough to make the pipeline investments profitable. The natural gas prices from national sources are estimated based on market prices in the various countries. Prices of natural gas supplied to the recipient country are shown in Table 6.

Table 6. Prices of natural gas delivered mainland, Nkr/Sm³

Gas from ↓, to →	<i>Norway</i>	<i>Sweden</i>	<i>Denmark</i>	<i>Finland</i>
Troll	0.65	0.84	0.74	1.00
Haltenbanks	0.85	0.95		1.06
National sources		1.13	0.80	0.73

4. Calculations

We run four scenarios on the model to illustrate the effect of different regulatory regimes on the energy and electricity market and on welfare. The model is simulated from 1991 (the base year of the model) to the year 2010. In the reference scenario, there is no trade in electricity or natural gas among the countries, and the level of CO₂ taxes is the same as in the base year. In the next scenario we add free trade in electricity among the Nordic countries. In the third scenario, we also allow for trade in natural gas among the Nordic countries. Finally, we study a regime involving free trade in electricity and gas combined with a high Nordic CO₂ tax.

4.1 Reference scenario

An important explanatory factor for the change in energy consumption from the present time to the year 2010 is the change in the level of economic activity. Economic growth is specified for each sector and is largely based on national projections. Economic growth is exogenous in the sense that it is the same for all scenarios. Average economic growth over the period for each country and each sector is shown in Table 7.

Table 7. Average economic growth by sector and country. Percentage

	<i>Denmark</i>	<i>Finland</i>	<i>Norway</i>	<i>Sweden</i>
Metals	-0.5	-0.5	-0.5	-0.5
Pulp and paper	1.0	-0.5	-0.5	-0.5
Other manufacturing	1.0	1.0	1.6	1.5
Services	2.5	2.0	3.0	1.9
Residential	2.0	1.5	2.5	1.7

Another important exogenous variable is the world market price of crude oil. It is assumed to be independent of the Nordic energy market and is held constant at USD 18 per barrel (1991-prices) throughout the simulation period.

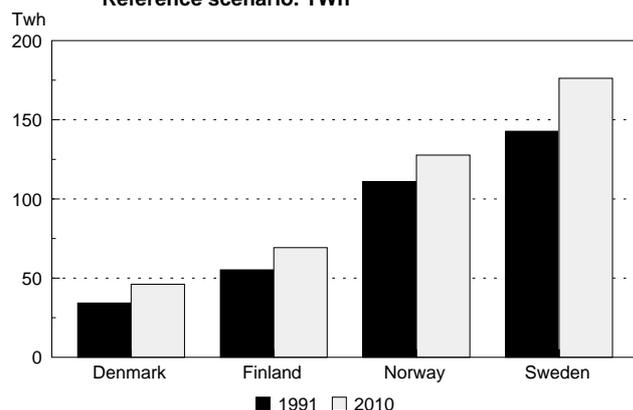
In the reference scenario we assume free competition in the domestic electricity markets, even though this does not correspond to the actual situation in all countries. This has been done in order to isolate the effects of more international and market-based trade in electricity and natural gas in the Nordic countries from the national deregulation effects⁶.

Electricity generation in the base year (1991) and the simulated production in 2010 in the reference scenario are shown in Figure 4. With an annual growth of 1.6 per cent, Denmark shows the highest

⁶ Bye and Johnsen (1991) analyse the domestic effects of deregulation of the Norwegian electricity market.

percentage rise in production. Estimated production will be 46.1 TWh in 2010. In Finland and Sweden, the annual growth is 1.2 and 1.1 per cent respectively. Finland's electricity generation in 2010 amounts to 69.2 TWh, while in Sweden it is 176 TWh. In relative terms, the lowest production growth is found in Norway, with an annual rate of 0.75 per cent. This results in a production of 127.6 TWh in 2010. In total, electricity generation in the Nordic countries increases from about 340 TWh in 1991 to a little less than 420 TWh in the year 2010, which corresponds to an annual growth of 1.1 per cent.

Figure 4. Production of electricity in 1991 and 2010. Reference scenario. TWh



Another important explanatory factor for the growth in electricity consumption and production is electricity price changes. Since neither price movements nor economic growth vary to any great extent between the countries, the main reason for the differences in the development of electricity consumption must be found elsewhere.

The new Energy Act in Norway came into force on 1 January 1991. This means that the Norwegian electricity market in 1991 was less regulated than the other Nordic electricity markets. Since the model presumes deregulated markets in all Nordic

countries, a large part of the estimated increase in electricity generation in Denmark, Finland and Sweden is ascribable to domestic deregulation, while this is not the case in Norway to the same extent.

It is important to note, however, that in our calculations the effects of internal deregulation in Norway are underestimated. Even though deregulation entails that all price discrimination ceases, Norwegian power-intensive industries maintain their pre-deregulation production levels and, in part, their electricity consumption as well. This is because the model is a partial energy model in the sense that production levels are exogenously determined. In Bye and Johnsen (1991) it is estimated that 5 - 8 TWh per year might be freed if power-intensive industries were faced with the same transport-adjusted prices as other electricity purchasers. The consequence of this for the scenarios with Nordic electricity trade, presented below, is that the potential for Norwegian export of electricity is underestimated, and the need for expanding Norway's electricity generation is overestimated.

The growth in Denmark's electricity generation of 12 TWh over the simulation period is primarily from coal-based thermal power, partly combined with district heating. The growth in Finland's electricity production largely consists of gas-generated power (14 TWh) based on imports of Russian natural gas. In Norway new waterfalls are developed, increasing hydro power production by 14 TWh. In addition, a gas-generated power station with a production of about 5 TWh is built. The growth in Sweden's electricity generation of 33 TWh is based on oil-fired and coal-fired thermal power. Sweden's thermal power is partly combined with district heating. An important assumption is that Sweden's nuclear power is maintained at the existing level. With a scaling back of nuclear power the need for new power generation in Sweden (or the need to import power) will increase dramatically.

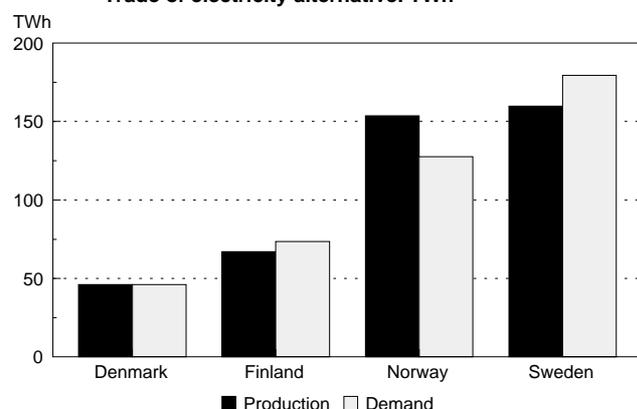
4.2 Nordic free trade of electricity

In this scenario, free trade in electricity among the countries is permitted, while trade in natural gas is not. Producers and consumers in each country can thereby trade electricity with participants in other Nordic countries. Figure 5 shows the production and consumption of electricity in the year 2010 in the four countries. Finland and Sweden are net importers of electricity while Norway is a net exporter.

Norway's electricity export is as high as 26 TWh, of which 19.5 TWh goes to Sweden, while 6.5 TWh goes to Finland. In this scenario Denmark is self-sufficient in electricity in the year 2010.

If we compare this with the scenario with no trade in electricity (reference scenario), we see that consumption in the year 2010 is higher in Sweden and Finland (5.7 TWh and 4.6 TWh respectively), unchanged in Denmark and lower in Norway (0.7 TWh). Similarly, the c.i.f. electricity price is lower in Sweden and Finland, unchanged in Denmark and higher in Norway. In total, production and consumption in all four Nordic countries are about 8 TWh higher than in the scenario with no trade in electricity. In the three importing countries, the increase in imports is higher than the increase in consumption from the reference scenario. This implies lower national production than in the reference scenario. Electricity generation in Norway is nearly 26 TWh higher than in the reference scenario. The entire production increase in Norway is exported.

Figure 5. Production and demand of electricity in 2010.
Trade of electricity alternative. TWh



Higher consumption and lower prices in the year 2010 in Sweden and Finland are due to the supply of relatively cheap Norwegian electricity. In Sweden, the use of pulverised coal-based power generation is eliminated when imports of Norwegian electricity are permitted. The same occurs for peat-based condensed power in Finland.

In order to be able to export the quantities referred to above, Norway must build up a large-scale gas-based generation capacity, which in the year 2010 will be as much as 32 TWh. Norway's gas-based electricity

generation uses gas from the Troll field. Hydro power production will be the same as in the reference scenario. As a result of the opportunity to import Norwegian electricity, Sweden can refrain from expanding its coal-fired power production, which in the reference scenario amounted to 16 TWh in 2010.

Even though electricity generation and consumption are higher in this scenario than in the reference scenario, the stationary CO₂ emissions will be lower in the year 2010. The lower emissions can primarily be attributed to the use of gas-based power generation instead of coal-based thermal power production. The effects vary sharply, however, in the four countries. While Norway, due to considerable gas-based power production, will have emissions that are twice as high as the emissions in the reference scenario, Sweden's emissions will be reduced by more than 25 per cent.⁷

The results show that the introduction of trade in electricity increases the sum of consumer and producer surpluses in the Nordic countries by Nkr 1.4 billion (approximately .07 per cent of total GDP, i.e. almost negligible). The effects for individual sectors and countries, however, are far greater than this number indicates. For example, electricity consumers in Sweden and Finland each benefit by Nkr 3 billion due to the introduction of trade in electricity. Power producers in these same countries are adversely affected by an equivalent amount. These effects are due to the fact that Sweden and Finland at the outset (i.e. following national deregulation, but before trade) have the highest domestic electricity prices.

⁷ This corresponds to the scenario of Svenska Kraftnät. Compared with our alternative, gas-based power production in Norway would have to increase more if it is also to replace Sweden's nuclear power.

4.3 Free trade in electricity and natural gas among countries

When, in addition to free trade in electricity, free trade in natural gas is also permitted (essentially Norwegian natural gas exports), the consequences for the Nordic energy market are important. In this scenario both Denmark and Sweden import natural gas and produce their own gas-generated electricity. Denmark's gas-based electricity generation in the year 2010 is 21 TWh, while in Sweden it will be as much as 29 TWh. Norway's gas-based electricity generation in this scenario is a little more than 3 TWh (i.e. too small to warrant a gas-generated power station) compared with nearly 32 TWh in the scenario entailing no possibilities for trade in natural gas. In this scenario the capacity limit for natural gas from the Troll field is reached, but the extraction of gas from the Haltenbanks is still too expensive for electricity production.

Compared with the scenario involving no trade in natural gas, coal-based power is replaced by gas-generated power in Denmark, while in Sweden electricity imports from Norway and some oil-based thermal power are replaced by gas-generated power. In the model simulation, however, Sweden's heating coefficient for gas-based power is set higher than that for Norway. This takes into account that Sweden can combine its gas-based power with local district heating, a possibility which Norway does not have due to very high distribution costs in district heating. Thus, Norway exports natural gas to Sweden. In 2010 Norway's exports of natural gas to Denmark and Sweden will be between 6 and 7 billion Sm³. This is a sufficient quantity to make a gas pipeline profitable (pipeline alternative via Jutland to west Sweden).

As Figure 6 shows, the only trade in electricity in 2010 is Sweden's exports to Finland of nearly 6 TWh, which replaces Norway's exports to Finland in the scenario with no trade in natural gas. Compared with the last scenario, the consumption of electricity is higher in Denmark and Sweden (1 TWh and 3.7 TWh) and lower in Finland and Norway (0.8 TWh and 2.3 TWh). Similarly, electricity prices in Denmark and Sweden are slightly lower (0.025 Nkr/kWh and 0.015 Nkr/kWh), while in Finland and Norway electricity prices are slightly higher (0.01 Nkr/kWh and 0.015 Nkr/kWh).

Lower prices in Denmark and Sweden are ascribable to the availability of Norwegian natural gas and thus cheaper electricity. Increased demand for Norway's natural gas in the gas trade scenario implies that the available limit from the Troll field is reached. Norway's electricity price thus rises, but not to the extent that new and more expensive power generation in Norway (hydro power or gas-based power using gas from the Haltenbanks) becomes profitable. The high Norwegian price also results in a higher electricity price in Finland.

In the scenario involving trade in natural gas, total CO₂ emissions in the Nordic countries in 2010 are nearly 8 million tons (about 7 per cent) lower than in the scenario without this trade, even though total electricity generation is slightly higher than in the previous scenario. The main reason for lower total emissions is that Denmark's coal-based power generation is replaced by gas-based power generation using imported natural gas from Norway.

The right to trade in natural gas increases the total consumer and producer surplus by a further Nkr 0.7 billion. The greatest individual effects from introducing gas trade are found in Norway where electricity purchasers are adversely affected and producers benefit as a result of the higher Norwegian electricity prices. In Sweden, on the other hand, electricity consumers benefit, while power producers

Figure 6. Production and demand of electricity in 2010.
Trade of electricity and gas alternative. TWh

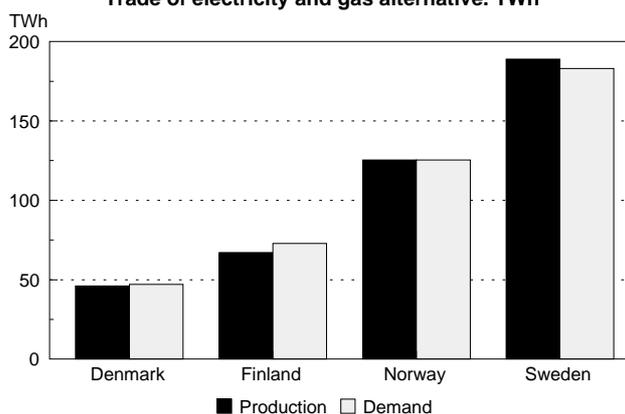
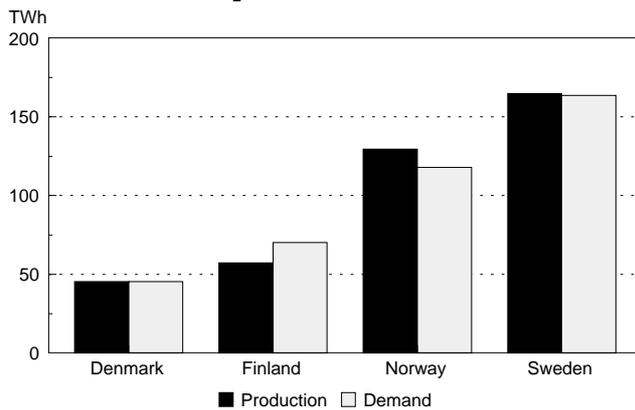


Figure 8. Production and demand of electricity in 2010. Trade and CO₂-tax alternative. TWh

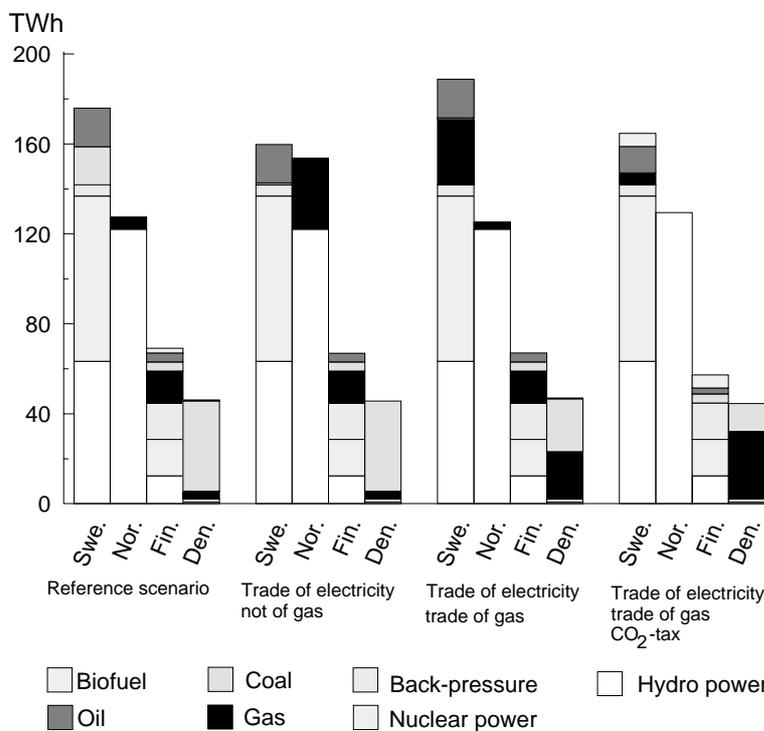


are adversely affected as a result of gas trade. An increased supply of gas results in lower electricity prices in Sweden.

4.4 Free trade in electricity and natural gas under a CO₂ tax regime

In the three scenarios referred to above, CO₂ taxes are held constant at the 1991 level. There are thus considerable variations in the tax level among sectors and countries, cf. Bye et al. (1994). In this scenario, CO₂ taxes are equalized among sectors and countries. The

Figure 7. Electricity production in 2010. TWh



tax rate is projected on a linear basis up to a level of Nkr 350 per ton CO₂ in all Nordic countries in 2000, after when it is held constant up to 2010. This tax level also corresponds to the current CO₂ tax on petrol (0,80 Nkr per litre) in Norway.

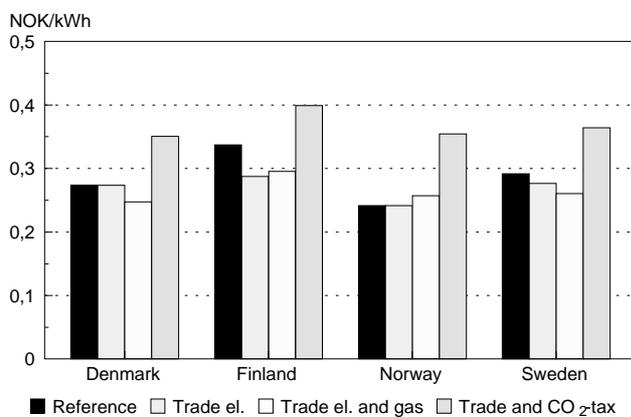
Figure 7 shows the composition of the national power systems in the four scenarios. The introduction of trade in electricity and natural gas as well as higher CO₂ taxes all reduce the use of coal in Nordic electricity generation. Oil, which to a large extent is used in local district heating/back pressure generation in Sweden and Finland, is reduced as a result of higher CO₂ taxes. Biofuels, whose price is not influenced by CO₂ taxes, take over part of oil's role as a fuel in local district

heating/back pressure production. Trade in electricity and natural gas contributes to a greater use of natural gas in electricity generation. Higher CO₂ taxes, on the other hand, reduce the use of natural gas substantially, but it is still used more than in the scenario involving no trade in electricity/natural gas. High CO₂ taxes result in the total elimination of Norway's gas-based power generation. It is replaced by an increase of 7.5 TWh in Norway's hydro power generation. This means that all available hydro power projects in Norway are developed. The development of relatively expensive Norwegian hydro power takes place because the export price of electricity rises considerably. The Norwegian c.i.f. price of electricity in the year 2010 is 0.355 Nkr/kWh, i.e. 0.10 Nkr higher than in the scenario involving a lower level of CO₂ taxes.

Figures 8 and 9 show that trade in electricity is slightly higher with a high tax level than without. Finland is still an importing country, but in this scenario it is Norway which accounts for the electricity exports that now reach about 12 TWh. Finland's electricity imports are more than twice the level of the last scenario. Finland has no gas-generated electricity production based on Russian natural gas, but it has a biofuel-based thermal power production of nearly 6 TWh.

In the scenario with high CO₂ taxes, the c.i.f. price of electricity in the four Nordic countries is about 0.10 Nkr higher than in the scenario with low taxes (Figure 10), which means that total Nordic consumption of electricity is nearly 35 TWh lower. This effect is greatest in Sweden where consumption is nearly 20 TWh lower, primarily because gas-based power using Norwegian natural gas becomes too expensive as a result of the high CO₂ taxes. Electricity consumption in Norway is 7.5 TWh lower as a result of higher demand for Norwegian hydro-

Figure 10. Electricity prices in 2010. NOK/kWh



based electricity for export.

Increased exports occur when higher prices displace domestic demand and trigger the development of additional and more expensive hydroelectricity.

Figure 12. Stationary emissions of CO₂ in 2010. Millions of tons

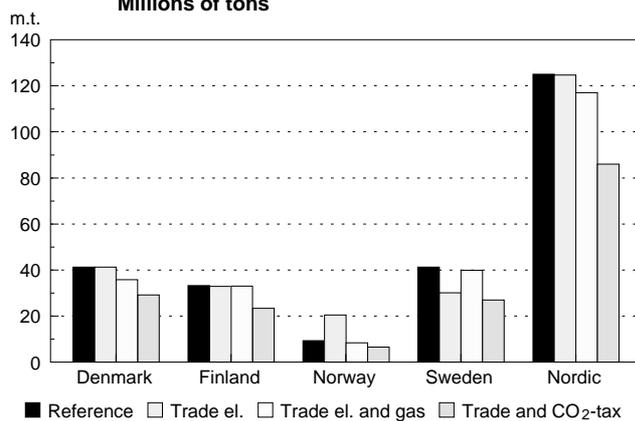


Figure 9. Net export of electricity in 2010. TWh

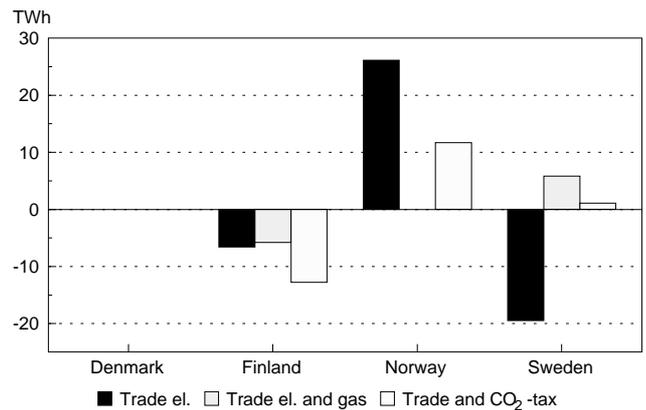
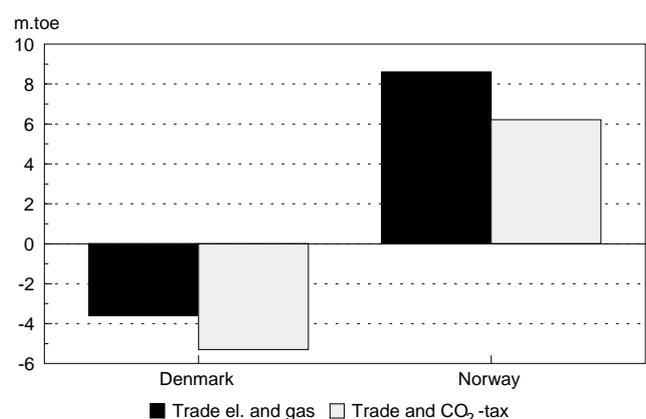


Figure 11. Export of natural gas in 2010. Mtoe



The considerably lower production of coal-, oil- and gas-based power in the year 2010 compared with the last scenario means that stationary CO₂ emissions are sharply reduced. As shown in Figure 12, emissions decline from 117 million tons in the scenario with low taxes to 86 million tons in the scenario with high taxes (both scenarios with trade in electricity and gas). This represents a decrease of more than 25 per cent. The reduced final use of oil contributes about 3.5 million tons to the total reduction of 31 million tons. We see from the figure that the relative reduction in emissions is considerable in all countries and greatest in Finland.

The sharp increase in CO₂ taxes in the last scenario pushes up electricity prices, contributing to a substantial reduction in the consumer surplus of the purchasing sectors. All power producers record higher product prices and some higher fuel prices. Producers in Norway and Sweden largely rely on hydro power and nuclear power and benefit from the tax. Power producers in Denmark and Finland depend more on taxed inputs like gas, coal and oil and lose as a result of the tax. For the Nordic countries combined, however, consumers and producers suffer a loss of Nkr 43 billion. The countries'

revenues from the CO₂ tax amount to Nkr 23.7 billion. This means that the utility gain from reduced CO₂ emissions and the accompanying reductions in SO₂, NO_x- emissions, etc. should exceed Nkr 19.3 billion if the introduction of this CO₂ tax is to be profitable.

5. Conclusions

Our simulations show that opening up the electricity market among the Nordic countries increases the efficiency in production and electricity use. The distributional effects may be substantial both between producers and consumers in each country and also among the Nordic countries. Deregulation also positively affects the ability of the Nordic countries to meet their goal of reducing total climate gas emissions. However, deregulation only contributes partly towards reaching this goal. Standardising the tax regimes is far more important.

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