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The Kyoto Agreement Consequences for Nordic Electricity Markets

Jens Hauch

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The Kyoto Agreement
Consequences for Nordic Electricity Markets

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Working Paper 1999:5

Abstract:
The Kyoto agreement changes the basic conditions for use of fossil fuels and by that the Nordic electricity markets. This paper describes, by using an equilibrium model the future perspectives for the Nordic electricity markets of meeting the Kyoto targets. It turns out that strict regulation is necessary. The shadow value on the emission constraint is rapidly increasing until 2010, the target year for the Kyoto agreement. Also the electricity price will be significantly higher under the Kyoto agreement. Emission permits will, if allowed, be widely traded among the countries. If permit trading is not possible, trading of electricity serves in some cases as a substitute. Other models have been used for similar analyses. A rough comparison reveals that quantitative differences can be explained by differences in which elements that are included in the models.

Keywords: Electricity markets, Kyoto, environment, energy, Nordic.

JEL: D4, Q2, Q4.

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1. Introduction [1]

In 1997, the developed countries agreed in Kyoto to reduce emissions of greenhouse gasses of which the most important is CO_2, see United Nations (1998).[2] The Annex one countries have agreed upon a system of unequal percentage reductions. The target year is 2010, while the bench mark levels for the emission level are the average emissions in the period 1990 to 1995. After having promised a total reduction, the EU countries agreed upon how this reduction should be distributed among the individual countries. Also at this level there was agreed upon different percentage reductions in the countries. Denmark has agreed to reduce emissions by 21 per cent, Finland has agreed to keep emissions unchanged, while Sweden and Norway have agreed not to increase emissions by more than 4 and 1 per cent, respectively.[3] Norway, Sweden and Finland have therefore committed themselves to a target that seems relatively little ambitious compared with that of Denmark. Norway and Sweden have, however, already low emissions from electricity and district heating production. They may therefore have committed themselves to tight targets in relation to their abatement costs.

Sweden has furthermore officially decided to phase out nuclear power. This creates special problems in meeting the emission target as the bygone production must be substituted by other maybe more CO_2-intensive production, see, Nordhaus (1995), Löfstedt (1997) and Barrett (1998). All Nordic electricity markets are now liberalised, which can create both risks and possibilities with respect to environmental policy, see, Eikeland (1998) and Hauch (1999b).

This paper concentrates on the consequences for the Nordic electricity markets of reaching the emission targets given by the Kyoto agreement are analysed. Previous analyses covering similar aspects of the Kyoto agreement includes

1) The views posed in this paper are not necessarily shared by the Chairmanship of the Danish Economic Council. The author would like to thank Jan V. Hansen, Peter Brixen, Jørgen Birk Mortensen and several others for many helpful comments and clarifying discussions. The author is however solely responsible for the paper and problems and mistakes it may contain. Financial support form Nordic Energy Research Programme and The Danish Environmeltal Research Programme is greatly acknowledged.

2) The agreement has not yet been ratified, and the main result of the follow up meeting in Buenos Aires was to prolong this decision.

3) The exact method to calculate emission levels is still debated but with the method used here, these percentage targets correspond to emission levels of 34500, 57700, 46600 and 53800 thousand tons for Norway, Sweden, Denmark and Finland respectively.

Lindholdt (1998), Aune et al. (1998) and Jacoby et al. (1998) among others. Electricity production, especially in Denmark, causes large CO_2-emissions and the basic conditions for electricity production may change when strict emission regulation is imposed. This can imply changes in prices caused by changes in technology use and changes in the electricity trade pattern. In Kyoto it was also agreed that emission permits could be traded internationally. This may reduce total costs of emission reductions, and calls for an inclusion of several countries in the analyses. The importance of international emission trading will be analysed below.

An international Nordic equilibrium model is suitable for analysing the agreement. One such model is Elephant, see Hauch (1999a). Central elements in Elephant are described in Appendix 1. In Section 2, the results of the analyses are presented

Contrary to much of the previous work on this subject the analyses presented here deals directly with the consequences of the Kyoto agreement. Also the importance of including several countries together with district heating directly into the analyses have only been investigated scarcely in the past, but they will be included here. All sources of emissions will furthermore be included here, which is important to get an overview of the minimal costs of emission reductions.

In section 3, the importance of including these elements is analysed by comparing the results with results found using other similar models.

The paper is concluded in Section 4.

2. The Analyses

The scenarios rest on several assumptions: The Kyoto agreement is assumed to be fulfilled in 2010. After that there is no agreement on the emission level, but it is here assumed that the emission level from the agreement is kept unchanged from 2010 to 2020. The emissions targets are assumed to develop linearly from the base year level to the 2010 target level. It is furthermore assumed that Swedish nuclear power is phased out linearly terminating in 2020. The model includes also several assumptions about future development in fuel prices and technological possibilities which are obviously uncertain. These reservations should be taken into consideration when interpreting the results of the analyses.

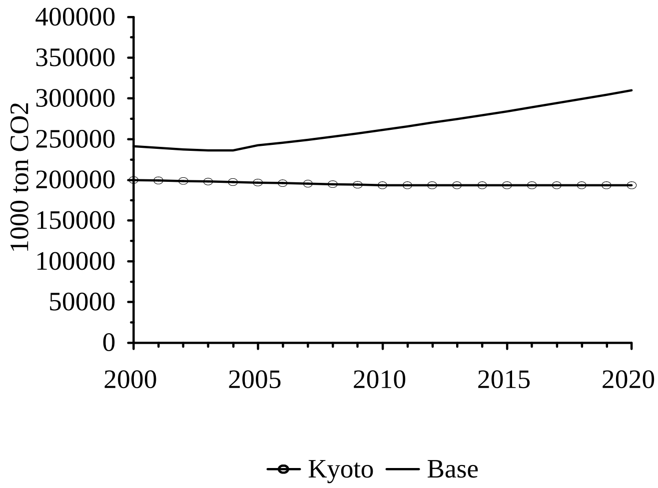
International trading of emission permits can help minimizing the costs of emission reductions, see Baumol and Oates (1988). An experiment including Denmark, Norway, Sweden and Finland shows that achieving the major part of the potential gains is possible also when trade is only bilateral, see Bohm (1997). Quantification of the cost reduction will be given below. In Section 2.1, the Kyoto scenario where trading emission permits among the Nordic countries is assumed possible is presented, while a scenario in which emission trading is prohibited is presented in Section 2.2. Comparing these scenarios reveals the importance of international emission trading.

2.1 Emission Trading

This free emission trading scenario is first compared with a “base” scenario that differs from the Kyoto scenario with respect to the imposed environmental regulation. In the base scenario no emission constraints are assumed, but the base year environmental tax structure is assumed unchanged through the simulation.

The total Nordic emission target does not imply much more than a stabilisation in 2010, see Figure 1. This should be no surprise as Denmark is the only country that has accepted a reduction compared with the 1990/1995 level. By comparing with the base scenario, business as usual with respect to the tax system is clearly not sufficient to achieve the Kyoto target. Emissions in the base scenario are 35 per cent higher than the Kyoto target in 2010 and 60 per cent higher in 2020.

Figure 1 Nordic CO_2-emission levels in the base and Kyoto scenarios



Source: Scenarios with Elephant.

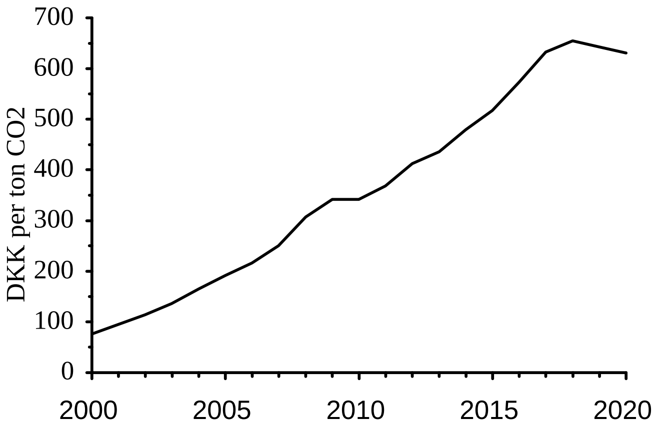
Traditionally Denmark is producing CHP based on coal. Recently, however, subsidized investments have been made in natural gas based small scale CHP. Norwegian electricty production is solely based on hydro power while the Swedish is based on hydro power and nuclear power. Finnish production is based both on coal, hydro and nuclear power. This pattern is largely continued in the base scenario. Coal use is, however, substituted by natural gas s new investments in coal based technologies are politically unrealistic. Also the Swedish nuclear power is phased out, cf. above.

In electricity and district heating production, the emission reduction in the Kyoto scenario is caused by changes in the technology choice: Denmark will produce CHP electricity and district heating in most of the period based on natural gas. New combined cycle plants and gas turbines will be used. At the end of the period, investments are made in Danish wind power capacity. Norway invests in new hydro power capacity and will increase the annual hydro power capacity by more than 20 TWh through the simulation period. Sweden invests in new wind power by the end of the period. Finland invests in new combined cycle natural gas-based plants and by the end of the period also a small investment in CHP based on bio fuels will be made.

As international trading of emission permits without administrative costs is allowed, there will be one international price of the permits. Marginal abatement costs in the countries will therefore be equal, and an emission reduction at lowest possible costs is the result. The equilibrium price of the emission permits is shown in Figure 2.

The emission permit price is increasing through most of the period and in 2010, the target year for the Kyoto agreement, the emission price is 340 DKK per ton CO_2. Keeping the emission level after 2010 is increasingly expensive as increased economic activity gives an upward pressure on demand for energy. A surprising development is, however, seen at the end of the simulation period where the marginal abatement costs fall slightly. The primary reason for this is the development in fuel prices. Prices of coal, oil and natural gas are assumed to be increasing, while the price of renewable fuels is not assumed to increase. Eventually the price of using renewable fuels will be so low compared with the price of the exhaustible fuels that the emission permit price can fall.

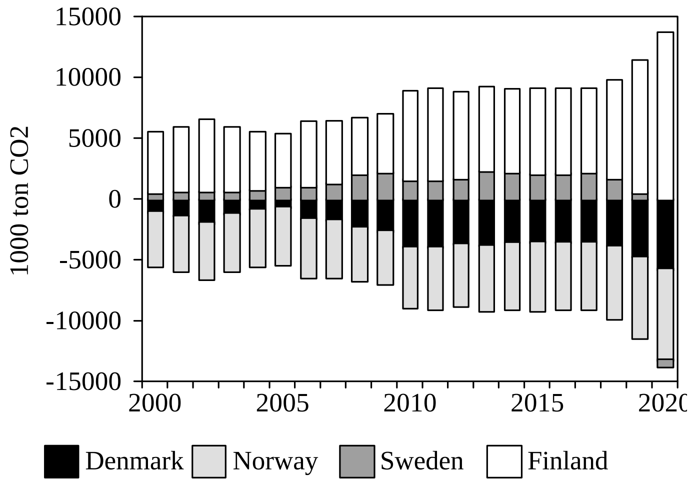
Figure 2 Equilibrium price of emission permits



Source: Scenarios with Elephant.

Finland is selling many emission permits, see Figure 3. Denmark and Norway import permits in the long run, while Sweden is selling some permits. This result is surprising as Sweden with the phase out of nuclear power would have been expected to import emission permits. Figure 4 shows, however, that Sweden imports large amounts of electricity and by that ease the emission target. The permit trade pattern can be used to indicate whether the countries got a good bargain in Kyoto: If emission targets that imply equal marginal costs in the countries are taken as a fair way to decide the initial distribution of permits, or national targets, Figure 3 says that Finland has got a good bargain in Kyoto.[4] Finland can in 2020 export emission permits corresponding to more than 13 million tons CO_2 before their marginal abatement costs equal the Danish. In 2010, Finland will sell permits for 7.3 million tons of CO_2 at a price of 342 DKK per ton, i.e. they will get a profit of more than 2.5 billion DKK in that year. In 2020, the Finnish gain will be 8.7 billion DKK.

Figure 3 Net exports of emission permits in the Nordic countries



Source: Scenarios with Elephant.

The national targets may reflect more than just bargaining power in Kyoto. Denmark finds that committing to a tight emission level puts a pressure on other countries to also accept tight emission levels for which Denmark has high preferences. If Denmark succeeds in this, accepting a tight emission target that looks like a bad bargain can be optimal for Denmark in the long run.

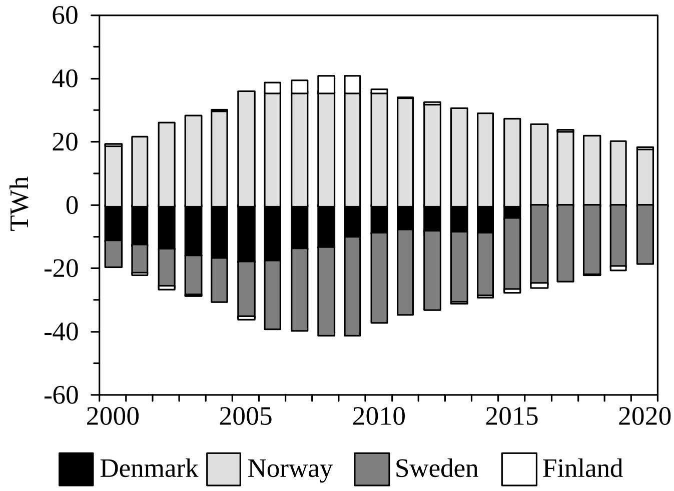
Compared with the base scenario, the electricity trade is primarily changed by a lower electricity trade from Finland to Sweden at the end of the period, and Denmark being a net electricity importer through the whole period.[5] The reason

4) There is no “correct” way to distribute the initial amount of permits, equalizing marginal costs is just one way, see, e.g. Kverndokk (1995). Other schemes could be equal percentage reductions or equal per capita reductions.

5) Norwegian investments in hydro power capacity of this size may not be technically possible or politically realistic that early in the simulation period. In Denmark large imports may neither be politically realistic.

is changed technology use in electricity and district heating production that makes other technology investments optimal and that Denmark ease the emission target by importing not only emission permits, but also electricity.

Figure 4 Net electricity exports



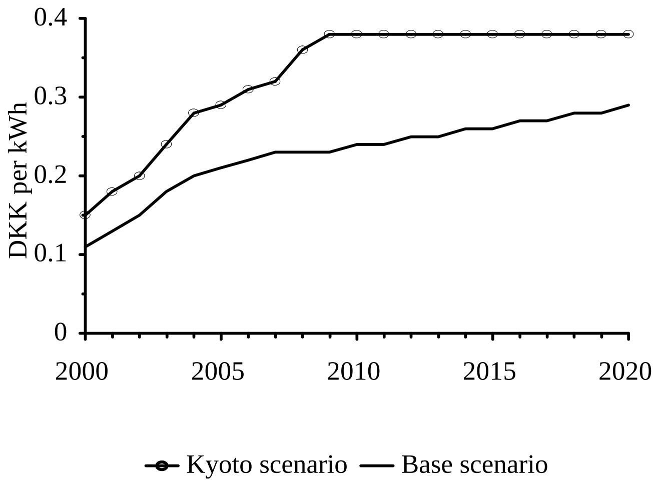
Source: Scenarios with Elephant.

The electricity supply price in the Kyoto scenario is significantly higher than the supply price in the base scenario from the beginning of the simulation period, see Figure 5. It is constant from 2009. The reason is that a group of back-stop technologies is being used from then on.

The increased electricity supply price changes the demand price and by that the demand for electricty. Electricity demand decreases in all countries compared with the base scenario, but Danish electricity demand will nevertheless be 30 per cent higher in 2020 than in 2000. The corresponding figures are 11, 13 and 9 per cent for Norway, Sweden and Finland, respectively.

Also the demand for other energy commodities will be influenced by higher energy prices caused by the cost of emitting CO_2. Demand for most energy commodities (exclusive fuels used in electricity and district heating production) are lower in the Kyoto scenario than in the base scenario. In absolute terms the demands for natural gas, fluid fuels and district heating increase through the Kyoto simulation, while the demand for solid fuels is almost constant.

Figure 5 Electricity supply price in base and Kyoto scenarios



Source: Scenarios with Elephant.

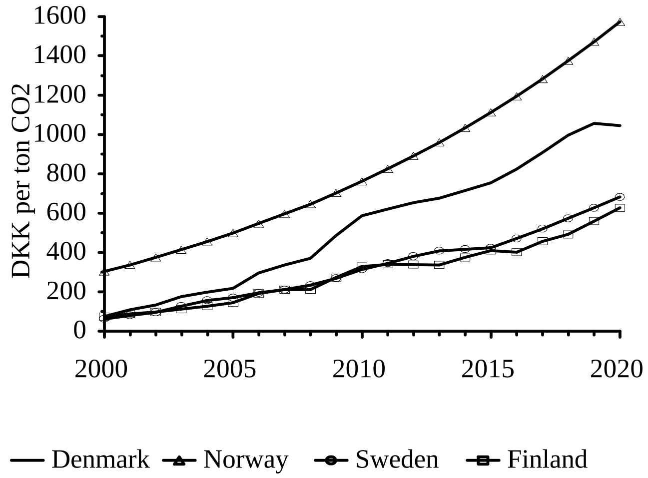
2.2 No Emission Trading

In this section, the importance of the possibility of trading emission permits internationally in the Kyoto scenario is analysed. To do this, national emission targets are imposed as constraints on the national CO_2-emission. Instead of a common Nordic emission permit market, a permit market for each country is therefore created. The permit prices can therefore differ between countries. Economic theory tells us that with a global emission type, different marginal abatement costs in countries in the standard case reduce efficiency in emission reduction. This result is supported as the total welfare level is lower in the scenario with restricted emission trading than in the scenario with free emission trading.

In the scenario with restricted emission trading, Denmark will invest in new natural gas based combined cycle plants and gas turbines from the beginning of the period. At the end of the period investments are made in Danish wind power. Finland invests in new natural gas based combined cycle plants. In Sweden investments are made in new wind power capacity. In Norway new investments are made in hydro power.

The Norwegian emission price is almost 1600 DKK in 2020, see Figure 6. This is high considering that the Norwegian target is an emissions increase of no more than 1 per cent compared with the 1990/1995 level. The Norwegian target is therefore ambitious considering the Norwegian possibilities of emission reduction.

Figure 6 Emission permit price

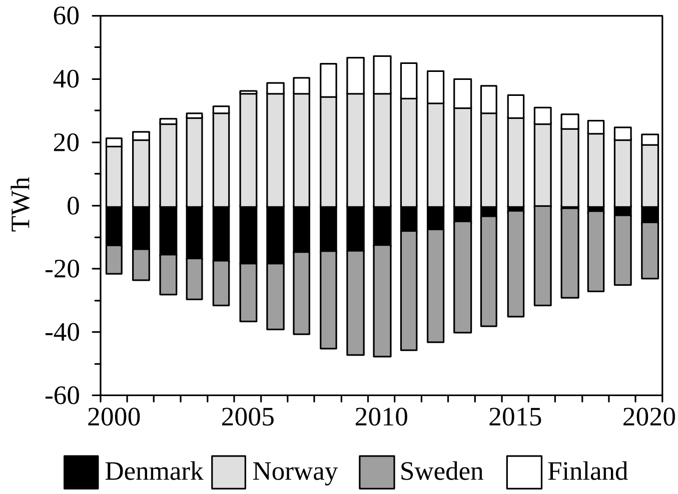


Source: Scenarios with Elephant.

The Danish permit price is lower than the Norwegian, but still high. The result found in Section 2 that the Danish target is tight compared with the possibilities of reducing emissions is supported by this. Like Norway, Denmark could benefit from importing emission permits from Sweden and Finland. The demand for district heating in Denmark must, however, be satisfied by district heating produced in Denmark. A large part will, however, optimally be supplied by natural gas-based CHP production that limits the Danish possibilities for reducing emissions by electricity import.

The Swedish and Finnish permit prices develop similarly through the whole period. This can be a coincidence, but it is possible that electricity trade between Finland and Sweden works as a substitute for permit trading and partly equalizes marginal abatement costs in the two countries. In Figure 7, the net electricity trade between the countries is shown.

Figure 7 Net electricity exports



Source: Scenarios with Elephant.

Comparing Figure 7 with Figure 4 shows that Norwegian and Danish electricity trading is largely unchanged. The Finnish electricity exports to Sweden have increased compared with the scenario with international emission permit trading. Sweden imports therefore Finnish electricity to reduce emissions as using renewable technologies is cheaper in Finland. In Finland, on the other hand, the emission constraint is so unambitious that producing natural gas-based CHP and exporting it to Sweden is possible, i.e. electricity trade serves as a substitute for permit trading. At the end of the period the emission constraints become so tight and marginal abatement costs consequently so high that it pays to invest in Swedish wind power.

3. Results From Other Models

In this section the results found by Elephant are compared with results from similar analyses with “Delmark” and “the Bergen model”, see Andersson and Hådén (1997) and Ammundsen et al. (1998), respectively. Similar analyses have also been made using Normod-T, see Aune et al. (1998), but environmental regulation is there made using taxes instead of emission constraints, which makes the results less comparable. The purpose of the comparison is to reveal the importance of the different elements included or not included into the models. The models are all within the same modelling tradition and consist of similar elements. In Table 1 is given a brief overview of central components that differ between the models.

These differences will in several cases explain differences in the results obtained by using the models. The analyses made by the models have also different focuses and are therefore often not directly comparable. It is, therefore, in the following important to remember that the comparison is only very rough.

In Delmark a scenario is carried out where Swedish nuclear production is phased out and emissions are stabilized at the 1990 level. The emission constraint in Elephant is formulated as a constraint on national emissions of CO_2, while the constraint in Delmark is on emissions from electricity and district heating production. Fuel input prices are in Delmark assumed constant, while they are increasing in Elephant.

Table 1 Central components in the models

	Elephant	**Delmark**	**Normod-T**	**Bergen**
Countries	Denmark, Norway, Sweden, Finland	Sweden	Denmark, Norway, Sweden, Finland	Denmark, Norway, Sweden, Finland
Simulation horizon	1995-2020	1991-2020	1991-2030	2000
District heating	Yes	Yes	No	No
Included CO_2-emission sources	Total national use of fossil fuels	Production of electricity and district heating	Stationary sources	Production of electricity and district heating
Energy sources in final consumption	Electricity, solid fuels, fluid fuels, district heating, natural gas, trans-portation fuels	Electricity and district heating	Electricity and oil	Electricity
Seasonality	No	Yes	Yes	No

Source: Amundsen et al. (1998), Andersson and Hådén (1997), Aune et al. (1998) and Hauch (1999a).

In Delmark a shadow value on the emission constraint of 125 DKK per ton CO_2 in the year 2000 increasing to 1045 DKK per ton CO_2 in 2020 is found. If the Elephant results for Kyoto without international trading of emission permits is compared with this, large differences are found.[6] In Elephant the Swedish shadow price on the constraint is increasing from 62 DKK per ton CO_2 in 2000 to 680 DKK per ton CO_2 in 2020. One explanation for this difference is the Swedish imports of electricity in Elephant. In Delmark, the Swedish imports are 9 TWh annually in 2010 to 2020. The large imports in Elephant will ease the emission constraint compared with Delmark. Another explanation is the possibility in Elephant to reduce emissions from other sources than electricity and district heating production. Also the constant fuel input prices in Delmark will, ceteris paribus, increase the shadow value on the emission constraint compared with Elephant. The influence from seasonality in Delmark is not clear.

The high costs of constraining emissions in Delmark are also reflected in higher electricity prices at 0.53 DKK per kWh. The corresponding price in Elephant is around 0.43 DKK per kWh.[7] This difference is probably explained by the higher shadow values on emissions in Delmark.

The Bergen model is only solved for the year 2000 and comparing development in different variables is consequently not possible. The Bergen model is used for analysing a Swedish nuclear phase out together with Nordic emission constraints. Emissions are assumed to be stabilised at the 1990 level and electricity markets are assumed to be liberalised. Both situations with and without trading of emission permits are analysed. This is similar to the Kyoto analyses carried out with Elephant, though some differences remain: the emission target in Elephant relates primarily to the year 2010. It can, however, from Figure 1 be seen that emissions in Elephant in 2000 are at almost the same level as in 2010, i.e. the timing of the target is only a minor difference. A more important difference is that the emission target analysed with Elephant is total CO_2-emissions, while the target in the Bergen model is emissions from electricity production only.

In the case with free emission permit trade, the equilibrium permit price is in the Bergen model 65 DKK per ton CO_2. The corresponding number in Elephant is

6) As Delmark only includes Sweden, international trading of emissions is not possible.

7) Note that these prices are consumer prices for light industries, i.e. they are not directly comparable with Figure 4.

75 DKK per ton CO_2, i.e. very similar results. In the case without emission trading, permit prices are in the Bergen model 69 DKK per ton, 203 DKK per ton, 81 DKK per ton and 24 DKK per ton for Denmark, Norway, Sweden and Finland, respectively. The corresponding numbers in Elephant are 75 DKK per ton, 303 DKK per ton 63 DKK per ton and 75 DKK per ton for Denmark, Finland and Norway respectively. These similarities can, however, be coincidental as several model elements are different.

Wholesale electricity prices are in the Bergen model very similar in the cases with and without emission. The level is between 0.24 and 0.29 DKK per kWh.[8] This is significantly higher than in Elephant where the price is 0.15 in 2000. One explanation of these differences can be the modelling of district heating in Elephant, but also other differences in the modelling of supply can influence the results.

4. Conclusion

Several factors in the real world are not included in details in Elephant that in several respects gives a rough description. This should be remembered when the results are interpreted. The uncertainty on, e.g., future technological development also reduces the validity of the analyses.

The Kyoto agreement is analysed for the four countries Denmark, Sweden, Norway and Finland. International emission trading is a part of the agreement and is assumed possible among the countries in the model. For the target year, 2010, an equilibrium price of CO_2-reductions of 340 DKK per ton is found. The price will increase to a level above 600 DKK per ton in 2020. This is caused by increasing economic activity that, ceteris paribus, increases the use of fossil fuel and electricity. The emission constraints are met through a combination of reductions in use of fossil fuels in final consumption and changes in the technology choice in electricity and district heating production. Finland has through most of the analysed period a large export of emission permits. This indicates that Finland has managed to get a good bargain in Kyoto, if marginal reduction costs at the target level are used as an indication.

8) The price differs between countries because of higher assumed transmission costs than in Elephant.

It can furthermore be concluded that even though electricity trading serves to equalize marginal abatement costs in Sweden and Finland, these costs are different from abatement costs in Denmark and Norway. Prohibiting international permit trade will therefore imply a welfare loss. Electricity trading can sometimes serve as a substitute for permit trading. It will not always be the case, and it is here found only between Sweden and Finland. This is, however, an example of how a liberalised electricity market can help reducing abatement costs when the emission permit market is less free. Denmark does not ease the emission target by electricity imports as district heating must be produced domestically, using CHP some electricity must also be produced domestically. Norway cannot ease the emission target by electricity imports as Norwegian production of electricity is already without emissions of CO_2.

The quantitative results in this paper support in many respects the results from the other similar partial equilibrium models. Some differences are, however, found. These differences can generally be explained by differences in which elements are included into the models.

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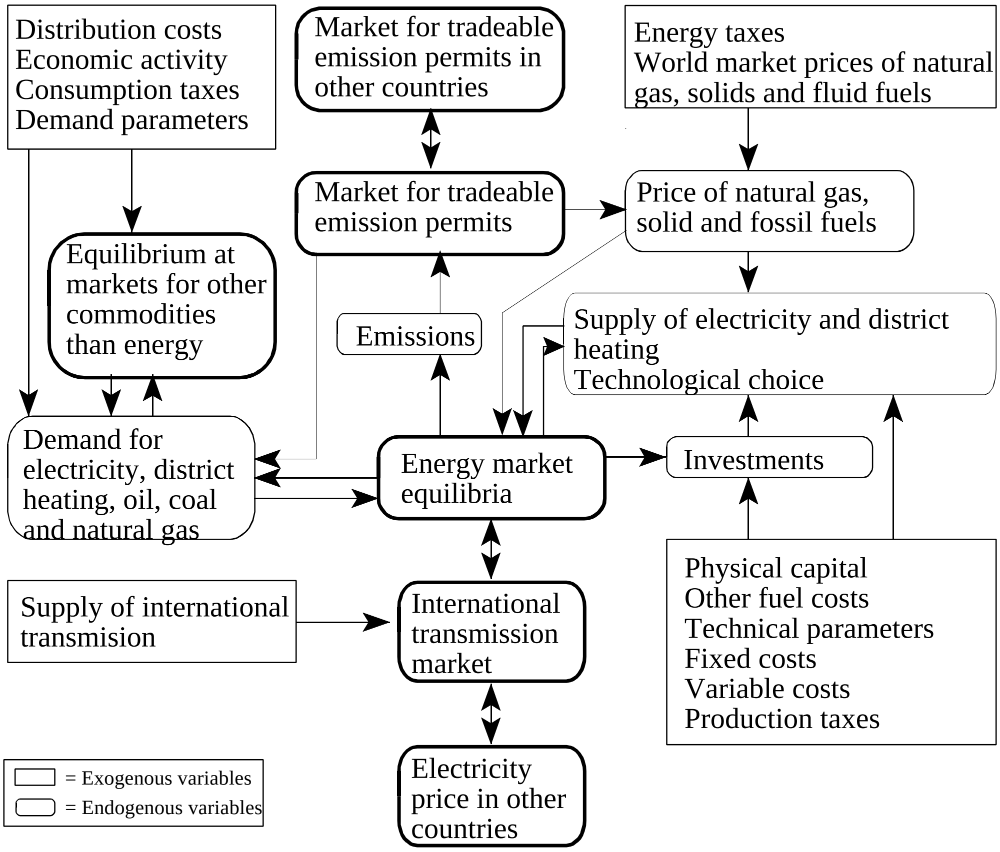
Appendix

Elephant is a partial equilibrium model covering the Nordic countries; Denmark, Sweden, Norway and Finland. Elephant simulates equilibria in energy markets from 1995 to 2020. An overview of the model and central assumptions are summarized here. Figure A.1 gives a graphic presentation of the model.

The central part of the model is the equilibria at the energy markets. Perfect competition is a basic assumption in the model and all markets are assumed to clear. The demand side is described using a system of nested utility functions for the representative consumer and a system of nested production functions for other sectors than electricity and district heating production, see the upper left hand corner of Figure A.1. The household demand for commodities is determined by a system of nested utility functions, and a budget which is determined by the overall level of economic activity. The economic activity is assumed to increase exogenously by 2 per cent annually. Taxes and distribution costs affect the demand for energy. Apart from energy inputs, households demand industrial and service outputs. Supply from those sectors is via the production functions determined by input costs. These input costs are among other things determined by energy prices and the structure of the production function. In equilibrium, the markets for other commodities clear and an endogenous price is found. We therefore have energy demand from two sources: Directly from household demand for consumption and from industry and service input demand.

Supply of natural gas, solid and fluid fuels is modelled simplistic, see the upper right hand corner of Figure A.1. The net supply prices are exogenously given by a world market price and transportation costs. The world market prices for fluid fuels, solid fuels and natural gas are assumed to increase annually by 2.2 per cent, 2.5 per cent and 1.3 per cent respectively. The total supply prices are also influenced by the cost of emission regulation.

Figure A.1 Elephant an overview



Note: Bold frames symbolize markets.

Supply of electricity and district heating is determined by a set of available technologies, see the bottom right hand corner of Figure A.1. Each of these technologies is described by technical parameters, and economic parameters like fixed and variable costs and taxes. The maximum supply from a technology is also determined by the amount of that technology installed at the beginning of each year plus possible technology specific investments.

The energy supply and demand systems meet at the energy markets, which determines the clearing equilibrium prices. The equilibrium demand level affects the level of new investments in physical capital for electricity and district heating production. These investments are also determined by the potential for utilising new technologies. Investments also influence the supply of electricity and district heating, which again affect the equilibrium level.

The equilibrium level for energy demand and supply determines emissions from consumption and production of energy. If environmental targets exist, emission regulation can be imposed in the model and will imply a cost of emission. This cost of polluting will affect both the supply and demand side of the energy markets. The supply side will change as other technologies in electricity and district heating production may be found optimal as fuel input prices change. This will influence the supply of electricity and district heating. The demand side will be affected as the price of emission permits must be added to the price of using other energy products than electricity and district heating. Direct emission regulation in a command and control regime is not modelled via the emission block. It can be modelled as exogenous conditions on the available technologies.

An international electricity transmission block is modelled with an endogenous determination of the level and the price of international transmission. Equilibria at the national electricity markets will therefore also be influenced by similar systems in other countries in the model.

This system is solved for every year in the solution period. Each year, some exogenous variables are determined in earlier periods while others are truly exogenous. Parameters determined in earlier periods are primarily the capacities for electricity and district heating production.