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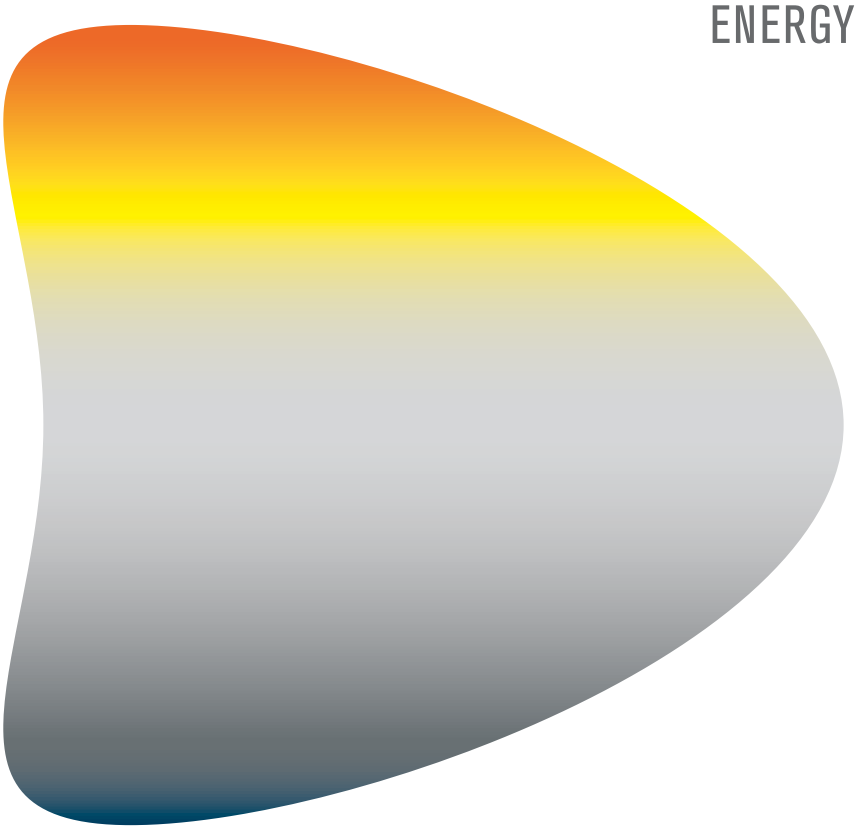

ENERGY SCENARIOS FOR THE NORDIC REGION TOWARDS 2035

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Abstract

This report summarizes the assumptions, methodology and main results of the MARKAL analysis of options for a sustainable energy future in the Nordic region.

The work is based on the Nordic MARKAL model, which has been modified such that it may be used to analyse a large number of scenarios, typically 500 to 5000.

The scenarios are developed by analysis a set of *strategies* and *uncertainties*. All these strategies and uncertainties are combined such that we generate in total 1152 scenarios.

The main purpose of generating a large number of scenarios was to facilitate for multi-criteria trade-off analysis. Overall results from this analysis show that large reductions of CO_2 emissions are possible at CO_2 cost below 50 EUR/t CO_2.

Keywords: Energy system analysis, MARKAL, multi scenario analysis, sustainable energy system

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1 Introduction

The overall aim of the TRANSES[1]-project (2004-2007) is to evaluate technology portfolios, development paths and policy options to meet future energy service needs in a sustainable manner.

Here, we have applied a multi-scenario approach where we investigate a huge number of strategies and uncertainties aiming at identifying robust strategies towards a sustainable energy system. This report contains a description of the MARKAL modelling framework, assumptions and main results.

Previously, we have analysed different energy polices such as green certificates and CO_2-quotas [1]. The main outcome of [1] was that CO_2-quotas are a more effective than green certificates in order to reduce emissions and contributing to changing the energy system towards a ‘sustainable energy system’.

However, the scenarios analysed did not have large variations in technology and policy options compared to the reference scenario (BAU). Hence, in order to find robust paths towards a sustainable energy system we need to develop more, but also wider scenarios. By doing so we may apply multi criteria decision-making (MCDM) methods to evaluate optimal scenarios.

Based on discussions at the TRANSES Workshop at Gardermoen, February 1-2, 2006 and a project meeting at MIT [2] we have considered different *strategies* for energy supply and demand and *uncertainties* on future demand and prices. Now, by combining a broad range of strategies with different uncertainties, we may easily produce a large number of scenarios. The aim of this work is that these scenarios should provide insight to develop energy policies that lead towards a sustainable energy system.

2 Methodology

2.1 The Nordic MARKAL model

The Nordic MARKAL model is an optimisation tool for the energy system. The model is developed based on four national models for Norway, Sweden, Finland and Denmark [1]. In order to get consistent results for the complete region major cost and technical assumptions are homogenized. However, e.g. assumptions of total investment costs of installing wind turbines in each country may differ due to variation in addition cost on grid expansion, civil works or similar.

The MARKAL model assumes perfect foresight, i.e. all agents have complete information about the future development of energy demand system (energy demand growth, fuel prices etc.). The *objective function* in MARKAL is to minimize total

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[1] Alternatives for **Tran**sition to **S**ustainable **E**nergy **S**ervices in Northern Europe

system costs (equally maximizing consumer and producer surplus) subject to constraints such as resource availability, regulations, etc. In this work we have given a large number of exogenous constraints to the model regarding investment levels, and to some extent use of renewables, nuclear, as well as end use actions. By combining the different alternatives such as large increases in the amount of windpower with reference level of new nuclear we could develop a large number of different future scenarios. The restrictions on the model force the model to find suboptimal solutions. A simple illustration of the effect of inserting restrictions on the level of renewables, nuclear and fossil is shown in the Figure 1. Here, a supply shift is forced by limitation of use of coal or vice versa by forcing a given amount of nuclear and windpower into the system.

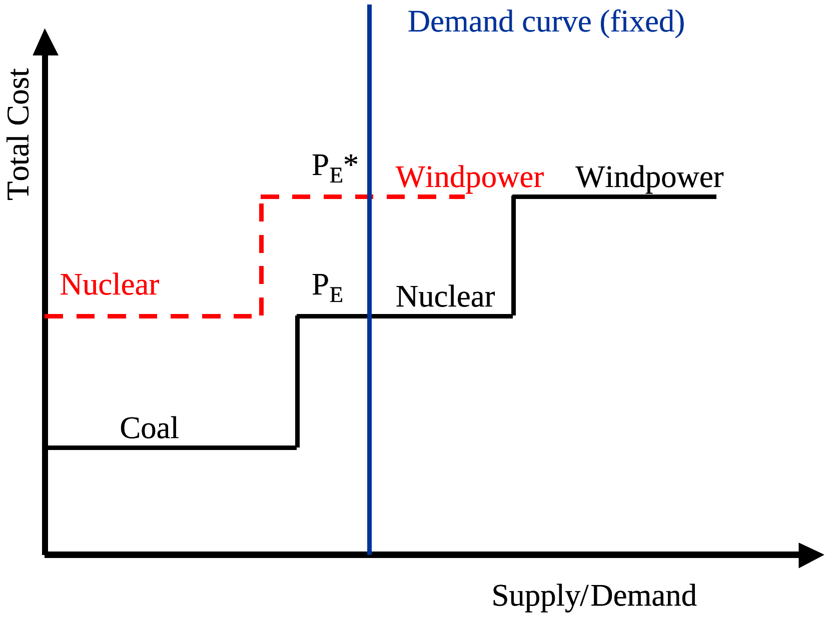

Figure 1 Shift in supply curve due to restrictions inserted into the model. The red dotted line show the modified supply curve due to exogenously given constraints on the supply.

Uncertainties are taken into account in a similar way. We run the model with different level of future development for the identified uncertainties, e.g. energy demand growth and future fuel prices.

At the workshop at Gardermoen , Nov. 7-8, 2006 a first set of strategies and uncertainties were presented. Based on the results and discussions from the workshop a slightly modified set of strategies and uncertainties have been analysed. A complete list of the modified set of strategies and uncertainties is summarised in Table 1 and Table 2 respectively. In Chapter 3 and 4 the all the individual strategies and uncertainties are described in detail.

Table 1 List of strategies in the modified set.

Scenarios **1152**

Ref Scenario: **RYVAB-BE-ERUC-EBUB**
Extreme Scenario: **GEGEB-BE-ERUB-UHAL**

ElSup	CHP/Heat	EUE	AThF	ATR	Total
16	**02**	**01**	**01**	**02**	**64**

Strategies	*Markal*	*Short*			***Comments...***
Electricity Supplies					
Windpower & Solar Electric				02	
Ref. Onshore & Offshore	01ER	R	√	*Ref*	*No wave power/tidal/salt grad./*
Moderate On/Ref. Off	01EM	M		*Mod*	*solar electric etc. options yet.*
Lrg. On/Mod. Off.	01EL	L		*Lrg*	
Lrg. On/Lrg. Off	01EW	G	√	*Gigantic*	
Hydro				02	
Ref. Hydro	02EY	Y	√	*hYdro*	
Some More Hydro	02EO	O		*mOre*	
We Love Hydro	02EE	E	√	*lovE*	
Nuclear				02	*(NG, NG+CCS, CL, CL+CCS, NFI)*
Choose Among All	03EV	V	√	*eVerything*	
4 GW New Nuclear	03EF	F		*Four GW*	
8 GW New Nuclear	03EG	G	√	*eiGht GW*	
Coal and gas w. CCS				02	
Choose Among All	04EV	A	√	*All*	*(NG, NG+CCS, CL, CL+CCS, NFI)*
4 GW gas fired plants in Norway	04EF	O		*Gas in Norway*	
8 GW new fossil w CCS	03EG	E	√	*Eight GW (Denmark and Norway, gas and coal)*	
Import/export				01	
Balance	05EB	B	√	*Balance*	
Allow import/export	05EA	M		*Net Import*	
Heat Supplies (Centralized, incl. CHP)				**02**	
Biomass				02	
Ref. Biom	06HB	B	√	*Biomass*	
Optimistic Biomass	06HO	K	√	*marKal*	*Let Biomass expand in Markal*
Max. By-Products from Forest Industry	06HM	M		*Max Forest*	*Linked to forestry industry development*
Max by-products total	06HT	T		*max Total*	
Imported biomass	06HP	P		*imPorted biomass*	
Waste				01	
Ref. WTE and CHP	07HE	E	√	*rEf*	*Large amount of recycling*
Max. WTE and CHP	07HA	A		*mAx*	*Max. Waste for energy production*
End-Use Efficiency				**01**	
Resid & Commercial EUE				01	
Reference R&C EUE	08DE	E	√	*rEf*	*Will develop based upon EPLAN analysis*
Moderate R&C EUE	08DO	O		*mOd*	
Aggressive R&C EUE	08DA	A		*Agg*	
Industrial EUE				01	
Reference Ind. EUE	09DR	R	√	*Ref*	
Improved Ind. EUE	09DM	M		*iMp*	
Alternative Thermal Fuels				**01**	*Decentralized heating demands*
Resid & Commecial ThFuels				01	
Reference Fuel Mix	10DU	U	√	*fUels*	
Lots of Wood	10DV	O		*wOod*	*Wood, pellets etc*
Alternative Transportaton Fuels				**02**	
Road Transportation				02	
Conventional Fossil Fuels	11TC	C	√	*Conventional*	*Other possible extenstions included*
Conv. But Lots of Hybrids	11TH	H		*Hybrids*	*Plug in Hybrids*
Eth/BioD & Hybrids	11TB	B	√	*Biofuels*	*Hydrogen Vehicles*

Table 2 List of uncertainties analysed in the modified set.

Futures				EnGr	FPr	CO2T	Elec	Total
Uncertainties				**03**	**03**	**02**	**01**	**18**
Energy Demand Growth				03				
Lower Growth	12UO	O	√	*lOver*		*+9% from 2005 to 2030, stabilisation from 2015*		
Reference Growth	12UE	E	√	*rEf*		*+19% from 2005 to 2030*		
Higher Growth	12UI	I	√	*hIgh*		*+43%, increase from 2005 to 2030, gradually from 2015*		
Troublesome Growth	12UU	U		*troUblesome*		*+63 % increase from 2005to 2030, gradually from 2015*		
Fuel Prices				03		*Updated based on forcast from IEA (WEO2006) and EIA (AEO2007)*		
Reduced	13UR	R	√	*Reduced*		*Oil and gas prices reduced to historic level (oil price at 30 USD/bbl)*		
Baseline	13UB	B	√	*Baseline*				
Worse	13UW	W		*Worse*				
Awful	13UF	F		*awFul*		*Double long-term trend*		
Horrendous	13UH	H	√	*Horrendous*		*Step Doubling in 2015, and trend towards 2030*		
CO2 Taxation				02		*All... €15/tonne CO2 (towards end of Kyoto period 2012)*		
Current level (to €10/t CO2)	14UC	U	√	*cUrrent*		*2015 and beyond = 20€/tonne CO2*		
						(Emissions included in quota system, incl free alloactions)		
Moderate Increase (to €20/t CO2)	14UO	O		*mOderate*		*2015 and beyond = 20€/tonne CO2*		
						(On all CO2 emissions, replacing exisiting tax and quota system)		
Large Increase (to €100/t CO2)	14UA	A	√	*lArge*		*2015 and beyond = 100€/tonne CO2*		
						(On all CO2 emissions, replacing exisiting tax and quota system)		
European electricity prices				01				
Baseline	15UB	B	√	*Base forecast*		*From analysis 2005*		
Moderate Increase	15UM	D		*moDerate*				
Large Increase	15UL	L		*Large*		*Double long-term trend, gradually from 2015*		

2.2 Data handling

With the approach applied here we could easily generate several thousand scenarios. However, the MARKAL model is usually applied to analyse typically 5-10 scenarios and possibly some sensitivity analysis of the important parameters, thus modifications are needed to analyse such a large number of scenarios.

The MARKAL model is written in the GAMS modelling language [4] and is usually run by applying a user shell like ANSWER [5] or VEDA [6] developed for the MARKAL model.

At IFE we have applied the ANSWER user shell for several years and it has proven to be very efficient both to develop models and to analyse results from a few scenarios. Nevertheless when increasing the number of scenarios to several hundred or more, Answer’s use of Microsoft Access proved to be inefficient due to the volume of model inputs and outputs. Access’s 2 GB maximum was insufficient for the number of scenarios envisioned. We have tested the ANSWER user shell on a few hundreds of scenarios and found out that there are an upper bound on around 3-400 scenarios depending on the level of details in the model analysed. Therefore we have started applying the VEDA tool for post processing. This tool is more flexible, but it is set up to analyse some general results from MARKAL and could not easily be modified to get all the results needed for trade-off analysis.

A modified version of the ANSWER user shell has been developed which allows the user to generate 2^11 (2048) scenarios in one single batch run. Using a high performance solver like XPRESS around 1000 scenarios of the Nordic MARKAL model could then be run in a few hours.

Our first attempt of post processing 1152 scenarios for the TRANSES workshop in November 2006 showed that the VEDA tool is not very efficient when the number of scenarios is more than two hundred. This is related to the handling of data that the user shell is using. Therefore, in order to develop a general approach that could be used for a very large number of scenarios direct manipulations of the result files (text files) seems to be the only viable solution. The most efficient way of handling the data seems to be depending of the number of scenarios. If we increase the number of scenarios to say 10000, the current approach with a mix of ANSWER for generating results and VEDA to post processing the results should be replaced by a simple text based batch run system, at least for post processing.

3 Strategies

At this stage we have analysed in total 64 strategies for energy supply and end use. The main focus of this project has been alternatives for energy supply to the stationary sector with focus on the alternatives for electricity supply.

Strategies for end use have not been analysed in detail, thus detailed specification of the different alternatives are not given. In the following sections a description of the different strategies is given. A complete list of strategies analysed is given in Table 1.

3.1 Electricity supply

We have analysed the effects of increased amount of renewables (wind and hydro), increased use of fossil power generation with carbon capture and storage (CCS) and nuclear energy in the Nordic system.

In this analysis we have not analysed strategies for technologies that are currently on a prototype level such as tidal or wave power. However using learning curves from IEA [10] we see that these technologies could contribute significantly to the generation mix by the end of the analysing period depending of among other assumptions on oil and gas price.

3.1.1 Windpower

Future deployment of windpower is highly dependent of policies in the four Nordic countries. Each of the four countries has different policies to support windpower deployment. In this study the current policies are applied for each country. However, with the approach applied here, we force the model to select a fraction of windpower into the system. Thus we are not analysing the effects of the current wind energy policies directly.

For windpower we have analysed four levels of future deployment. For simplicity we have assumed that future deployment of windpower is fractions of the overall techno-economical potential that is available in each scenario. In the reference case we have assumed that 50% of the onshore and 25% of the offshore potential will be utilised by 2020. A complete list of the four alternatives is given in Appendix 1. In the "Gigantic" wind case we have assumed the total potential is utilised.

The total investment and operating cost and utilisation factor is site specific within the Nordic region. For example, for the installations in Norway the cost assumptions are estimated by including additional cost based on necessary grid expansion at three different levels. Further, the utilisation time is dependent of the wind speed at the site. For the Nordic region as a whole, the range investment cost and maximum utilisation time are given in Table 3.

Table 3 Investment cost and operating costs for windpower

	Investment costs [EUR/kW]	Utilisation time [hours]
Onshore	700-1750[2]	2300-3100
Offshore	1300-3750[3]	3200-3750

3.1.2 Hydropower

The electricity supply in the Nordic region is dominated by hydropower, currently covering about 54% of the total supply. The current policies do not allow new large scale installations. However, the Norwegian Water Resources and Energy Directorate (NVE) has estimated the potential from hydro power in Norway to approximately 205 TWh, which is about 70% more than the existing 119 TWh, see Figure 2. A large fraction of the potential (44 TWh) is restricted area.

In this study we have analysed of the effect of increasing the level of hydropower in Norway, by increasing the amount small hydropower and using restricted areas. The potential for more hydropower in Sweden and Finland is not included.

In the reference case only existing plans, with possible modifications, and some small hydro (25%) is included. In the extreme case 'we love hydro', the complete potential for small hydro and the restricted areas are used. Further details on the assumptions for the alternative scenarios for hydropower are given in Appendix 1.

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[2] The investment cost of windpower available today is around 700-1000 EUR/kW. The total investment costs used in this analysis also include additional grid investments as well as civil works.

[3] The cost of offshore windpower is highly dependent of the site. In this study the lower cost assumption are for shallow waters and the higher investment costs are (insecure) assumptions for deep water installations.

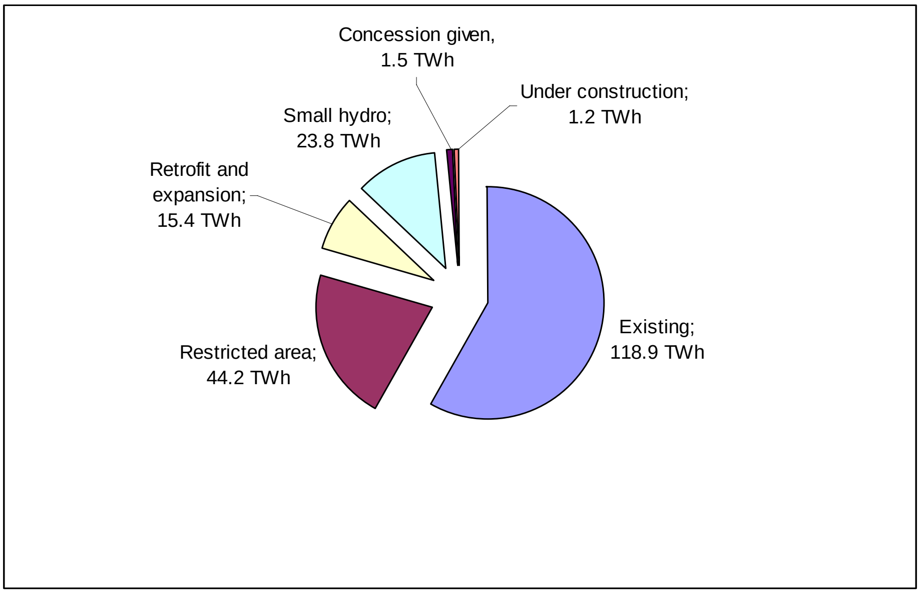

Figure 2 Hydropower potential in Norway, 2005.(Source: NVE)

3.1.3 Large Thermal Generation

Conventional thermal power production contains coal, gas, nuclear, peat and multi-fuel power plants. In the reference case we let the market (i.e the MARKAL model) choose the level of thermal production. In addition we have analysed the effect of increasing the level of nuclear power in Sweden and Finland and installing a large portion of coal and gas fired power plants with Carbon Capture and Storage (CCS) in Norway and Denmark.

The status for large-scale power production is quite different in the four Nordic countries. In Finland the new Olkiluoto (1.6 GW) nuclear power plant will make a major contribution to the Finish power production.

In Sweden the planned decommissioning of all nuclear power (around 66 TWh) could make a major impact on the system. Yet, only Barsebäck at 2 x 600 MW has been closed. The future of nuclear power in Sweden is still uncertain. Therefore, in the reference case we have assumed that the existing nuclear production is decommissioned by 2035, starting in 2020, unless there are new reinvestments to keep the plants in operation. In the reference case we have not allowed any new nuclear power plants in Sweden or Finland except the Olkiluoto plant.

In Norway gas turbines have been used offshore for several years and onshore in at the LNG-plant at Melkøya. For several years there have been plans for construction of new gas power plants, but none of these have yet been built. Currently, a 400 MW plant at Kårstø is under construction and there are other plants on the line. All these plants will probably be installed with CCS, partly financed by the government. In this analysis we have not included any additional governmental subsidy or financing of CCS in the reference case, but we have included two scenarios with large penetration of gas and coal with CCS in alternative scenarios.

3.1.3.1 Nuclear power

The future of nuclear power have been analysed at two levels in addition to the reference case. Using the new Olkiluoto plant in Finland at 1.6 GW as reference we have analysed the effect of installing another three more plants (in total 4,8 GW) and five more plants (in total 8 GW). These plants are installed in Sweden and Finland, which today have nuclear power as shown in Table 4. It is assumed that the new nuclear power plants are installed stepwise as shown in Figure 3.

Table 4 New nuclear power capacity in the two alternative scenarios

Scenario	New capacity	
	Sweden	Finland
4 GW	1.6 GW (1x)	3.2 GW (2x)
8 GW	3.2 GW (2x)	4.8 GW (3x)

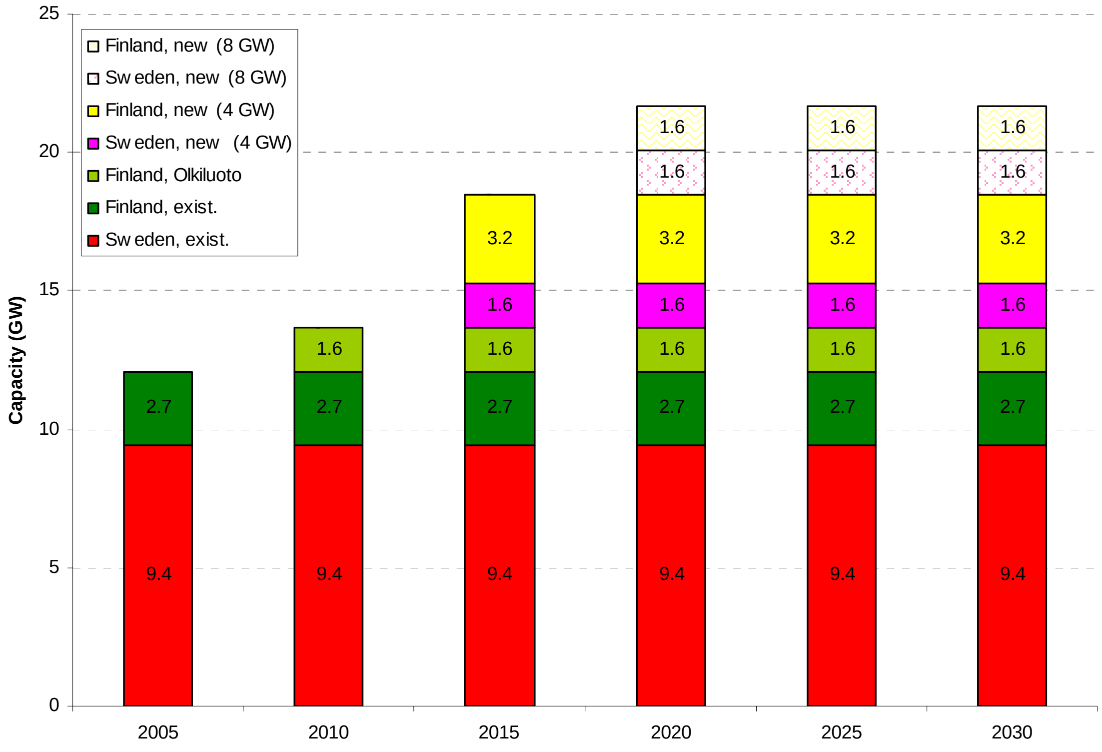

Figure 3 Installed capacity of nuclear power in the two alternative scenarios "4 GW" and" 8 GW". The Olkiluoto power plant with planned start-up in 2009 is the only new plant before 2015.

3.1.3.2 Fossil with Carbon Capture and Storage (CCS)

Similarly to new nuclear power plants we have analysed three levels of coal and gas with CCS. In the reference case the model may choose to invest in CCS technologies based on market figures, whereas in the two alternatives the amount of gas and coal with CCS is fixed.

In this study we have assumed that storage of CO_2 is available in the North Sea either in depleted oil and gas reservoirs or for enhanced oil recovery. Therefore, we have limited the possibility to invest in new gas and coal power plants with CCS to Norway and Denmark. In this analysis we have included the additional cost of carbon capture and compression of CO_2 at the power plant. Pipelines for transport of CO_2 is not included in the cost assumptions, hence it is assumed that these costs are covered by others than the power producers. The cost and efficiency assumptions for power plants with CCS is mainly adapted from IEA's CCS study [8]. In [8] it is assumed that gas power combined cycle increase the cost from 400 USD/kW to 800 USD/kW when CCS is included. Similarly for coal it is assumed that the investment cost increase from 1075 USD/kW to 1850 USD/kW (2010) and 1720 USD/kW (2020).

In a moderate development scenario we have forced the model to install 4 GW gas power with CCS in Norway (typically 10 plants similar to Kårstø). In a high penetration scenario we add 4 GW of coal to the 4 GW of gas in Norway. 4 GW of coal with CCS in Denmark is about 50% of the existing capacity of coal fired power plants in Denmark. The scenarios are summarized in Table 5.

Table 5 New fossil capacity with CCS

Scenario	New capacity	
	Norway	Denmark
4 GW	4 GW gas power	0
8 GW	4 GW gas power	4 GW coal power

Based on the existing plans for new gas power with CCS in Norway we have assumed that there are 700 MW_{el} with CCS available from 2010. Further, from 2015 we have assumed that another 3-4 gas power plants are in operation, equally a total cumulative generation of 2 GW_{el}. From 2020 towards 2030 4 GW_{el} of gas power is available.

In the high penetration scenario we have included coal with CCS in Denmark starting from 2015 with 2 GW and increasing to 4 GW in 2020 in addition to the gas in Norway. In Figure 4 the level of introduction of CCS into the Nordic system is shown.

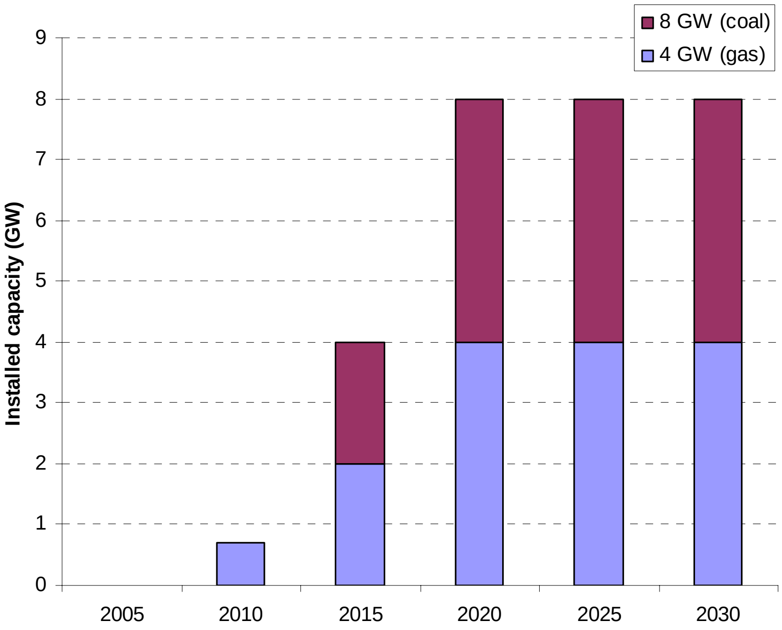

Figure 4 Level of coal and gas with CCS in the two scenarios. In the 4 GW scenario only gas power in Norway is included, whereas in the 8 GW scenario also coal in Denmark is included.

3.1.4 Electricity balance versus import

Import and export of electricity to or from the Nordic region is an important factor to a model like MARKAL where the investment level and timing of investments are optimised. It is two obvious alternatives; namely annual balance or allowing net import/export. Further, the Nordic model contains a grid in each country, hence also balance in each country versus allowing net import and export could be analysed. In this work we have focused on the Nordic region as a whole and hence only import/export from the Nordic countries to the neighbouring European countries have been considered. In the model the existing cables and grid connections between the countries are modelled as well as the planned new connections such as e.g. the new cable to Netherlands, which is assumed to be available from 2010.

In the current MARKAL analysis only the option with balance of annual import or export is analysed. Hence, the model may take advantage of day-night import/export, but not net import to cover the future energy demand.

3.2 Heat supply

In the MARKAL model there are a number of options for serving heat demand in the stationary sector. Both district heating and a large number of boilers are available as well as electrical heating.

Here, we have analysed the effects of increasing the biomass and waste use for energy production, i.e. both electricity and heating.

3.2.1 Biomass

The level of biomass in the reference case is taken from the analysis in the TRANSES project during 2005 [1]. Here, the amount of biomass (primary energy) used in the Nordic region increases from about 150 TWh in 2005 to 200 TWh in 2030.

The costs of biomass resources are highly dependent of the quality and type of biomass. Therefore, we have included a number of different cost classes. The costs of the biomass resource range from ‘free’ waste from the pulp and paper industry to around 15 EUR/MWh for wood waste/wood chips and a few more expensive options like e.g. biogas at around 30 EUR/MWh.

We have identified a number of options for future penetration of biomass, but in the current work we have only included the reference development and ‘optimistic’ case. In the optimistic’ case we let the market (i.e. the MARKAL model) choose the level of biomass use, hence the level of biomass use may differ significantly due to changes in demand, CO_2-price etc.

3.2.2 Waste-to-Energy

The total potential for waste to energy in the Nordic model is around 50 TWh in the Nordic region as a whole. We have considered two future scenarios for waste; a reference development and scenario with maximum use of waste to energy.

The reference scenario is developed based on use of waste in the BAU scenario from [1]. The use of waste is an inexpensive option and thus the BAU case use all the available waste to energy by 2030. Thus, in order to analyse a wider use of waste to energy further analysis of the potential should be analysed.

3.3 End-use of energy

The growth in energy demand (useful) is considered an uncertainty and is described in section 4.1. This is due in part to the fact that many of the national forecasts for energy demand growth contain different levels of embedded energy efficiency improvements.

3.3.1 End-use efficiency

In the MARKAL model energy efficiency actions are physical measures such as e.g. insulation. The model does not consider changes in behaviour due to changes in prices, e.g. lower indoor temperature as a response to increased prices on energy.

In the Nordic MARKAL model energy efficiency is not homogenised within the four countries. This is related to how the energy demand forecasts are developed. When forecasting (final) energy demand, the amount of energy conservation and improvement of equipment needs to be taken into account. In the Nordic model the energy demand for industry in Finland is modelled as final energy demand, whereas the other sectors are modelled as useful energy demand.

In order to analyse options for energy efficiency the potential in the four countries needs to be analysed further. Within the TRANSES project the ePlan subproject are currently working on further scenarios for end use of energy and thus in future analysis we plan to include data from this analysis into the modelling scope.

Based on the lack of data so far we have only included a reference scenario with only a small amount of energy conservation similar to the BAU scenario analysed in [1]. However, in order to illustrate the effect of increased energy conservation, we have included a reduced (‘stabilisation’) scenario on the future energy demand projects, refer to sec. 4.1.

3.3.2 Transportation

Technologies in the transport sector are not modelled in the current Nordic MARKAL model. Therefore we cannot analyse the effect of alternative strategies on new technologies directly. However, in this analysis we have included a link between the transport sector and the stationary sector by introducing alternative fuels such as biofuels and electricity as options in the transport sector.

In the reference scenario all cars are using a mix of gasoline and diesel only. Now, we introduce two alternative scenarios were a large introduction of plug-in-hybrids and biofuel cars are used.

In order to take into account the additional costs of alternative cars we have estimated the additional cost of new cars compared to conventional cars. According to The California Car Initiative (CCI) plug-in-hybrids typically costs around $2-3000 more than regular hybrid cars for sedans and around $5000 for SUVs [11]. Further CCI claims that plug in hybrids may reduce US’ oil dependency by 55% if all cars where replaced by plug-in hybrids.

Lindberg [12] has compared the cost of regular gasoline and diesel cars compared to hybrid cars. She found that on average, a hybrid car (Toyota Prius) is only 2% more expensive than a typical cost of a conventional car. However, comparing the cost of a Toyota Prius and a Toyota Corolla 5 doors the cost is increased by almost 50%, from NOK 213 000 to 315 000. In this analysis we have used the latter approach in order to get a conservative estimate for the additional cost. The total additional cost per car is then around NOK 125 000 or around EUR 16 000[4].

For biofuel driven cars we have assumed that the additional costs of the cars are small. This certainly holds for biodiesel cars, which only needs smaller modifications compared to regular diesel cars. Today, there are quite a few ethanol cars in Sweden, whereas in Norway only a few are available. In Norway, Saab has launched their BioPower Saab 9-5, which costs only slightly more than a conventional gasoline type. For example the price of a new Saab 9-5 2.0t150 hp and Saab BioPower 9-5 2.0t 180 hp are currently NOK 403 000 and NOK 412 000, equally 2% additional cost [13]. Therefore, we have not included additional cost for biofuels cars into the model.

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[4] Assuming a rate of 8 NOK/EUR and 6.5 NOK/USD.

In Norway the total energy demand for transport has increased from 45 to 57 TWh from 1990 to 2005 according to Statistics Norway [14]. Road transport covers around 80% of the transport demand (vehicle km) in Norway, refer to Figure 5.

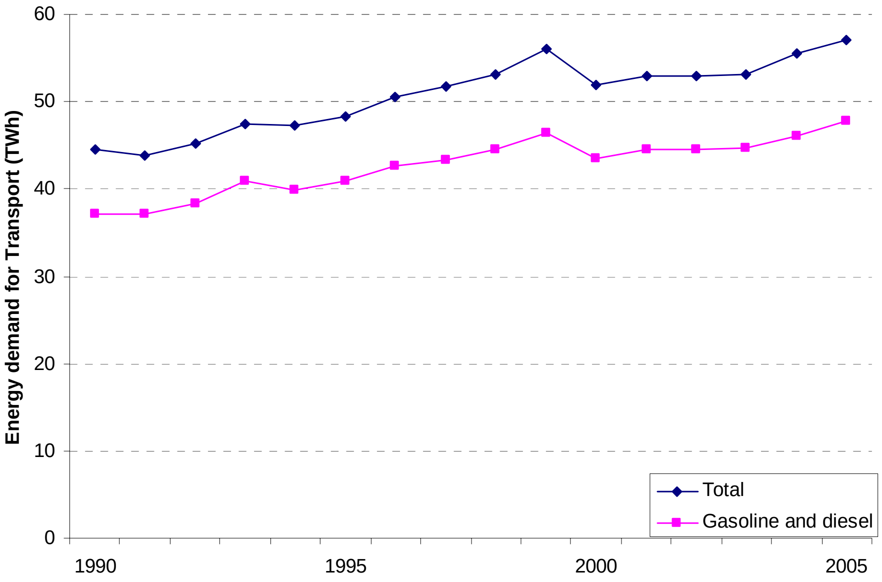

Figure 5 The energy demand for transport in Norway TWh. (Source: SSB)

In this analysis we have assumed that the road transport covers 80% of the total energy demand for transport for all the Nordic countries. Further, the additional cost of replacing existing conventional cars by hybrids is calculated based on the total numbers of cars, that is the cost of busses, trucks etc is not included here. In 2004 the total number of cars in the Nordic countries was around 10.3 millions, refer to Table 6. For hybrid cars we assume that 50% of the energy demand is covered by electricity and that the additional cost per car is 16 000 EUR. The three scenarios for road transport are summarized in Table 7.

Table 6 The total numbers of cars and private cars in the Nordic region (Source: SSB) (All numbers in 1000 units.)

	1990		**2000**		**2004**	
	Cars, total	**Private cars**	**Cars, total**	**Private cars**	**Cars, total**	**Private cars**
Norway	1939	1613	2303	1852	2458	1978
Denmark	1886	..	2237	1843	2360	1914
Finland	2198	1926	2449	2121	2708	2331
Sweden	3926	3601	4387	3999	4567	4113
Total	9948		11376	9814	12093	10337

Table 7 List of technologies and energy carriers in the three transport alternatives

Scenario	Technology	Energy carrier
Ref	Conventional (all)	Gasoline and diesel
Hybrids	Conventional (2/3)+ Plug-in Hybrids (1/3)	Gasoline, diesel and electricity
Hybrids and biofuels	Conventional (1/3) + Plug-in Hybrids (1/3)+ Biofuels cars (1/3)	Gasoline, diesel, electricity, biodiesel and ethanol

4 Uncertainties

There are several major uncertainties regarding the development of the future energy system. We have identified four uncertainties that are important for the modelling results. These are development of energy demand, fuel prices, CO_2-taxation/quota price and the European electricity price. In addition to these factors the learning rates of different technologies (especially renewables) are a major uncertainty. However, with the approach used here with exogenously bounds on the level of renewables role of technological learning will be less important, except for the overall costs of the system. A complete list of the set of uncertainties is given in Table 2.

4.1 Energy demand growth

The projected energy demand in [1] is used in the base case. Here the total energy demand increases from 1060 to 1260 TWh from 2005 to 2030, equally 18% growth.

In addition to this scenario we have analysed the effect of increasing the demand by additional 20 and 40% respectively. After the initial screening, at the November 2006 workshop, we have included a scenario with stabilisation of the energy demand by 2015 in all sectors except the Danish household sector which is assumed to reduce the demand also in the base case, refer to Figure 2 in [1]. This stabilisation may be due to reduced activity or energy efficiency. However, it should be mentioned that the additional costs for reducing the demand is not included in the model endogenously. The demand growth alternatives are summarized in *Table 8*.

Table 8 Energy demand forecasts used in the model (TWh).

Scenario	2005	2030	Per cent change
Stabilisation	1061	1151	8%
Ref	1061	1260	19%
+20%	1061	1512	43%
+40%	1061	1764	66%

4.2 Fuel Prices

Prices on fossil fuels are probably the most uncertain of the identified uncertainties. In the period from mid 80s to end of 90s the oil price was around 15 to 20 USD per barrel. After 2000 the price increased to around 30 USD per barrel and was stable until 2004 when the oil price increased towards 60-70 USD per barrel, which is the current level. The price development of natural gas has shown similar trends; refer to Figure 6 and Figure 7.

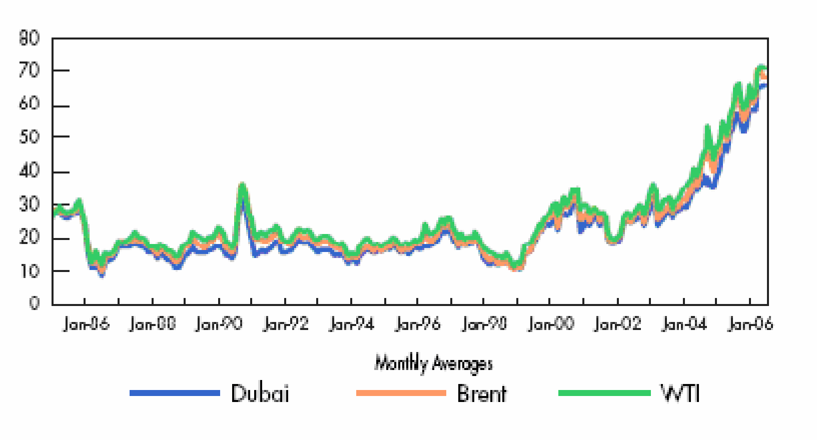

Figure 6 Crude oil spot price USD/barrel (Source: IEA 2006)

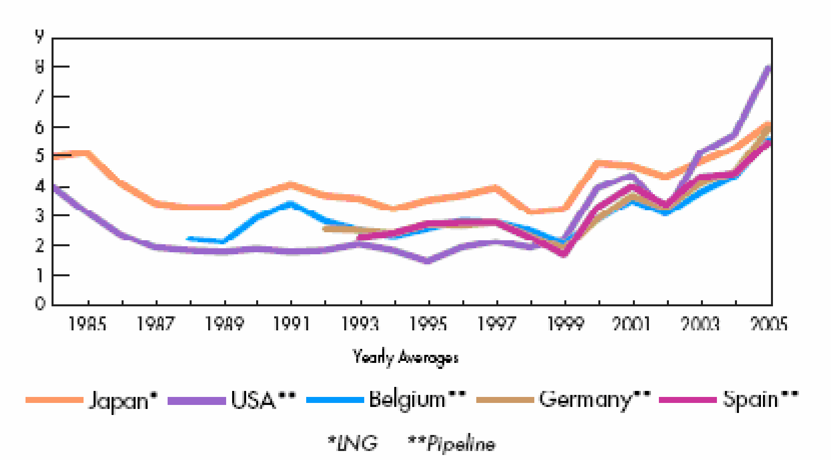

Figure 7 Natural gas import price USD/MBTu. (Source: IEA 2006 [9])

Due to the sharp increase of the oil and gas prices the baseline development needs to be updated to current level. In the present work we have applied forecasts from IEA's World Energy Outlook (WEO) 2004 [10], which assumes that the oil price in 2030 is around 24 EUR per barrel and the natural gas price at 3.5 EUR per MBTu. Based on the latest 2006 version of WEO and US DOE's Annual Energy Outlook 2007 [18] we assume that the oil price will stabilise at current level of 60 USD per barrel in the baseline scenario. However, in order to take into account the possibility of a decrease in future oil and gas prices we also include a reduced scenario where the price drops back to 30 USD per barrel.

In addition to these scenarios we include a scenario with a doubling towards 2030 'awful' and a 'horrendous' scenarios with a step doubling in 2015 and increasing towards 2030.Other fossil fuel products such as LPG, coke, and distillates are calculated based on the prices on gas, coal and oil. The price development in the different scenarios for oil, gas, coal and nuclear is shown in Figure 8 to Figure 11.

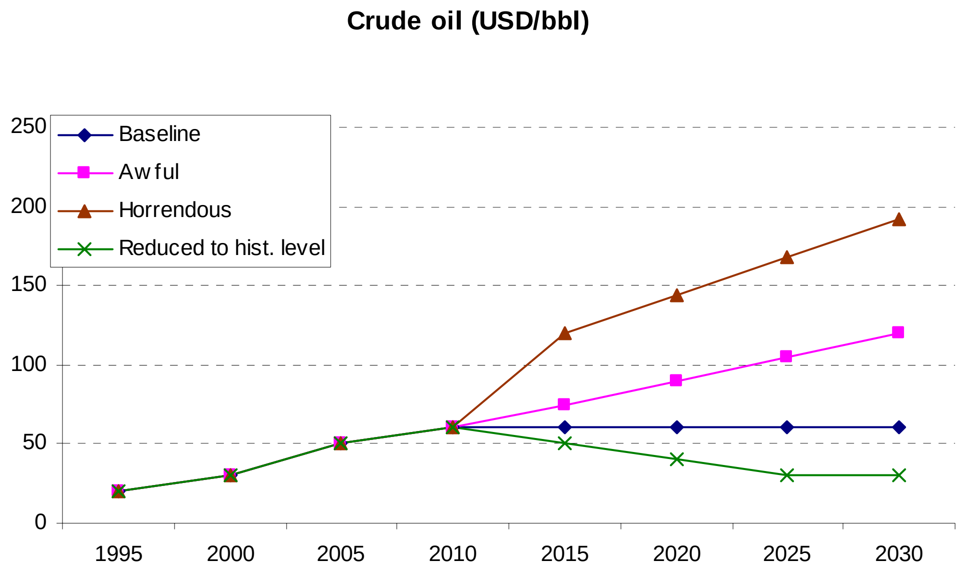

Figure 8 Price developments for crude oil in the four scenarios.

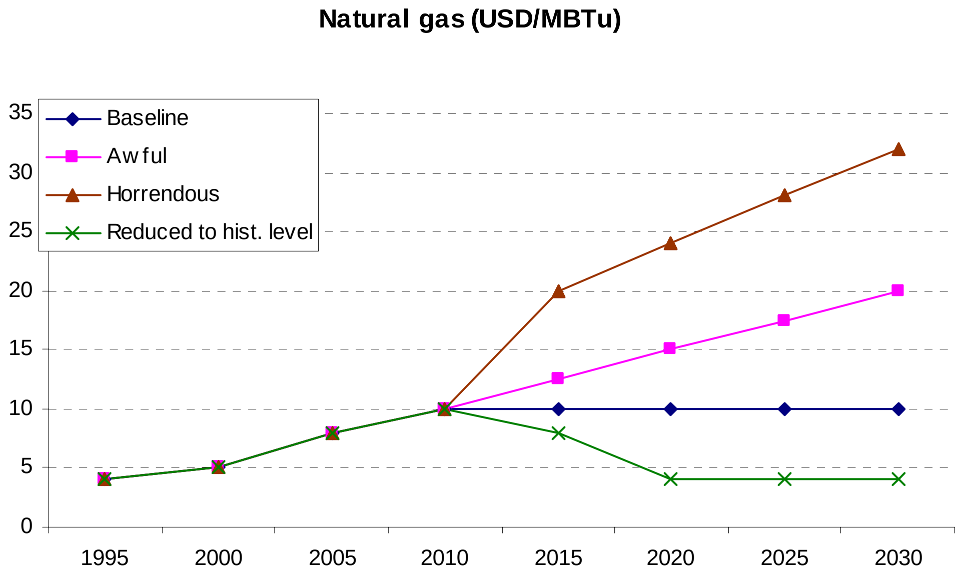

Figure 9 Price developments natural gas in the four scenarios.

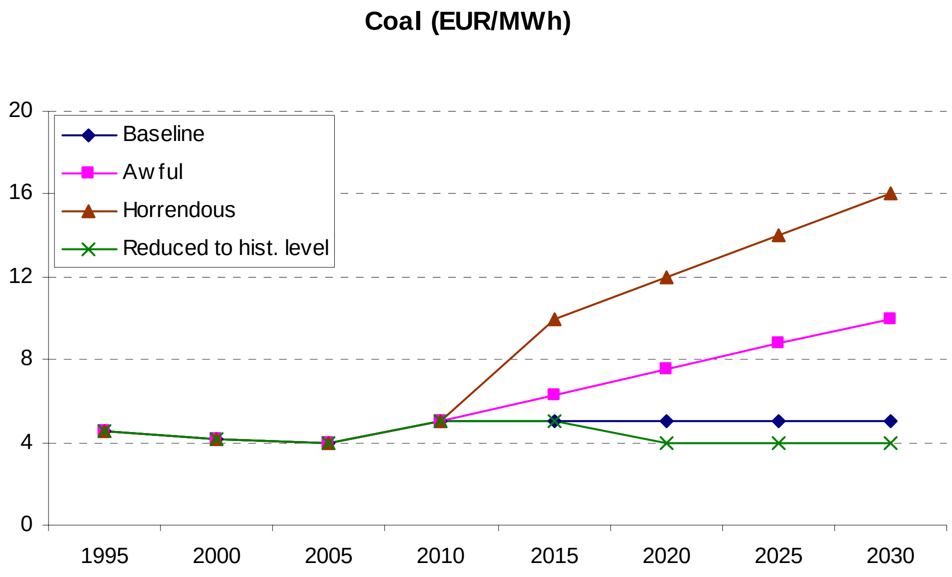

Figure 10 Price developments coal in the four scenarios.

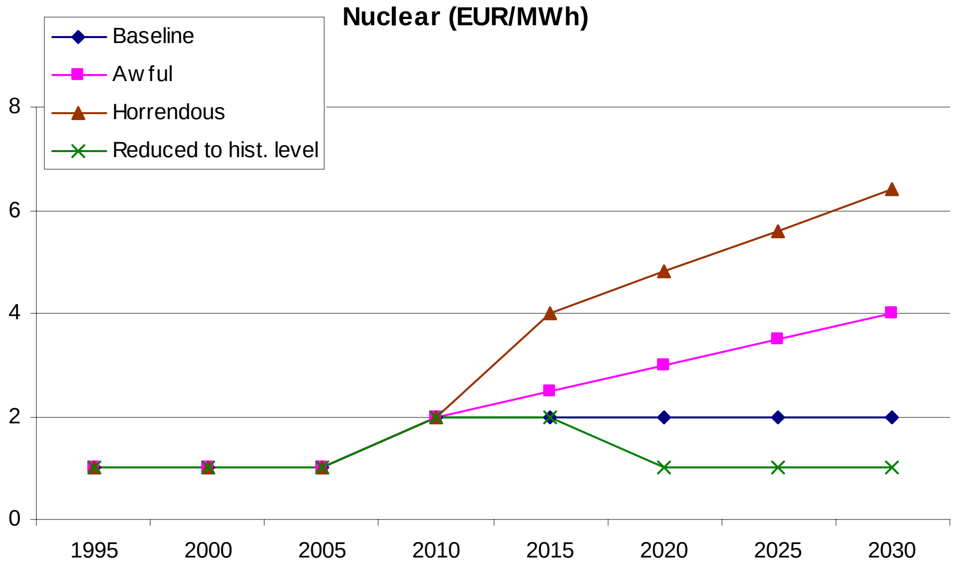

Figure 11 Price developments for nuclear fuels in the four scenarios.

4.3 CO_2 taxation and quotas

There are a large number of CO_2-taxes in the Nordic system in addition to the CO_2 quota system. All these taxes and quotas are implemented in the model. However, due to the free allocations (95%), the effect of CO_2-quotas is very limited in the period towards 2010 with the current modelling approach.

In the base case we have assumed that the current system is unchanged, i.e. that the free allocations will continue also after the Kyoto period, 2008-2012. From 2015 we have assumed that the quota price is stable at 20 EUR/t CO_2.

In addition to the reference case we have included two alternative scenarios were all CO_2 emissions are included in a quota system without any free allocations. We have considered two price developments from the period after 2015. Either, the price of all emissions is 20 EUR/t CO_2, or a large increase is seen towards 100 EUR/t CO_2. In the MARKAL analysis only the reference case and the case with a large increase to 100 EUR/t CO_2 is analysed.

4.4 European electricity prices

The future development of the electricity prices in Europe is another uncertainty that will influence the Nordic energy system. On the German European Energy Exchange (EEX) the price of electricity has increased during the last few years. In 2002 the price on the EEX was around 23 EUR/MWh [7] whereas today the price is around 60 EUR/MWh [17]. The forward price on the German market is at today's level towards 2012. We have used the trend analysed by for future prices from [7], but calibrated the data based on the existing spot price.

We have assumed that the price in the Netherlands is equal the price in Germany. Further, the price of import from Poland and Russia is expected to be between 2-4 EUR/MWh below the current Nordpool price.

We have considered three levels of price developments of the European market. In addition to the baseline with an almost fixed price we have included a moderate increase and a large increase. The price development of the baseline and large increase case is shown in Figure 12.

The initial screening face, where we included both the baseline and a large increase case proved, as expected, that the effect of increased European prices do not make any significant impact on the overall results as long as only the balance of annual electricity import/export option is chosen. Therefore, we have only included the baseline case when an annual balance is selected.

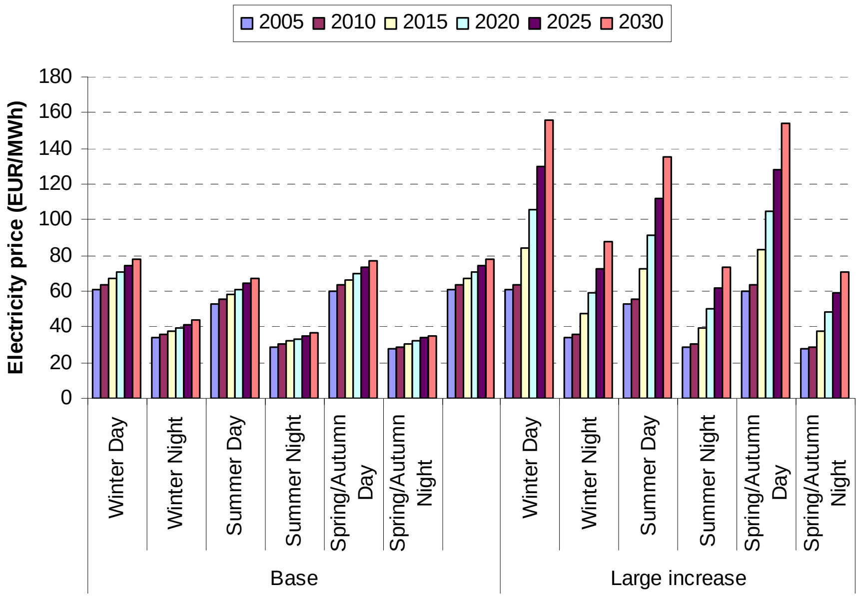

Figure 12 Electricity prices in the different seasons in Germany in the base case and the case with large price increase.

5 Main results and discussions

The Nordic MARKAL model consists of a more than 1000 technologies, thus the amount of results available with the 1152 scenarios analysed here are very large. Thus, we have selected a set of important parameters for the trade-off analysis.

In this report we focus on the overall indicators of the scenarios, which is total system cost (the parameter minimised in MARKAL) and CO_2 emissions.

The variation of all the 1152 scenarios with respect to total system costs and cumulative CO_2-emissionsis for the period 2005-2034 is shown in Figure 13 (blue dots). Here, the scenarios with all strategies maximised is shown with green dots and the scenarios with all uncertainties maximised is shown with brown dots and the baseline scenario is shown with a red dot. From Figure 13 we see that if all the uncertainties are at their maximum level (i.e. high demand growth, horrendous fuel prices etc) the total system cost is at its maximum for all the 64 strategies. On the other side, the different strategies reduce the cumulative emissions differently such that the emissions range from around 4500 to 7000 Mt CO_2.

When the strategies are maximised we see that there is a wide range in cost, and that all 18 uncertainties all reduce cumulative emissions to 4000-6000 Mt CO_2 compared to around 7000 Mt CO_2 in the baseline scenario. Further, we see that favourable combinations of strategies and uncertainties reduces the cumulative emissions from around 7000 Mt to 5000 Mt CO_2 without increasing the total cost significantly. By increasing the total cost from 700 to 800 Billions EUR the cumulative emissions could be reduced to 4200 Mt CO_2.

From Figure 13 it is clear that the future uncertainties are very important for the overall system cost. Here, it should be mentioned that the costs of increased/reduced demand are treated as an uncertainty. Thus, the cost from the model shows the system cost of fulfilling some given demand projections at different levels, but not the cost of reducing demand.

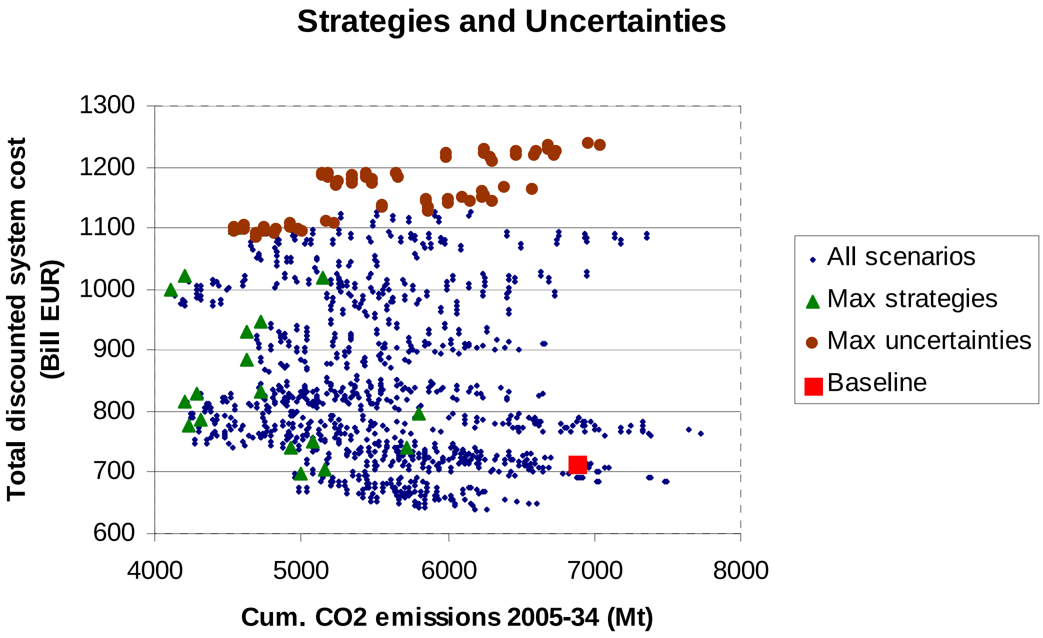

Figure 13 Total discounted system cost and cumulative emissions 2005-2034.

In the following the effect of single strategies and uncertainties on the overall cost and emissions is shown.

5.1 Strategies

5.1.1 Windpower

The effect of increased amount of windpower into the system is shown in Figure 14. The figure shows that by increasing the amount of wind power there is a shift towards lower emissions without increasing the total cost significantly. On average the emissions are reduced by 4% and the cost is increased by 2%.

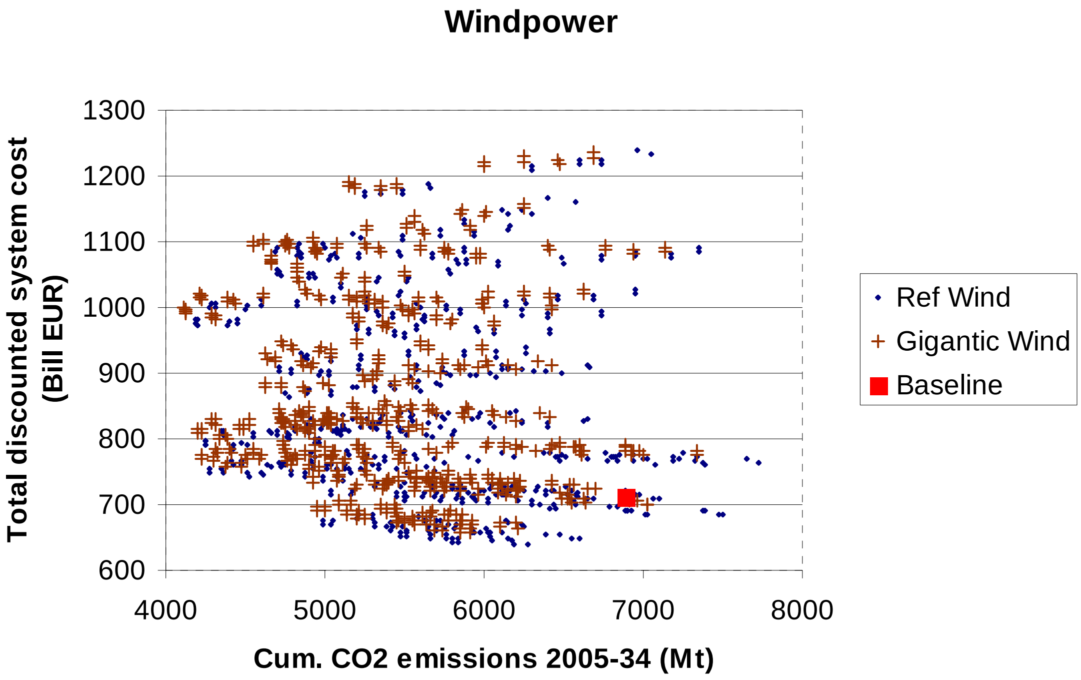

Figure 14 Total discounted system cost versus cumulative emissions with a reference development of wind power and a "gigantic" use of windpower.

5.1.2 Hydropower

The effects of increasing the amount of hydropower show very similar effects on the system as the case with increased amount of windpower, see Figure 15. On average the emissions are reduced by 6% without any significant additional cost.

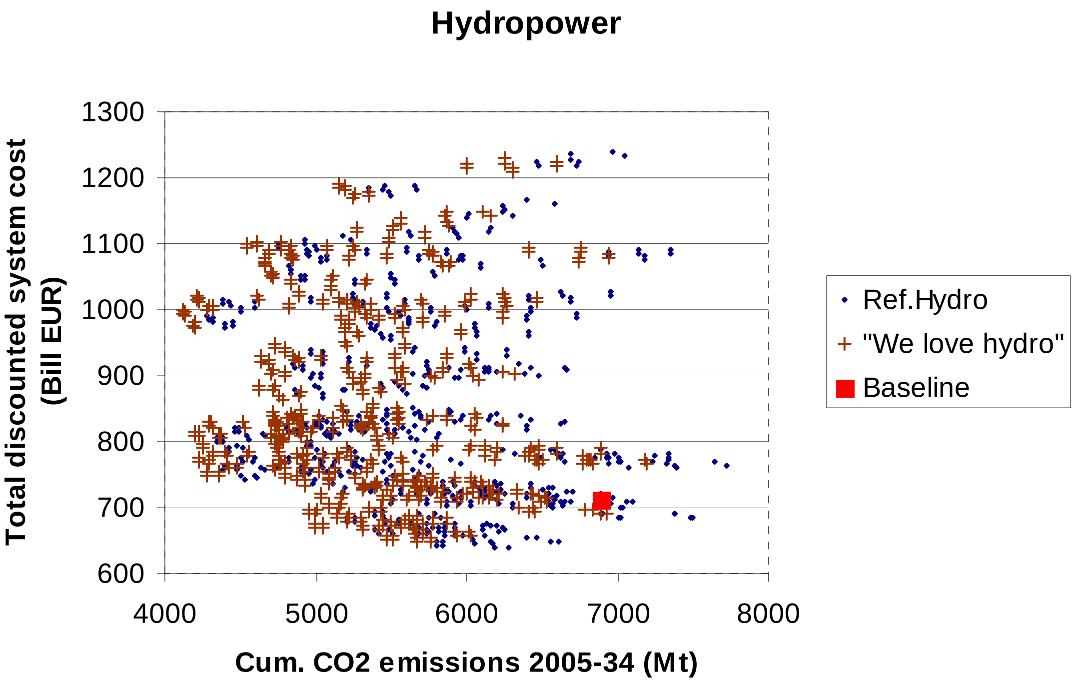

Figure 15 Total discounted system cost versus cumulative emissions for the reference case for hydropower and the case with a lot of new hydro power "we love hydro".

5.1.3 Nuclear power

The scenario with increased amount of nuclear power in Sweden and Finland show that more nuclear will decrease the emissions, but not increase the cost significantly, see Figure 16. On average the emissions are reduced by 4% and total cost is unchanged.

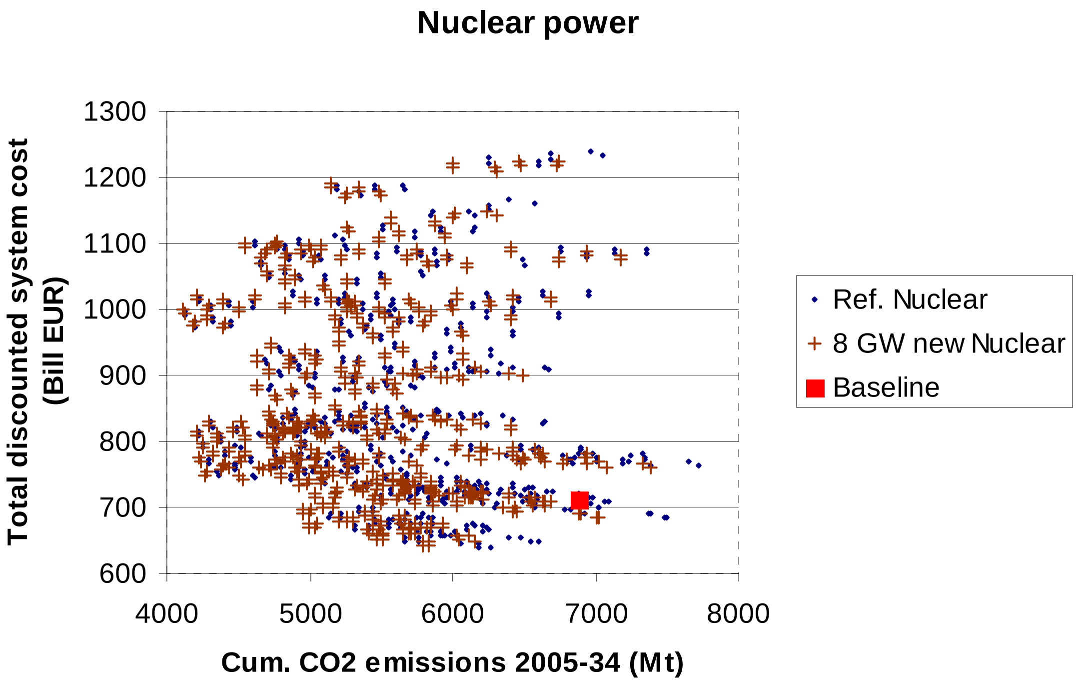

Figure 16 Total discounted system cost versus cumulative emissions for the reference case for nuclear and the 8 GW of new capacity case.

5.1.4 CCS

The effect of installing a lot of gas and coal power plants with CCS in Norway and Denmark show very little effect on the emissions and total system cost see Figure 17. The reason for this result is that CCS is too expensive in most scenarios and hence will not be applied to a great extent. On average the emissions are unchanged and the cost is increased by 1%.

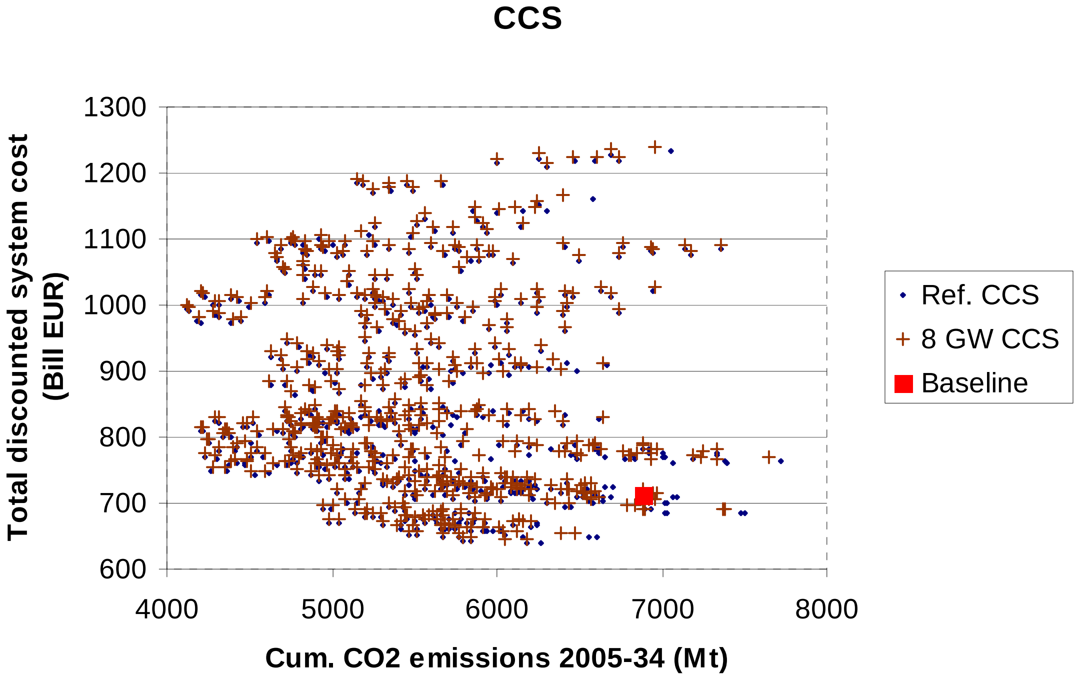

Figure 17 Total discounted system cost versus cumulative emissions for the reference case for coal and gas power plants with CCS and the 8 GW case.

5.1.5 Biomass

The effects of letting the MARKAL model choose the level of biomass for stationary applications ("optimistic") versus the reference use of biomass, results in large CO_2 reductions, see Figure 18. The "optimistic biomass" case removes all the high cost and high emissions scenarios. Further, we see that all the scenarios with the lowest emissions are included in the "optimistic biomass" cases. Hence, increased use of biomass seems to be very cost effective in order to reduce the CO_2-emissions. On average the emissions are reduced by 9% and the cost is reduced by 2%.

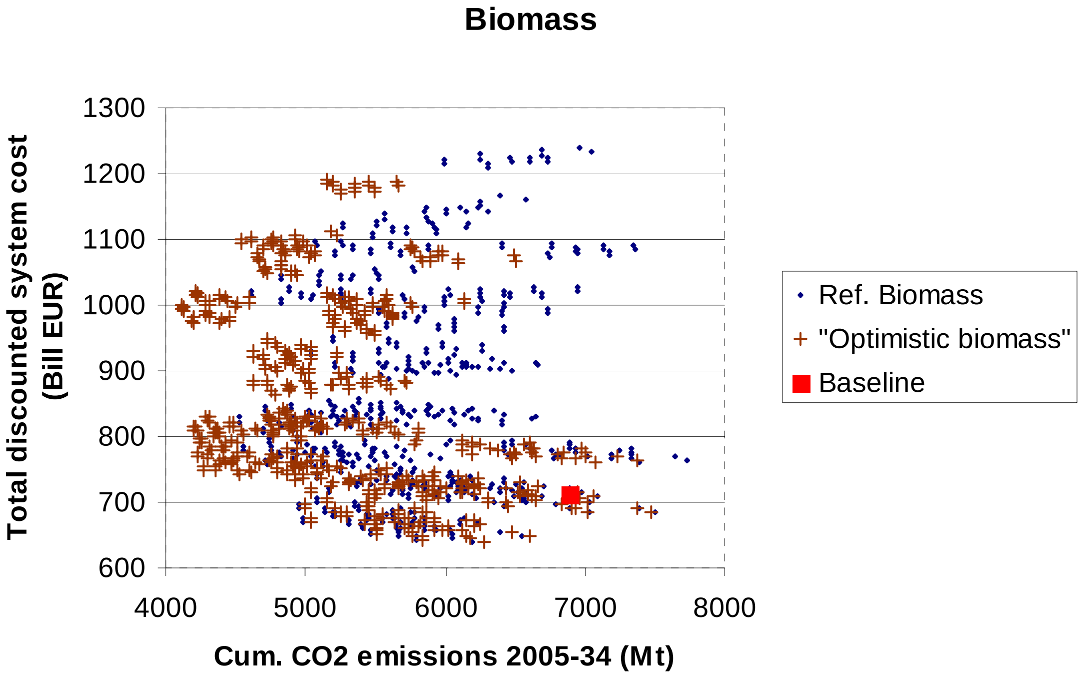

Figure 18 Total discounted system cost versus cumulative emissions for the two biomass cases.

5.1.6 Transport

The effect of the two transport alternatives are shown in Figure 19. The alternative transport option with plug-in hybrids needs more electricity than in the reference case. However, the results shown here seems promising with regards to achieving reductions of CO_2 emissions by replacing gasoline and diesel with alternative fuels such as biomass and electricity. It should be mentioned that we have not included additional costs for necessary infrastructure for neither biomass nor electricity and that the cost of biomass is kept at constant level. This may not be the case if there will be a large shift towards biofuels in Europe. The price will most probably increase and hence the total cost of the shift to biofuels will increase. For electricity the effects is taken into account because the electricity price is endogenous and thus increased demand for electricity will increase the price. On average the emissions is reduced by 8% and the cost is by 2% with increased amount of biomass and electricity for transport.

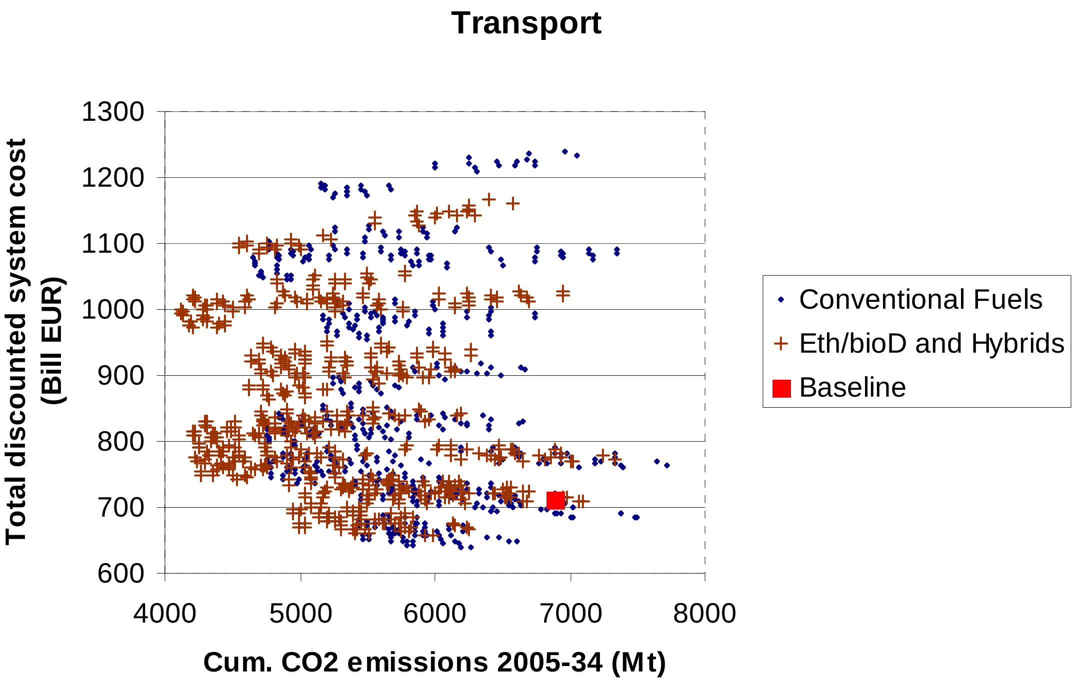

Figure 19 Total discounted system cost versus cumulative emissions for the two transport alternatives.

5.2 Uncertainties

5.2.1 Demand growth

Figure 20 shows the effect of changes in demand on the overall cost and CO_2-emissions. From Figure 20 it is evident that in order to reduce emissions and total cost the future demand is a crucial parameter.

On average the emissions are increased by 12% and the cost by 7 % in the high demand scenarios and the emissions are reduced by 4% and the cost by 2% in the low demand scenarios.

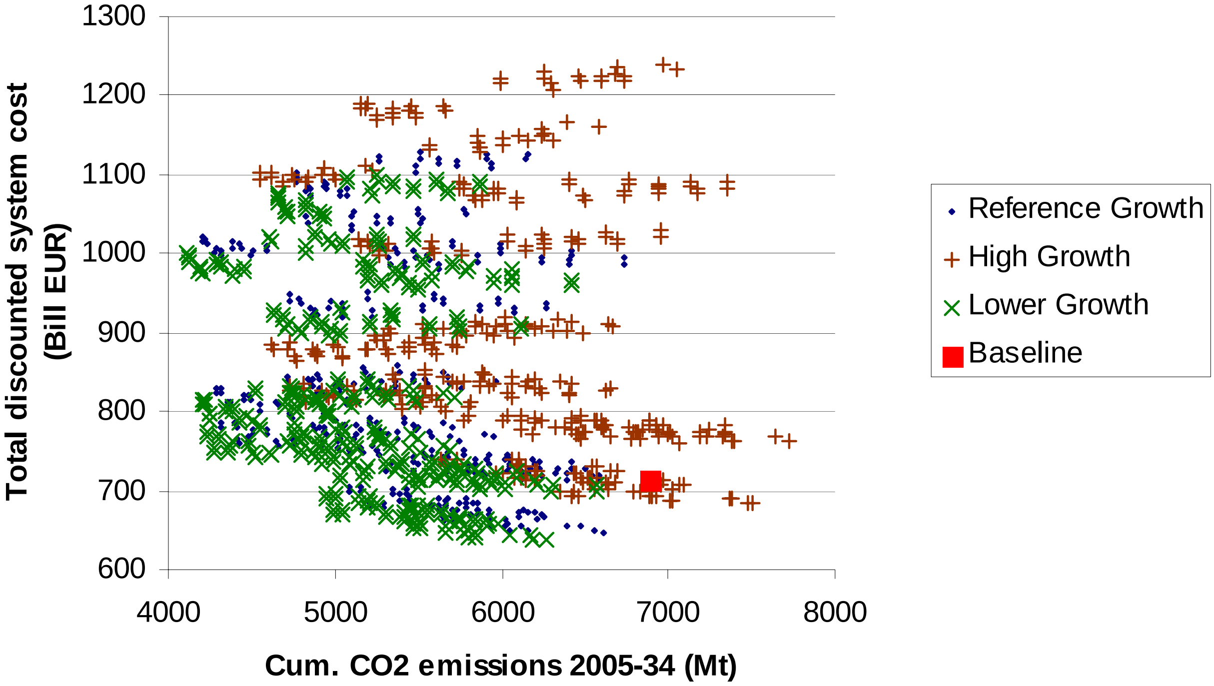

Figure 20 Total discounted system costs versus cumulative emissions for the three levels of future demand projections.

5.2.2 Fuel price

Figure 21 shows that if the price increases to the “horrendous” alternative, i.e. oil price increasing towards 200 USD/bbl in 2030, then almost all scenarios show higher costs than in the baseline projection, where the oil price is stable at 60 USD/bbl. On average the emissions are reduced by 3% and the cost are increased by 30% when the prices are increased to the ‘horrendous’ alternative and the emissions are reduced by 1% and the cost by 7% when the fuel prices are reduced.

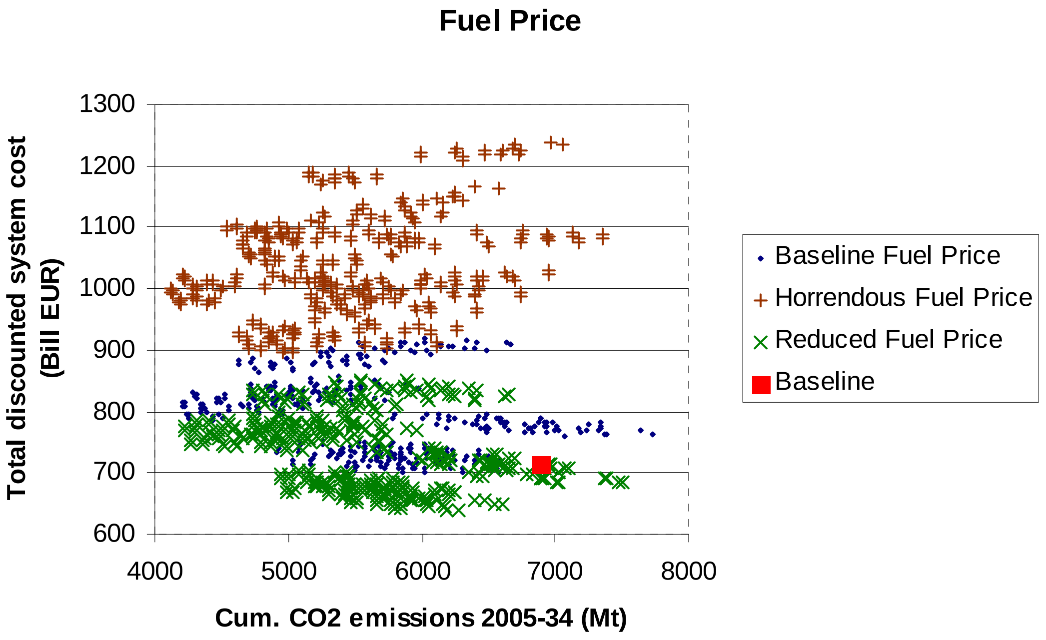

Figure 21 Total discounted system cost versus cumulative emissions for the three levels of fuel prices

5.2.3 CO_2 taxation

Figure 22 shows the effects of increasing the CO_2 cost for all emissions from current level to 100 EUR/tCO_2. Here, it is evident that the increased cost on CO_2 decreases the emissions in all the scenarios. Comparing the shift in fuel prices with the shift in CO_2-price we see that the shift in fuel price will mainly increase the cost whereas the increased CO_2 cost do not increase the overall cost very much in most scenarios, but reduces the emissions. On average the large increase in CO_2 costs reduces emissions by 13% and simultaneously increases the cost with 13%. Compared to increased fuel costs CO_2-taxation seems to be much more effective in order to the reduce CO_2 emissions. The reason for this result is that increased fuel cost leads to a fuel shift from gas to coal while increased taxation will replace the coal first and then gas. Further, when the fuel costs are reduced gas will be more competitive and thus some coal will be replaced by gas and hence the emissions could be reduced be reduced fuel costs.

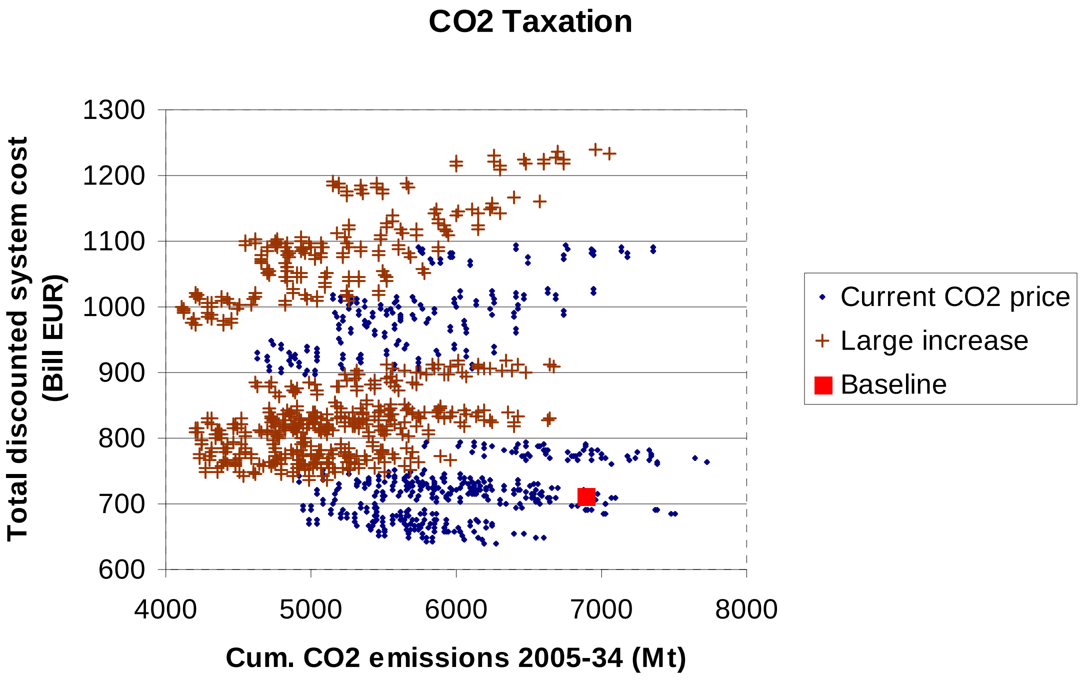

Figure 22 Total discounted system cost versus cumulative emissions for the two levels of CO_2- taxation/quota prices analysed.

5.3 Summary strategies and uncertainties

Figure 13 to Figure 22 show that the cost of CO_2 reductions varies a lot between the scenarios. This result is reasonable as there must be some inefficient scenarios with the approach applied here. The MARKAL model optimises the energy system for the modelling horizon with respect to investments and use of technologies. The methodology applied here with exogenously given investments and use of different technologies decreases the possibilities to optimise the system, hence some of the scenarios are ‘sub-optimal’ and some are not reasonable. For example introduction of a lot of new nuclear and CCS technologies for electricity production at high fuel costs and low demand increase will not be a cost effective solution. In Figure 23 and Figure 24 a summary of the strategies and uncertainties are shown. Here, an arrow is indicating the average effect of the strategy and uncertainty on the costs and emissions.

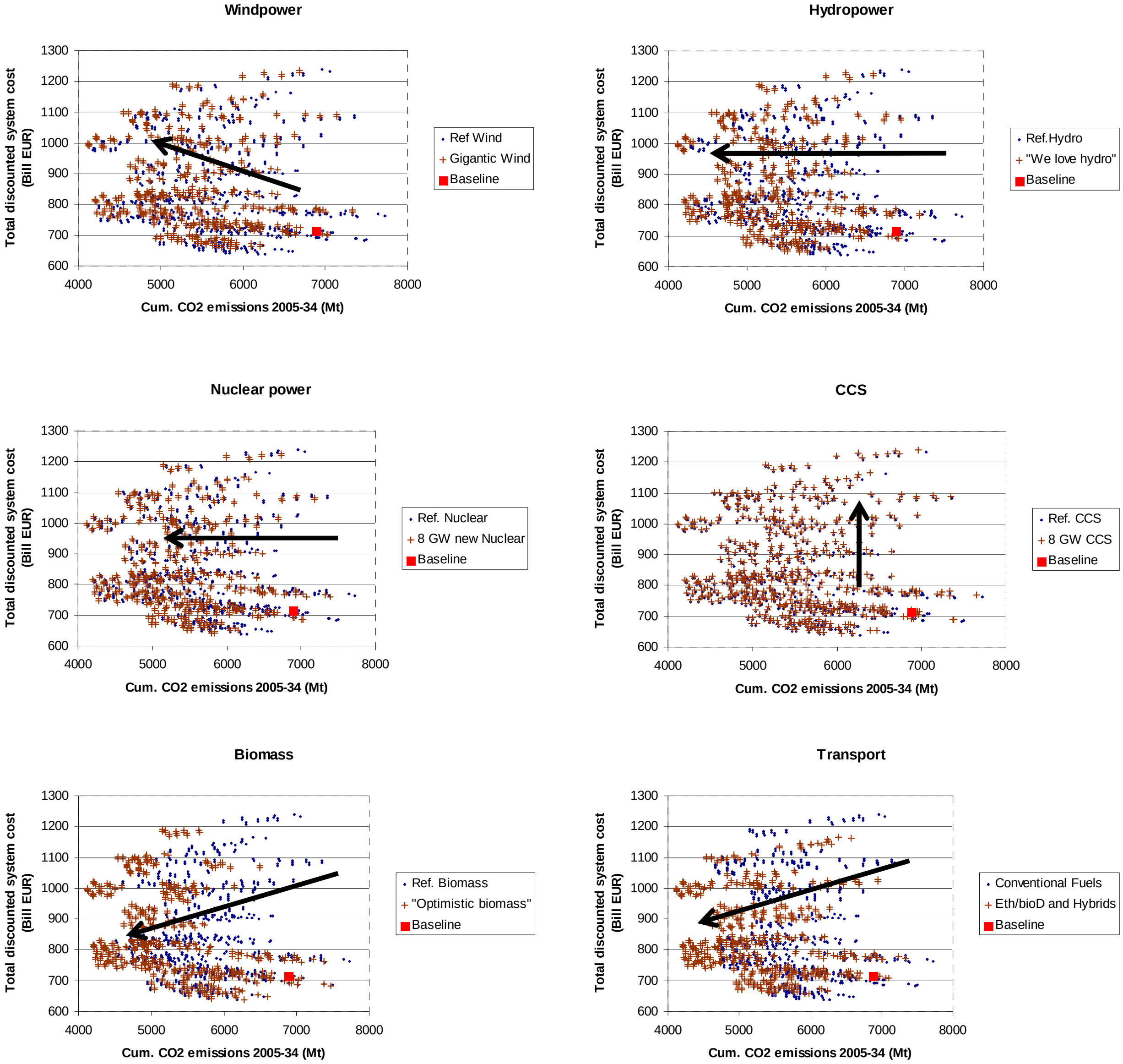

Figure 23 Summary of strategies with an arrow indicating the average change in cost and emissions.

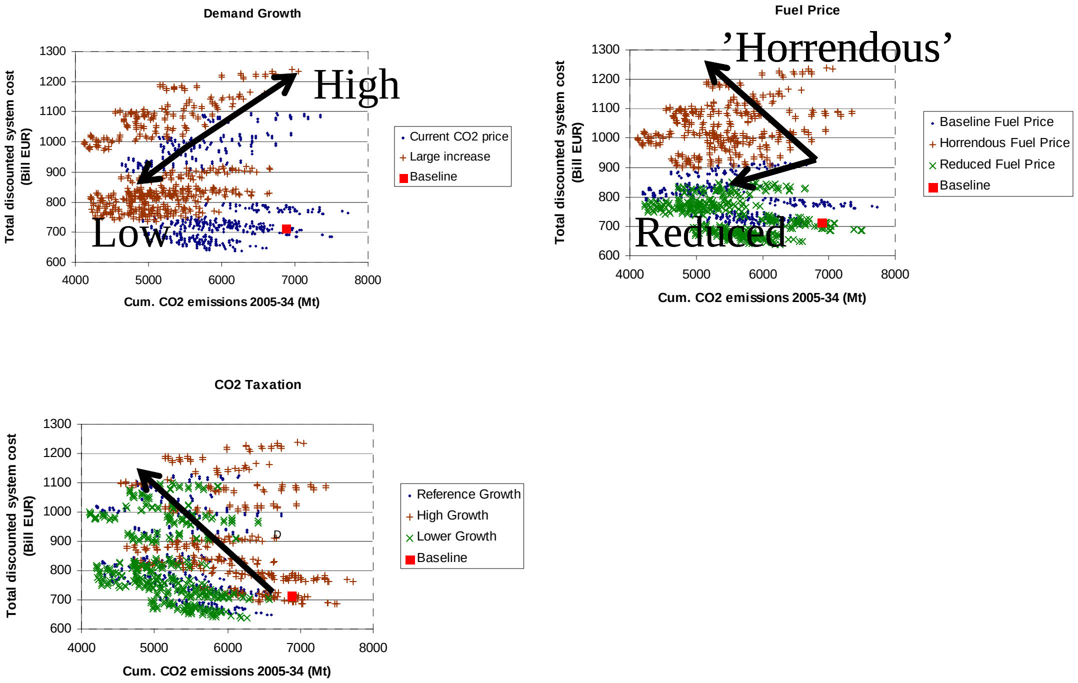

Figure 24 Summary of uncertainties with an arrow indicating the average change in costs and emissions.

Another way of presenting the cost-emissions are by calculating the marginal abatement cost (MAC). In this study we have calculated the MAC by comparing the total system cost and CO_2-emissions for an alternative scenario with the baseline. In the following the cost of reducing the emissions compared to the reference scenario is shown.

5.4 Marginal abatement cost (MAC)

In the baseline scenarios the CO_2 emissions increase to 240 Mt CO_2 in 2030 which is about 20% increase from the 1990 level and 25% above the Kyoto target of 193 Mt CO_2.

Figure 25 shows the marginal abatement cost (MAC) for all scenarios with MAC below 200 EUR/t CO_2 and baseline demand projection. Figure 25 shows that there is a large variation of the abatement costs among the scenarios. Several of the scenarios are rather poor in order to reduce CO_2 emissions in a cost effective way.

The most promising scenarios with a low MAC and large reductions, indicated with a red circle at the figure, all have a lot of biomass, alternative transport fuels and high CO_2 prices. The other strategies vary among these 'optimal' scenarios.

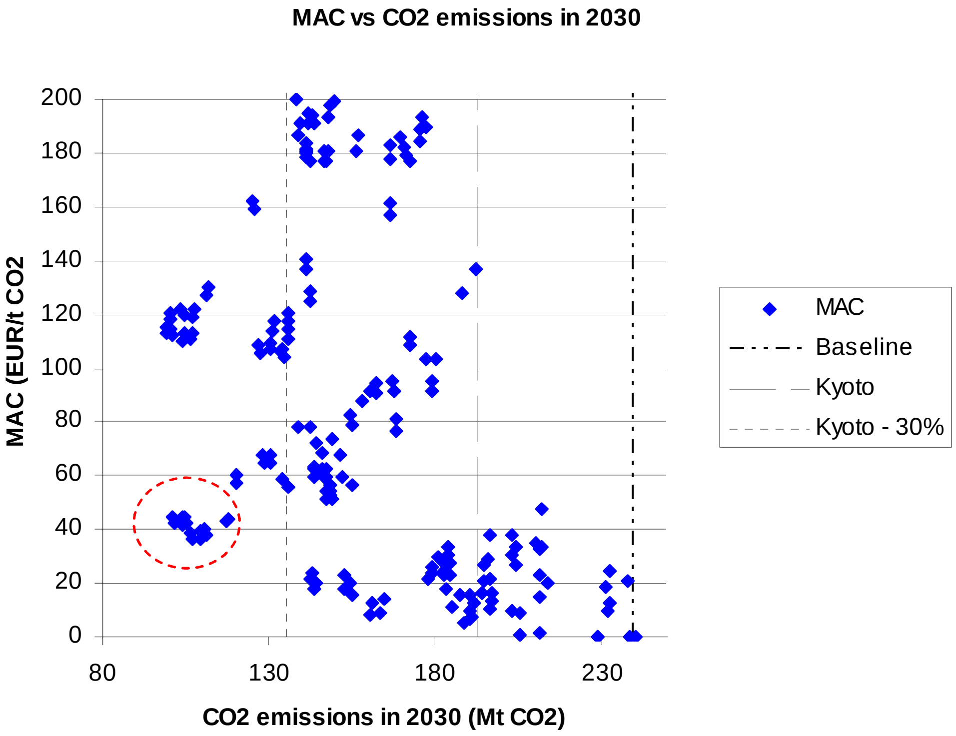

Figure 25 MAC for all scenarios with baseline demand projections and except the reduced fuel price scenario. The optimal scenarios are marked with a red circle.

Now, focusing on only the strategies, for the reference development of the uncertainties, we see that large reductions could be achieved for around 20-25 EUR/t CO_2, see Figure 26. The 'best' scenarios are a combination of different strategies. The effect of a single strategy on the MAC is included in the figure.

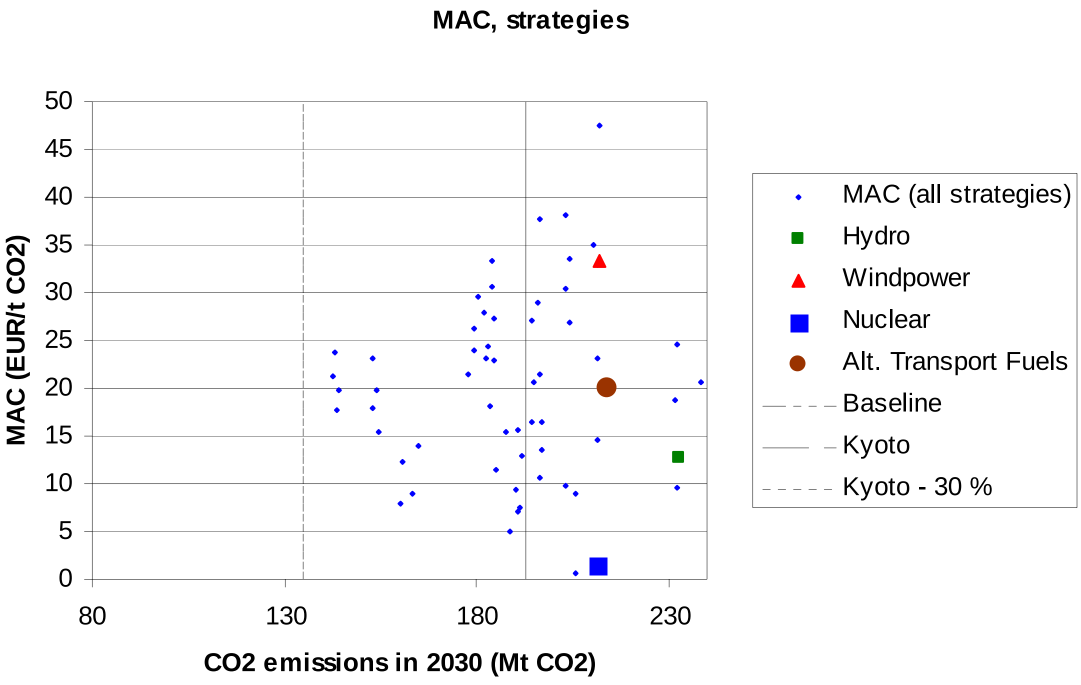

Figure 26 MAC for the different strategies at reference development of the uncertainties.

5.5 Conclusions and recommendations for further work

Based on Figure 25 and Figure 26 we see that increased use of biomass, both for stationary and transport, combined with a high increase of the cost of CO_2 emissions seems to be most favourable with respect to reducing CO_2 emissions towards 2030 in a cost effective way.

Looking at the alternative strategies for electricity supply analysed it is evident that no single strategy could reduce the emissions to below 130 Mt CO_2, equally 30% below the Kyoto target, without increasing the cost of CO_2 emissions. Here, the time frame of the analysis could be an important factor. Towards 2030 the existing system is still dominant and hence new renewables, nuclear and CCS will not necessarily replace the existing power producers unless the cost of CO_2 is increased. By expanding the time frame towards, say 2050, the existing system would not play such an important role by the end of the period and thus new capacity would make a larger impact on the system.

In a traditional MARKAL analysis we analyse typically 3-6 policy scenarios and analyse the effect of these on renewables, CO_2 emissions etc. Here, we have analysed 1152 scenarios which is a combination between strategies and uncertainties. This methodology has shown that it may gain insight that we can not necessarily achieve by analysing only a few scenarios. Firstly, we have shown that by combining the strategies analysed here we could reduce the emissions significantly for a low cost. Further, increasing the amount of biomass seems to be a robust strategy, i.e. effective for all future uncertainties. Secondly, only focusing of the strategies are not enough if we are want to reduce the emissions to below 100 Mt CO_2 which is around 50% of today' s level.

In this report we have focused on the cost and emissions only. Looking at scenarios for sustainable development we definitely would need more parameters, for example the amount of renewables, to identify the 'optimal scenarios' and future policy recommendations.

In Appendix 2 selected results for each country are presented for the reference scenario and a low emission scenario.

6 References

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Appendix 1 Description of strategies

Windpower

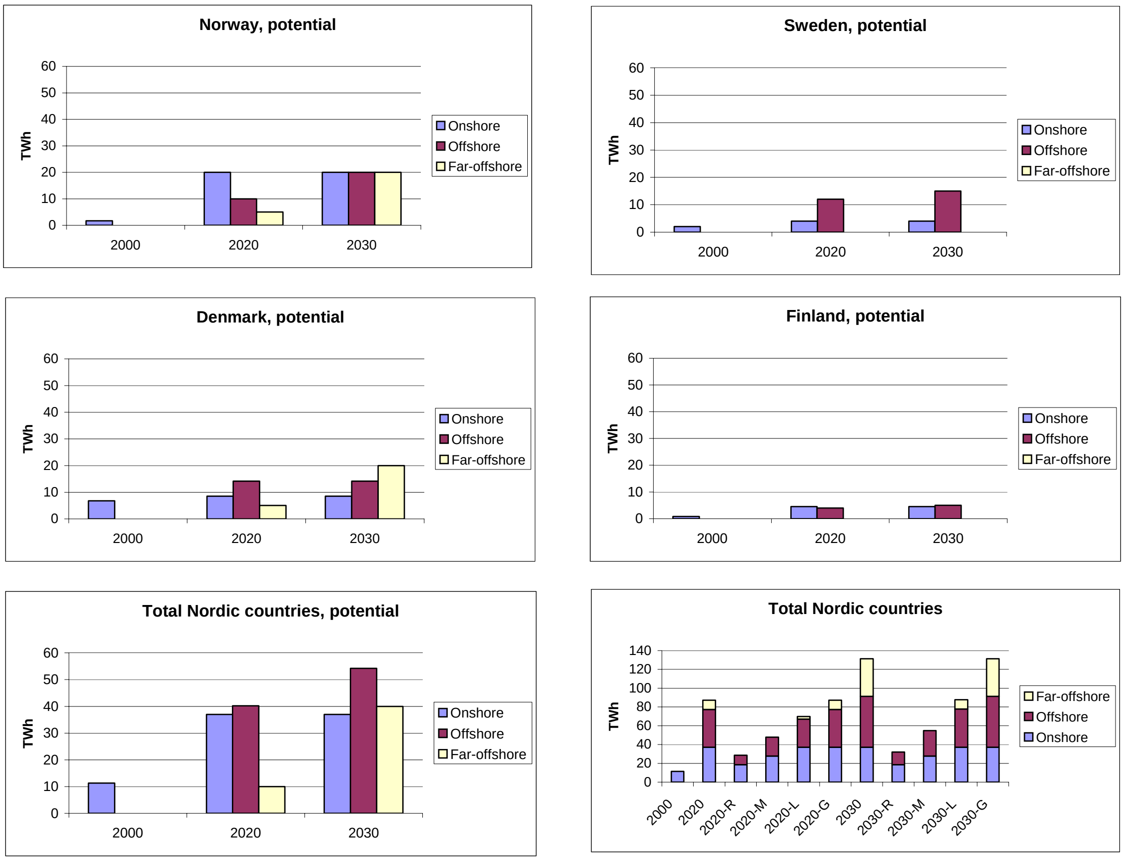

Figure 27 Potential for windpower in the Nordic model and scenarios

Table 9 Description of strategies for windpower

Scenarios/case	Code	Description
Reference onshore and offshore	R	50% onshore 25 offshore
Moderate onshore and moderate offshore	M	75% onshore 50 % offshore
Large onshore and moderate offshore	L	100% onhore 75 % offshore 25% far-offshore
Large onshore and offshore	G	Complete potential[5]

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[5] The potential for far offshore wind turbines in deep waters is limited to 20 TWh based on [15]

Hydropower

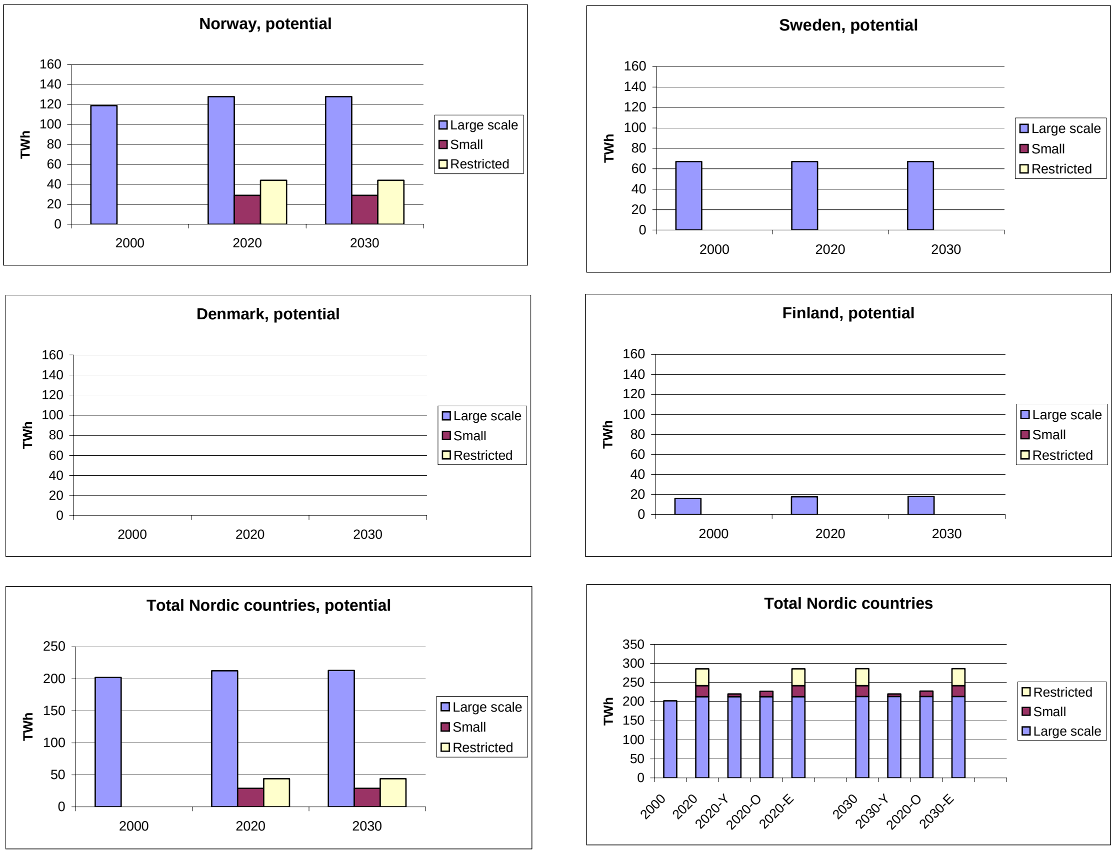


Figure 28 Potential for hydropower by country in the scenarios.

Table 10 Description of strategies for hydro power.

Scenarios/case	Code	Description
Reference	Y	100% large 25% small
Some more hydro	O	100% large 50% small
'We love hydro'	E	100% large 100% small 100% restricted areas

Appendix 2 Country specific results

This appendix contains detailed results for the baseline scenario and two low emissions scenarios. The scenarios are selected based on the trade-off analysis presented at the workshop May 31, 2007.

In addition to the baseline scenario we have selected a scenario with maximum on all strategies except CCS and a scenario with a lot of nuclear. In the following these two scenarios have reference demand growth, high fuel- and CO_2 -prices. These three scenarios will be further analysed with the MPS model during autumn 2007. In Table 11 a short description of the scenarios are given.

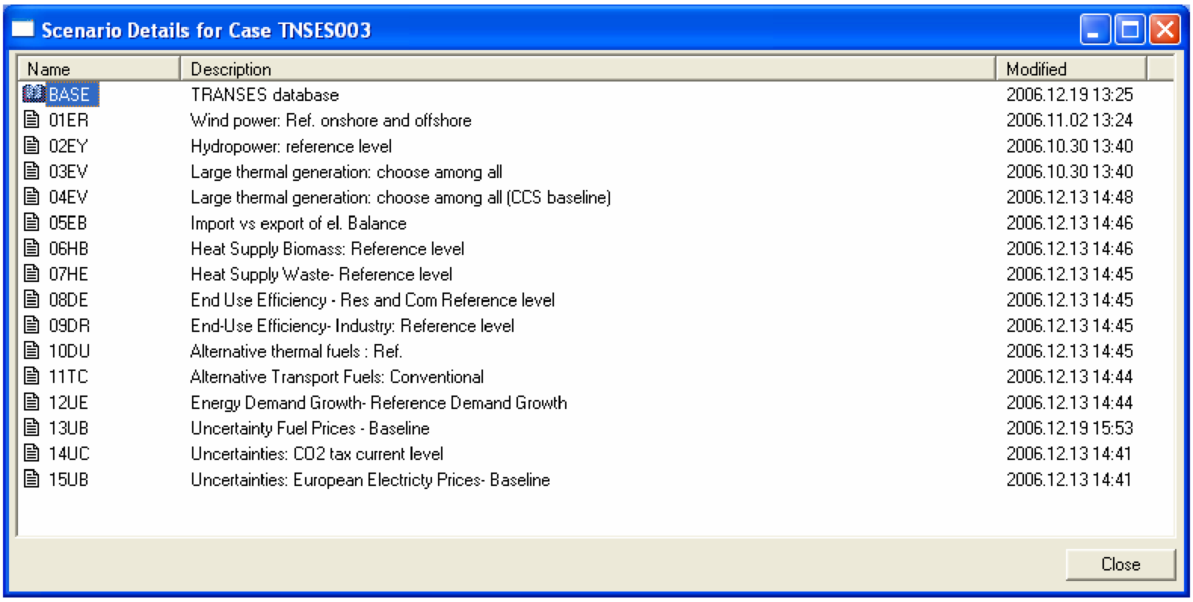
Table 11 Description of the three selected scenarios. The short code refers to the code used in the Trade-Off analysis.

MARKAL code	Short code	Description
TNSES003	RYVA-BC-EBU	Baseline
TNSES138	RYGA-KB-EHA	A lot of nuclear+ biomass and alt. Transport fuels. Reference demand growth and high fuel and CO2- prices.
TNSES714	GEGA-KB-EHA	All strategies maximised except CCS option. Reference demand growth and high fuel and CO2- prices.

Input data for scenarios

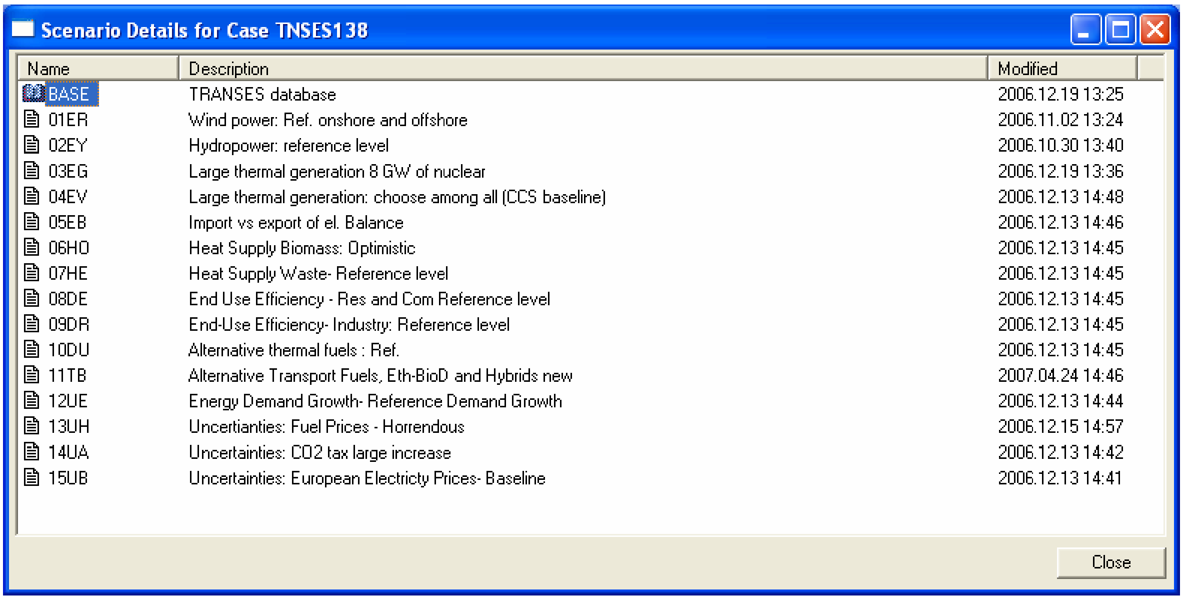
In Table 12 the scenario details for the three scenarios are listed:

Table 12 Description of the three scenarios.



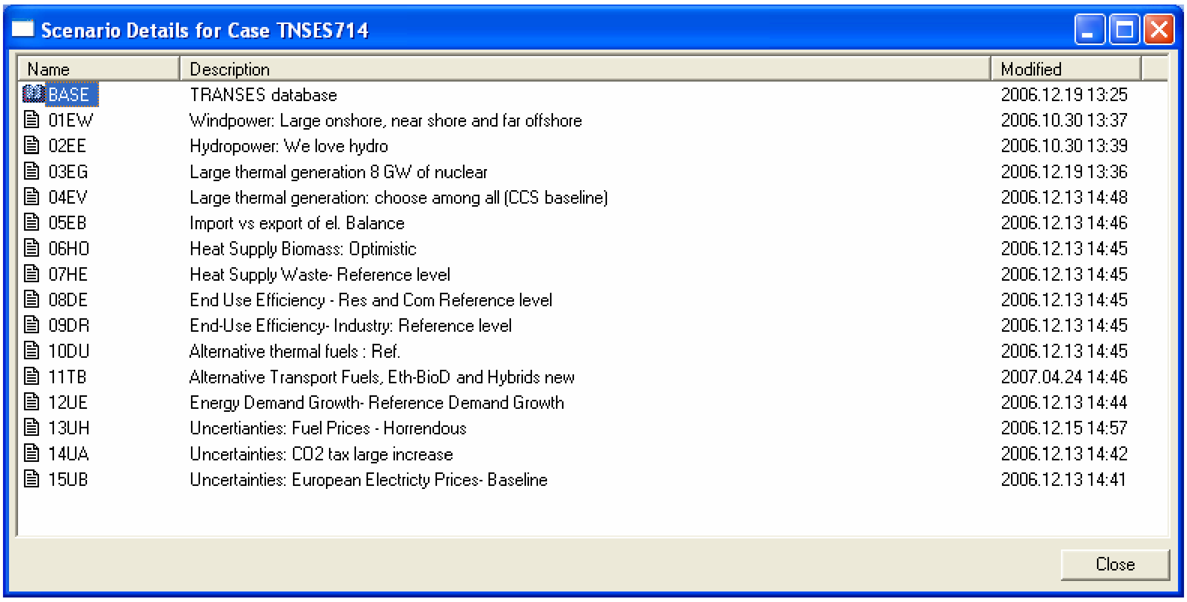
Scenario Details for Case TNSES003

Name	Description	Modified
BASE	TRANSES database	2006.12.19 13:25
01ER	Wind power: Ref. onshore and offshore	2006.11.02 13:24
02EY	Hydropower: reference level	2006.10.30 13:40
03EV	Large thermal generation: choose among all	2006.10.30 13:40
04EV	Large thermal generation: choose among all (CCS baseline)	2006.12.13 14:48
05EB	Import vs export of el. Balance	2006.12.13 14:46
06HB	Heat Supply Biomass: Reference level	2006.12.13 14:46
07HE	Heat Supply Waste- Reference level	2006.12.13 14:45
08DE	End Use Efficiency - Res and Com Reference level	2006.12.13 14:45
09DR	End-Use Efficiency- Industry: Reference level	2006.12.13 14:45
10DU	Alternative thermal fuels : Ref.	2006.12.13 14:45
11TC	Alternative Transport Fuels: Conventional	2006.12.13 14:44
12UE	Energy Demand Growth- Reference Demand Growth	2006.12.13 14:44
13UB	Uncertainty Fuel Prices - Baseline	2006.12.19 15:53
14UC	Uncertainties: CO2 tax current level	2006.12.13 14:41
15UB	Uncertainties: European Electricty Prices- Baseline	2006.12.13 14:41



Scenario Details for Case TNSES138

Name	Description	Modified
BASE	TRANSES database	2006.12.19 13:25
01ER	Wind power: Ref. onshore and offshore	2006.11.02 13:24
02EY	Hydropower: reference level	2006.10.30 13:40
03EG	Large thermal generation 8 GW of nuclear	2006.12.19 13:36
04EV	Large thermal generation: choose among all (CCS baseline)	2006.12.13 14:48
05EB	Import vs export of el. Balance	2006.12.13 14:46
06HO	Heat Supply Biomass: Optimistic	2006.12.13 14:45
07HE	Heat Supply Waste- Reference level	2006.12.13 14:45
08DE	End Use Efficiency - Res and Com Reference level	2006.12.13 14:45
09DR	End-Use Efficiency- Industry: Reference level	2006.12.13 14:45
10DU	Alternative thermal fuels : Ref.	2006.12.13 14:45
11TB	Alternative Transport Fuels, Eth-BioD and Hybrids new	2007.04.24 14:46
12UE	Energy Demand Growth- Reference Demand Growth	2006.12.13 14:44
13UH	Uncertianties: Fuel Prices - Horrendous	2006.12.15 14:57
14UA	Uncertainties: CO2 tax large increase	2006.12.13 14:42
15UB	Uncertainties: European Electricty Prices- Baseline	2006.12.13 14:41

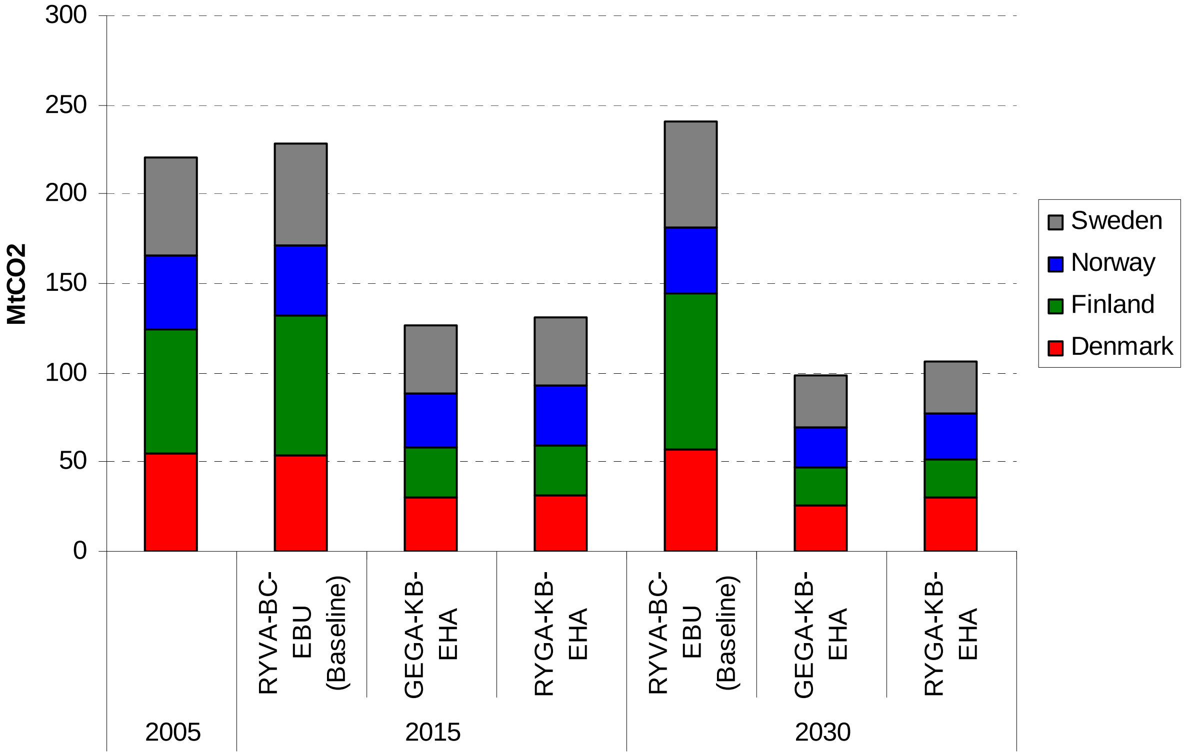


Scenario Details for Case TNSES714

Name	Description	Modified
BASE	TRANSES database	2006.12.19 13:25
01EW	Windpower: Large onshore, near shore and far offshore	2006.10.30 13:37
02EE	Hydropower: We love hydro	2006.10.30 13:39
03EG	Large thermal generation 8 GW of nuclear	2006.12.19 13:36
04EV	Large thermal generation: choose among all (CCS baseline)	2006.12.13 14:48
05EB	Import vs export of el. Balance	2006.12.13 14:46
06HO	Heat Supply Biomass: Optimistic	2006.12.13 14:45
07HE	Heat Supply Waste- Reference level	2006.12.13 14:45
08DE	End Use Efficiency - Res and Com Reference level	2006.12.13 14:45
09DR	End-Use Efficiency- Industry: Reference level	2006.12.13 14:45
10DU	Alternative thermal fuels : Ref.	2006.12.13 14:45
11TB	Alternative Transport Fuels, Eth-BioD and Hybrids new	2007.04.24 14:46
12UE	Energy Demand Growth- Reference Demand Growth	2006.12.13 14:44
13UH	Uncertianties: Fuel Prices - Horrendous	2006.12.15 14:57
14UA	Uncertainties: CO2 tax large increase	2006.12.13 14:42
15UB	Uncertainties: European Electricty Prices- Baseline	2006.12.13 14:41

CO_2 emissions pr country

In Figure 29 the CO_2 emissions for the each country is shown.



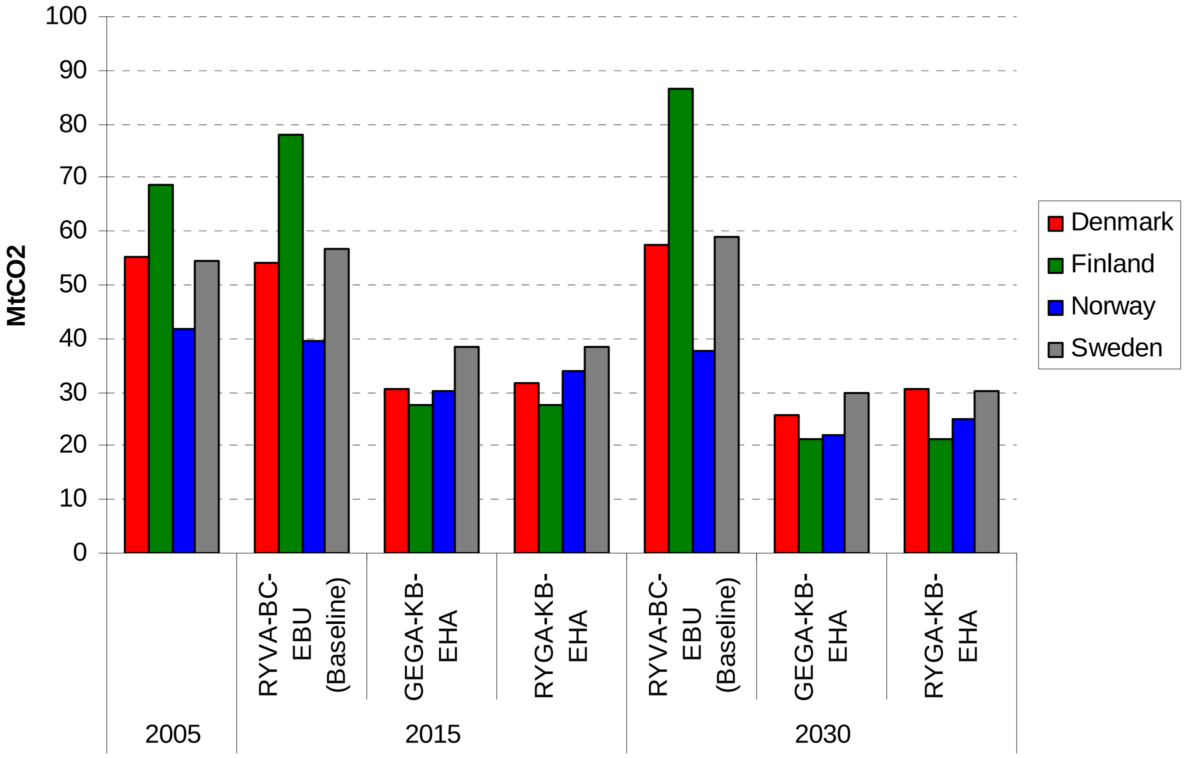


Figure 29 CO_2 emissions by country for the three scenarios.

Electricity Production

Figure 30 shows electricity production in the three scenarios for the Nordic region. In Figure 31 to Figure 34 results for each separate country are shown.

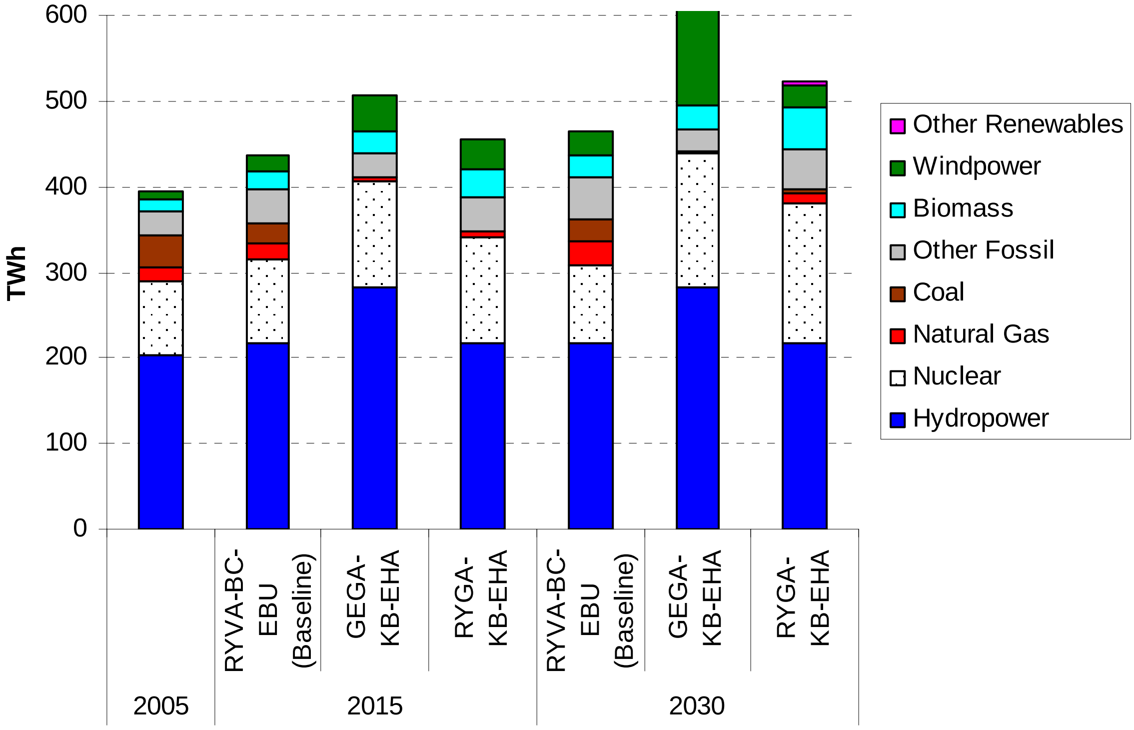


Figure 30 Electricity production (TWh) in the Nordic region in the three scenarios.

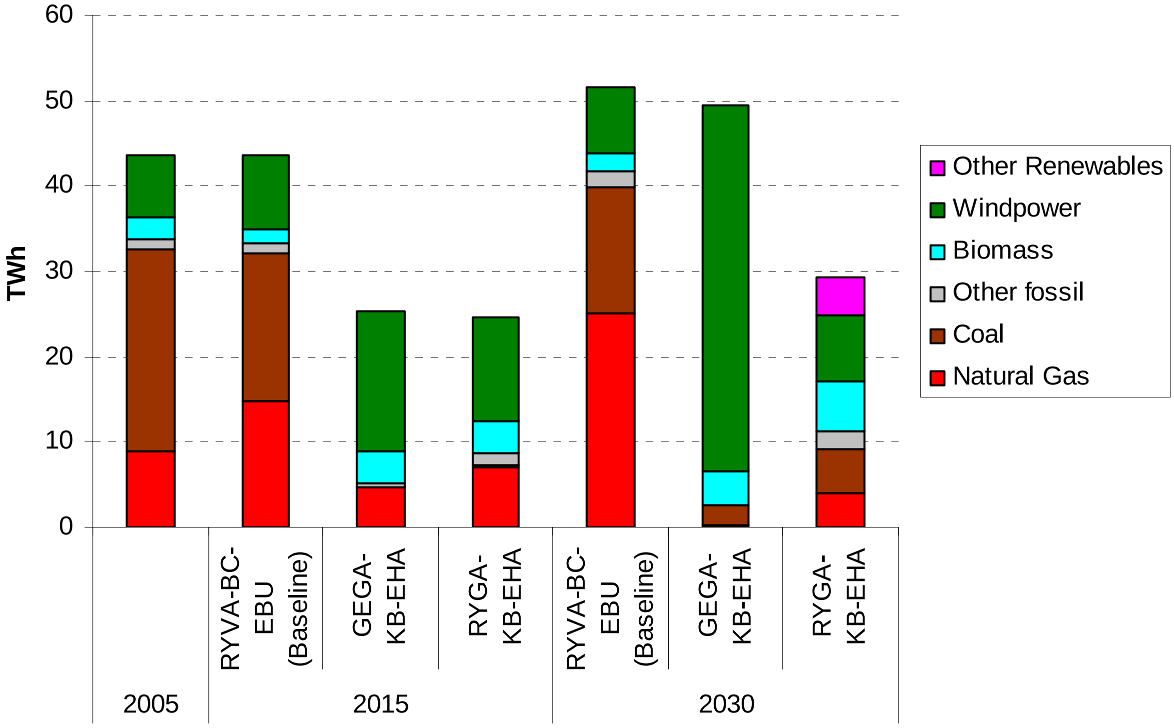


Figure 31 Electricity production in Denmark.

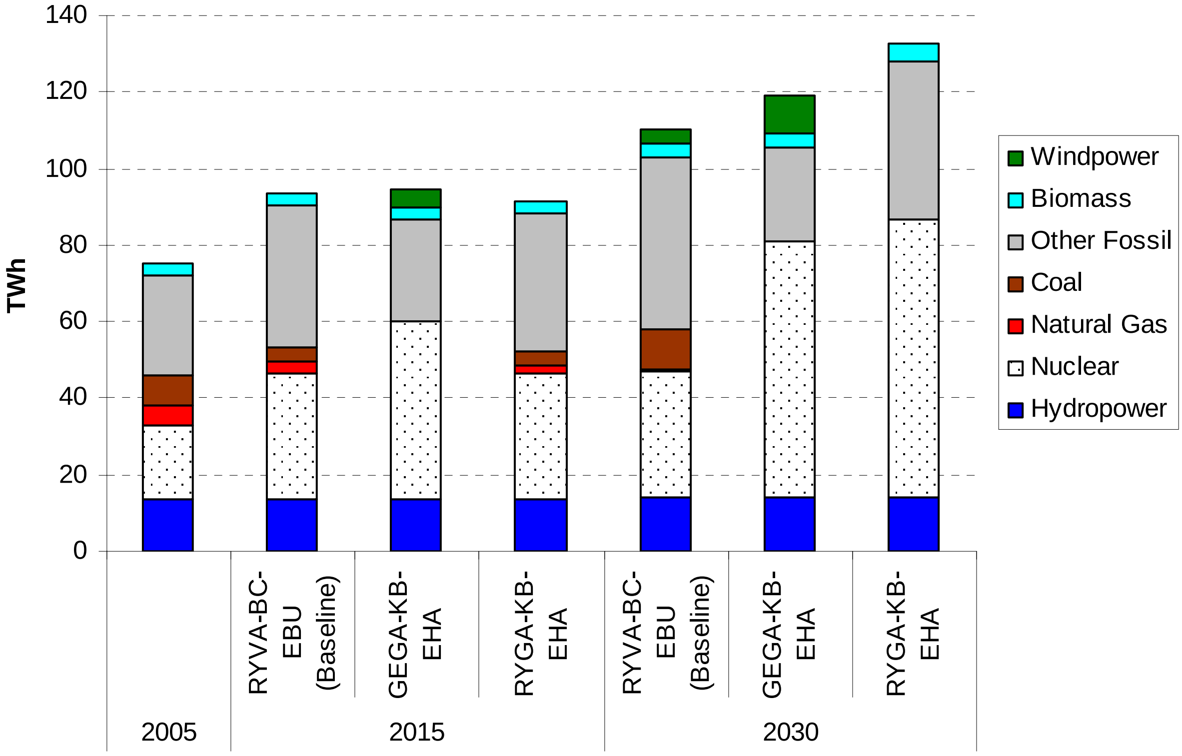


Figure 32 Electricity production in Finland.

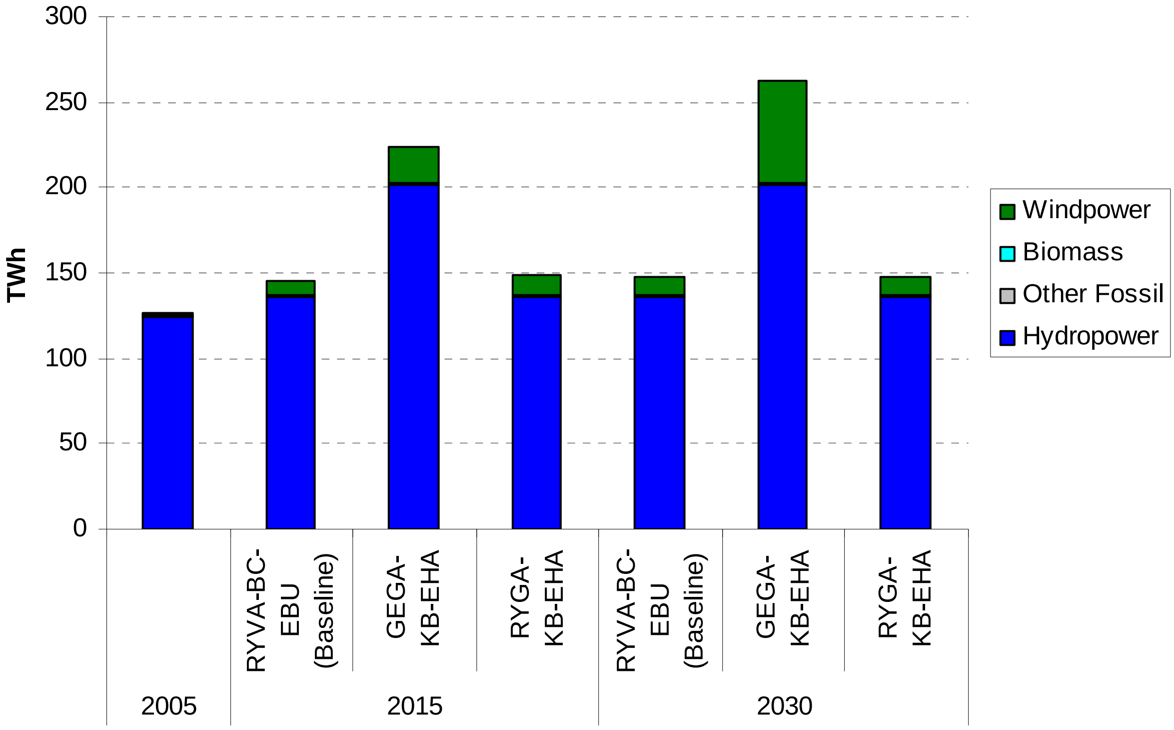


Figure 33 Electricity production in Norway.

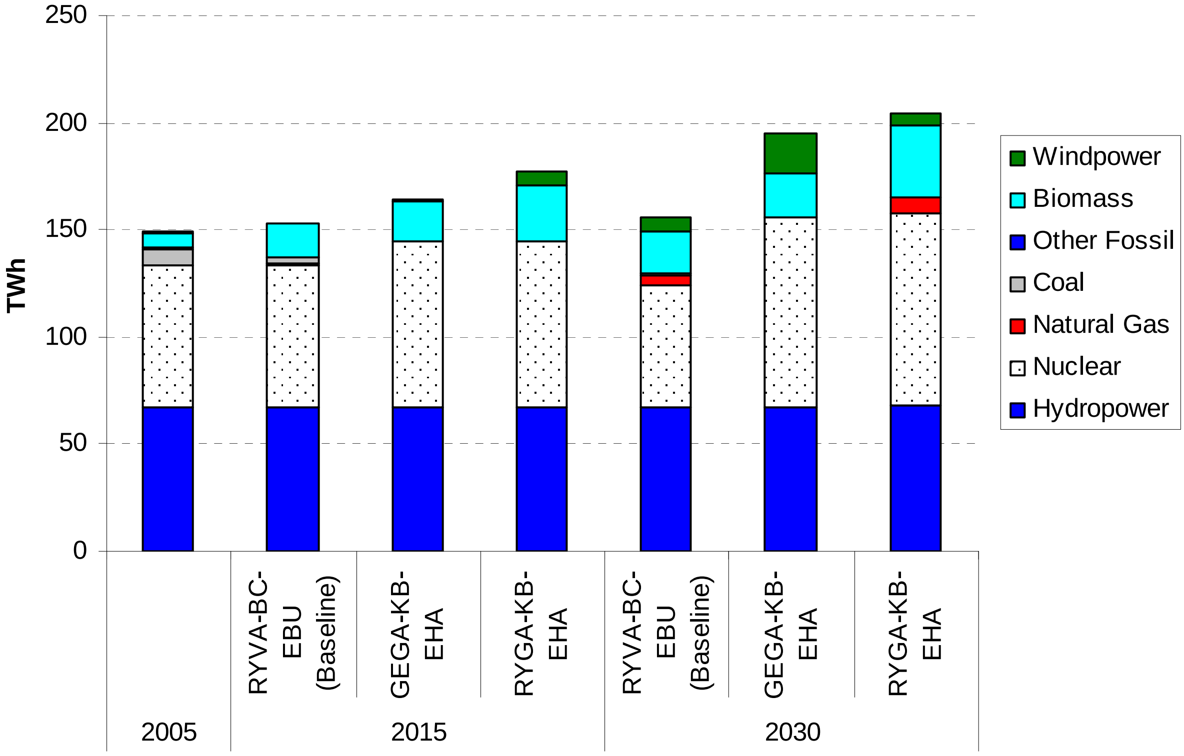


Figure 34 Electricity production in Sweden.

Fuel Use

Figure 35 shows the fuel use in the three scenarios for the Nordic region. In Figure 36 to Figure 39 results for each separate country are shown.

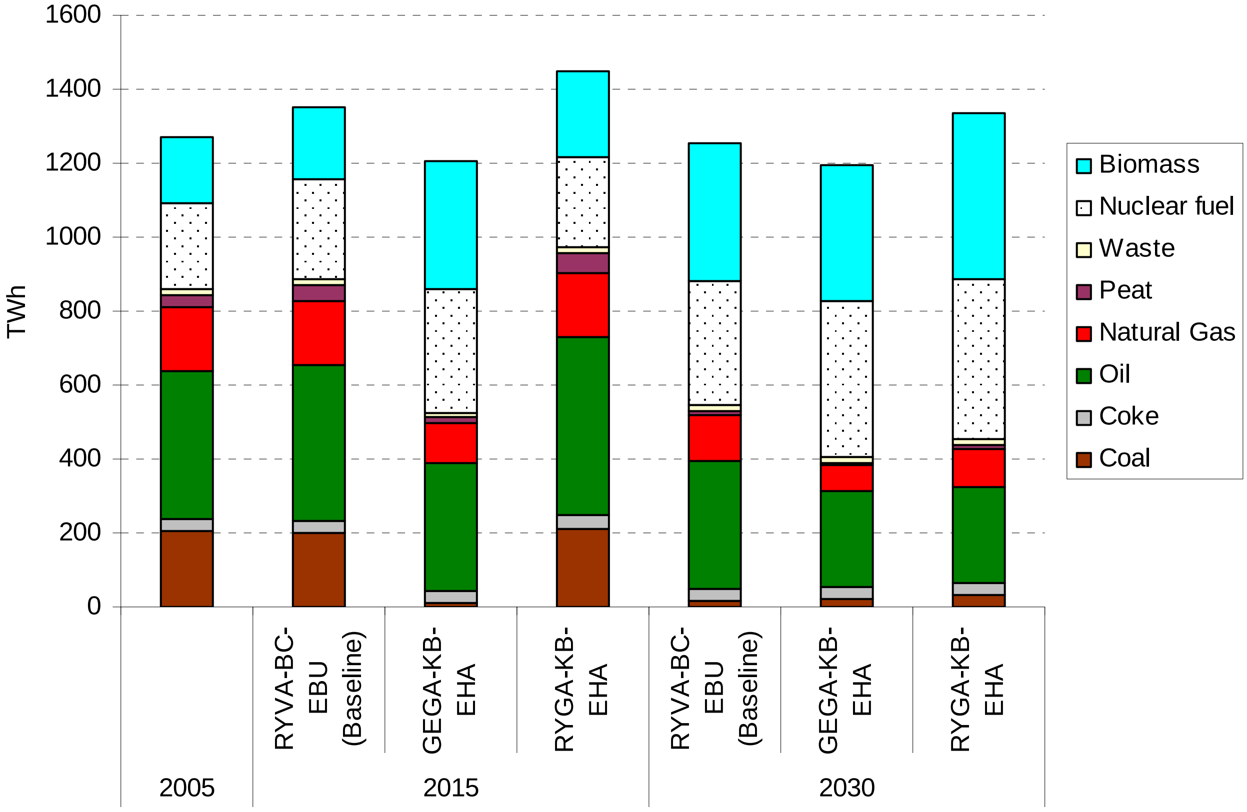


Figure 35 Fuel use in the Nordic region.

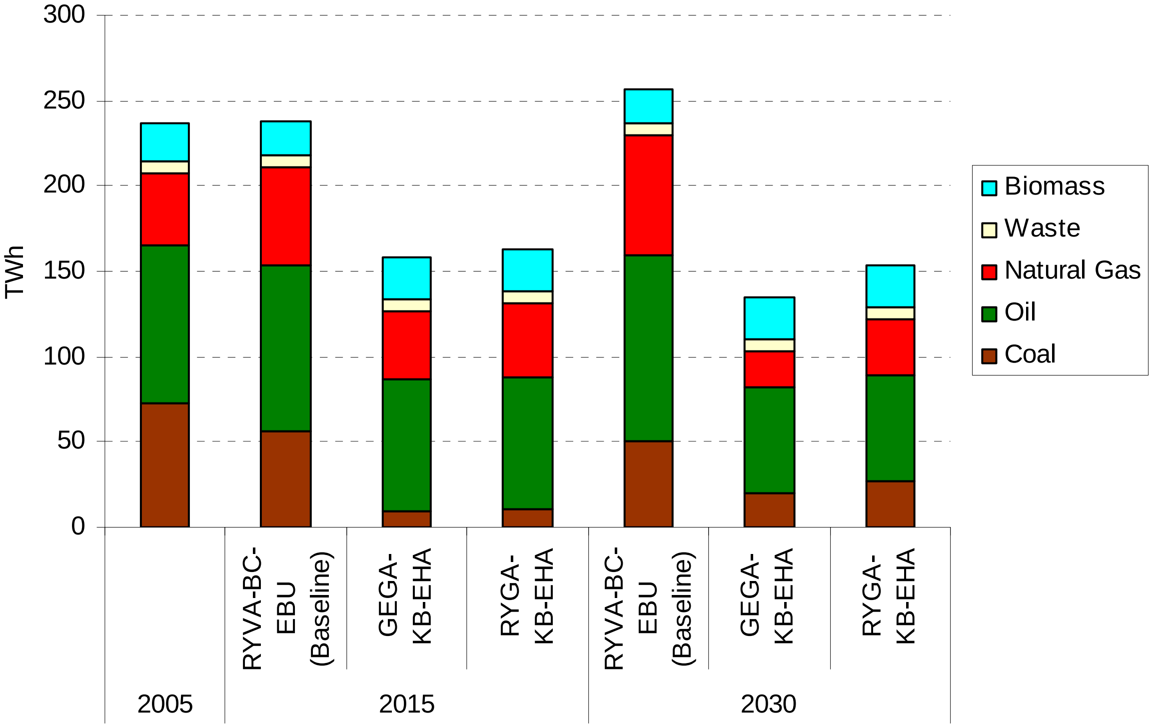


Figure 36 Fuel use in Denmark.

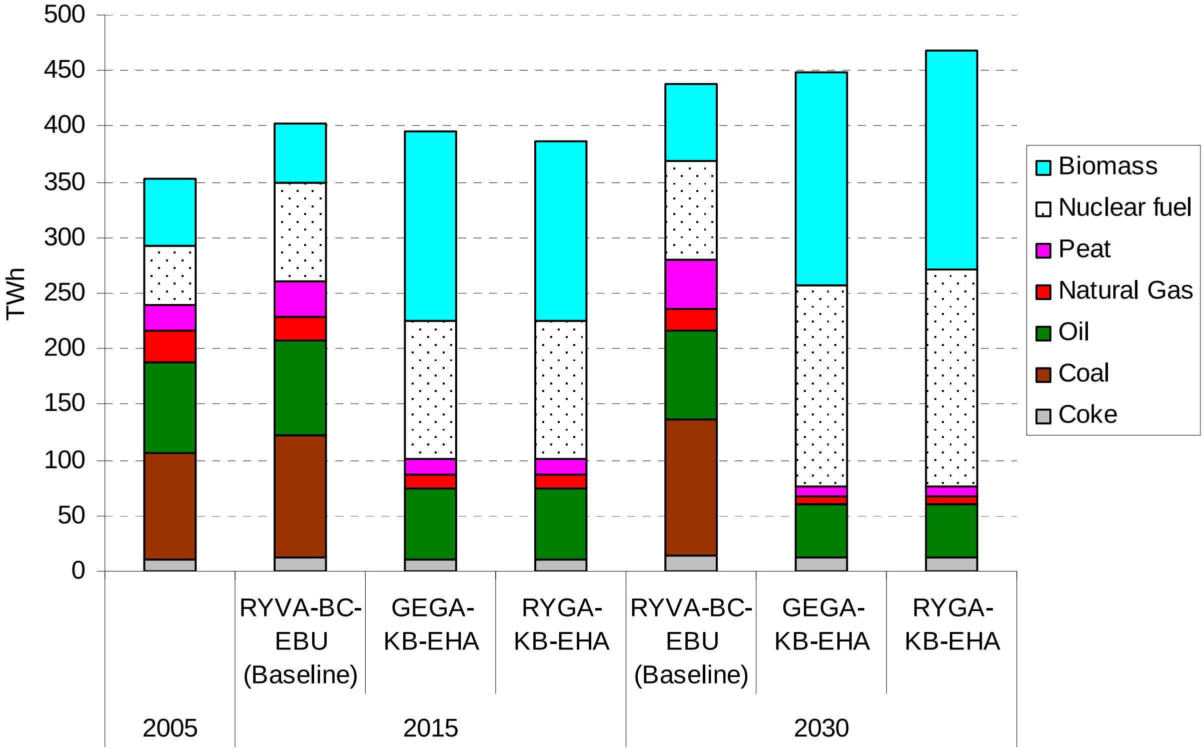


Figure 37 Fuel use in Finland.

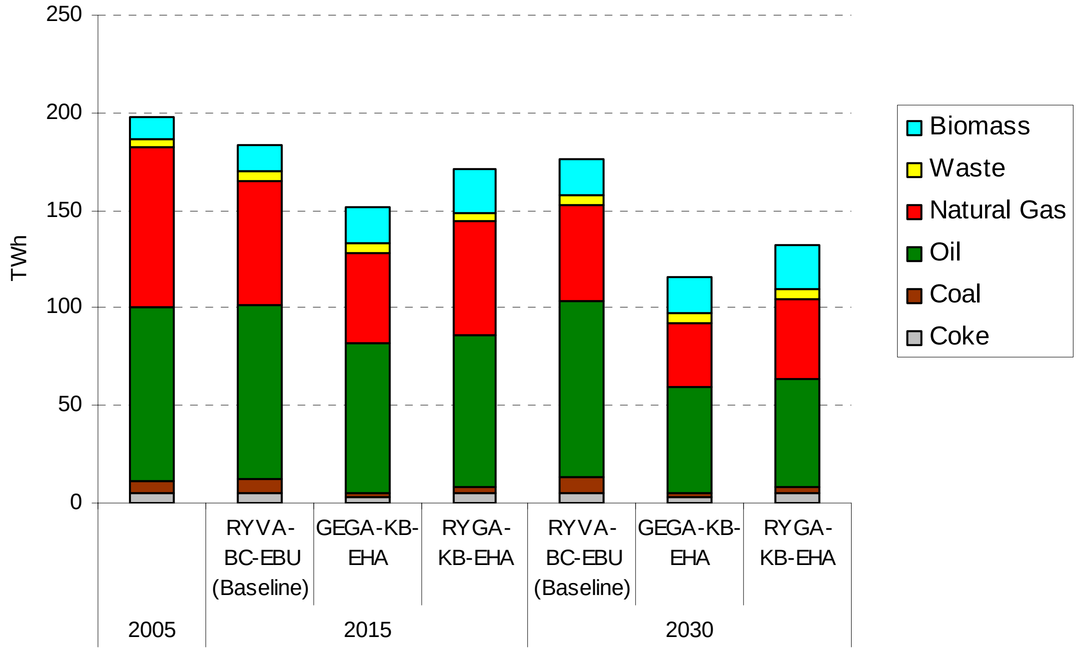


Figure 38 Fuel use in Norway.

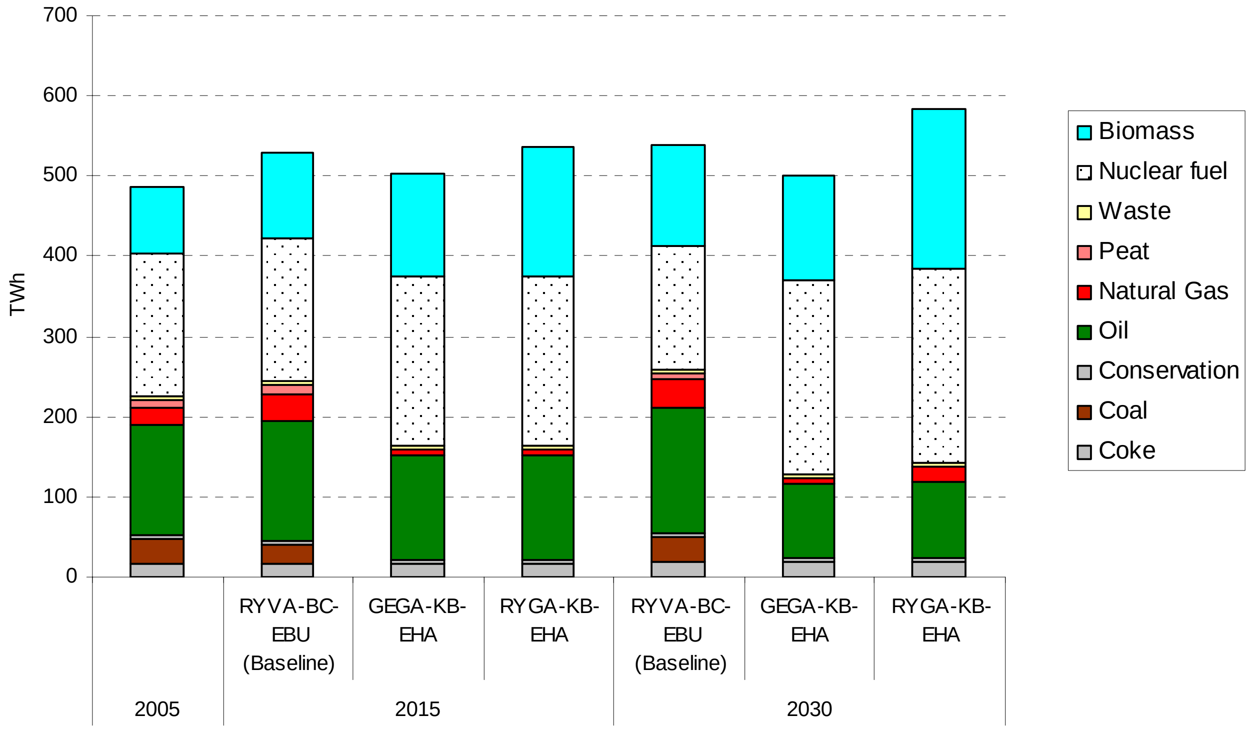


Figure 39 Fuel use in Sweden.

Use of electricity and district heating

Figure 40 shows the electricity production in the three scenarios for the Nordic region. In Figure 41 to Figure 44 results for each separate country are shown.

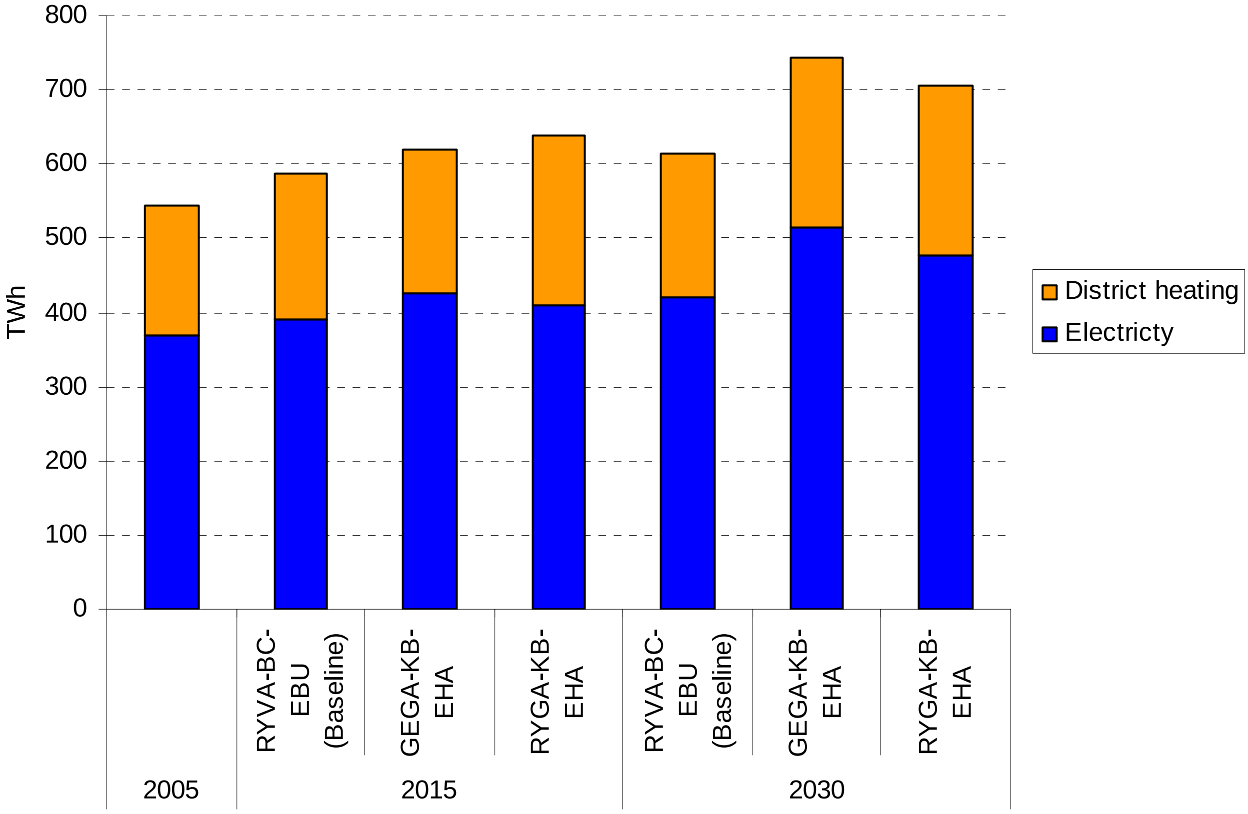


Figure 40 Use of electricity and district heating in the Nordic region.

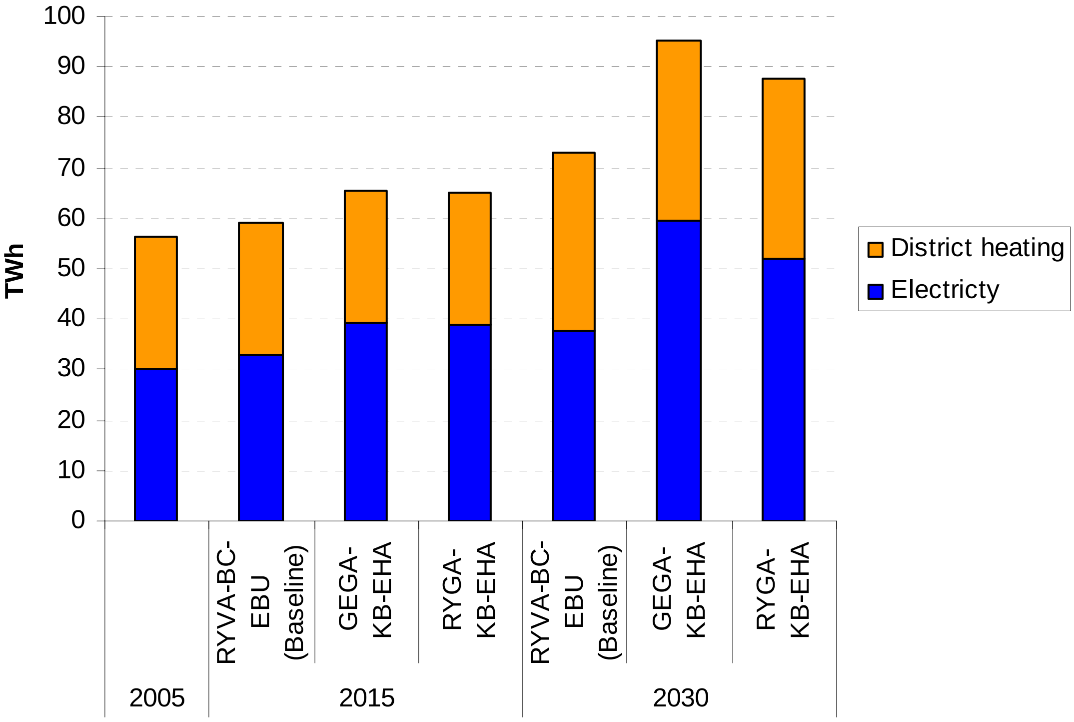


Figure 41 Use of electricity and district heating in Denmark.

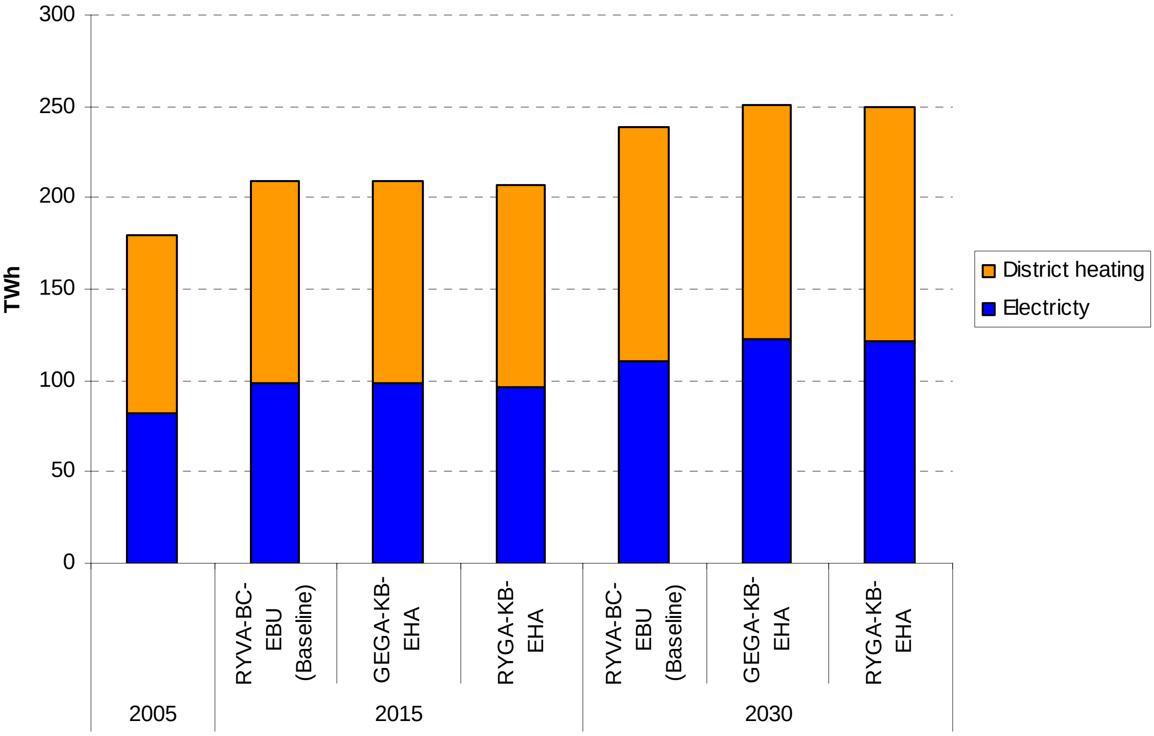


Figure 42 Use of electricity and district heating in Finland.

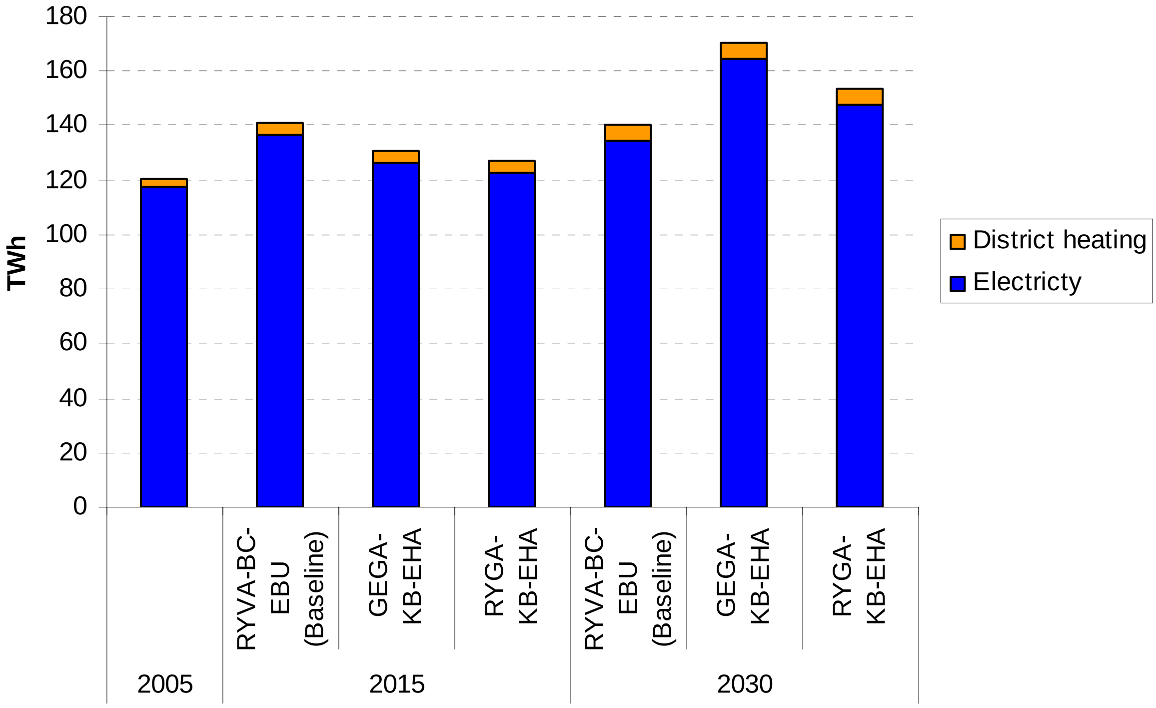


Figure 43 Use of electricity and district heating in Norway.

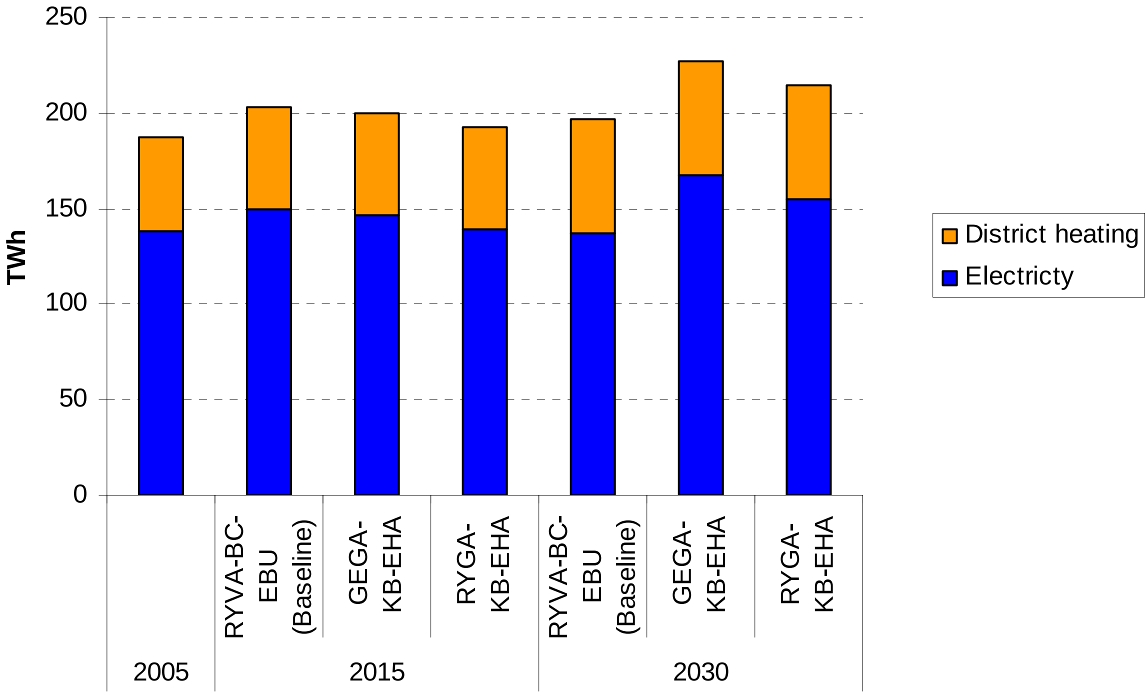


Figure 44 Use of electricity and district heating in Sweden.

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