



The Impact of Renewables and Energy Efficiency on Greenhouse Gas Emissions

The Impact of Renewables and Energy Efficiency on Greenhouse Gas Emissions

TemaNord 2007:558

© Nordic Council of Ministers, Copenhagen 2007

ISBN 978-92-893-1538-8

Print: Ekspresen Tryk & Kopicenter

This publication can be ordered on www.norden.org/order. Other Nordic publications are available at www.norden.org/publications

Nordic Council of Ministers

Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0200
Fax (+45) 3396 0202

Nordic Council

Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0400
Fax (+45) 3311 1870

www.norden.org

Nordic co-operation

Nordic cooperation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and three autonomous areas: the Faroe Islands, Greenland, and Åland.

Nordic cooperation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

Nordic cooperation seeks to safeguard Nordic and regional interests and principles in the global community. Common Nordic values help the region solidify its position as one of the world's most innovative and competitive.

Content

Preface.....	7
Summary	9
1. Introduction	13
2. Historical GHG emissions	15
2.1 Total Nordic GHG emissions 1990–2004	15
2.2 GHG emissions in Denmark 1990–2004.....	16
2.3 GHG emissions in Finland 1990–2004.....	17
2.4 GHG emissions in Iceland 1990–2004.....	18
2.5 GHG emissions in Norway 1990–2004.....	19
2.6 GHG emissions in Sweden 1990–2004	20
3. Historical CO ₂ emissions.....	23
3.1 Total Nordic CO ₂ emissions 1990–2004	23
3.2 CO ₂ emissions in Denmark 1990–2004.....	24
3.3 CO ₂ emissions in Finland 1990–2004	25
3.4 CO ₂ Emissions in Iceland 1990–2004	26
3.5 CO ₂ emissions in Norway 1990–2004.....	27
3.6 CO ₂ Emissions in Sweden 1990–2004	29
4. Impact of renewables and energy efficiency on emissions from stationary energy use	31
4.1 Energy supply: Fuel mix and penetration of renewables	31
4.1.1 Denmark.....	31
4.1.2 Finland	35
4.1.3 Norway.....	39
4.1.4 Sweden.....	41
4.2 Energy consumption: Energy efficiency	45
4.2.1 A few words about measuring energy efficiency	45
4.2.2 Energy intensity and GDP.....	46
4.2.3 Energy intensity in industries	48
4.2.4 Energy intensity in the service sector.....	50
4.2.5 Energy intensity in the household sector.....	51
4.2.6 Energy efficiency indicators by country.....	53
4.2.7 Comments	61
4.3 The effect of improved energy efficiency 1990–2005.....	61
4.3.1 Modelling assumptions	62
4.3.2 Model results.....	63
5. Scenarios towards 2015	67
5.1 The impact of CO ₂ pricing and renewables support	68
5.1.1 CO ₂ emissions	68
5.1.2 The impact of different CO ₂ prices	70
5.1.3 Electricity production.....	70
5.1.4 District heating supply	72
5.1.5 Energy use.....	73
5.2 The effect of energy conservation measures.....	73
References.....	77
Abbreviations	78

Norwegian summary	79
Appendix 1: Overview over relevant policy measures.....	83
Energy and carbon taxation	83
Energy efficiency measures	90
Support to renewables.....	92
Appendix 2: MARKAL-Nordic	97
The MARKAL-NORDIC model	99

Preface

The Climate Change Policy Working Group of the Nordic Council of Ministers is a co-operation between energy and environmental division under the Nordic Council of Ministers. The most important task of the Nordic Group for Climate Change Issues is to look into international climate change policy issues linked to the UN Framework Convention on Climate.

The Climate Change Policy Working Group has commissioned ECON to prepare this report “The Impact of Renewables and Energy Efficiency on Greenhouse Gas Emissions”. The report analyses the impact of renewables, CO₂ pricing and energy efficiency improvements on CO₂ emissions from stationary energy use in the Nordic countries except Iceland.

The Climate Change Policy Working Group does not necessarily share the views and conclusions of the report.

Oslo, June 2007

Jon D. Engebretsen
Chairman

Summary

Abstract

This report analyses the impact of renewables, CO₂ pricing and energy efficiency improvements on CO₂ emissions from stationary energy use in the Nordic countries except Iceland. Electricity and heat production (and use) account for the largest emissions from the Nordic economies. The analysis shows that CO₂ emissions from 1990 to 2005 could have been as much as 30–50% higher without the penetration of renewables in the energy system and the improvement in the energy intensity of GDP. Looking ahead, it is clear that both the EU ETS and renewables policies may have a significant impact on CO₂ emissions. For moderate CO₂ prices, the overlap between the two types of measures is not found to be substantial, although both yield significant CO₂ emission reductions applied separately. This is because the measures to some extent apply to different sectors and uses. The effectiveness of energy efficiency improvements is also found to have a significant effect on emissions. Measures leading to a reduction in electricity consumption are found to be more effective than measures leading to a reduction in heat consumption.

Background and problem statement

The main purpose of the project is to analyze the impact of renewable energy and energy conservation on CO₂ emissions from the Nordic countries. In accordance with the request for proposals, the project consists of three main parts:

- The historical development in GHG emissions from the Nordic countries from 1990 up till the present. In which sectors has the development been positive, and where has it been negative? What are the likely causes?
- What impact has the development in stationary energy demand had on the development of CO₂ emissions? Particular attention is to be given to the role of renewable energy use and energy conservation in this respect.
- What role has CO₂ taxes and quota systems played for the development of renewables and energy conservation? What is the possible development towards 2015? What is the impact of other policy measures?

Main conclusions

Development in GHG emissions

Total GHG emissions in the Nordic countries increased 4.5% from 1990 to 2004. In 2004 the total emissions in CO₂ equivalents were 277.6 Mtons. This is 8.4% higher than the Kyoto target of 255.9 Mtons.

While 2004 emissions from Finland, Denmark and Norway were above the target, Iceland and Sweden have emissions well below their targets. Some of the “overshooting” emissions from Finland and Denmark are explained by low precipitation in 2003, leading to lower than normal hydro power generation in 2003 and 2004. Apart from the energy sector, which shows a varying picture, emissions from transport are generally increasing, while emissions from agriculture and waste are decreasing.

Development in CO₂ emissions

Total CO₂ emissions from transport, energy and industry in the Nordic countries were increased by 18.4% between 1990 and 2004.

The energy and transport sectors are the largest emitters. There are however, large differences in the composition of emissions between the Nordic countries. The reason is differences in energy structure and fuel mix in electricity and district heating.

Emissions from the energy sector vary substantially between years because of variations in inflow to the hydro power stations in Norway, Sweden and Finland, plus variations in temperatures affecting heat demand. The redundancy in the hydro reservoirs is made up for by increased fossil fuelled electricity consumption in Denmark and Finland, and to some extent by increase use of oil.

The largest increases in emissions are found in the energy sector in Norway, explained by the increase in extraction of oil and gas on the Norwegian Continental Shelf, and in the industry sector in Iceland, which have had significant investments in new energy intensive industries in recent years.

In Denmark emissions from the energy sector has declined, and it is clearly due to significant investments in renewable energy sources in electricity (wind) and district heating (bio fuels).

Impact of renewables

We find a clear effect of the penetration of renewables in the Nordic market. Emissions from the Danish energy sector would have been up to 8 Mtons higher without the investments in renewable capacity. Even in final energy demand in the residential sector and commercial sector, the

use of renewables instead of mainly oil products, has reduced CO₂ emissions by 1 mill. ton.

We find similar effects in Finland, but there the penetration of renewables (bio fuels) is still rather modest. In the residential sector the use of oil has steadily declined.

In Sweden there has been a significant shift from fossil fuels to bio fuels in district heating because of CO₂ taxation, and in combined heat and power due to the electricity certificate scheme. This has had a significant impact on CO₂ emissions. If the bio fuelled CHP and DH schemes built after 1990 had used coal instead, CO₂ emissions from the energy sector would have been three times higher than today. In the residential and commercial sectors, oil has been gradually replaced by district heating and electricity.

Impact of energy efficiency improvements

Measured in terms of energy intensity of the economies, energy efficiency has improved in all the Nordic countries, except Iceland, in the period investigated, i.e. the energy needed to produce one unit of GDP has declined. The development differs between the countries due to structural differences, but studying the development in different sectors, we find that the development is largely in line with the development in other countries (IEA, EU-15).

Energy efficiency improvements result from structural changes in the economies, price effects, productivity improvements, technical development and conscious energy efficiency efforts. It is not possible to separate the effect of trends from the effects of policy measures.

A model analysis of the effect of energy efficiency improvements, show that without the decline in energy intensities, CO₂ emissions from the Nordic area, except Iceland, would have been 30–50% higher than today. This is the result when we compare a simulation of the actual development with a case where the GDP and energy use growth rates are the same (no structural changes and no energy efficiency improvements). The effect on emissions depends on the assumption about other policy measures such as taxation and support for renewables.

Looking ahead at the impact of energy efficiency improvements for the next 10 years, we have analyzed two cases; one where energy efficiency improvements are targeted at electricity consumption, and one where energy efficiency improvements are targeted at heat consumption. We find that CO₂ emissions are reduced in both cases, but that in terms of emissions reductions per energy unit saved, reduced electricity consumption is more effective. This is because reductions in heat demand reduce the use of a mix of fuels, while reductions in electricity demand to a larger extent reduces the use of coal in electricity generation.

The role of CO₂ taxation and quotas

The impact of CO₂ taxation and quotas is investigated using a set of scenarios with different mixes of policy instruments. The main conclusions are:

- Without any climate policy measures at all, emissions would increase 24% to 2015, because coal would be the preferred fuel in energy production. This is the reference scenario.
- Compared to the reference scenario both a scenario with a combination current energy and CO₂ taxes and support for renewables, and a scenario with emission trading, have a significant impact on CO₂ emissions, but emissions still increase compared to 2005.
- Emission trading and taxation/renewables affect emissions differently because emission trading applies to electricity generation and industries as well.
- Emission trading has a substantial impact on emissions even if we assume that taxation/renewables policies are carried out as well. The emission reduction is only slightly reduced compared to the emission trading only case. This suggests that emission trading and taxation/renewables support are only slightly substitutes when it comes to emission reductions.
- Increasing EUA prices (from 10 to 40 €/ton) yields increasing emission reductions. In the case with a EUA price of 40 €/ton, emissions are 50% lower than in the reference case and 40% lower than in 2005.

1. Introduction

The report presents an analysis of the effect of renewables, energy taxation, energy efficiency and tradable CO₂ emission quotas on the CO₂ emissions in the Nordic countries.

In line with the issues to be discussed, chapter 2 gives an overview of total Greenhouse Gas (GHG) emissions from the Nordic countries from 1990 to 2005. The emissions are presented according to country and according to sector. Chapter 3 then describes the countries' historical CO₂ emission developments.

In chapter 4, we take a closer look at the development in the stationary energy sector, i.e. energy production and industry. First we present the development in penetration of renewable energy, and then give an overview of the development in energy efficiency. Energy efficiency indicators for the economy as a whole as well as for different sectors are presented and discussed. In order to analyse the impact of energy efficiency improvements and the penetration of renewables, a counterfactual model analysis is carried out.

In chapter 5 we analyse the development in energy use and emissions, using a multitude of different policy scenarios. The focus of the analysis is on the impact of renewables policies and CO₂ pricing, and on the effect of energy efficiency measures.

An overview of policy measures in the Nordic countries as well as a presentation of the model, MARKAL Nordic is presented in the appendix. The model is particularly suited to analyse the topic for this report since it covers all stationary energy use in the Nordic countries.

The presentation of historical emission developments covers all of the Nordic countries. Total GHG emissions are presented by sectors. All figures are excluding emissions from Land-use, Land-use Change and Forestry (LULUCF).¹ Iceland represents a very small fraction of CO₂ emissions from the Nordic countries; it does not have emissions from the energy sector, and is not connected to the Nordic electricity market. It is also not represented in the applied model. The situation in Iceland is therefore not analysed in depth in the report.

¹ All GHG figures derive from the latest countries' National Inventory Report to the UNFCCC.

2. Historical GHG emissions

2.1 Total Nordic GHG emissions 1990–2004

Total GHG emissions in the Nordic countries increased 4.5% from 1990 to 2004. In 2004 the total emissions were 277.6 Mtons. This is 8.4% higher than the Kyoto target of 255.9 Mtons.²

As shown in figure 2.1, energy related emissions account for more than 50% of the total GHG emissions over the whole time period. In 1990 energy related emissions represented 51% and in 2004 54%. Energy related emissions include all emissions deriving from stationary fuel combustion processes both in the energy industry and other industry sectors plus fugitive emissions from fuels.

The transport sector represents on average about 20% of the total GHG emissions. From 1990 its share of the total increased from 19.8% to 22% in 2004.

The remaining sectors (waste, industrial processes, solvent and other product use, agriculture and others) represent 23.7% of the total GHG emissions in 2004. These sectors show a general decrease in their GHG emission from 1990 to 2004. In total, emissions from these sectors decreased by 17%. Emissions from the waste and agricultural sectors showed the highest percentage decrease. The reduction in emissions from waste is probably due to reduced deposit of organic waste and increased recycling of plastic materials. For Norway, changes in calculation methods also play a role.³ (See <http://www.ssb.no/vis/magasinet/miljo/art-2006-02-09-01.html>)

In the years 1996 and 2003, annual emissions are relatively high compared to the surrounding years. This goes back to higher emission levels in the energy sector. The main reason for this is low precipitation and reduced electricity generation in hydro power plants. Further explanations can be found in the next chapter discussing CO₂ emission levels.

² All Kyoto targets derive from the following source: "GHG DATA 2006", GHG emission data for 1990–2004 for Annex I Parties, United Framework Convention on Climate Change

³ See <http://www.ssb.no/vis/magasinet/miljo/art-2006-02-09-01.html>

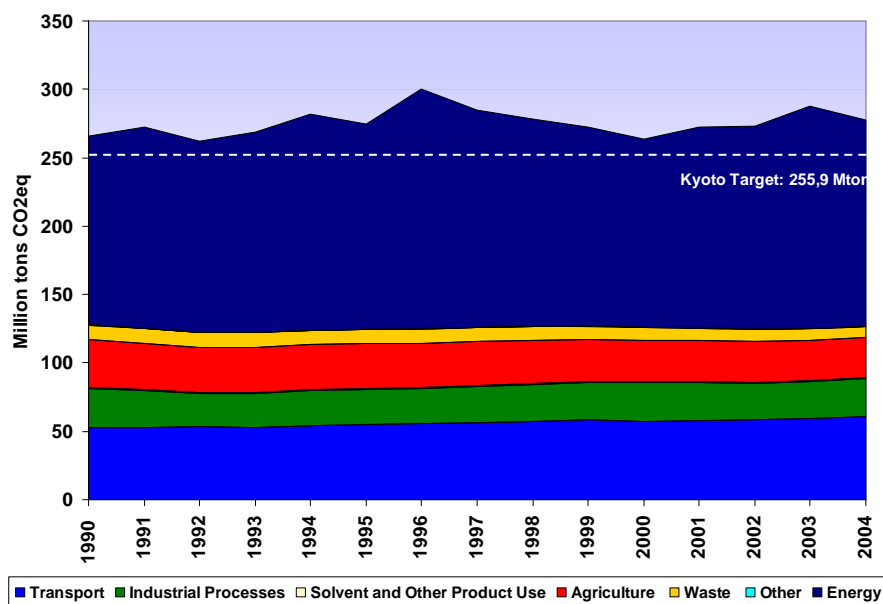


Figure 2.1 Total GHG emissions in the Nordic Countries by sector.

Source: National GHG inventory reports 2006 and 2007 to the UNFCCC

2.2 GHG emissions in Denmark 1990–2004

Denmark's overall GHG emissions declined by 7.3% from 69 Mtons in 1990 to 68.2 Mtons in 2004, which can be seen in figure 2.2. The main reductions are found within the agricultural and waste sector. Emissions from these two sectors declined on average by 16%. Furthermore, the energy sector reduced emissions by 2.5%. In the remaining sectors, transport and industrial processes, total GHG emissions increased by 30% on average in the same time period. Nevertheless, since their share of the total emissions is rather low, Denmark's total emissions did slightly decrease from 2004 to 1990.

The share of CO₂ emissions of the total GHG emissions in Denmark has been growing over time. In 1990, 76% of the total GHG has been CO₂ emissions. In 2004 CO₂ emissions represent a share of 79% of Denmark's total GHG.

In regard to the Kyoto target, Denmark's total GHG emissions in 2004, 68.2 Mtons, are about 22% higher than the country's target of 55.6 Mtons. The production of hydropower in Norway was however lower than normal in 2004, implying higher than normal fossil fuel generation in Danish power plants.

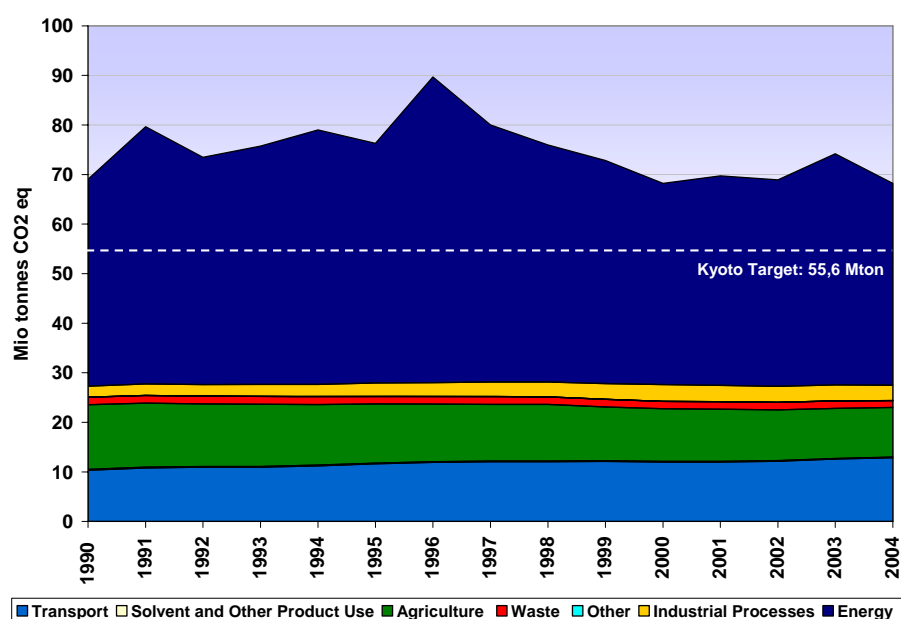


Figure 2.2 Denmark's total GHG emissions by sector.

Source: Denmark's National GHG Inventory Report 2007 to the UNFCCC

The peak in emissions in 1996 has already been mentioned in the description of the total Nordic countries' GHG development. The very dry weather, which leads to decreased hydro power generation and increased coal power production in this year, is the main explanation for the energy sector's high emissions.

2.3 GHG emissions in Finland 1990–2004

Finland's total GHG emissions in the year 2004 are 14% higher than the country's Kyoto target of 71.1 Mtons, which is equal to 1990 emission levels. The development of total GHG emissions from 1990 to 2004 can be seen in figure 2.3.

A closer look into the different sectors gives a varying picture. In energy, industrial processes and transport emissions increased from 1990 to 2004. The increase in the transport sector is the lowest and is 7% from 1990 to 2004. Emissions from industrial processes were growing by 21.6% and in the energy sector by 25.7%.

However, the remaining sectors present a different development. In the agricultural sector total GHG emissions decreased 21% from 1990 to 2004. Emissions from the waste sector also decreased, by 33%.

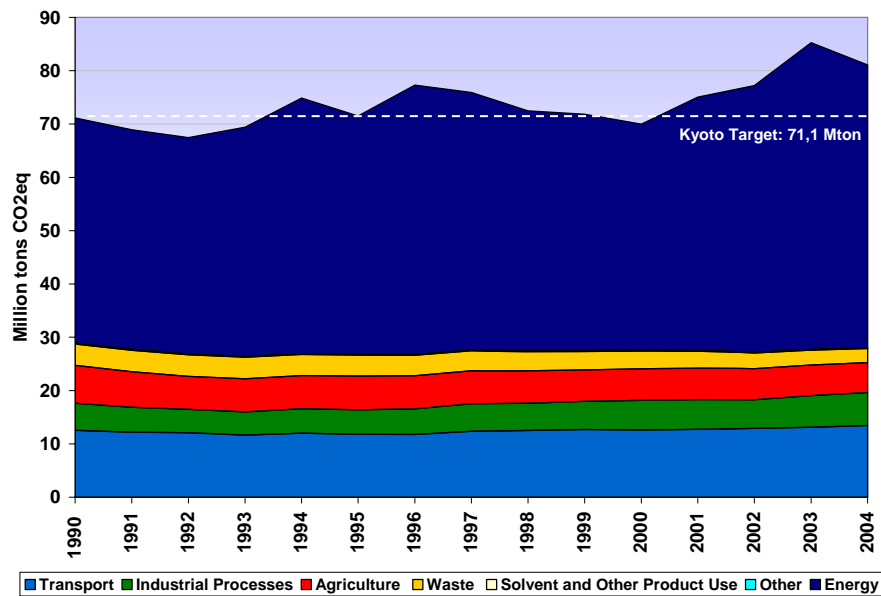


Figure 2.3 Finland's total GHG emissions by sector

Source: Finland's National GHG Inventory Report 2007 to the UNFCCC

In 2003, total GHG emission levels in Finland were 85 Mtons, which is very high. Again, the explanation is found in the energy sector, representing 67% of the total GHG emissions in this year. Due to dry weather conditions in the Nordics, CO₂ emission levels from fossil power production increased strongly in this year. Even in 2004, hydro generation was lower than normal. In 2003 CO₂ emissions represented a share of 85% of the country's total GHG emissions. In the other years between 1990 and 2005 the average share of CO₂ emissions was at 82% of total GHG emissions.

2.4 GHG emissions in Iceland 1990–2004

Iceland's energy sector has, due to a high share of renewable power capacity, very low GHG emissions. The sector's share of the country's total GHG emissions has been lower than 1% during the whole time period from 1990 to 2004.

According to figure 2.4, total GHG emissions increased by 7.7% from 1990 to 2004. Emissions from the energy sector and from the agricultural sector decreased, but energy- and agriculture related emissions only represent about 20% of the country's total GHG emissions. The energy sector reduced emissions from 1990 to 2004 by 7%, the agricultural sector by 13%.

All other sectors' emissions grew from 1990 to 2004. Emissions from transport increased 13%, emissions from industrial process increased 9% and emissions from waste increased 22%.

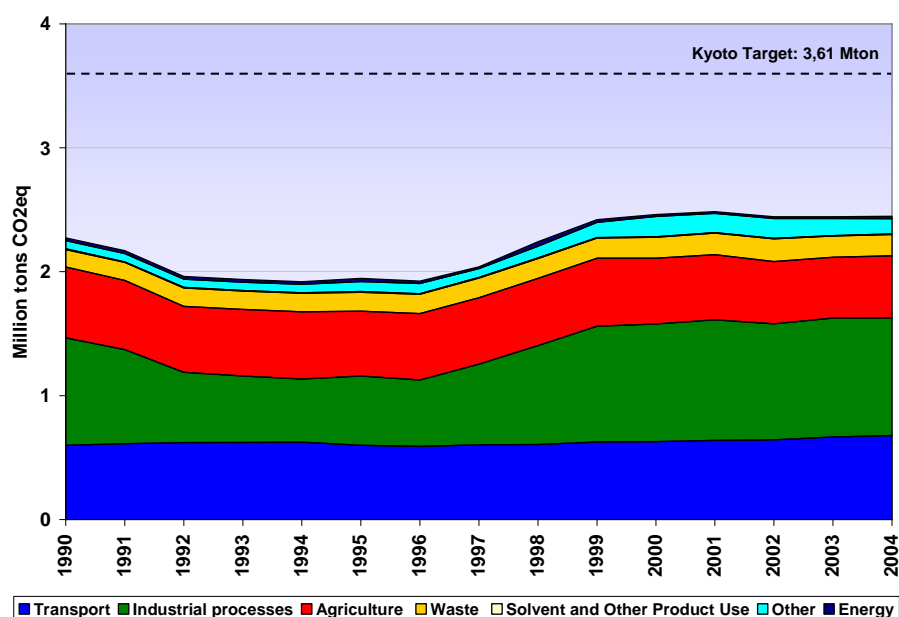


Figure 2.4 Iceland's total GHG emissions by sector

Source: Iceland's National GHG Inventory Report 2006 to the UNFCCC

In 1990 Iceland's total CO₂ emissions represented a share of 56% of the countries' total GHG emissions. This share increased over the years and represented 68% in the year 2004.

In 2004 Iceland's total GHG emissions were 32% lower than the country's Kyoto target. Total GHG emissions in 2004 have been at a level of 2.45 Mtons. The Kyoto target is 3.61 Mton.

2.5 GHG emissions in Norway 1990–2004

Norway's energy and transport sector together represent 59% of the country's total GHG emissions in the year 1990 and 70% in the year 2004. In figure 2.5, there can be seen a clear growth in GHG emissions from both sectors from 1990 to 2004. Emissions from transport grew by 27%, and the energy sector's emissions increased by 32%.

Also the share of CO₂ emissions, mainly deriving from fuel combustion processes, of the total GHG emissions increased from 69% in 1990 to 76% in 2004.

The total GHG emissions of Norway grew by 10% from 49.8 Mtons in 1990 to 54.9 Mtons in 2004 despite the strong growth in energy and transport. The reason is that emissions from all other sectors decreased from 1990 to 2004. Industrial process emissions declined by 24%, agricultural emissions by 3% and waste emissions by 17%.

Compared to the Kyoto target at 50.3 Mtons, total GHG emissions in 2004 were 8.5% higher than the target.

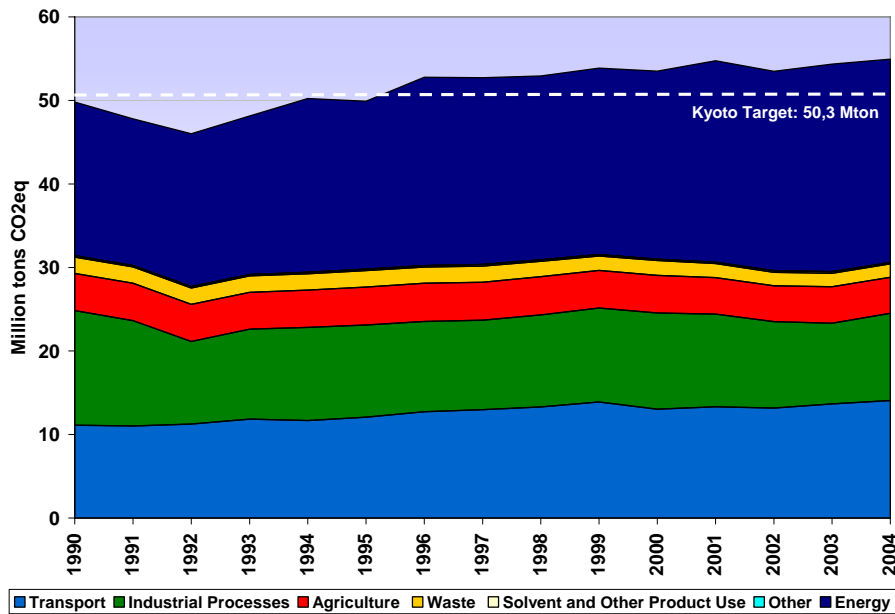


Figure 2.5 Norway's total GHG emissions by sector

Source: Norway's National GHG Inventory Report 2006 to the UNFCCC

2.6 GHG emissions in Sweden 1990–2004

Sweden's Kyoto target is 75.3 Mtons GHG emissions. From 1990 to 2004, the country's total GHG emissions have been higher than its Kyoto target only once, in 1996, when the total GHG emissions were 77.4 Mtons, 2.7% higher than the Kyoto target (cf. figure 2.6). Again, this is explained by the dry year conditions, implying that fossil fuelled generation capacity that is normally held in reserve was used.

However, Sweden's total GHG emissions in 2004, at 69.6 Mtons, were 3.5% lower than emissions in 1990. The energy sector, agriculture and waste, present a decrease in total emissions from 1990 til 2004. Emissions from the energy sector declined by 8.6%, the emissions in agriculture declined by 8.3% and the waste sector's emissions declined by 35%.

In comparison, emissions from the transport sector and from industrial processes increased by 8% and 4% from 1990 to 2004.

The share of CO₂ emissions of the total GHG emissions stayed relatively constant at 78% over the whole time period 1990–2004.

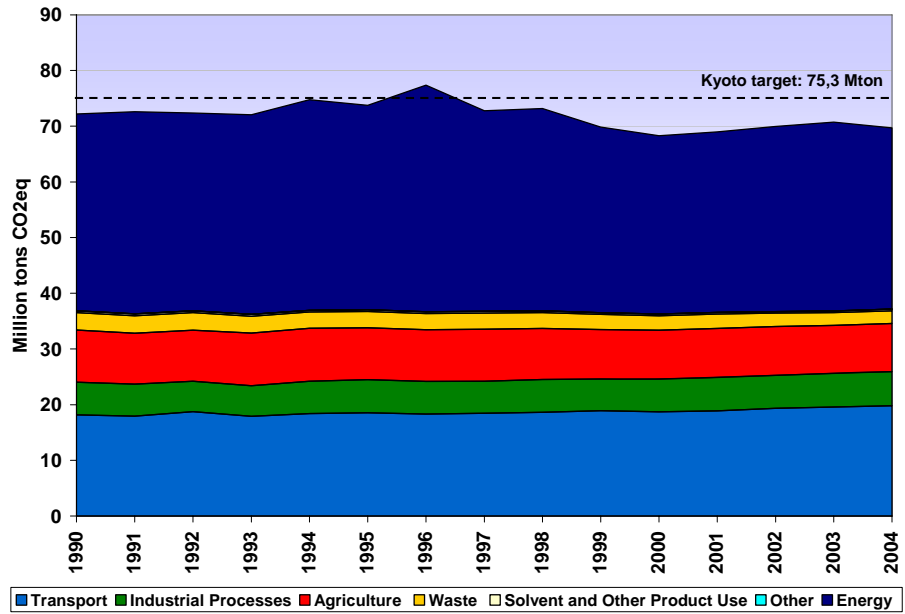


Figure 2.6 Sweden's total GHG emissions by sector

Source: Sweden's National GHG Inventory Report 2007 to the UNFCCC

In 2004, Sweden's total GHG emissions were at 69.6 Mtons. This is 7.5% below the country's Kyoto target of 75.3 Mtons.

3. Historical CO₂ emissions

3.1 Total Nordic CO₂ emissions 1990–2004

In the Nordic countries Denmark, Finland, Iceland, Norway and Sweden, total CO₂ emissions in the year 2004 were at a level of 224.6 Mtons. This is 80.9% of the countries' total GHG emissions in the same year. In comparison, in 1990, total CO₂ emission of the Nordic countries represented with 202.9 Mtons only 76.4% of the countries' total GHG emissions.

CO₂ emissions from the transport sector, the industry sector and the energy sector increased by 15% from 1990 to 2004, see Figure 4.1. The largest increase was seen in the energy sector, where emissions increased by 31%. It has to be taken into account though, that 1990 was a year with high hydro power production in the Nordic area. Hence fossil fuel production was lower than normal. Compared to emissions from the energy sector in 1991, the increase was 15% to 2004.

Transportation and energy are the largest emitters. In 2004 energy accounted for 39% of total Nordic emissions and transportation for 27%. The corresponding numbers in 1990 were 32% for energy and 26% for transportation. In the transport sector CO₂ emissions increased 15% from 1990 to 2004 (Figure 3.1).

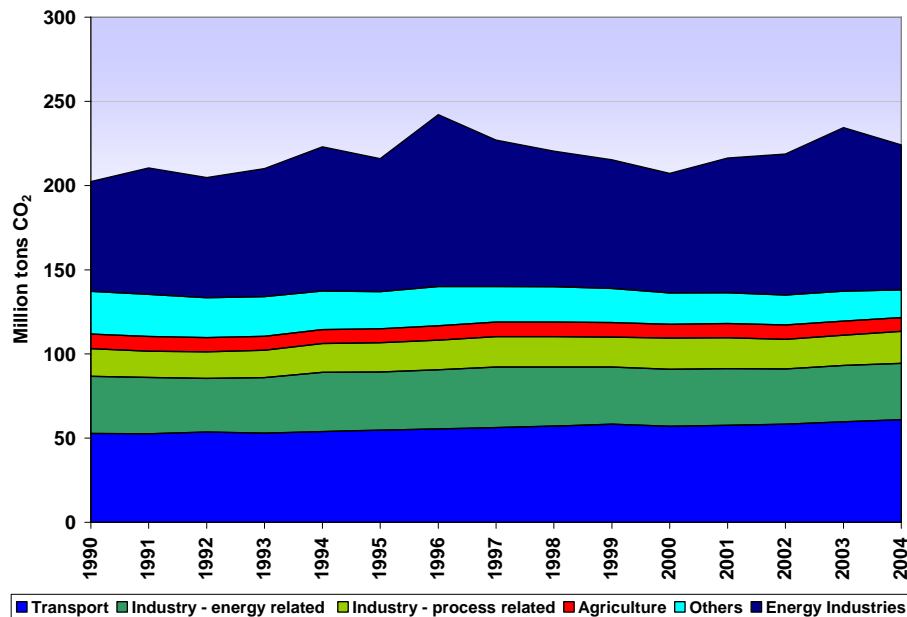


Figure 3.1 Total CO₂ emissions in the Nordic countries by sector.

Source: The Nordic countries' National GHG Inventory Report 2006 and 2007 to the UNFCCC

The industry sector accounts for 23% of emissions in 2004, with 8% from processes and 15% from combustion. Industry was the only sector studied in this report in which the CO₂ emissions declined from 1990 to 2004 by 1%. However, the CO₂ emissions from processes increased by 15% from 1990 to 2004.

The increase in CO₂ emissions from the transport sector and industry processes has been relatively stable during the studied period. As we explain in the next chapter, the energy intensity has declined in the industry sector, but increased activity levels mean that emissions do not decline correspondingly. The development in CO₂ emissions from fuel combustion in the industry sector has also developed relatively stable but in this sector it has declined. The decline is due to energy efficiency measures and fuel switching in the industry sector. We return to this in more detail below.

In the energy sector, the increase is related to increased energy demand, but as we show below, the increase in emissions from energy production would have been much higher without the penetration of renewables in both electricity and district heating production. The variation in emissions from the energy sector are partly explained by variations in temperature between years, but the largest variations occur due to the substantial share of hydro power in the Nordic electricity market. As we can see from figure 3.1 CO₂ emissions are particularly high in 1996 and 2003. The increase in CO₂ emissions during these years is due to dry years in the Nordic area when lower hydro power production must be replaced by increased production from fossil fuelled power plants, mainly in Denmark and Finland. The decline in CO₂ emissions during 2005 is correspondingly due to increased hydro power production; 2005 was an unusually wet year with very high inflow to the Nordic hydro power reservoirs.

3.2 CO₂ emissions in Denmark 1990–2004

The energy sector is by far the largest emitter of CO₂ in Denmark with a share of 48% in 2004 and an average share of 50.5% in the last five years. Transportation accounts for slightly less than one quarter of CO₂ emissions in 2004.

Among the four Nordic countries investigated in this report, Denmark is the only country where total CO₂ emissions are reduced from 1990 to 2005 (Figure 3.2). The change is however modest, only 4% in total. The energy sector is the main contributor to this decline; CO₂ emissions in the energy sector in 2004 were 15 per cent lower than in 1990. But 1990 was an unusually wet year, though, it is not representative for the “normal” emission level, i.e. emissions in a year with normal temperatures and inflows would have been higher. We also notice the peaks in the emissions from the energy sector in the dry years 1996 and 2003. Increased

production from coal fired power plants in Denmark is the major explanatory factor to the peak emissions this year.

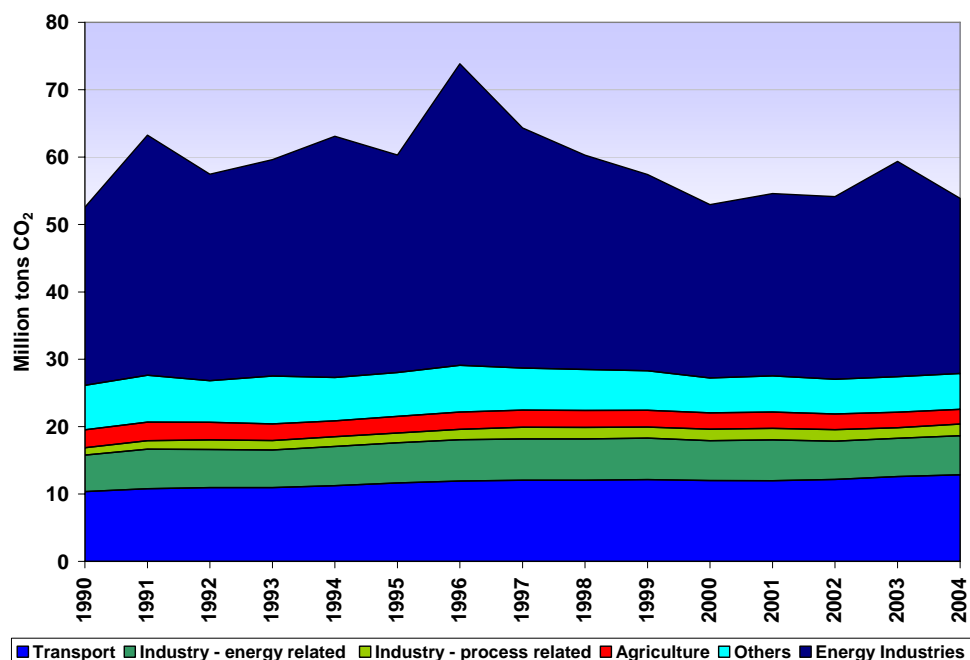


Figure 3.2 CO₂ emissions from the Energy, Industry and Transport sectors in Denmark, 1990–2004.

Source: Denmark's National GHG Inventory Report 2007 to the UNFCCC

In the transport sector the, the CO₂ emissions in Denmark has increased 26% from 1990 to 2004. This increase is in line with the development in the other Nordic countries. The largest increase came from the road transportation sector. CO₂ emissions from aviation and railways declined substantially.

Emissions from fuel combustion in the industry sector have been relatively stable with an increase of 3% from 1990 to 2004. Process emissions have increased by 51%, while emissions from fuel combustion have declined. However, emissions from the industry sector are only a small share of total emissions in Denmark.

3.3 CO₂ emissions in Finland 1990–2004

The energy sector is the largest CO₂ emitter in Finland, with about 47% of total emissions in 2004. Industry and transportation make up about less than one quarter each.

In Finland CO₂ emissions were 20% higher in 2004 than in 1990, see Figure 3.3. The main increase was seen in the energy sector, where CO₂ emissions increased by 70% from 1990 to 2004. As for Denmark, emis-

sions peaked in 1996 and 2003 because of increased fossil fuel generation due to the dry year conditions in the Nordic market.

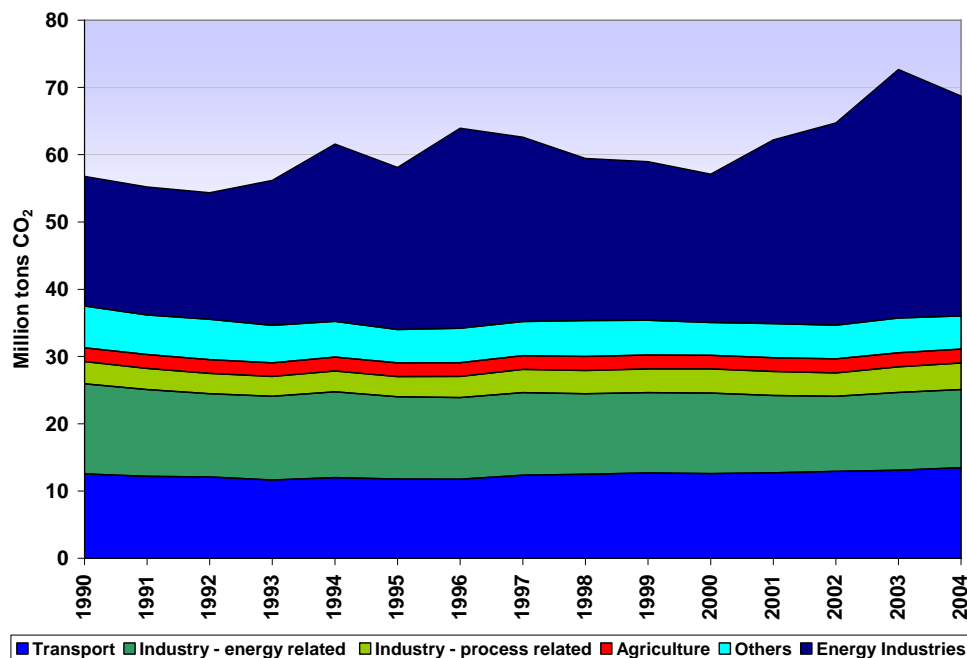


Figure 3.3 CO₂ emissions from the Energy, Industry and Transport sectors in Finland, 1990–2004. Source: Finland's National GHG Inventory Report 2007 to the UNFCCC

Emissions from fuel combustion in the industry sector declined 13% from 1990 to 2004. This was mainly due to fuel switching in the industry sector. However, CO₂ emissions from industry processes increased 19% from 1990 to 2004. This was due to increased activity due to the expansion in Finland during the 1990ties and in beginning of the 21st century.

The CO₂ emissions from the transport sector increased 7% from 1990 to 2004. This is lower than the Nordic average. The largest increase came from navigation (21%) and from road transportation (8%), whereas CO₂ emissions from aviation and railways declined during the period.

3.4 CO₂ Emissions in Iceland 1990–2004

CO₂ emissions in Iceland are small compared to the CO₂ emissions in the other Nordic countries (Figure 3.4). As can be seen from the figure, the energy sector hardly has any emissions at all. This is due to the fact that Iceland is endowed with large hydro and geothermal energy resources.

In 1990 industrial CO₂ emissions were more than twice as large as emissions from transportation, but in 2004 the industry sector has three times larger emissions and accounts for 70% of total emissions. This is mainly due to an increase in emissions from industrial processes. Due to

the ample endowments of cheap and emission free energy resources, Iceland has attracted substantial investments in energy intensive industry facilities in recent years.

Like in all the other Nordic countries, the emissions from the transport sector increased as well. In Iceland the increase from 1990 to 2004 was 13%. The largest increase came from road transport.

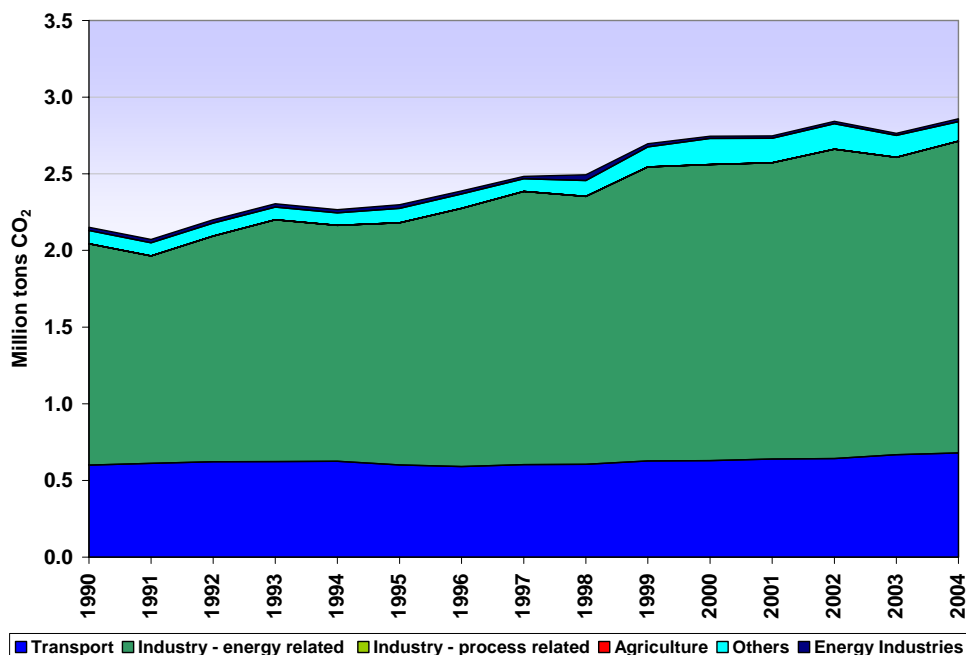


Figure 3.4 CO₂ emissions from the Energy, Industry and Transport sectors in Iceland, 1990–2004.

Source: Iceland's National GHG Inventory Report 2006 to the UNFCCC

3.5 CO₂ emissions in Norway 1990–2004

The transport sector has been the largest emitter of CO₂ in Norway 1990, but the energy sector has had the largest increase in emissions since 1990, cf. Figure 3.5. In 1990, the energy sector had a share of 26% of Norway's total CO₂ emissions; in 2004 the share was 34%. In comparison, the transport sector holds its share of 32% in 1990 and 2004.

Total CO₂ emissions from all sectors increased 27% from 1990 to 2004.

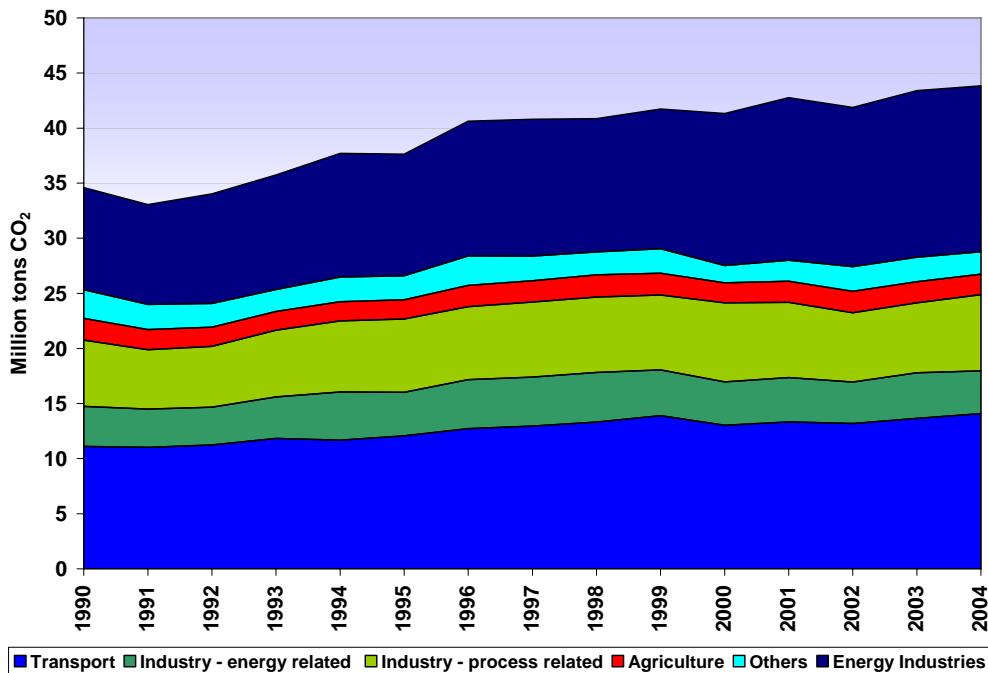


Figure 3.5 CO₂ emissions from the Energy, Industry and Transport sectors in Norway, 1990–2004.

Source: Norway's National GHG Inventory Report 2007 to the UNFCCC

This largest increase is explained by increase in extraction of oil and gas on the Norwegian Continental Shelf (part of the energy industry sector). Emissions more than doubled from 1990 to 2004, in tonnes of CO₂ the emissions increased from 5.4 mill. ton to 11.1 mill. ton. The energy mix on the Norwegian mainland is dominated by hydro power, and the shortfall in dry years is imported from the Nordic neighbours. There is however some increase in the use of oil when in electrical boilers and in households and industries when electricity prices are high, hence emissions increase somewhat in dry years, even in Norway. In wet years we cannot detect a similar reduction in emissions.

In the industry sector, CO₂ emissions from combustion increased 7% and process emissions increased 15% from 1990 to 2004.

The emissions from the transport sector also increased considerably in Norway and were 26% higher in 2004 than in 1990. Emissions from aviation increased 28%, and emissions from road transportation and navigation increased 20%.

3.6 CO₂ Emissions in Sweden 1990–2004

Transportation remains the largest CO₂ emitter in Sweden with a share of just above 32% in 1990 increasing to 37% in 2004, cf. Figure 3.6. In 2004, the energy sector accounts for 23% and industries for 29%, of which 8% is process emissions.

In Sweden, there was a 3% decrease in the total CO₂ emissions from 1990 to 2004. The largest decrease can be seen, in figure 3.6, in the category “others”, with a decrease of 58% in 2004 compared to 1990. This is mainly due to emission reductions in the residential-, the commercial/institutional- and the military sector.

However, the energy industry sector shows an increasing emission development over the time period 1990–2004. In total, emission of the energy sector increased by 20%.

The increase is due to an increased energy demand which has during the period been met by increased energy production from fossil fuelled power plants. As in Denmark and Finland, peaks in CO₂ emissions can be seen in 1996 and 2003 due to dry year effects. Similarly, CO₂ emissions are reduced in 2005 due to the wet year effects.

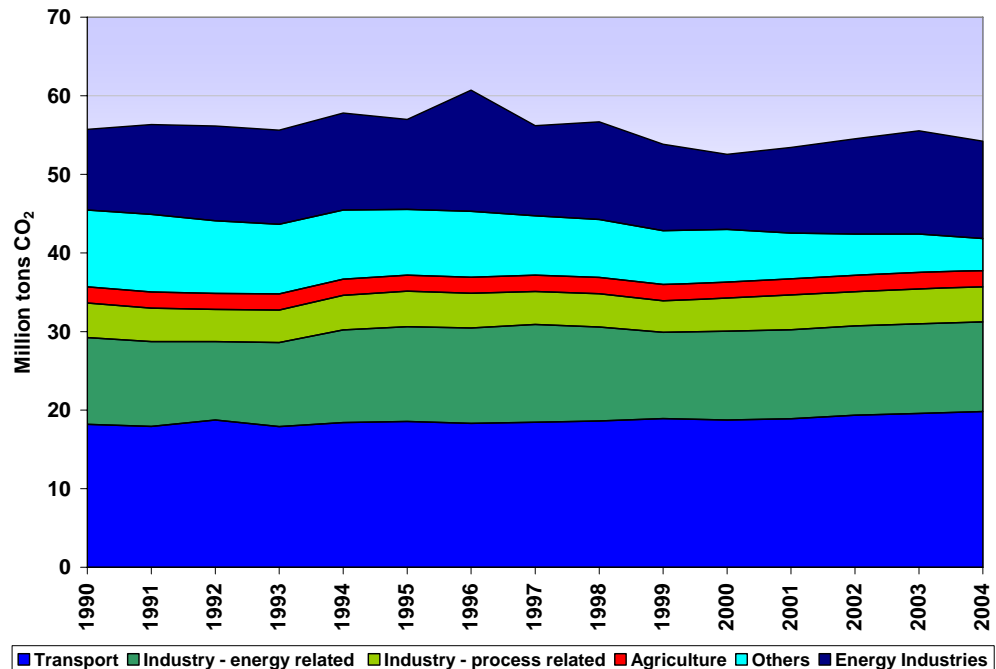


Figure 3.6 CO₂ emissions from the Energy, Industry and Transport sectors in Sweden, 1990–2004.

Source: Sweden’s National GHG Inventory Report 2007 to the UNFCCC

During the same period CO₂ emissions from combustion in the energy sector increased 3%. The process emissions in the sector however, have been only 1.2% higher in 2004 than in 1990.

Emissions from the transport sector increased 9% from 1990 to 2004. The largest increase in relative figures came from the sector “off-road vehicles and other machinery” which includes for example all kinds of machines used in forestry. The largest increase in absolute emissions came from road transportation.

4. Impact of renewables and energy efficiency on emissions from stationary energy use

This part focuses on emissions related to the development in stationary energy use, i.e. heat and electricity plus industries, from 1990 up to the present. First we present the development in renewable energy, i.e. the development in the fuel mix on the supply side of the market. Then we discuss the development in energy efficiency, i.e., the demand side of the market.

Due to the minor contribution to emissions from the Icelandic energy sector, we have not looked at the development in Iceland in further detail.

4.1 Energy supply: Fuel mix and penetration of renewables

4.1.1 Denmark⁴

Electricity and district heating

The development in electricity production and district heating is shown in Figure 4.1. Since the beginning of the 1990s there has been a constant growth in district heating. Electricity production increased until the mid 90ies and has shown more of a declining tendency since then. Still, Danish electricity production is around 20% higher today than in the late 1980ies and early 1990ies. Annual variations have been significant due to annual variations in hydro power from the neighbouring countries Sweden and Norway, to which Denmark has substantial interconnected capacity.

⁴ Source: Danish Energy Authority, statistics published at www.ens.dk

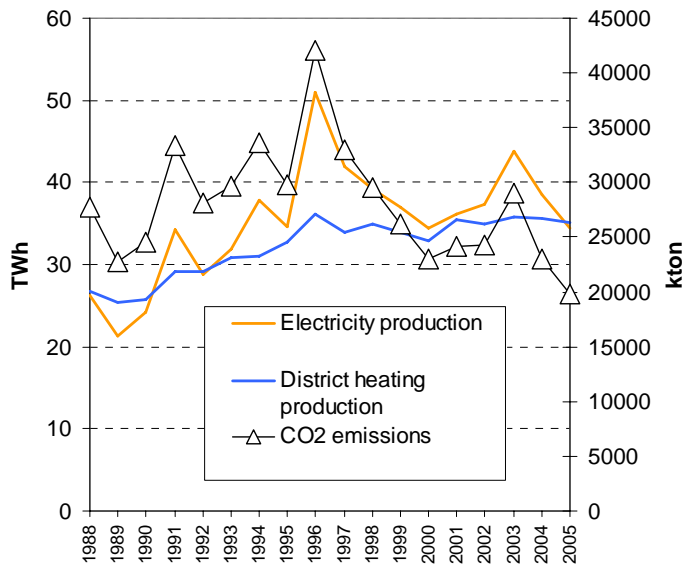
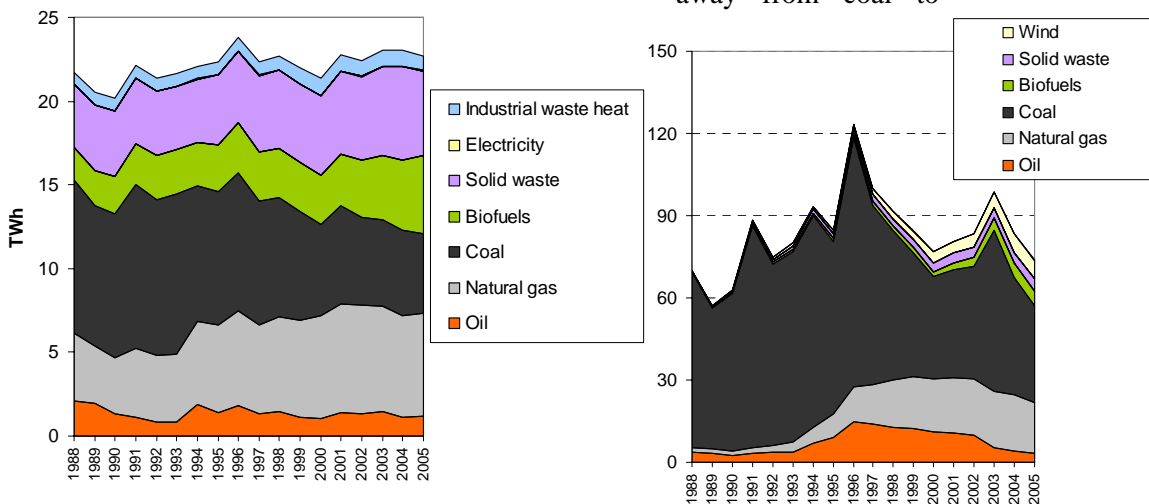


Figure 4.1 Net electricity and district heating production in Denmark.

Source: Danish Energy Authority.

The figure also shows that CO₂ emissions from electricity and district heating production have declined slightly. This becomes even more obvious if one considers the corrected (for variations in hydro production) figures. The main reason for the decline in CO₂ emissions is a switch away from coal to



natural gas and renewable sources (Figure 4.2).

Figure 4.2 Fuel use for electricity production (left) and district heating production (right) in Denmark.⁵

Source: Danish Energy Authority

⁵ Since fuel use for electricity in combined heat and power (CHP) schemes is calculated according to corresponding fuel use in condensing power schemes, district heat produced in CHP plants receive extremely high efficiencies (typically larger than 200 percent).

A simple illustration of the amount of mill. ton CO₂ avoided, due to the increasing penetration of renewables in electricity and district heating supply, is found in Figure 4.3. In this figure the actual emissions since 1988 are compared to two hypothetical emission developments. The first hypothetical case assumes that the entire increase in renewables (wind and bio fuels) since 1990 has been supplied by natural gas, whereas the second case assumes that coal is used instead. We assume the same consumption level in all cases. The “switching” ratio between bio fuels on one hand and coal and gas on the other is assumed to be 1:1. In the case of wind power, we assume that the electricity production is replaced by gas (or coal) generation capacity with historical average electric efficiency factors for these fuels. The argument for using historical efficiencies in the illustration is that there has been excess capacity in the market. Hence, the alternative to the renewable capacity would most likely have been higher utilization of existing (conventional) capacity.

According to Figure 4.3 emissions from the Danish electricity and district heating systems would have been up to 8 mill. ton higher (depending on the fuel used instead) if the penetration of renewables had remained on the level of 1990.

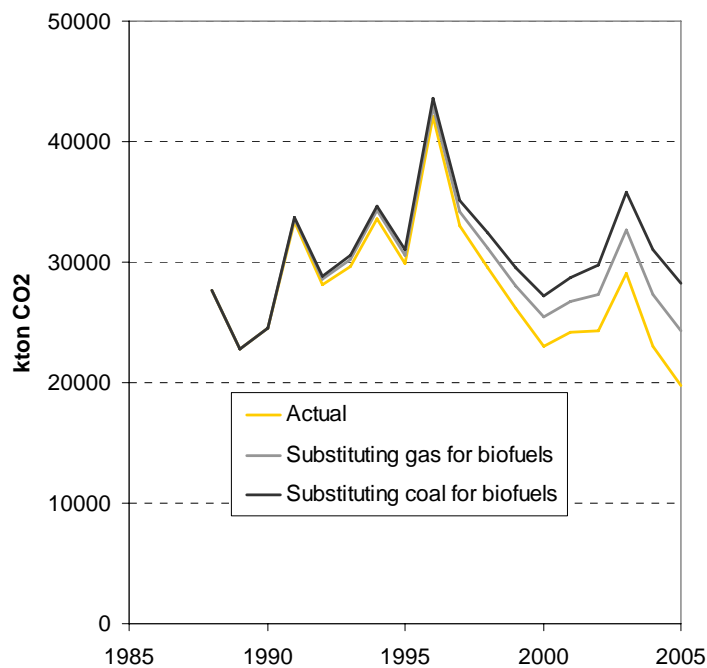


Figure 4.3 CO₂ emissions from electricity and district heating supply in Denmark. Actual outcome and two hypothetical cases.

Source: Own calculations

The residential and commercial sectors

Total final energy demand has, very slightly, increased since 1990. Oil products have gradually been replaced by, primarily, natural gas and district heating, but also renewables. The use of renewables has increased from roughly 5 to 9 TWh by 2005. Had this increase not come about and had the use of oil instead been 4 TWh higher, CO₂ emissions from the residential and service sectors would, accordingly, have been around 1 mill. ton higher.

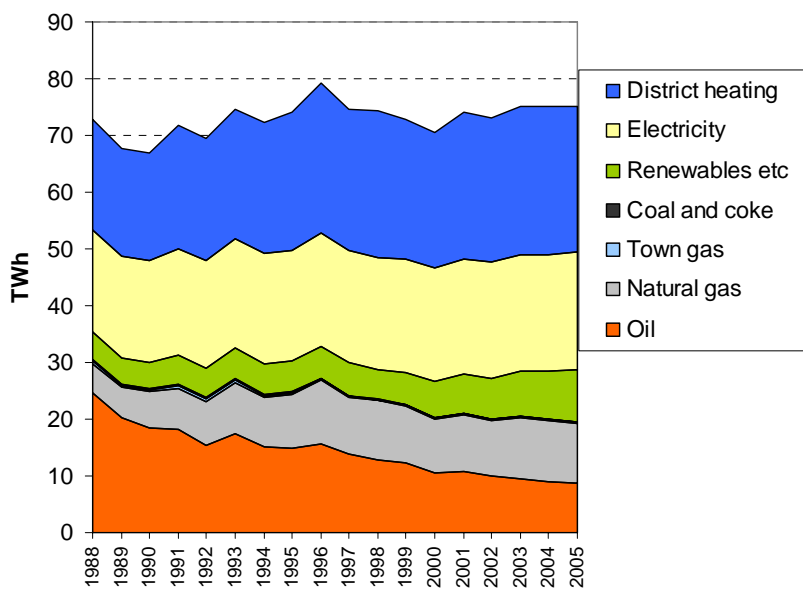


Figure 4.4 Final energy uses in the residential and service sectors in Denmark.

Source: Danish Energy Authority

Industry

In industry, there has not been a notifyable increase in the use of bio fuels, cf. figure 4.5.

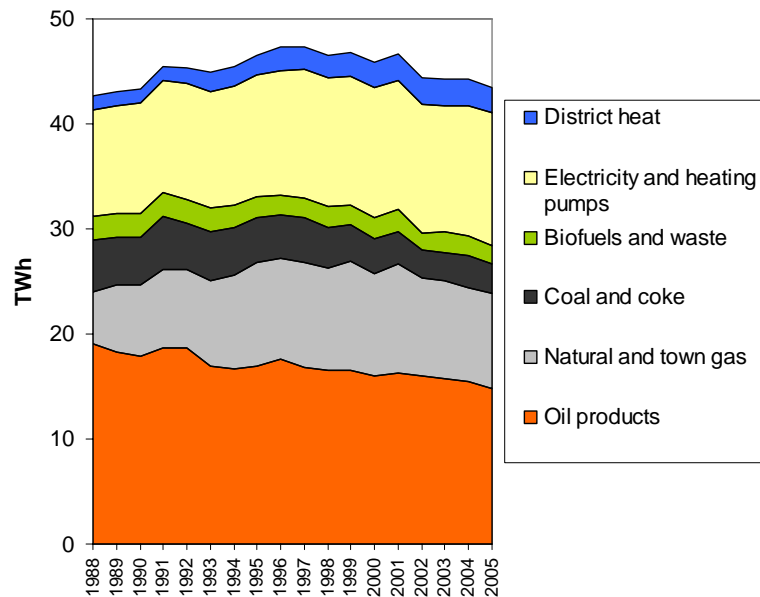


Figure 4.5 Final energy uses in industry (including agriculture, fishing and construction) in Denmark.

Source: Danish Energy Authority

4.1.2 Finland

Electricity and district heating

Finland has the most diversified of the Nordic countries' electricity generation systems.

Since the introduction of the EU ETS there has been a significant pressure on peat and hard coal use, especially in condensing power plants where these fuels account for the lion share. However, annual production from condensing power units depends highly on the hydro-reservoir status in the Nordic countries. This implies large annual variations in CO₂ emissions. According to recent estimates for the year 2006, electricity generated in condensing power plants increased to almost 18 TWh compared to a total of 6 TWh in 2005 (www.energia.fi). Most of that increase was supplied from coal fired condensing power plants (up 8 TWh compared to 2005) and peat (up 2 TWh compared to 2005). This means that annual generation and emissions from both coal and peat are "back" at the same high levels as in the years preceding the EU ETS (see bottom pane in Figure 4.6). The share of renewables in condensing power schemes has slowly risen during the past years to an annual level of around 3 TWh today.

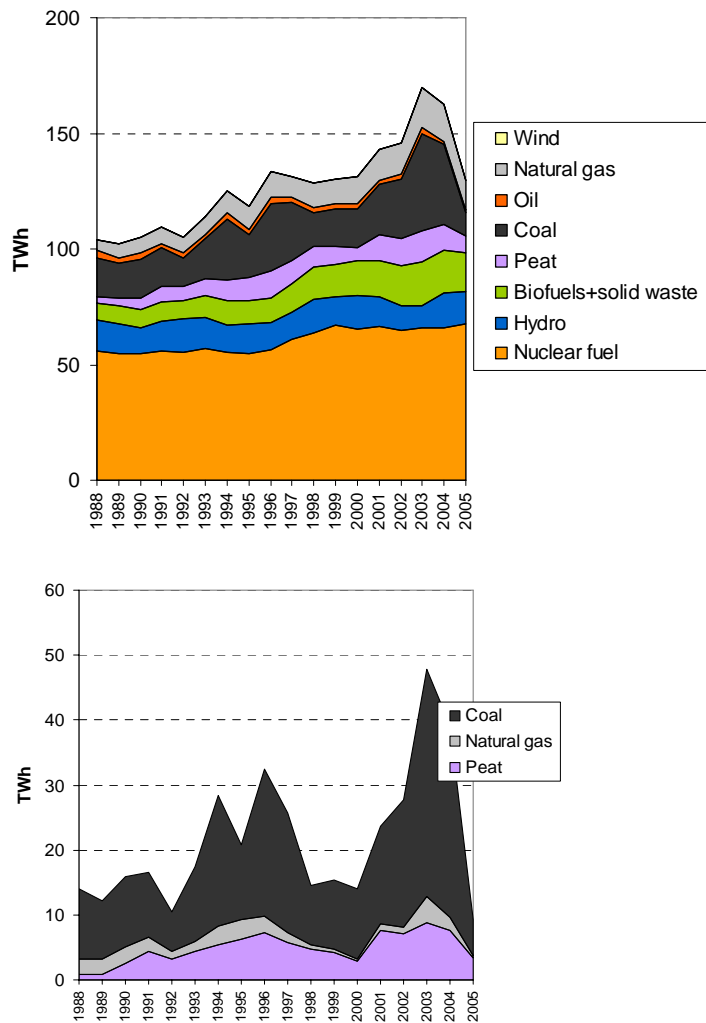


Figure 4.6 Fuel use in electricity generation (top) and fuel use in condensing power schemes (bottom) in Finland.

Source: Statistics Finland

When it comes to district heating, the most significant trend in Finland has been increased reliance on natural gas (see Figure 4.7 – which also includes fuels for electricity generation in CHP schemes). The use of coal has declined somewhat while the use of bio fuels has been constantly increasing and accounts for almost 15% of total fuel use in the sector today.

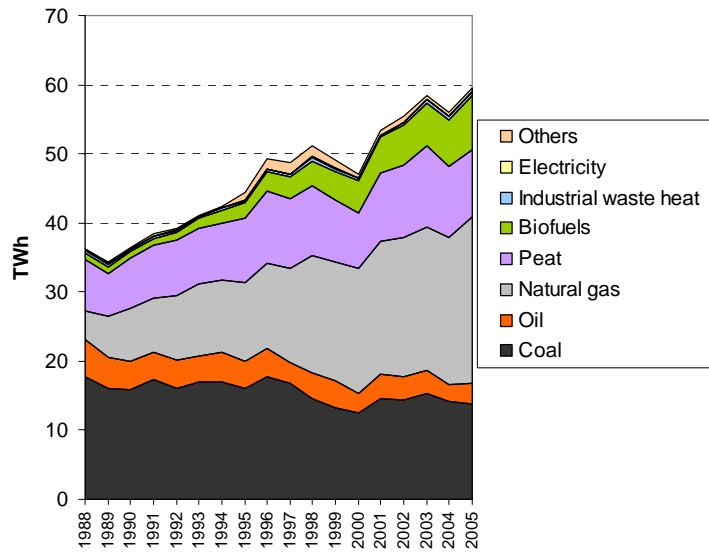


Figure 4.7 Fuel use in combined heat and power schemes and heat-only boilers in Finland.

Source: Statistics Finland

CO₂ emissions from combined heat and power schemes and heat stations have increased since 1990 (see Figure 4.8). Since the share of bio fuels is still rather modest, CO₂ emissions would not have been dramatically higher without the penetration of bio fuels since 1990.

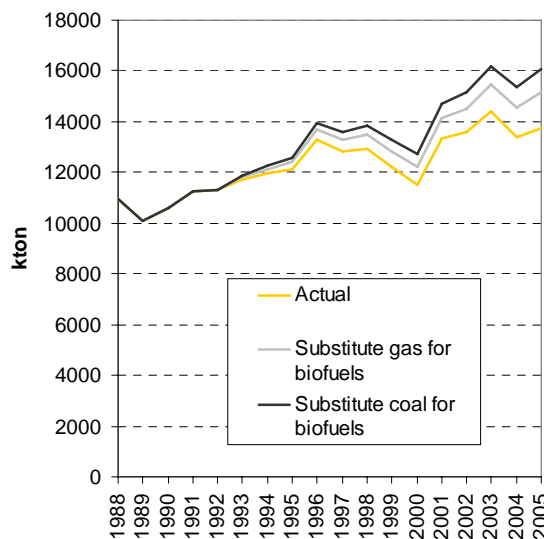


Figure 4.8 CO₂ emissions from CHP and heat stations in Finland, actual outcome and two hypothetical cases.

Source: Own calculations

The residential and commercial sectors

In the residential and service sectors, the use of oil has steadily declined since the beginning of the 1990s while the use of district heating and electricity has increased, leading to an overall increase in final energy use. The estimated use of bio fuels, almost exclusively fire wood, has remained stable throughout the period.

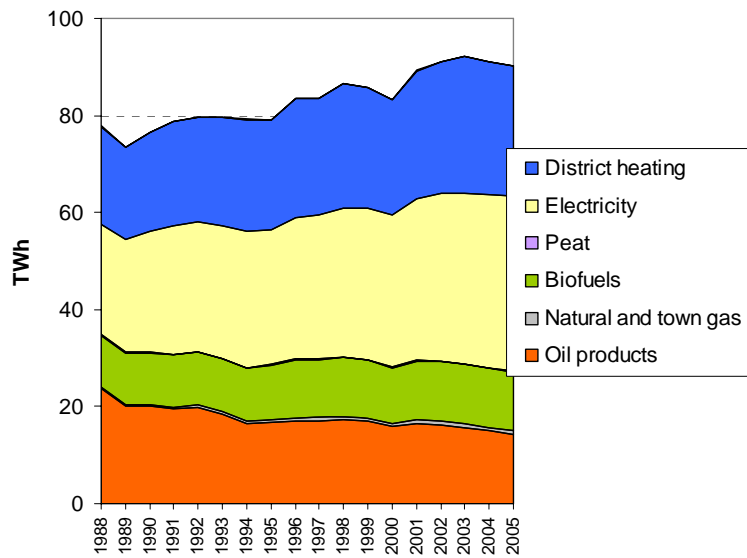


Figure 4.9 Final energy use in the residential and service sectors in Finland (excluding construction and agriculture).

Source: Statistics Finland

Industry

Even in industry, the main picture is the increase in the use of gas.

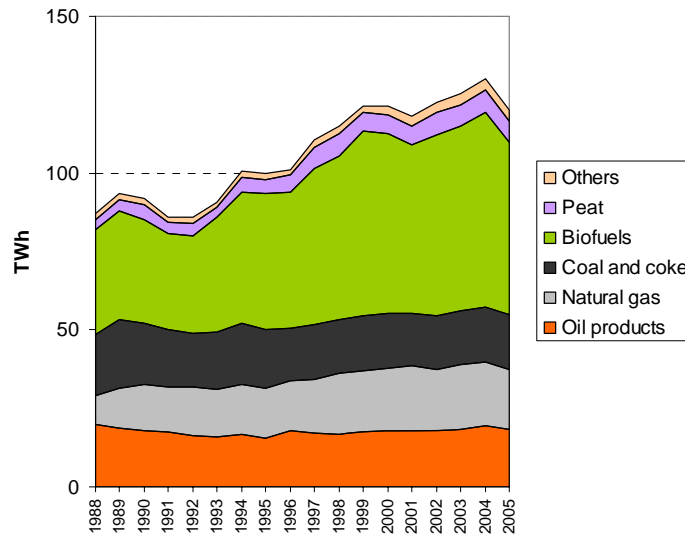


Figure 4.10 Final energy uses in industry in Finland (including fuels for industrial back-pressure generation).

Source: Statistics Finland

4.1.3 Norway⁶

Electricity and district heating

The Norwegian electricity and district heating supply systems are practically emission free compared to the neighbouring countries. The reason is that electricity is supplied almost exclusively from hydro power, while district heating production only amounts to roughly 2.5 TWh annually and is dominated by solid waste incineration (see Figure 4.11). Since the turn of the century the share of bio fuels has increased significantly both in relative and absolute numbers. The annual growth is around 0.5 TWh.

⁶ Source: Statistics Norway

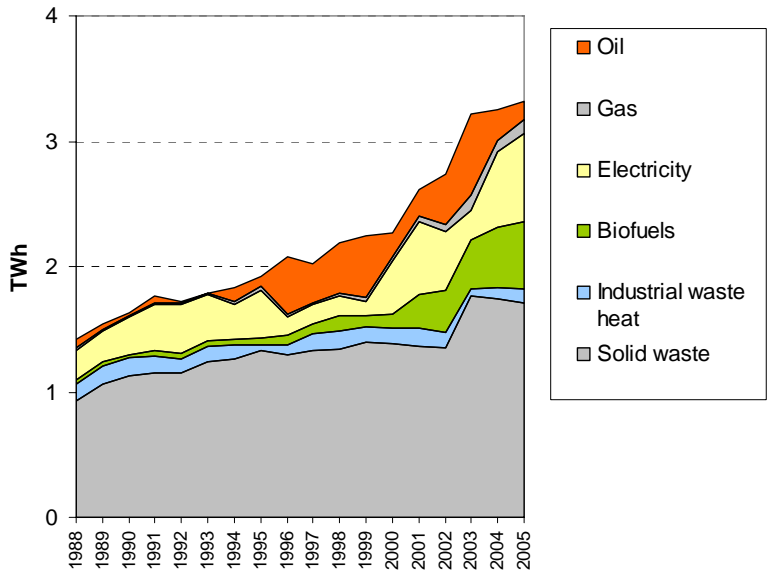


Figure 4.11 Fuel use in district heating supply in Norway.

Source: Statistics Norway

The residential and commercial sectors

Electricity completely dominates energy use in the residential and service sectors. More than 60% of the Norwegian heat market is supplied by electricity (Enova 2003 – Varmestudien).

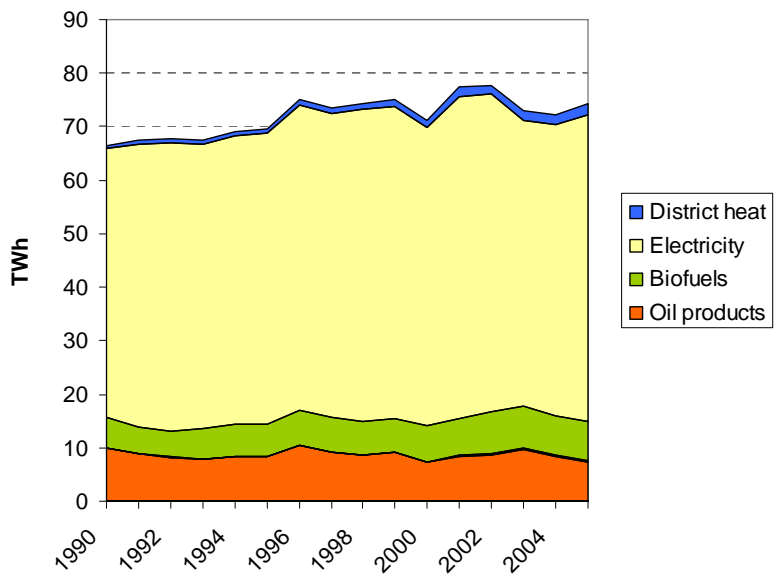


Figure 4.12 Final energy use in the residential and service sectors in Norway.

Source: Statistics Norway

Industry

Even in industry electricity is the dominating energy source, and has increased its share since 1990.

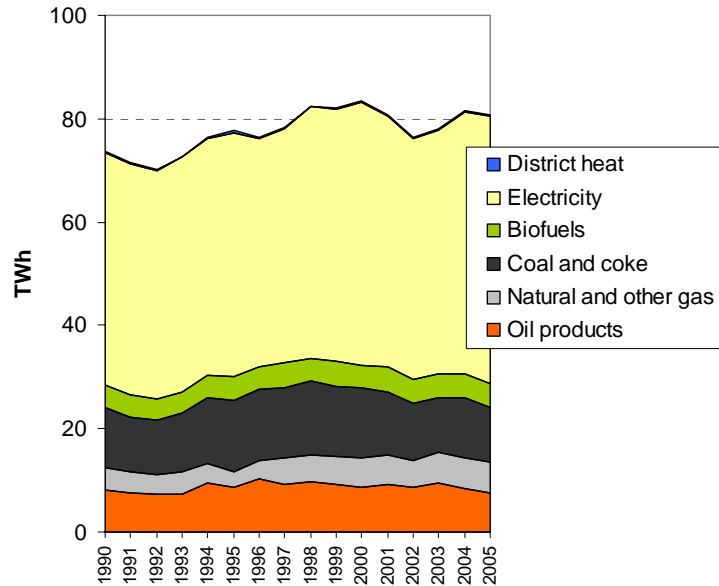


Figure 4.13 Final energy use in industry in Norway.

Source: Statistics Norway

4.1.4 Sweden⁷

Electricity and district heating

Even though Swedish electricity supply is still dominated by hydro and nuclear power, the contribution from other thermal power schemes (mostly CHP schemes) is increasing. Over the past few years there has been a significant shift towards renewables in non-nuclear thermal electricity supply and in district heating (see Figure 4.14). In district heating supply this trend took off in the early 1990ies due to constantly increasing carbon taxes on fuel in heat production. In thermal electricity supply the trend set off in 2003 when the electricity certificate scheme was introduced. Before then, bio fuels in thermal electricity generation were used mainly in industrial back-pressure schemes.

Wind power is still a rather modest supplier of electricity in Sweden, with close to 1 TWh generated in 2005.

⁷ Source: Swedish Energy Agency: Energy in Sweden 2006

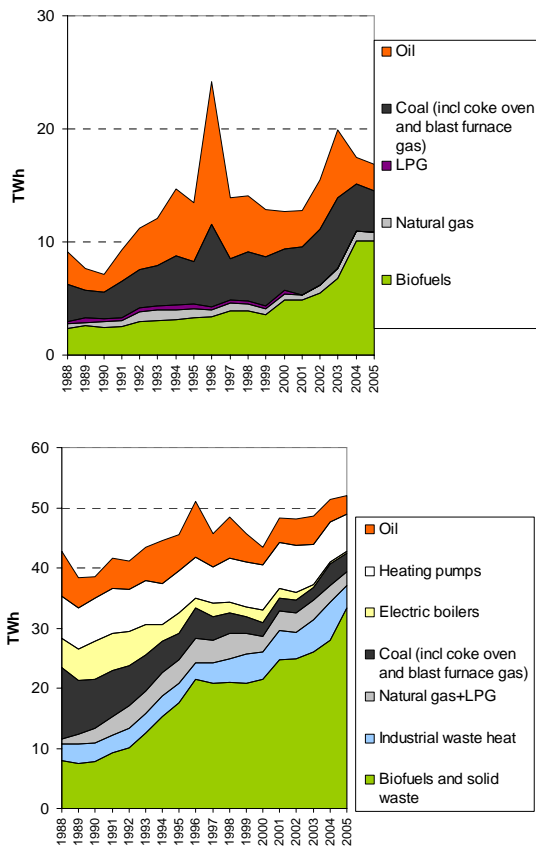


Figure 4.14 Fuel use in electricity (top: hydro, wind and nuclear are excluded) and district heating generation (bottom) in Sweden.

Source: Swedish Energy Agency

The significant increase in the use of bio fuels in the stationary energy sector has had a significant impact on CO₂ emissions. If the use of bio fuels had not increased, and this capacity had used natural gas or coal instead, emissions would have been considerably higher (see Figure 4.15). Correspondingly, if the bio fuelled CHP and district heating schemes which have been converted or built after 1990, had been fuelled by coal instead, CO₂ emissions from electricity and district heating in Sweden would have been three times higher than today.

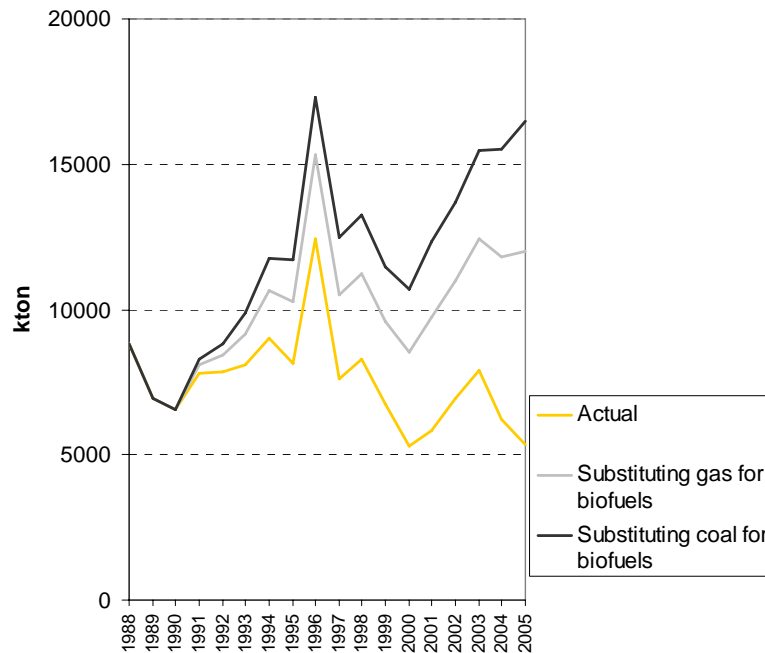


Figure 4.15 CO₂ emissions from electricity and district heating generation in Sweden. Actual outcome and two hypothetical cases.

Source: Own calculations

The residential and commercial sectors

Total final energy use has remained at the same level since the early 1990ies. Oil has been gradually phased out while both electricity and district heating have increased. Two significant recent trends in heating markets are the switch from oil and electricity to heating pumps and bio fuels. High energy taxes (both on electricity and oil) and carbon taxes combined with subsidies for switching to district heating, bio fuels and certain types of heating pumps explain this. Electricity accounts for about 20% of the total heating market in Sweden (Swedish Energy Agency 2002: "Värme i Sverige").

While the estimated use of fire wood has been virtually the same throughout the entire period, the use of pellets for space heating has increased from being practically non-existing in 1996 to almost 3 TWh in 2005.

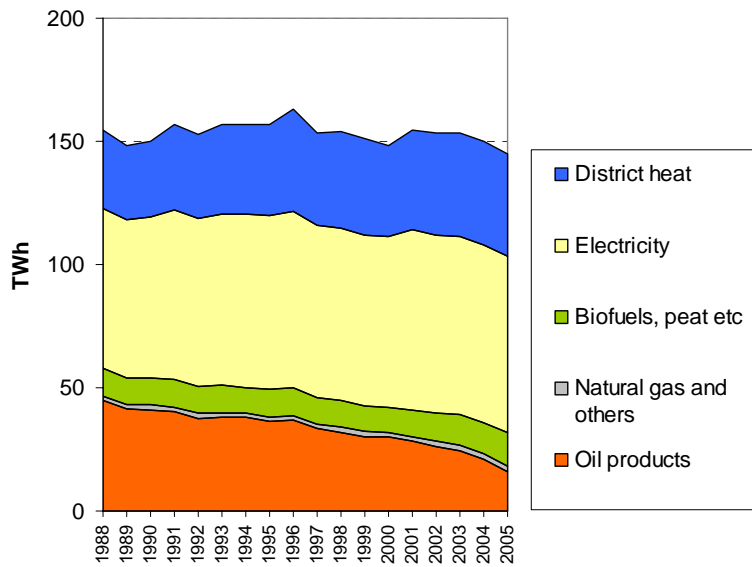


Figure 4.16 Final energy uses in the residential and service sectors in Sweden.

Source: Swedish Energy Agency

Industry

Total energy consumption in industry has increased since 1990. There is no clear “switching” trend, but the share of bio fuels, peat and waste seems to have increased some (cf. Figure 4.17).

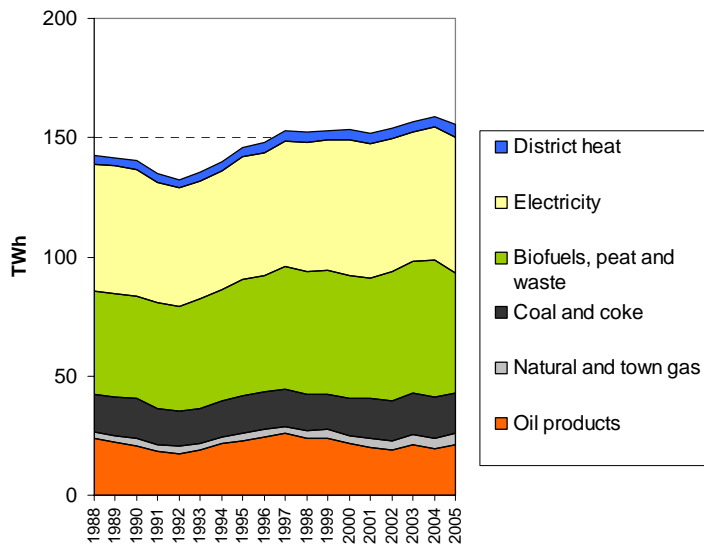


Figure 4.17 Final energy use in industry in Sweden (excluding fuel use for industrial back-pressure (electricity) generation).

Source: Swedish Energy Agency

4.2 Energy consumption: Energy efficiency

The International Energy Agency, IEA, has performed an in-depth study of energy demand in the member states (IEA, 2005). The study assesses how energy use and CO₂ emission trends have evolved in IEA countries, and shows that the overall energy intensity of the IEA economies is substantially reduced since the 1970ies. Compared to 1973 the energy needed to produce one unit of GDP in 2002 is reduced by 1/3. But recent trends indicate that savings in both fossil fuels and electricity has slowed down. This is the case for the Nordic countries as well. While the weighted sum of sub-sectoral energy intensities fell 2% p.a. between 1973 and 1990 the decline in the same indicator is 0.7% from 1990 to 1998, according to the IEA study. This may suggest that the energy savings potential for the future may be smaller than the energy savings realized historically. The factors explaining the development in energy intensities are however complex, as we will see in the following, and one cannot conclude on the basis of a simple trend.

4.2.1 A few words about measuring energy efficiency

Energy efficiency can be measured in several ways and on several levels. Apart from the meaning of not wasting energy – as is a welfare economic goal for all resources – energy efficiency is first and foremost interesting in order to *compare* different countries, sectors and installations, or to follow the *development* in countries, sectors or installations. Energy efficiency is typically measured by energy use per unit of GDP, usually referred to as the *energy intensity* of GDP. A decline in energy intensity is an *indicator* of energy efficiency improvements. Energy efficiency in different industry branches and sectors is similarly measured by various energy indicators. An energy indicator typically measures the input of energy relative to a variable measuring the production in the industry, like the gross product or ton produced in manufacturing industries, and gross product or the number of employees in the service sector.

The challenge when trying to compare different sectors, sectors in different countries or the development in a sector over time, is that there are a number of changes that affect energy use that are going on, and that different indicators can give very different results regarding the development in energy intensities.

A given development in one (or several) energy indicators can be explained by many factors, for example:

- Changes in the use of energy and electric appliances, and technological development
- General development in energy prices
- Changes in relative energy prices

- Taxes, levies and subsidies
- Structural changes in the economy, e.g., reduced share of energy intensive products in manufacturing or increased share of service industries
- Structural changes within an industry sector, e.g., changes in product mix within an industry branch or in the service sector
- Energy savings or energy conservation

Energy indicators are just technical measures of energy efficiency levels and energy efficiency improvements. The indicators do not contain information about the reason for a given development. In the report we take energy efficiency improvement to mean a reduction in energy intensity measured by some energy efficiency indicator. For the different countries and sectors we report different energy efficiency indicators and discuss what they mean. To what extent the observed developments are results of conscious or policy induced *energy saving* (or conservation) is generally not straight-forward. Whereas it is easy to conclude that energy saving has taken place when for example the indoor temperature in a building is reduced by e.g. 1 degree, in other cases it is a complex mix of changes in appliances and technological change, which may be confused with general technology development trends. Even changes in production modes and structural changes may be the result of conscious energy conservation measures or policies, but these may be difficult to separate from general economic trends.

4.2.2 *Energy intensity and GDP*

The overall energy intensity of the economies, i.e., the energy needed to produce one unit of GDP, has declined in most OECD countries, on average by 10%, from 1990 to 2002. There are however, large differences between the countries, and large differences even between the Nordic countries. Figure 4.18 shows the development in overall energy intensity for the Nordic countries, France, USA and the OECD area, according to IEA data. We see that, with an exception for Iceland, there is a general falling trend since 1970. The biggest reduction is found from 1980 to 1990, a development which to a large extent can be attributed to the oil price shocks in the 80'ies. During the 1990ies the decline in energy intensity is substantially slower, and for the years 2000–2002 hardly detectable. As there is a decline for the OECD as a whole, the development in the Nordic region shows an increase, explained by increased energy intensities in Finland, Sweden and Iceland. As high energy prices explain the decline in energy intensities in the 80ies, low energy prices may partly explain the slower development in the 90ies. In this decade, oil prices were low and coal prices declining. In addition, the Nordics saw

the deregulation of the electricity market and a number of wet years produce very low electricity prices.

At the same time there are large differences in the energy intensities of the Nordic economies. These differences must be seen in relation to differences in industry structure and in electricity conversion factors. Finland, Sweden and Norway have large energy intensive industry sectors, whereas Denmark does not. On the other hand, Norway has a low ratio of primary to final energy demand because of the large share of hydro electricity in the system.

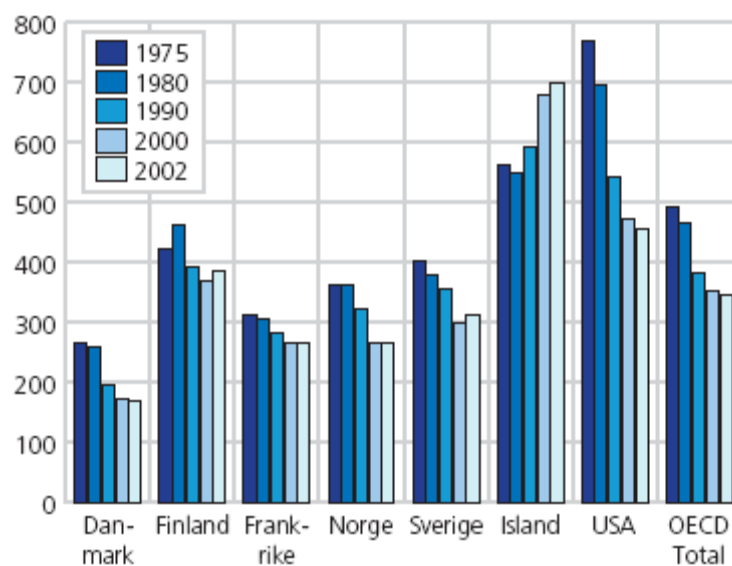


Figure 4.18 Energy intensity in selected countries and in the OECD. Total primary energy supply per unit of GDP (in fixed 1995 currency). GWh/bnNOK.

Source: Bøeng, A. C. and D. Spilde (2006): Energiindikatorer 1990–2004. Gir økt verdiskapning mer effektiv energibruk? Økonomiske Analyser 3/2006, Statistics Norway.

As indicated above, energy saving or conservation is not necessarily the main explanation for the decline in overall energy intensities. General technological change, price effects, changes in industry structure, and productivity growth are important factors. Differences in energy intensity between countries are explained by climate, size of dwellings, number of people per dwelling, floor area of service sector buildings per output (labour intensity), share of energy-intensive products in manufacturing, transportation of goods, travel distances, transport modes, etc.

According to the IEA study energy service demand grew less than GDP in most IEA countries from 1973 to 1998, partly because production of energy-intensive goods became a smaller share of GDP. Hence, the reduction in the energy per GDP ratio overestimates the improvements in

energy efficiency. The energy intensity declined 37% in the period, but one fifth is accounted for by a decline in energy services.⁸

4.2.3 Energy intensity in industries

Manufacturing remains the most significant energy consuming end-use sector (IEA, 2005). Energy use in the IEA countries fell 15% between 1973 and 2000. Oil consumption fell 62%. At the same time, manufacturing output increased 90%. The decline is due to structural changes and improved energy efficiency of sub-sectors. For the IEA-11 group⁹, structural shifts account for about one third of the decline. The impact of structural changes varies among countries. Price appears to be an important factor for the development in sub-sector efficiencies. (This suggests that taxes may be powerful measures for energy savings.)

There are substantial differences in the energy intensity of the industrial sector in the Nordic countries, as can be seen from Figure 4.19.

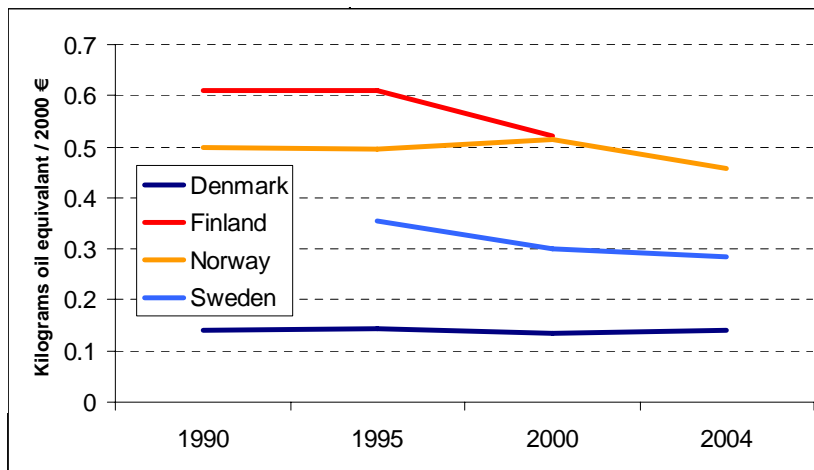


Figure 4.19 Energy consumption of manufacturing per unit of GDP (in 2000 €, at ppp)¹⁰ in the Nordic countries.

Source: ODYSSEE data base

The ODYSSEE energy efficiency indicators offer information about the overall development in energy efficiency (www.odyssee-indicators.org). In order to assess the energy efficiency progress on an aggregate level, macro indicators (ODEX) are calculated according to a bottom-up approach. The ODEX index is cleaned from structural changes and other factors not related to energy efficiency, but influencing the energy intensity of the economies:

⁸ This result is obtained for a group of 11 IEA member countries. See footnote 9.

⁹ A group of 11 IEA countries of which all Nordic countries except Iceland are included.

¹⁰ Final energy consumption in which the GDP is converted into 2000 € using purchasing power parities instead of exchange rates

The ODEX is calculated as a weighted average of the unit consumption index of each sub-sector or end-use, with a weight based on the relative consumption of each sub-sector in the base year.¹¹

The base year is 1990. Since 2006 the ODEX is calculated as a *sliding index* in which energy efficiency gains are measured in relation to the previous year. Moreover, a 3 year moving average is used to smooth out fluctuations (and capture trends).

We will use the ODYSSEE database and ODEX indicators to illustrate the development in energy efficiency in the Nordic countries. The advantage of using the ODYSSEE data is that they should be comparable. They have all been reported as part of a common project (part of the EU EIE), and they are recently reported. However, the data reported from the different countries are not of the same format. For example, if the aggregation level of the sectoral data is different, the index will include structural changes within a sector to different extents. Therefore, one should be careful to draw too strong comparisons from the data.

It should also be noted that structural changes may also be the effect of energy efficiency measures.

The graph below shows the ODYSSEE energy efficiency indicator for some major energy intensive industries in Europe. As can be seen, there are large differences between the branches, with chemicals showing very strong energy efficiency improvement, whereas paper has had a much more modest development. This picture partly reflects a change in technology and for paper, probably a change in the composition of products. These differences will be reflected in the energy intensity development in different countries according to their industry structure and the speed and scope of structural changes.

¹¹ Further information on the ODEX can be found under <http://www.odyssee-indicators.org/Indicators/PDF/odex.pdf>

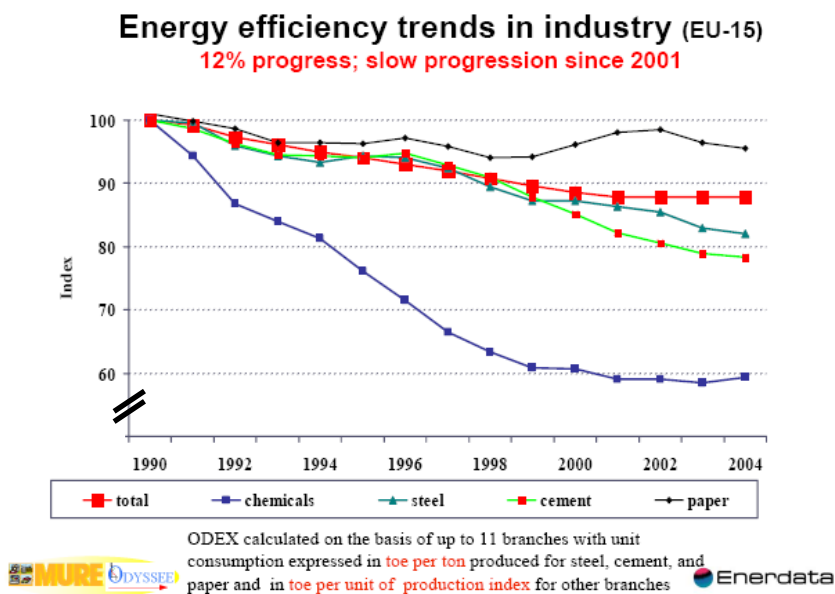


Figure 4.20 Industry energy efficiency indicators in Europe.

4.2.4 Energy intensity in the service sector

The service sector consumes 13% of final energy use in IEA countries (IEA, 2006). In the IEA-11 group energy consumption in the service sector increased 35% from 1973 to 2000. The sector’s energy use is dominated by electricity.

The main factor explaining the growth in energy use in the service sector is the growth in floor area, and the growth in electrical equipment such as cooling, ventilation, lighting and network equipment.

Energy efficiency is improved through a reduction in fuel use per square meter of building area (excluding electricity). The largest decline is found in Denmark, where fuel use per square meter is reduced 5.2% per year.

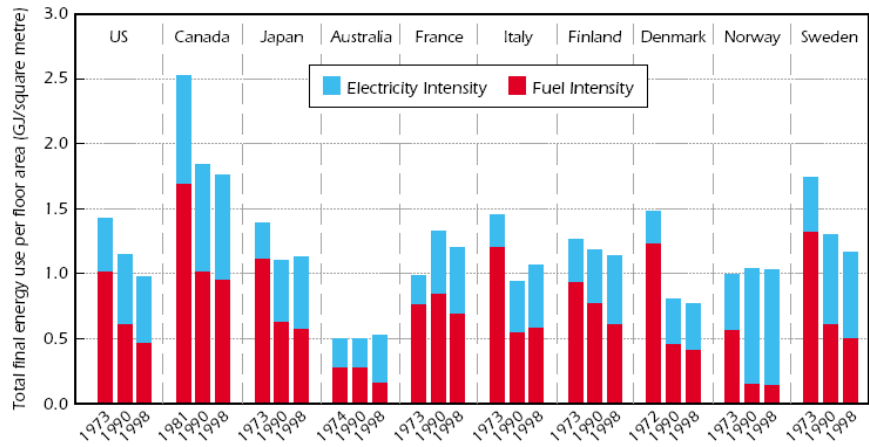


Figure 4.21 Electricity and fuel use per unit of floor area in the service sector, IEA-11
Source: IEA (2005)

The figure shows large differences between the countries, but it is a general picture that the electricity intensity has increased, whereas fuel intensity has declined. It should be noted, though, that electricity is widely used for space heating in Finland, Norway and Sweden. The low fuel intensity in the Norwegian service sector is mainly explained by the use of electricity for space heating.

The energy intensity of the service sector measures as energy use per unit of value added has declined in the IEA-11, as can be seen in Figure 4.22.

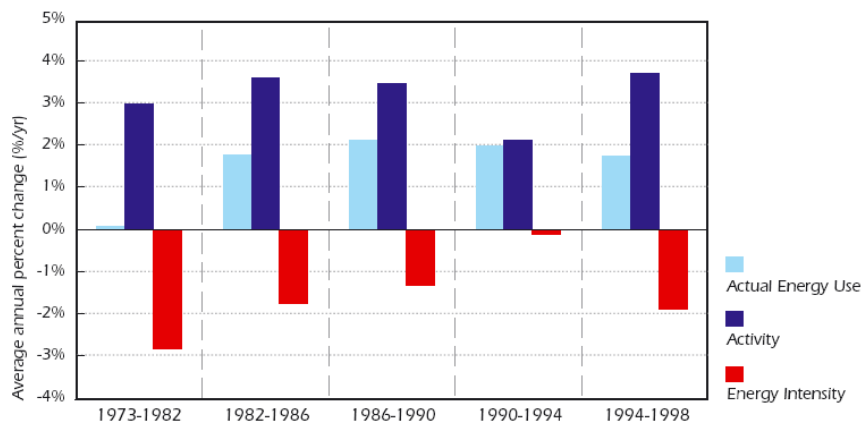


Figure 4.22 Decomposition in changes in service sector energy use, IEA-11
Source: IEA (2005)

4.2.5 Energy intensity in the household sector

Reductions in energy end-use intensities have slowed in most IEA countries and sectors since the end of the 1980ies. While the weighted sum of

sub-sectoral energy intensities in the IEA-11 fell by 2% per year on average between 1973 and 1990, this intensity indicator declined by only 0.7% per year averaged over the 1990–1998 period.

The figure below shows the level of energy consumption per dwelling, scaled to European normal climate. We can see that there are important differences between the Nordic countries. Norway has had the largest improvement in energy efficiency in households, but had the highest level of consumption in the base year. Energy efficiency in Finland has not improved, but Finland still has the lowest level of energy consumption per household dwelling in the Nordics.

The picture reveals very different developments in the Nordics, where the energy efficiency in Norwegian, Danish and Swedish households has improved since 1995, whereas energy efficiency in Finland has declined, as has the EU15 average.

The energy efficiency index for households is calculated on the basis of 3 end-uses (heating, water heating, cooking) and 5 large appliances (refrigerators, freezers, washing machines, dishwashers and TVs). Heating is calculated for unit consumption per m² at normal climate, water heating according to unit consumption per dwelling with water heating, cooking per unit consumption per dwelling and large electrical appliances according to specific electricity consumption per appliance (kWh/year).

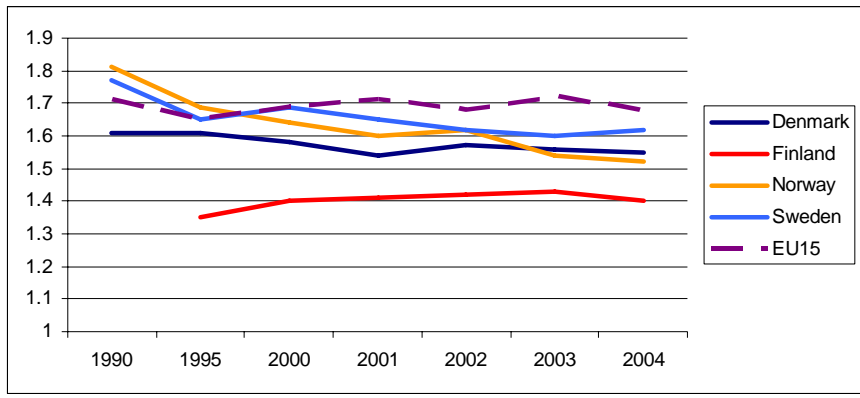


Figure 4.23 Consumption per dwelling scaled to EU average climate

Source: ODYSSEE Data Base

4.2.6 Energy efficiency indicators by country

Denmark

The Danish ODEX data is presented for Households, Transport, Industry and Final consumption, see Figure 4.24.¹² The strongest energy efficiency progress is seen in the household sector, where energy efficiency measures and high energy taxes have been applied during the 90ies.

The energy efficiency of the industry sector was constant until 1997, but has shown a strong reduction since then, and has almost caught up with the development in the transportation sector.

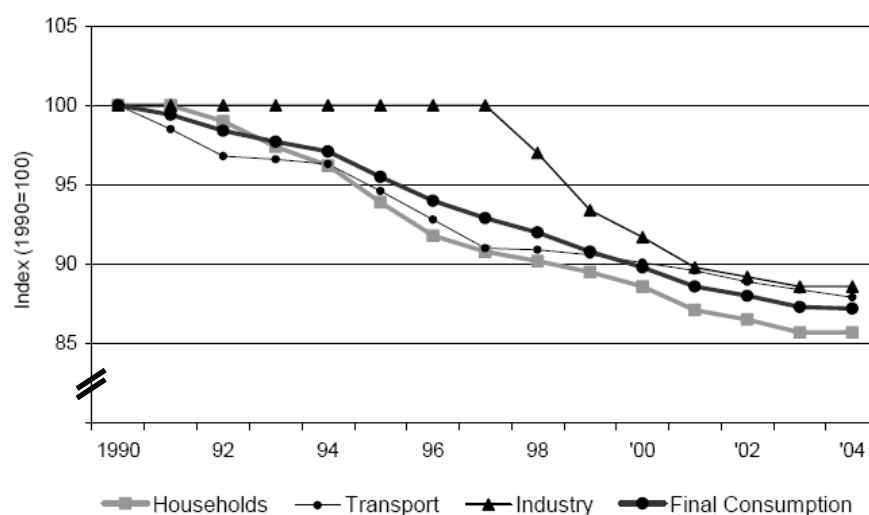


Figure 4.24 Energy efficiency progress in Denmark

Source: Danish Energy Authority (2006)

The overall energy efficiency improvement is approximately 13% from 1990 to 2004. The average annual GDP growth in the same period was 2.1% per year, i.e. a total of 34%.

Private consumption in households has increased 2.0% p.a., i.e. 32% in the same period.

Finland

Due to lack of data the ODEX index for Finland can only be calculated for the period 1995 to 2002, see Figure 4.25.¹³ The technical ODEX shown in the figure is a measure of the development in energy intensity if it had followed the technical progress. When the actual ODEX is above

¹² “Energy Efficiency Measures and Policies in Denmark 2006”, Danish Energy Authority, MURE ODYSSEE, Intelligent Energy Europe, 2006.

¹³ “Energy Efficiency Measures and Policies in Finland 2006”, Motiva OY, MURE ODYSSEE, Intelligent Energy Europe, 2006.

the technical ODEX, it is a sign of rebound-effects, i.e., efficiency improvements are offset by increased energy consumption.¹⁴

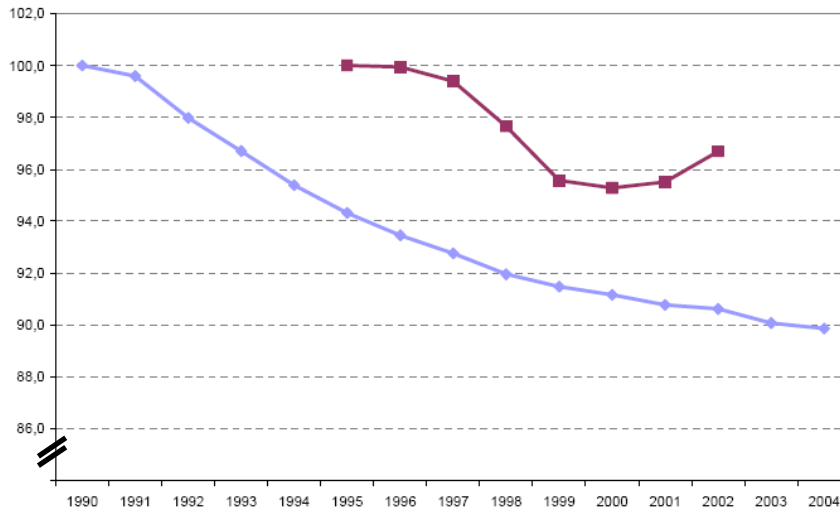


Figure 4.25 Energy efficiency progress of Finland measured by the ODEX indicator.

Source: Motiva (2006)

The overall energy efficiency improvement is 3–5%, and energy intensity was reduced in all sectors. While GDP grew more than 40% from 1994 to 2004, primary energy use increased about 30%.

Data for industry is available from 1990 to 2002, see Figure 4.24. The paper industry is dominating in Finnish industry, and the development in the industry ODEX closely follows the energy indicator for this industry, measured by the unit consumption index of the paper industry, see Figure 4.26.

¹⁴ An example of this would be purchase of bigger cars when engines become more efficient (and fuel use relatively cheaper), or higher indoor temperatures when heating becomes more efficient (and cheaper per square meter).

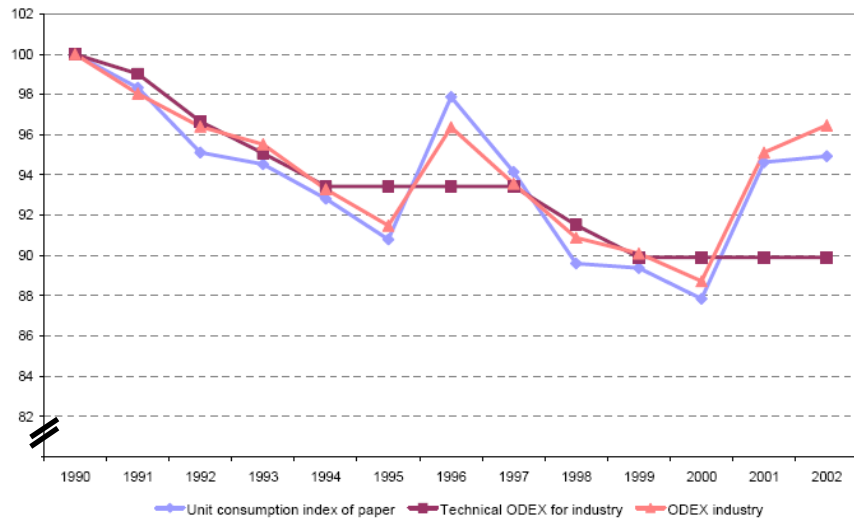


Figure 4.26 Energy efficiency progress in Finnish industry (Technical and observed ODEX for industry and the unit consumption index for paper)

Source: Motiva (2006)

The figure shows that there has been a declining trend in the energy intensity of Finnish pulp and paper. Although there was an increase from 2000 to 2004, energy efficiency has improved more than the IEA average (cf. Figure 4.23).

The annual changes in the index appear more dramatic than they are, due to the scale on the y-axis. Moreover, the large jumps from one year to another are probably explained by the way the ODEX is constructed, where changes in the index are measured against the preceding years, and not all from the base year. Moreover, we suspect that the variations are explained by the price and market conditions in the power market. The hypothesis is that in periods with high electricity prices the industry buys relatively more electricity from the market and reduces the share of own production. If own production has a lower conversion factor than electricity from the grid, the result will be an improved energy efficiency index. We do however not have data to confirm this hypothesis.

Figure 4.27 shows the development in the electricity intensity of three energy intensive industry branches in Finland.

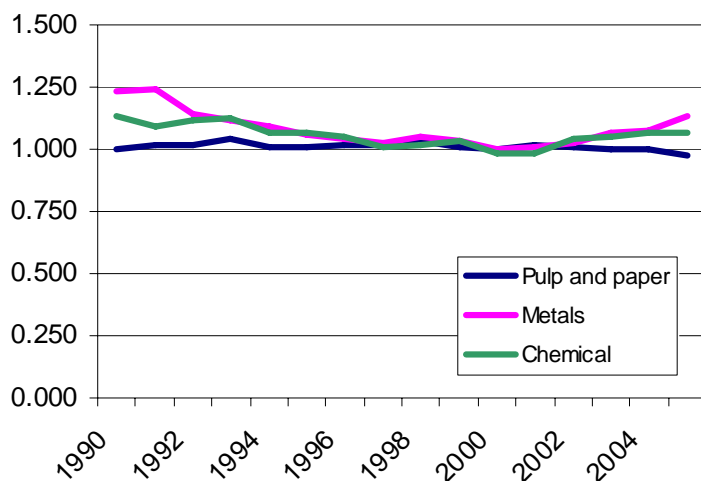


Figure 4.27 Energy indicator developments for industries in Finland. Ratio of electricity use index to production index. Base year 2000.

Source: Statistics Finland and ECOwin

The numbers are indexed with 2000 as the base year. The index shown is the ratio of the electricity use index to the production index. If the curve is flat, it means that a one percent increase in the production index gives a one percent increase in energy use. When the curve is decreasing, it means that the production growth is higher than the energy consumption growth (or, if production is declining, that energy use is declining by a higher pace than production). The figure shows that the electricity intensity of the pulp and paper industry has been practically constant since 1990. According to anecdotal information, energy efficiency has improved in the period, but this is counteracted by stricter environmental and product quality standards. This is also confirmed by the ODEX index.

The electricity intensity of the metal and chemical industries declined until the end of the 1990ies, but has been more or less constant until the last couple of years.

According to state agency Motiva, voluntary energy conservation agreements play a central role for the energy efficiency development in Finland. The voluntary agreements cover 60% of total energy consumption. Annual savings corresponds to the annual electricity and thermal energy consumption of more than 300,000 single-family homes. Almost a fifth of the energy saving is electricity. 85% of savings are realized in industry, altogether an estimated annual saving of 6.1 TWh and CO₂ emissions of 2.2 mill. ton has been realized. The total potential was estimated at 11 TWh (by 2010).

There is also a Motiva program for energy sector energy conservation which covers district heating (35 companies) and power generation (37 companies). Annual energy saving by the end of 2004 as a consequence of reported measures was 263 GWh in electricity and 528 GWh in district heating.

Norway

Norway presents ODEX indicators for Manufacturing, Transport and Households, see Figure 4.28.¹⁵ The strongest improvement in energy efficiency is found in the transportation sector. In manufacturing the improvements have been modest.

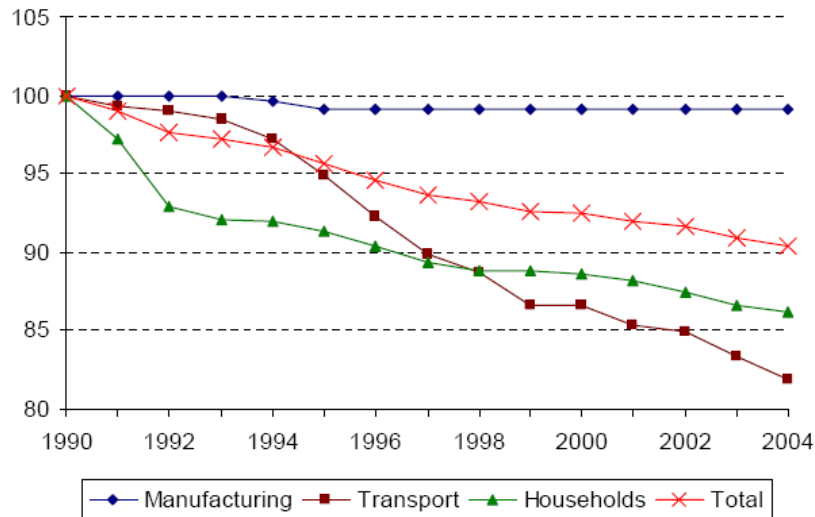


Figure 4.28 Energy efficiency progress of Norway measured by the ODEX indicator
Source: IFE (2006)

From 1990 to 2004, energy use in the Norwegian economy increased by 30% whereas the gross product increased by 60%. This implies that the energy intensity decreased by 19%.

From 1990 to 2004 the gross product¹⁶ of the manufacturing and service industries increased twice as much as the input of energy. International statistics show the same pattern in other OECD countries.

The industry accounted for about one third of energy consumption in Norway in 2004, i.e. a total of 72 TWh. The service sector accounted for 33.5 TWh. There may be a correlation between the labour intensity and the energy intensity of service industries. (If we look at energy user per employee, the reduction is only 5 per cent.) Energy use in primary industries and construction was 12 TWh in 2004.

Decomposition of three explanatory factors for change in energy consumption; activity level, energy intensity and industry structure, reveals that the change in industry structure is a very important factor (Bøeng og Spilde, 2006)¹⁷. With the same activity level and energy intensity as in 1990, the change in industry structure would yield a 9% reduction in total

¹⁵ “Energy Efficiency Policies and Measures in Norway 2006”. Institute for energy technology, MURE ODYSSE, Intelligent Energy Europe, 2006.

¹⁶ The gross product is the sum of wages, profits, capital depreciation and net industry taxes.

¹⁷ Bøeng and Spilde: Produksjon av varer og tjenester, Økonomiske Analyser 3/2006. Statistics Norway.

energy use in 2004. Looking just at the industry sector, the change in energy intensity is the most powerful explanation: With the same industry structure and activity level, energy use in 2004 would have been 4.8 % lower than in 1990.

If we look at the development in energy intensive industries in Norway, we find a mixed picture. There is a trend towards reduced energy intensity, but it is not clear-cut. Pulp and paper shows an undefined trend, whereas the energy intensity of chemicals and metals has declined. After 2000, it is however only in chemicals we can find a clear improvement. Behind these figures are intrabranched structural changes. The metal industry in Norway is almost exclusively aluminum. The aluminum industry has grown steadily over the last ten years, and electricity consumption has increased from 16,1 TWh in 1995 to 22,7 TWh in 2005.

The trend in chemicals is both closing of old plants and a general move towards less energy intensive products and technologies.

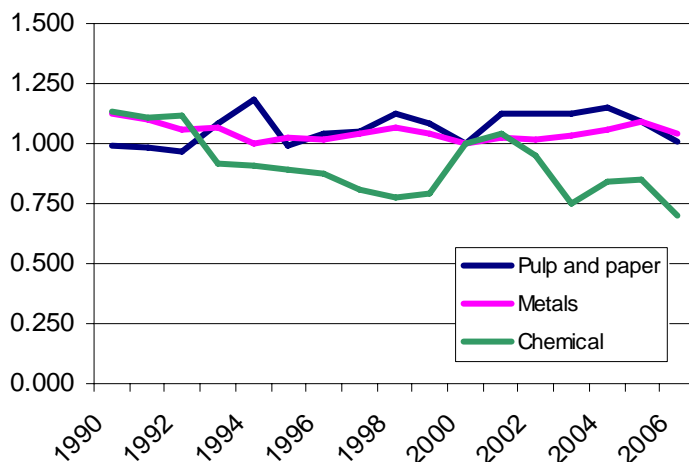


Figure 4.29 Energy indicator developments for industries in Norway. Ratio of electricity use index to production index. Base year 2000.

Source: Statistics Norway and ECOwin

Norwegian pulp and paper is dominated by chemical pulp whereas Swedish and Finnish pulp and paper is dominated by mechanical pulp. Chemical pulp is more electricity intensive than mechanical pulp measured against value added, but not when measured against production per ton. (It is however unclear whether the numbers in the ODYSSEE data base include the pulp and paper industry, or paper production only.) In paper production there are also structural differences between the Norwegian industry, with a dominance of newspaper paper, and the Swedish and Finnish industry, with more high quality paper products.

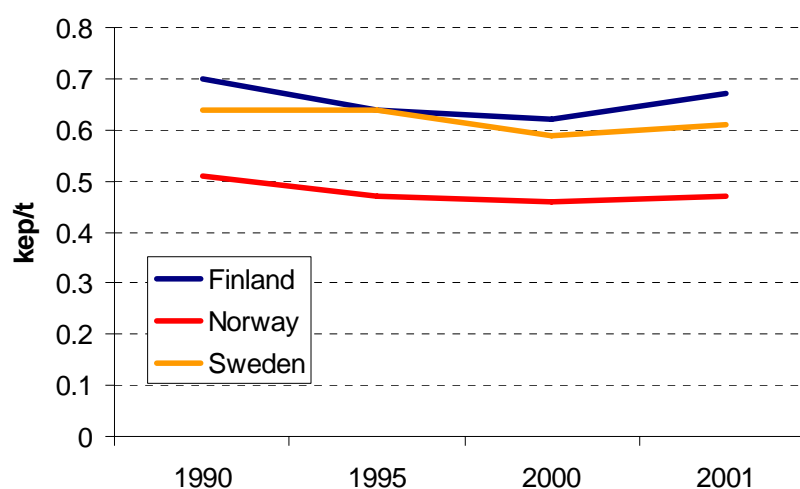


Figure 4.30 Energy consumption of paper industry per ton

Source: ODYSSEE data base

Energy use per heated square meter is reduced by 10% since 1990. According to a study by Larsen and Nesbakken (2005)¹⁸ the following trends can be found in energy use in households in Norway

- Average electricity consumption per household is approximately the same in 2001 and 1990. (There is an increase of 3%.)
- Electricity consumption for hot water (down 50%), lighting (down 18%), drying and dish washing has decreased.
- Electricity consumption for space heating and “other uses” (up 37%) has increased.
- One third of electricity consumption was used for space heating in 2001.
- Consumption for space heating varies substantially between years due to variations in temperature. Electricity for space heating was up 60% from 1990 to 2001. The reason is a combination of lower temperatures and higher oil prices.
- The share of households with electrical heaters or water cable heating increased from 92 to 98%, whereas the share of households with oil heaters decreased from 30 to 15%.

Hence it is clear that the development in energy use in households is composed by a complex set of factors.

¹⁸ Larsen and Nesbakken: Økonomiske Analyser 4/2005, Statistics Norway

Sweden

The Swedish MURE Odyssee report presents energy efficiency progress indexes for Final consumers, Households, Transport and Industry (manufacturing).¹⁹

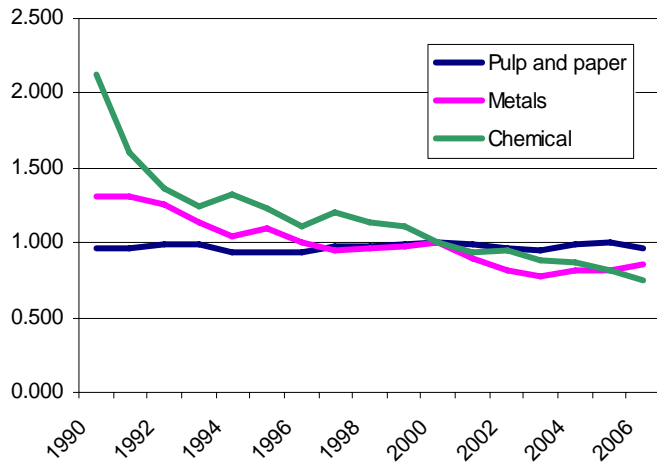


Figure 4.31 Energy efficiency progress of Sweden measured by the ODEX indicator.

Source: Swedish Energy Agency (2006)

Between 1990 and 2004 the average GDP growth in Sweden was 2%, while final energy use grew only 0.6% per year.

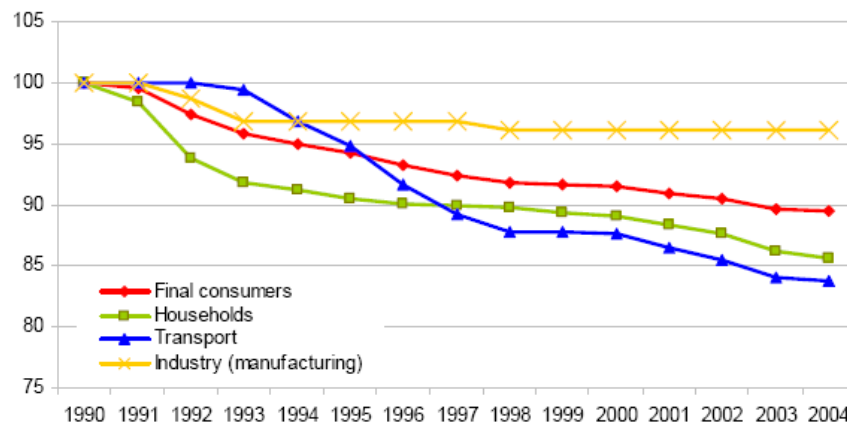


Figure 4.32 Energy indicator developments for industries in Sweden. Ratio of electricity use index to production index. Base year 2000.

Source: Statistics Sweden and ECOwin

¹⁹ "Energy Efficiency Policies and Measures in Sweden 2006". Swedish Energy Agency, MURE ODYSSEE, Intelligent Energy Europe, 2006.

The electricity intensity of the Swedish pulp and paper industry shows the same development as the EU 15 index. The chemical industry has shown a steep energy efficiency improvement, to a large extent explained by structural changes within the industry like in the rest of Europe.

The metal sector in Sweden is dominated by iron and steel production, where a large part of energy consumption is coal as reduction medium in the iron ore smelting process. Hence, it is difficult to reduce the share of coal in steel production, but electricity use has been reduced from 0,91 TWh/ton steel in 1990 to 0.75 TWh/ton steel in 2005.

According to a study by the Swedish Energy Agency, STEM, published in 2006²⁰, it is concluded that depending on the calculation method and model, Sweden has realized between 3 and 90 per cent of the energy efficiency target set out by the EU energy efficiency directive (since 1995). Energy services and measures with the most significant impact on (primary) energy savings are conversion from oil and electricity to district heating and heat pumps, in addition to efficiency improvements in production and distribution in the production of district heating and combined heat and power. But even other measures are shown to contribute to the improvements.

4.2.7 Comments

Some general comments on the relevance of energy efficiency and energy conservation:

- Energy savings and energy conservation seem to play a significant role in explaining the decline in energy intensity of the economies, but it is not the only explanation
- Changes in industry structure – with a decline in energy intensive industries' share of GDP – account for a substantial decline in overall energy intensity in most countries. There are, however, large differences between countries in this respect.
- It is also clear that policy measures or conscious energy conservation measures are not the only explanation for the decline in energy intensities in sub-sectors. Price developments and technological changes and trends contribute as well.

4.3 The effect of improved energy efficiency 1990–2005

As pointed out above (in section 3.2), the energy intensity of the Nordic economies, measured in relation to GDP, has declined since 1990. This means that the economies have become more energy efficient, although the improvements cannot necessarily be attributed to energy conservation

²⁰ STEM (2006): Effektivare energianvändning

measures. In this section we will take a brief look at what would have happened to emissions if the energy intensity had not declined. (It should be noted that the energy intensity of almost all western economies have declined in the same period, cf. Figure 4.208.)

4.3.1 Modelling assumptions

In order to estimate the benefit of end-use energy conservation and efficiency measures between 1990 and 2005, in terms of avoided CO₂ emissions and avoided energy use a contra factual model analysis has been carried out. For this purpose a MARKAL database for the Nordic countries including data between 1990 and 2005 was used. The database covers Denmark, Finland, Norway and Sweden, as does the MARKAL Nordic model as well.

Two scenarios are compared, the actual outcome between 1990 and 2005 (the “actual case”), and a contra factual scenario where we assume that no energy conservation is realized during this period (the “alternative” case). In the “alternative” case it is assumed that the growth in energy use (final demand) equals the growth in the economy, i.e. GDP growth, i.e. all sectors in the economy are growing at the same rate as GDP (no structural changes), and the energy intensity is not improved. This means, for example, that energy use in the “alternative” case in Sweden is around 40% higher in 2005 than in 1990 (corresponding to the actual GDP growth), while in the actual outcome energy use increases by only 10%.

In general, the development of energy use may be explained by evaluating three separate components: activity growth, structural changes and energy efficiency improvements (see e.g. Swedish Energy Agency, 2000). The *activity* component is associated with the activity level of the economy as a whole; a growing economy demands more energy input all else being equal. The *structural* component has to do with the composition of e.g. the industry; industries with different energy intensities grow at a different pace, and this affects the overall energy intensity, all else being equal. As we have seen above, economies with comparatively large shares of energy-intensive industry, as is the case for Finland, Norway and Sweden, in general have relatively higher energy intensity compared to economies dominated by e.g. the service industry. *Energy efficiency* improvements may be directly connected to energy conservation and efficiency measures *actively* undertaken in order to reduce or alter energy use, it may be the result of general technical development within each sector, or it may be a result of structural changes within a sector.²¹

By comparing the model results from the “actual” scenario with the “alternative” scenario it is possible to estimate the emission reductions

²¹ Please observe that technical development and intra-industry structural changes may also result in increased energy intensities.

accruing from the reduction in energy intensity of GDP (improved energy efficiency) during the time period in focus. However, the difference in energy use is composed of *both* the structural and the pure efficiency components. A further separation between these two components cannot be done here. Moreover, we cannot separate the emission reductions caused by active policy measures, such as taxes and energy conservation measures, from the emission reductions caused by technological development and structural changes. (It is important to note that both technological development and structural changes can be the result of energy conservation measures.) On the other hand, the focus of this exercise is not to investigate the impact of energy efficiency *measures*, but the impact of energy efficiency *improvements*.

We have chosen to compare the contra factual “alternative” scenario with the modelled “actual” scenario in order to get a more clear-cut comparison of the results. In the modelled “actual” scenario, observed fuel prices and selected policy measures (mainly carbon and energy taxes) have been included in the model description. However, since a model cannot capture all details of the market, there are some significant differences between the modelled “actual” outcome and what really happened between 1990 and 2005. For instance, the model formulation does not include the actual development of the capacity stock, i.e., the development in production capacity is a model result even in the “actual” case. By comparing the two modelled situations we obtain two scenarios where the “only” difference lies in the difference in energy demand, where one case mimics the actual development in energy intensity, and the other corresponds to a situation where energy demand grows at the same pace as GDP.

4.3.2 Model results

As we can see from Figure 4.33, there is a significant difference in energy demand in the two scenarios. In both cases energy demand increases, but in the “alternative” case, the growth is about 35%. This is, of course, the main assumption and the “only” input difference between the two scenarios as discussed above.

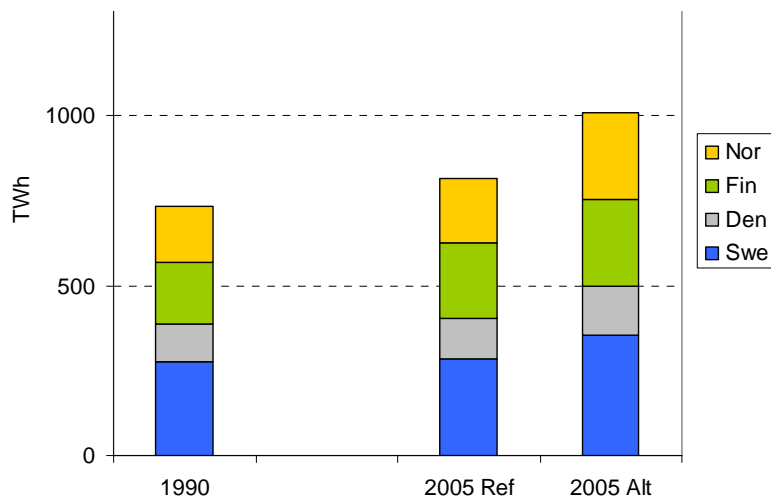


Figure 4.33 Total final energy demand (excluding transports) as obtained from the model runs

When comparing the “actual” case with the “alternative” case in 2005, cf. Figure 4.34, we note that emissions are around 40 percent higher. However, this figure is significantly affected by several important assumptions. We have, for instance, introduced certain limits to investments in new coal power. Thereby, the model chooses investments in alternative means of production (e.g. gas and renewables) that may be more expensive than coal-fired technologies. If the use of coal power had been unlimited, results would have ended according to “alternative high” as can be seen in the figure. In this case, virtually all of the increase in electricity demand between 1990 and 2005 would have been supplied from coal. For example, this case implies that coal power generation in Sweden is around 60 TWh (of which 15 TWh in CHP schemes) in 2005!

In the “alternative” case coal power generation in Sweden is almost 20 TWh (of which 15 TWh in CHP schemes) in 2005. In this case, gas power is an important supplier with Norway producing around 12 TWh. If we extend this discussion and assume that, instead, further efforts for promoting new emission-free generation would have been undertaken in the “alternative” scenario we could have ended up in the “alternative low” case. This case is not based on model calculations but rather on a simple view on what might have happen in the “alternative” case if 25 TWh of coal power is replaced with 10 TWh of nuclear power in Finland (corresponding to a fifth reactor brought forward ten years in time) and 15 TWh of renewable electricity generation. We still get a substantial increase in CO₂ emissions compared to the “actual” case (2005 Ref).

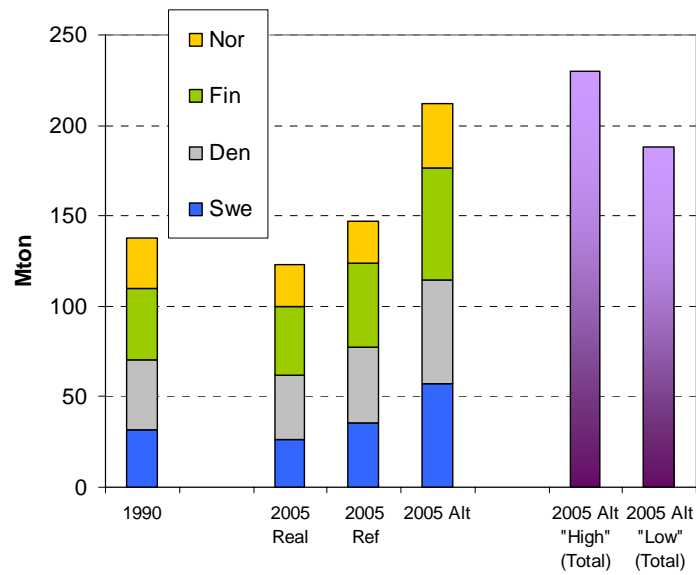


Figure 4.34 Total CO2 emissions (excluding transports) as obtained from the model runs

Figure 4.34 (and 4.35) also shows that there is a significant difference between “the actual” case in 2005 and the realized outcome in 2005 (compare “Ref” with “Real”). This relates to the discussion on model approach above where we concluded that the model used is not designed to fully simulate reality. For example, no climate policy measures are included in this version of the model, although climate policies in reality have governed new investments to a certain extent between 1990 and 2005, even though the EU ETS was not launched until the beginning of 2005. Furthermore, hydro power generation was roughly 20 TWh above normal in 2005, which explains a significant part of the difference between the model and the realized outcome. Such model-related issues do largely explain why e.g. coal and oil power generates around three times as much in the “actual” scenario as they do in the realized case.

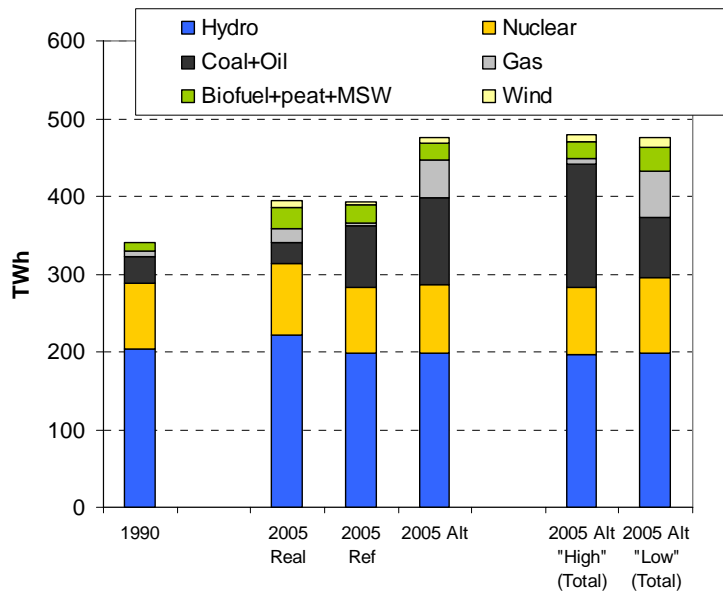


Figure 4.35 Total electricity production as obtained from the model runs

Putting it all together our analysis very roughly estimates that CO₂ emissions would have been around 30-50% higher in 2005 without the realized energy efficiency improvements. The methodological limitations and difficulties discussed above in making this estimate, in addition to uncertainties in estimating the needed supply for the additional energy use between 1990 and 2005, make it difficult to further limit the interval of outcome. If, for instance, the additional electricity use would have been supplied largely by coal power, which is suggested by the model, emissions would have been at the higher end of the interval. If, on the other hand, increasing electricity demand would have been supplied by a more balanced fuel mix including efforts to stimulate renewable electricity, the emission increase would have been at the lower end of the interval. Nevertheless, this model exercise clearly shows the significant effect energy efficiency improvements have had on energy use and, thus, CO₂ emissions, in the Nordic countries between 1990 and 2005.

5. Scenarios towards 2015

In this chapter we look ahead towards 2015 and analyze how future CO₂ emissions may be affected by different policy measures, i.e., renewables support, emissions trading, CO₂ and energy taxation and energy efficiency improvements.

We have used the MARKAL-Nordic model to estimate the effect of different policy measures, on the future development in CO₂ emissions from the stationary energy system in the Nordics. The focus year is the situation in 2015, but the model gives results for a longer time period.

The following cases or scenarios are studied:

- Reference scenario (Ref): No CO₂ or energy taxes, no emission trading system and no special support for renewables.
- Taxes and support (Tax+support): CO₂ and energy taxation as they are currently applied, but no emission trading²²
- Emission trading (ETS only): Only emission trading, no CO₂ taxation and no special support for renewables. EUA price 20 €/ton.
- All measures (Base): Taxes, support and emission trading are used. Three cases for EUA prices: 10 €/ton (Base 10), 20 €/ton (Base 20) and 40 €/ton (Base 40).
- Electricity conservation: Reduction in electricity demand by 15% in households and service.
- Heat conservation: Reduction in heat demand by 15% in households and service.

In the model, renewable support is generally associated with renewable electricity production and reflects a selection of the most important support measures that exist today in the Nordic countries. For Sweden the model description includes the electricity certificate scheme as a production goal. This means that 16 TWh of certificate eligible production has to be supplied by 2010 and 22 TWh by 2016. The amount supplied by wind, bio fuels and hydro is a result of the model optimization. For the other countries, the prime support measure included in the model is a fixed production subsidy for wind power which is assumed to be phased out by 2020.

In the following we will first present the results from the model runs with different combinations of renewables support, taxation and CO₂ pricing, and then the results from the scenarios with energy conservation.

²² This means that there is no CO₂ tax on electricity generation. See appendix 1 for more details.

5.1 The impact of CO₂ pricing and renewables support

5.1.1 CO₂ emissions

The calculations reveal that the use of policy measures has a substantial impact on CO₂ emissions in the Nordic countries. Without any measures, i.e. in the reference case, CO₂ emissions increase substantially to 2015, by 31,5 mill. ton or almost 24%, and continue to increase to 2025. The biggest increase is found in emissions from electricity and district heating production. The main reason for this is the choice of coal as the most profitable option for new generation capacity. Electricity production from coal increases by more than 24 TWh. In district heating there is an increase in production based on coal of 20 TWh. Even gas use increases slightly in district heating, whereas the use of renewables declines.

The results are sensitive for the gas price assumption (and the relative gas and coal prices). We have used a gas price of about 120 SEK/MWh for gas to power in Norway, and even higher prices for gas to power in the other market areas due to transmissions costs. For slightly lower gas prices investments in gas power in Norway would probably be profitable. The used gas prices are generally lower than the gas price level we have seen the last couple of years, but higher than a few years back. If gas is competitive to coal, emissions in the reference scenario would be lower. Coal has however historically been competitive towards coal, and would probably be so in a future without CO₂ pricing as well.

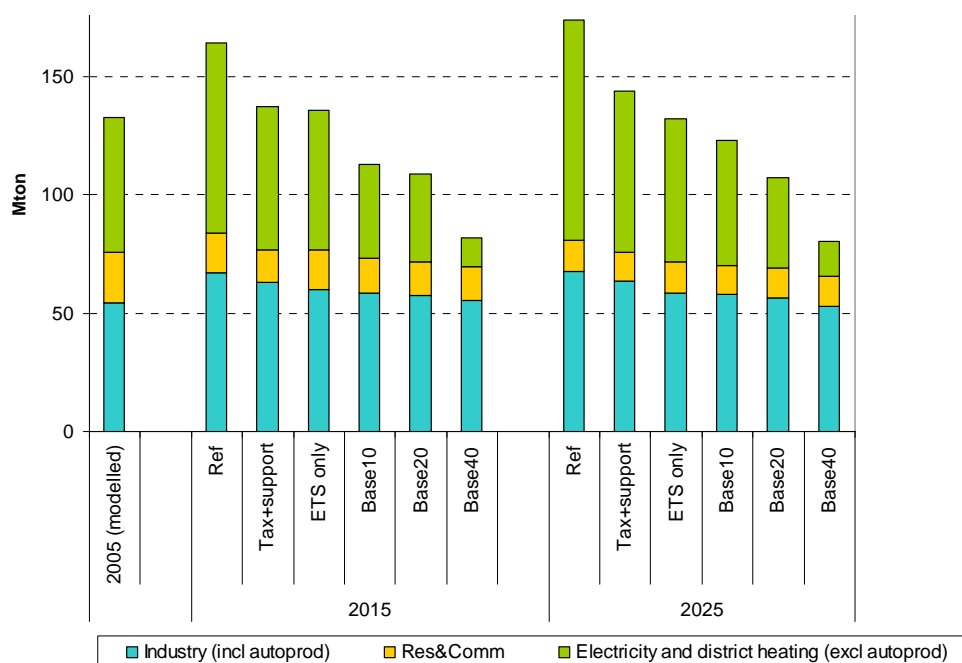


Figure 5.1 CO₂ emissions from stationary energy generation in the Nordics. Different renewables policy and CO₂ price scenarios.

As we apply the different measures in different combinations, CO₂ emissions decline. Accidentally, the case with taxes and support and the case with the ETS only – and a EUA price of 20 €/ton – has approximately the same effect on emissions in 2015, but this is not a general result. The reduction is 27.3 and 28.5 mill. ton respectively, and in both cases total emissions are almost kept at the same level as in 2005. Which scenario yields the highest effect depends of course on the specific EUA price level, the tax policy, the fuel price ratio (gas, coal and oil) and the renewables targets and support. Although the ETS can be said to be a more accurate measure with respect to the level of CO₂ emissions than taxes or renewables support schemes, this is not the case when we are looking only at Nordic emissions. The ETS sets a cap for emissions in the ETS sectors in all EU countries taken together, but does not define an emission level from the Nordic countries.²³ This is the rationale for the modeling of the ETS as an emission cost in a model covering the Nordic region.

However, the distribution of emission reductions is not the same in the tax+support scenario and the ETS only scenario. Carbon and energy taxation generally applies to the residential and service sectors while the EU ETS impacts on the trading sector which, generally, includes industry and electricity and district heating supply. Therefore, emissions are higher from the residential and service sectors in the ETS only scenario than in the tax+support scenario while the opposite is true for industry and electricity and district heating supply. Overall emissions are somewhat lower in the ETS only scenario than in the tax+support scenario.

None of the policy measure “packages” constitute optimal policies in the sense that the cost of emissions is the same in all uses. In the ETS case, only emissions from the trading sectors are priced, and in the tax+support scenario emissions from electricity generation is not priced and different tax levels apply in different sectors, uses and countries.

When comparing the effects of the ETS only and the tax+support scenarios on the residential and service sectors, we find that the ETS only scenario generates higher electricity prices than the tax+support scenario. This means that end use of oil (and other fuels) within the residential and service sectors becomes somewhat more competitive compared to electric heating, and this leads to higher emissions from this sector in the ETS only scenario.

The Base 10, Base 20 and Base 40 scenarios are scenarios where all measures are applied, but the EUA price is 10, 20 and 40 €/ton respectively. Compared to the ETS only case, the application of taxes and renewables support in addition, yields additional reductions in 2015 CO₂ emissions by 23 mill. ton (Base 20 case). In other words, the effect of introducing taxes and renewables support is slightly less if ETS pricing applies as well; the measures are slightly overlapping.

²³ Since it is possible to import credits from projects outside the EU, the ETS does not guarantee a certain emission level for the ETS area as a whole either.

5.1.2 The impact of different CO₂ prices

The impact of CO₂ pricing is shown in the table below. In the ETS only case, with an EUA price of 20 €/ton, emissions are reduced by 28.3 mill. ton in 2015 and 41.8 mill. ton in 2025. If taxes and renewables support are applied as well, the CO₂ reductions are still substantial, shown by the additional effects, Base 20 entry in the table. Even if renewables and taxes are applied, there is a substantial emission reducing effect of introducing a CO₂ price of 20 €/ton. The difference between the Tax+support case and the Base 20 case is a further reduction of 28.3 mill. ton CO₂. Increased CO₂ prices enhance the effects further. In the Base 40 case emissions in 2015 and 2025 are found to be about 50% lower than in the reference case and 40% lower than in 2005.

Table 5.1 Reductions in CO₂ emissions in different renewables policy and CO₂ price scenarios, compared to reference case. Mill.ton per year.

Scenario	2015	2025
Tax+support	-27.3	-29.8
ETS only	-28.5	-41.8
Base 10	-51.6	-50.9
Base 20	-55.6	-66.6
Base 40	-82.6	-93.1
Additional effect of ETS (Base vs. Tax+ support)		
Base 10	-24.3	-21.2
Base 20	-28.3	-36.8
Base 40	-55.3	-63.4

The main factors explaining emission reductions are found in changes in electricity and heat generation. Hydro and nuclear generation is basically the same in all scenarios. (Although some investments in hydro occur on the basis of renewables support.) The important variations occur in production based on coal, gas, bio fuel, and wind and other renewables. However, it is important to notice that reduced consumption plays a role as well. (Electricity import from non-Nordic countries is fixed in all scenarios, so changes in Nordic generation reflect changes in Nordic demand.)

5.1.3 Electricity production

Total Nordic electricity supply (and consumption) increases in all scenarios compared to 2005, but less in the policy scenarios than in the reference case. This results even though the price sensitivity of energy use in the model is somewhat limited. The demand for useful demand cannot be reduced. However, final demand of a specific energy carrier can be reduced through fuel conversion and/or through certain conservation measures (at a cost).

Figure 4.2 shows the mix of electricity generation in the scenarios. In the reference scenario the absence of policy measures leads to a revival of coal power. Electricity generation from gas and renewables stays at the same level as in 2005. The fifth nuclear reactor in Finland starts operation in 2009 in all scenarios.

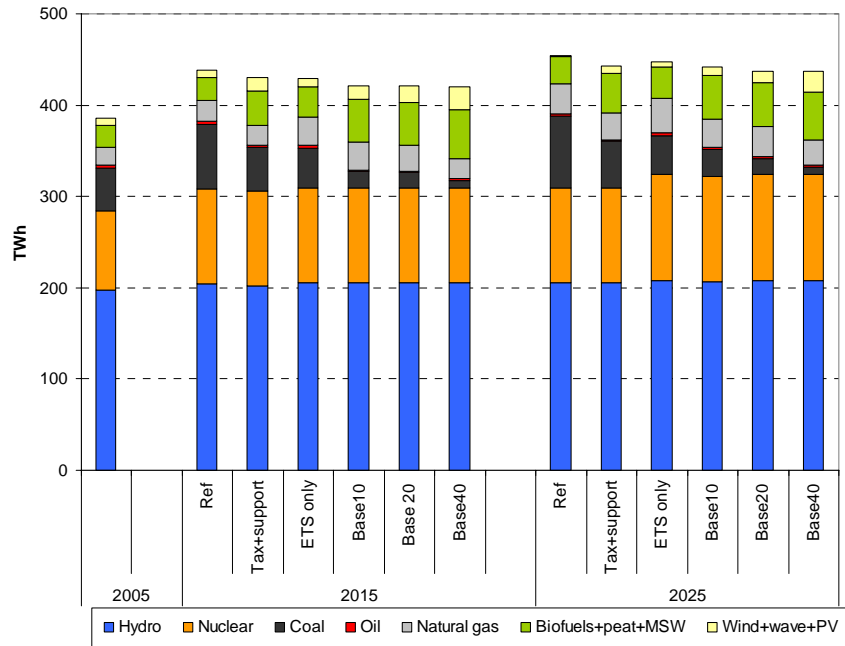


Figure 5.2 Electricity generation by fuel in the Nordic market, different policy scenarios.

Introducing policy measures, coal is the big loser compared to the reference case, whereas bio fuels, wind and other renewable sources benefit in all scenarios. Taxes and support schemes for renewables (subsidies to wind power in Denmark, Finland and Norway and electricity certificates in Sweden) increase renewable electricity supply. In this case there is no increase in the production from gas and coal from 2005. Introducing EU ETS instead (assuming a EUA price of 20 €/ton) leads to an increase in production from gas and renewables. The increase in renewables is less than in the renewables support case. When the EUA price is high, i.e. 40 €/ton, gas generation is lower and the share of bio fuels is higher. In the scenario where taxes, renewables support and the EU ETS are all used simultaneously, production from gas and renewables increases. There are significant reductions in coal fired production.

Whereas the ETS only scenario results in increased electricity prices, taxes and renewables support generally do not. Increased electricity prices also explain the investment in a sixth nuclear reactor in Finland in the ETS only case. The higher electricity prices in the ETS only scenario also explain why new investments in especially fossil fuelled (gas) CHP are profitable. This effect is to a large extent offset when support schemes

for renewable electricity are applied alongside the ETS. This becomes especially apparent in Sweden where gas CHP generates more than 13 TWh of electricity in 2025 in the ETS only scenario. In the Tax+support scenario the corresponding production is less than 4 TWh. The Swedish electricity generation system in the Base 20 scenario, where all policy measures are included, is very similar to that obtained in the Tax+support scenario, i.e. gas plays a minor role while renewable generation dominates new investments. This is due to the electricity certificate system.

Investments in gas power generation in Norway, in addition to the proximal 3 TWh already decided today, is not profitable in any of the scenarios before 2025. Production in the gas power plants approach zero after 2015 if the EUA price increases to 40 €/ton. However, this result depends highly on the gas price assumption.

Furthermore, a handful of hydro and wind power projects in Norway become profitable in the model results also without any policy measures due to favorable natural conditions. Including policy measures, even more hydro and wind projects become profitable. In 2015, almost 7 TWh of new hydro power and more than 5 TWh of wind power are generated in Norway in the “Base 20” scenario. Restricting the possibilities for such renewable penetration will, of course, also become beneficial for the expansion of gas power in Norway.

5.1.4 District heating supply

The use of taxes and support schemes for renewables has a significant impact on the development of district heating. This is because the CO₂ taxes apply to heat generation also in CHP and heat-only stations. In terms of renewables this has a greater impact than only introducing EU ETS. For relatively high EUA price, district heating supply in the Nordic countries may be entirely dominated by renewables. This is already the situation in Sweden.

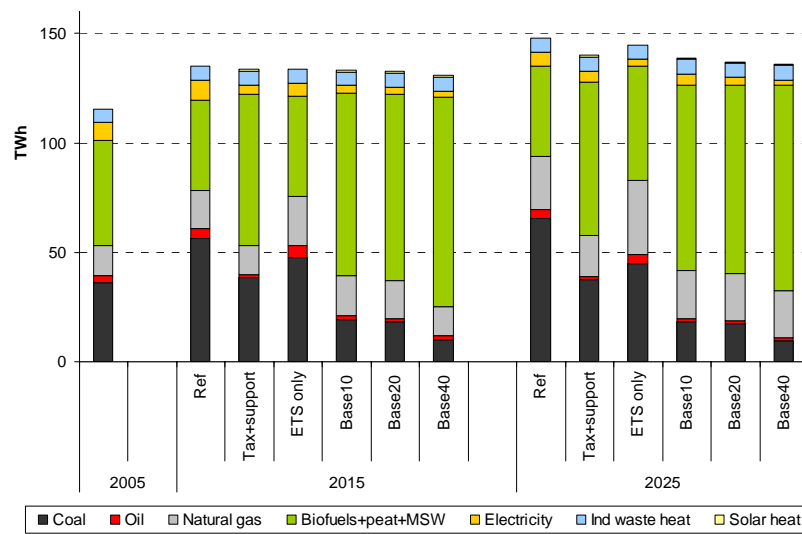


Figure 5.3 District heating by fuel in the Nordic market. different policy scenarios.

5.1.5 Energy use

The policy scenarios induce a general increase in the use of renewables, district heating and electricity, and less use of fossil fuels. There is a slight increase in natural gas use while oil use is steadily decreasing. In the ETS only case, oil use is somewhat higher than in the Tax+support case in the residential and service sectors. This was discussed earlier as being a result of the high CO₂ and energy taxation in these sectors and the price increase of electricity due to the EU ETS.

CO₂ and energy taxes are excluded in the ETS only scenario while electricity prices are higher than in the Tax+support scenario. At the same time, the residential and service sectors are not included in the EU ETS. Thus, oil heating in the residential and service sectors becomes more competitive in the ETS only scenario and this leads to higher emissions. For the industry, it is the other way around. Industry generally faces significantly lower (if any) CO₂ taxes, but is included in the EU ETS. Thus, emissions from the industry are higher in the Tax+support scenario than in the ETS only scenario.

5.2 The effect of energy conservation measures

Energy conservation measures, if effective, would result in lower energy intensities, and would typically be measured by reduced energy intensity compared to GDP, or different energy indicators per sector (cf. chapter 3). In the scenarios above some energy efficiency improvements are achieved through the policy measures applied, i.e. the price effects influence end-use of energy.

In this section we will take a closer look at what may be achieved, when it comes to emission reductions, if we assume that energy demand is reduced directly, i.e., through direct energy conservation measures. We have investigated this by means of two different scenarios:

- One scenario where energy conservation measures are targeted at electricity. We assume that electricity consumption in households and the service sector is reduced 15% from 2005 to 2015.
- One scenario where energy conservation measures are targeted at energy use for heating. We assume that heat consumption in households and the service sector is reduced 15% from 2005 to 2015.

Apart from the reduced electricity and heating consumption, both these scenarios are identical to the Base 20 scenario.

Figure 4.4 shows the changes in CO₂ reductions and Figure 4.5 the changes in energy use by fuel in the two cases. In both cases, changes are compared to the Base 20 scenario, i.e. we assume that renewables support and CO₂ and energy taxation are applied, and that the EU ETS price is 20 EUR/t.

In the electricity conservation case almost all of the savings are realized through lower electricity generation, but there are even some effects in the use of other energy sources. This is explained by price effects. Reduced electricity demand in the sectors in focus implies lower electricity prices, and enables other sectors, such as industries, to increase their electricity consumption somewhat. Hence, industries demand less bio fuels (in exchange for somewhat more electricity) and the use of bio fuels may increase somewhat in the household and service sectors. Bio fuels are modeled as limited resources with exogenously given costs for each class of bio fuels. However, these effects are very small and uncertain because they depend on the price elasticity and price formation in the bio fuel market. Nevertheless, these effects show the complexity of the matter and the importance of keeping a system perspective on the application of policies. Even though the effects are small, this is an example of how alternative means of supply may be affected when one specific energy carrier is targeted in a conservation campaign.

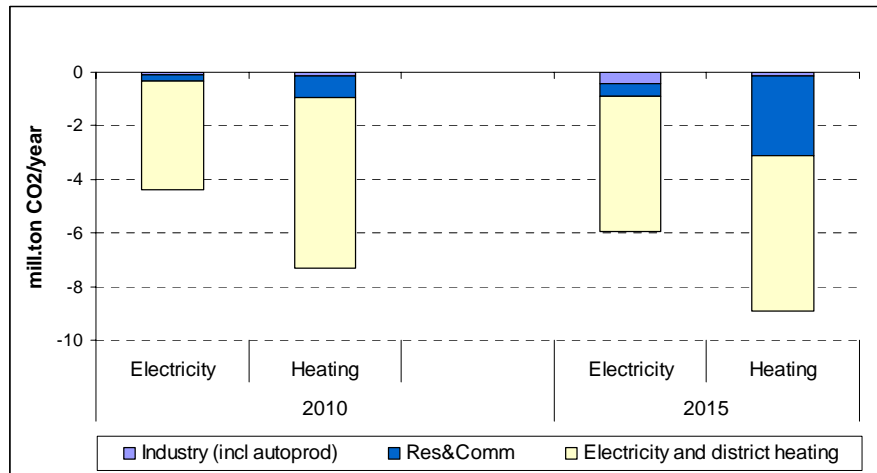


Figure 5.4 CO₂ emission reductions. two energy conservation cases. Compared to the base scenario.

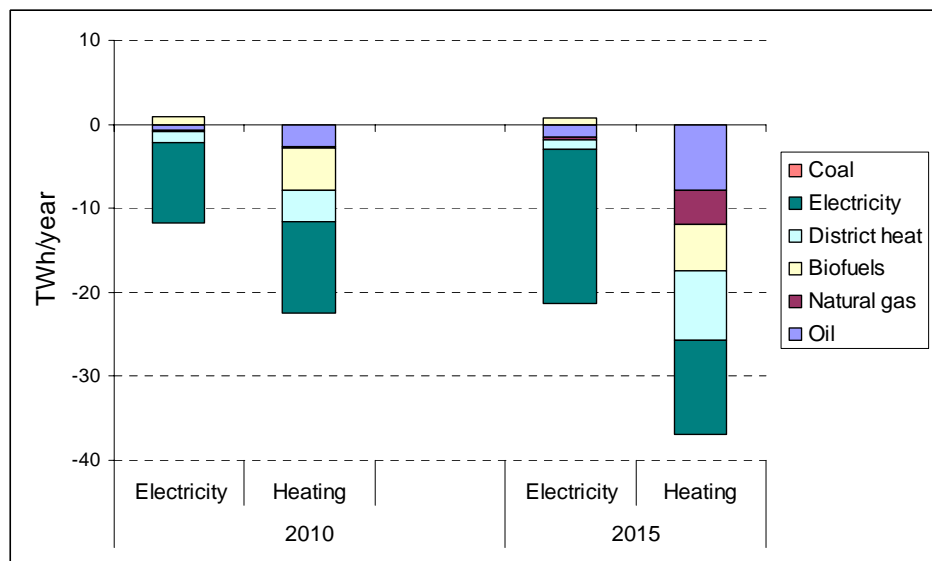


Figure 5.5 Changes in energy use. two energy conservation cases. Compared to reference scenario.

In the heat conservation case the reduction in energy use is distributed over a mix of different fuels. This is natural since the Nordic heating markets are rather heterogeneous in terms of energy carriers. Most of the reductions occur within electricity and district heating, and this is where we find the strongest effect on CO₂ emissions. In 2015, there are however, substantial reductions in CO₂ emissions in the residential and commercial sectors. This is explained by reductions in use of oil and gas.

The reduction in CO₂ emissions is largest in the case where heat consumption is reduced. That is explained by the fact that total heat consumption is larger than total electricity consumption in the households and service sectors. Hence, the results are not directly comparable, but

illustrate the relevance of *how* energy is saved when we focus on the *emission effects* of energy savings. In the electricity conservation case, final energy use is reduced by 21 TWh in 2015, whereas in the heating conservation case, final energy use is reduced by 37 TWh in 2015.

If we measure emissions per TWh saved, electricity conservation is the most effective instrument. In the electricity conservation case, CO₂ emissions are reduced by 0.4 mill. ton per TWh in 2010 and 0,28 mill. ton per TWh in 2015. The corresponding numbers for heat conservation are 0.33 mill. ton per TWh in 2010 and 0.24 mill. ton per TWh in 2015. An observation is that the relative emission reductions are smaller in 2015 than in 2010. In our scenarios, the energy system becomes cleaner over time, at least on the margin. This could happen even without renewables support or CO₂ pricing; If old inefficient plants are replaced by new more efficient plants, or new plants are more efficient than the average of the old production capacity, the emission reduction effect of energy conservation would be smaller.

The actual numbers, i.e., the effect on total emissions obviously depend on the chosen reference, and to some extent we can say that as emission reducing policy instruments, demand side efforts and supply side measures are substitutes.

References

- Danish Energy Authority. "Energy Efficiency Policies and Measures in Denmark 2006". MURE ODYSSEE. Intelligent Energy Europe. 2006
- Danish Ministry of Environment. "Denmark's National GHG Inventory Report 2007 to the UNFCCC". Common Reporting Format Tables
- Fishbone L. G. and Abilock H. 1981. "MARKAL, a Linear-programming Model for Energy Systems Analysis: Technical Description of the BNL Version". *Energy Research Vol. 5* (1981) pp. 353–375.
- IEA. 2005. "Oil crisis and climate challenges: 30 years of energy use in IEA countries".
- IFE. "Energy Efficiency Policies and Measures in Norway 2006". MURE ODYSSEE. Intelligent Energy Europe. 2006.
- Loulou R., Goldstein G. and Noble K. 2004. "Documentation for the MARKAL Family of Models". ETSAP. available at www.etsap.org (December 2006).
- Marcuse W., Bodin L., Cherniavsky E. and Sanborn Y. 1976. "A Dynamic Time Dependent Model for the Analysis of Alternative Energy Policies". *Operational Research* '75. North Holland Publishing Company. pp. 647–667.
- Ministry for the Environment Iceland. "Iceland's National GHG Inventory Report 2007 to the UNFCCC". Common Reporting Format Tables.
- Norwegian Pollution Control Authority (SFT), directorate under the Norwegian Ministry of Environment. "Norway's National GHG Inventory Report 2007 to the UNFCCC". Common Reporting Format Tables.
- Motiva OY. "Energy Efficiency Policies and Measures in Finland 2006". MURE ODYSSEE. Intelligent Energy Europe. 2006.
- Nyström I. 1995. "Improving the specification of the energy-economy link for a systems engineering model". thesis for the Degree of Licentiate of Engineering. ISBN 91-7197-230-7. ISSN 1103-4513.
- Statistics Finland. "Finland's National GHG Inventory Report 2007 to the UNFCCC". Common Reporting Format Tables.
- Swedish Energy Agency. "Energy Efficiency Policies and Measures in Sweden 2006". MURE ODYSSEE. Intelligent Energy Europe. 2006.
- Swedish Environmental Protection Agency. "Sweden's National GHG Inventory Report 2007 to the UNFCCC". Common Reporting Format Tables.
- United Nations Framework Convention on Climate Change. "GHG DATA 2006". GHG emission data for 1990–2004 for Annex I Parties.

Abbreviations

CO _{2eq}	Carbon dioxide equivalents
CHP	Combined Heat and Power
EU ETS	European Emission Trading Scheme
EUA	European Union Allowances
GHG	Greenhouse Gases
GDP	Gross Domestic Product
GWh	Giga Watt hours
IEA	International Energy Agency
IEA-11	IEA-11 denotes Australia, Denmark, Finland, France, Germany, Italy, Japan, Norway, Sweden, the United Kingdom and the United States. To 1973.
kWh	Kilo Watt hours
LULUCF	Land-use, Land-use Change & Forestry
MARKAL model	Generic Model by the Energy Technology Systems Analysis Programme
Mtons	Million tonnes
NCM	Nordic Council of Ministers
ODEX	Energy Efficiency Index
OECD	Organisation for Economic Cooperation and Development
STEM	Statens Energimyndigheten Swedish Energy Agency
TWh	Terra Watt hours
UNFCCC	United Nations Framework Convention on Climate Change

Norwegian summary

Resymè

Hovedtema for rapporten er en analyse av betydningen av fornybar energi, CO₂-prising og energieffektiviseringstiltak for utslippene av CO₂ fra stasjonært energiforbruk i de nordiske landene utenom Island. Rapporten gir også en oversikt over klimagassutslippene i de nordiske land, inkludert Island. Kraft- og varmeproduksjon (og -forbruk) står for størstedelen av utslippene i de nordiske landene. Samlet sett var utslippene i 2004 over Kyoto-målet, men Sverige og Island har utslipp under sine respektive Kyoto-mål. Analysen viser at CO₂-utslippene fra 1990 til 2005 kunne vært så mye som 30–50 % høyere uten utbygging av fornybar energi og forbedringen i energiintensitet. For fremtiden er det klart at både kvotehandelssystemet og fornybarpolitikken kan ha stor betydning for CO₂-utslippene. Ved moderate kvotepriser er det lite overlapp mellom de to virkemidlene. Begge gir betydelige utslipps-reduksjoner både samlet og hver for seg. Det kommer av at virkemidlene tildels retter seg mot ulike sektorer og bruksområder. Effektive energieffektiviseringstiltak vil også ha stor betydning for utslippene. Reduksjoner i elforbruket har imidlertid større effekt enn reduksjoner i varmemeforbruket.

Bakgrunn og problemstillinger

Hovedhensikten med prosjektet har vært å analysere betydningen av fornybar energi og energieffektivisering på utslippene av drivhusgasser i de nordiske landene. I henhold til prosjektinnbydelsen består prosjektet av tre hoveddeler:

- Den historiske utviklingen i klimagassutslipp fra de nordiske landene fra 1990 til i dag. I hvilke sektorer har utviklingen vært positiv og i hvilke sektorer har den vært negativ? Hva er sannsynlige årsaker?
- Hvilken betydning har utviklingen i stasjonært energiforbruk hatt for utviklingen i CO₂-utslipp? Særlig oppmerksomhet skal rettes mot rollen til fornybare energikilder og energieffektivisering.
- Hvilken rolle har CO₂-avgifter og kvotesystemet spilt for utviklingen av fornybar energi og energieffektivisering? Hvordan ser vi for oss utviklingen frem mot 2015? Hva er betydningen av andre politiske virkemidler?

Hovedkonklusjoner

Utvikling i totale klimagassutslipp

De samlede utslippene av klimagasser fra de nordiske landene økte med 4,5 % fra 1990 til 2004. I 2004 ble det sluppet ut 277,6 mill.tonn CO₂-ekvivalenter.

Mens utslippene fra Finland, Danmark og Norge i 2004 var høyere enn Kyoto-målet, hadde Island og Sverige utslipp godt under sine Kyoto-mål. En del av forklaringen til høye utslipp fra Finland og Danmark var lave tilsig i 2003, noe som førte til at vannkraftproduksjonen var lavere enn normalt både i 2003 og 2004. Utenom energisektoren, som viser et varierende bilde, øker utslippene fra transportsektoren jevnt over, mens utslippene fra jordbruk og avfall går ned.

Utviklingen i CO₂-utslipp

De samlede CO₂-utslippene i de nordiske landene økte med 18,4 % mellom 1990 og 2005.

Energi- og transportsektoren står for de største utslippene. Det er imidlertid store ulikheter i sammensetningen av utslipp mellom de nordiske landene. Hovedårsaken til det er store forskjeller i sammensetningen av energibærere i kraft- og varmeproduksjon.

Utslippene fra energisektoren varierer betydelig mellom år på grunn av variasjoner i tilsig til vannkraftverkene i Norge, Sverige og Finland, samt temperaturvariasjoner som påvirker etterspørselen. I tørrår med redusert vannkraftproduksjon, må produksjonen øke i andre kraftverk. Dette er i stor grad kullkraftverk i Danmark og Finland, og i noen grad verk som fyrer med olje.

Den største veksten i CO₂-utslipp fra 1990 til 2005 finner vi i energisektoren i Norge, på grunn av økt utvinning av olje- og gass i Nordsjøen, og i industrien på Island, der det er gjort store investeringer i ny kraftintensiv industri i senere år.

I Danmark har utslippene fra energisektoren gått ned, noe som har en klar sammenheng med store investeringer i fornybar kraftproduksjon (vind) og varmeproduksjon (biomasse).

Betydningen av fornybar energi

Vi finner at utbygging av fornybar energi har en klar effekt på utslippene i Norden. Utslippene fra den danske energisektoren ville vært opptil 8 mill. tonn høyere uten investeringene i fornybar energi. Også når det gjelder endelig forbruk av energi i husholdningssektoren og service og industri, har økt bruk av fornybare energikilder, først og fremst på bekostning av olje, redusert CO₂-utslippene med 1 mill. tonn.

Vi finner tilsvarende effekter for Finland, men der har utbyggingen av fornybare (biomasse) vært mer beskjeden. I husholdningssektoren er bruken av olje gradvis redusert.

I Sverige har det skjedd et betydelig skift fra fossile brensler til biomasse, i fjernvarmesystemet på grunn av CO₂-avgiftspolitikken, og i kombinert kraftvarmeproduksjon på grunn av elsertifikatsystemet. Dette har hatt stor betydning for CO₂-utslippene. Dersom den biobaserte kraftvarme- og fjernvarmekapasiteten som er bygd etter 1990 hadde brukt kull i stedet, ville CO₂-utslippene fra energisektoren i Sverige vært tre ganger høyere enn i dag. I husholdningssektoren og service og industri er olje gradvis erstattet med fjernvarme og elektrisitet.

Betydningen av energieffektivisering

Energieffektiviteten er forbedret i alle de nordiske landene, unntatt på Island, i den perioden vi har studert. Med det mener vi at mengden energi som kreves for å produsere en enhet av BNP har gått ned. Utviklingen varierer mellom landene p.g.a. strukturelle ulikheter, men utviklingen i alle landene er i linje med utviklingen i andre industrialiserte land (IEA, EU-15).

Energieffektivisering er resultat av strukturendringer i økonomiene, priseffekter, produktivetsforbedringer, teknologisk utvikling og bevisste energieffektiviseringstiltak. Det er ikke mulig å separere effektene av trender fra effektene av energieffektiviseringspolitikk.

En modellanalyse av effektene av energieffektivisering viser at uten reduksjonene i energiintensitet ville CO₂-utslippene i Norden, utenom Island, vært 30–50 % høyere enn i dag. Dette er resultatet av en sammenligning av den faktiske utviklingen med en utvikling der energiforbruket vokser med samme rate som BNP (ingen strukturendringer og ingen energieffektivisering). Effekten på utslippene avhenger av hvilke forutsetninger vi ellers legger til grunn når det gjelder avgiftspolitik og fornybarpolitikk.

Vi har analysert effektene av energieffektivisering de neste to årene med utgangspunkt i to ulike tilfeller; et tilfelle der energieffektiviserings tiltakene er rettet mot elforbruket, og et tilfelle der tiltakene er rettet mot varmeforbruk. Analysen viser at CO₂-utslippene reduseres i begge tilfeller, men at målt ved utslippsreduksjon pr spart energienhet, er det redusert elforbruk som er det mest effektive. Grunnen til det er at redusert varmeforbruk reduserer bruken av en miks av energibærere, mens redusert elforbruk i større grad reduserer bruken av kull i kraftproduksjon.

Betydningen av CO₂-avgifter og kvotehandel

Betydningen av CO₂-avgifter og kvotehandel er analysert ved hjelp av et sett scenarier med ulike kombinasjoner av virkemidler. De viktigste konklusjonene er:

- Uten klimapolitiske tiltak vil utslippene øke med 24 % til 2015, fordi kullkraft vil være den foretrukne energibæreren i energiproduksjonen. Vi bruker dette som et referansescenario.
- Sammenlignet med referansescenariet har både et scenario med en kombinasjon av dagens CO₂-avgifter og støtteordninger til fornybare, og et scenario med kvotehandel, betydelig effekt på CO₂-utslippene, men utslippene øker likevel sammenlignet med 2005.
- Kvotehandel og avgifter/støtte til fornybare påvirker utslippene forskjellig fordi kvotehandelen både omfatter kraftsektoren og industrien.
- Kvotehandel har stor betydningen for utslippene selv om vi antar at avgifter/støtte til fornybare også blir gjennomført. Utslippsreduksjonene blir bare litt mindre enn i tilfellet med bare kvotehandel. Dette tyder på at kvotehandel og avgift/støtte til fornybare bare i begrenset grad er klimapolitiske substitutter.
- Dersom vi øker kvoteprisen (fra 10 til 40 €/tonn) øker også utslippsreduksjonene. I tilfellet med en kvotepris på 40 €/tonn, er utslippene 50 % lavere enn i referansescenariet, og 40 % lavere enn i 2005.

Appendix 1: Overview over relevant policy measures

The Nordic countries have a long history of using energy-related taxes. The purpose of energy taxation has primarily been fiscal, but the taxes have nevertheless had an impact on the use of energy and hence the CO₂ emissions as well. In addition to taxes, other measures contribute to reduction of CO₂ emissions: voluntary agreements (primarily within the industry sector) to promote energy efficiency and subsidies to renewable energy sources. Since 2005, selected industries in Denmark, Finland and Sweden have been part of the European Union Emission Trading Scheme (EU ETS), while Norway has had a similar domestic emission trading system.

Energy and carbon taxation

Denmark

Carbon dioxide (CO₂) tax

The Danish CO₂ tax was introduced in 1992, revised in 1996 and modified again in 2005 when the EU ETS started. The CO₂ tax is levied with different tax rates on fuels used for space heating and on “light” and “heavy” industrial processes.

The base tax rate was DKK 100/ton CO₂ from 1992 to 2004. In 2005, the tax rate was reduced to DKK 90/ton CO₂; at the same time, the energy taxes were increased with an amount corresponding to the CO₂ tax reduction and the tax rebate to “light” process industries was cancelled. Fuels used in electricity production in power plants and CHP plants are exempted from the tax. Instead, there is a CO₂ tax on electricity consumption (DKK 0.09/kWh).

Originally, there were considerable tax rebates for industries. Process emissions from “light” processes got 10% tax reduction and particularly energy intensive processes got 75% tax reduction. There was also a possibility to get a 22% reduction with energy efficiency improvement agreements. In other words, industry with emissions from “light” and “heavy” processes can reduce their tax rate with 32% and 97% respectively through agreements. The increased revenue from the CO₂ tax was recycled back to industry and trade through reductions in the social security contribution supplementary pension payment and by giving invest-

ment subsidies for energy savings. From 2005, the tax reduction possibilities were reduced to 72.2% for “heavy” processes and abolished altogether for the “light” processes. The tax reduction for energy efficiency improvements was increased to 24%. With the start of EU ETS in 2005, industries that were subject to emission quotas within the EU ETS get the CO₂ tax refunded, and the distinction between “light” and “heavy” processes was abolished.

In 2001, Denmark introduced a national emission trading system for CO₂ emissions that covered the electricity industry except production relying entirely on renewable energy sources. Based on a yearly allocation of emission allowances, the electricity producers traded the permits bilaterally. The penalty for exceeding the quota was DKK 40/ton CO₂, which effectively capped the allowance price. Due to the obvious overlapping of the national system and the EU ETS, the national ETS was abolished in 2005.

Electricity tax

Fuels used for electricity production are exempted from taxation. Energy tax on electricity consumption is levied at the same rate regardless of how the electricity has been produced.²⁴ The current tax rate is DKK 0.511/kWh (consisting of DKK 0.465/kWh energy tax, DKK 0.006/kWh energy saving tax, and DKK 0.04/kWh electricity distribution tax) on consumption in permanent residences with electrical heating and annual consumption exceeding 4,000 kWh, and DKK 0.576/kWh on other consumption. Table A.1 shows the historical tax rates. The CO₂ tax (DKK 0.09/kWh) is added to this.

Industry and other VAT-registered companies are in practice exempted from the energy tax as they will be refunded the tax paid except the tax on the use of fuel for engines and for heating purposes.

Table A.1 Historical electricity tax level in Denmark, DKK øre/kWh

	General	Households with electrical heating, annual consumption exceeding 4,000 kWh
1996	36.0	32.5
1997	40.0	36.5
1998	46.6	40.1
1.1.1999-30.06.1999	48.1	41.6
1.7.1999-31.12.1999	52.1	45.6
2000	53.6	47.1
2001	55.1	48.6
1.1.2002-31.12.2004	56.6	50.1
2005-2007	57.6	51.1

Source: www.skat.dk

²⁴ Electricity produced by renewable energy sources for own use is exempted.

Energy tax

The energy tax that applies to the use of coal, oil, gas and electricity was introduced in the 1970-ies. The tax rate depends on the energy content of the fuel. The current rate on coal, oil and gas corresponds to DKK 51.9/GJ. For oil products used in engines the tax rate is higher.

Finland

Energy and CO₂ taxes

The present energy tax system has been in force since 1997 and consists of duties on fuels used for transportation, fuels used for heating and on electricity. The fuel tax (excise tax) is divided into a basic duty and an additional duty.

The basic tax is purely fiscal and only collected on oil products. The basic tax on petrol and diesel oil is, nevertheless, differentiated according to environmental characteristics; therefore, lower tax rates are applied to unleaded and reformulated petrol, as well as desulphurised diesel oil.

The additional duty, the CO₂ tax, was introduced on January 1, 1990. The tax rate depends on the carbon content of the fuel (see Table A.2 for the historical development). Since January 2003, the rate of the additional duty has been 18.05 €/ton CO₂ for liquid fuels and coal. Natural gas is subject to reduced rates (50%).

Peat has been exempted from the CO₂ tax since July 1, 2005, as a compensation for loss of competitiveness caused by the EU ETS. Earlier, small (less than 40 MVA) peat-fired power plants received subsidies for their electricity generation. Another target of the new law was to improve the availability of raw wood material needed in the particle- and fibre-board industries, since the improved competitiveness of peat will moderate the energy use of the raw wood material.

Table A.2 Excise taxes in Finland from 1990 to present

Excise tax:	Heavy Fuel Oil c/kg	Hard Coal €/t	Natural Gas c/nm3	Peat €/MWh
01.01.1990	0.34	2.69	0.17	0.34
01.01.1991	0.35	2.83	0.18	0.35
01.01.1992	0.35	2.83	0.18	0.35
01.08.1992	0.35	2.83	0.18	0.35
01.01.1993	1.12	5.61	0.35	0.70
01.07.1993	1.12	5.61	0.35	0.70
01.01.1994	1.98	11.30	1.09	0.35
01.01.1995	3.12	19.53	0.94	0.59
01.01.1996	3.12	19.53	0.94	0.59
01.01.1997	3.72	28.42	1.19	0.71
01.04.1997	3.72	28.42	1.19	0.71
01.01.1998	4.34	33.40	1.40	0.82
01.09.1998	5.40	41.37	1.73	1.51
01.01.2003	5.68	43.52	1.82	1.59
01.07.2005	5.68	43.52	1.82	–
Precautionary Stock Fees:				
01.07.1984	0.32	1.48	–	–
01.01.1997	0.28	1.18	0.084	–
Oil Pollution Fees:				
01.01.1990	0.037			
01.01.2005	0.050			

Source: Statistics Finland

Electricity tax

At present, electricity is only taxed at the consumer level and the fuels used for power generation are exempted from taxes.

The electricity tax is differentiated: a lower rate (0.44 cents/kWh) applies for industry and greenhouse cultivation, and a higher rate (0.73 cents/kWh) for other consumers (households and the service sector). In addition, the largest energy intensive companies have reduced rates: if electricity and CO₂ tax costs of an energy intensive company exceed 3.7% of its value added, it is entitled for a 85% refund of these taxes for the part that exceeds 50,000 €

Of fuel used in CHP plants, tax base of fuels used in heat production is 90% of produced heat. Fuels used for power generation in CHP plants are free of taxes.

Between 1993 and 1997, there was also a tax on electricity production and imports. Fuels in electricity production are exempted from taxes since 1 January 1997. Table A.3 shows the historical development of electricity taxes in Finland.

Table A.3 Electricity taxes in Finland. c/kWh

	Consumption		Production		
	General	Industry and greenhouses	Nuclear Power	Hydro Power	Imports
01.01.1993	0.25	0.25	0.10	–	0.10
01.07.1993	0.25	0.25	0.10	–	0.10
01.01.1994	–	–	0.35	0.03	0.22
01.01.1995	–	–	0.40	0.07	0.37
01.01.1996	–	–	0.40	0.07	0.37
01.01.1997	0.40	0.40	–	–	–
01.04.1997	0.56	0.24	–	–	–
01.01.1998	0.56	0.34	–	–	–
01.09.1998	0.69	0.42	–	–	–
01.01.2003	0.73	0.44	–	–	–
01.07.2005	0.73	0.44	–	–	–
Precautionary Stock Fees					
199701.01.	0.013	0.013	–	–	–

Source: Statistics Finland

Norway

Taxes have been the most important policy instruments used to curb greenhouse gas emissions in Norway. Today three different taxes are explicitly connected to the greenhouse gas emissions: the CO₂ tax, the waste treatment tax and the tax on HFK and PFK. However, several other taxes on energy use that are not directly imposed on CO₂ emissions or carbon content also contribute to limit greenhouse gas emissions.

CO₂ tax

The CO₂ tax is the most important policy instrument in the Norwegian climate change policy. The first tax on CO₂ was introduced in 1991, consisting of CO₂ components present in various taxes. In 1999, this tax structure changed and a separate CO₂ tax was introduced, replacing the charges on mineral oil, coal and coke and petrol charges.

Table A.4 shows that sectors and activities that are exposed to international competition are either exempted from the tax or enjoy a reduced tax rate. 85% of the CO₂ emissions from industry are exempted from the CO₂ tax or other GHG-related taxes. Most of the CO₂ emissions from industry are process emissions, i.e. emissions that are connected to the use of various fossil energy sources for feedstock or reduction purposes. Hence, it is difficult or even impossible to reduce emissions with current technologies.

In 2006, the reduced tax on domestic air transport, inland freight transport, costal water transport and activities in connection to the petroleum continental shelf sector was abolished and they now pay full tax.

In 2005–2007, a domestic emission quota system similar to the EU ETS was introduced in Norway. Industries that are included in the EU ETS and that had been exempted from the CO₂ tax became subject to the quota system. From 2008, the Norwegian quota system will supposedly be linked to EU ETS, implying that similar industries will be included in the system. For these industries, the quota system will replace the present CO₂ tax.

Table A.4 Present Norwegian CO₂-tax system (tax rates in 2007)

	Tax rate. NOK/liter. NOK/kg or NOK/Sm ³	Tax rate. NOK/tonn CO ₂
Gasolin	0.8	345
Mineral oil		
Light fuel oil. auto diesel etc.	0.54	203
Heavy fuel oil	0.54	172
Sectors with reduced rate (pulp and paper. fishmeal and herring meal industries):		
Light fuel oil. auto diesel etc.	0.27	101
Heavy fuel oil	0.27	86
Sectors exempted from the tax:		
International shipping	0	0
Coastal fishing fleet	0	0
Fishing and catching in distant waters	0	0
International aviation	0	0
Oil and gas extraction at the continental shelf		
Light fuel oil. auto diesel etc.	0.8	300
Heavy fuel oil	0.8	255
Gas at the continental shelf	0.8	342
Domestic use of gas		
Natural gas	0.47	201
LPG	0.6	200
Sectors not included in the CO₂ tax system:		
Use of coal and coke	0	0
Domestic use of gas (onshore)	0	0

Source: Ministry of Finance

Other fuel taxes

Norway also imposes several other taxes on mineral oil based fuels for transportation and heating purposes (see table A.5).

Table A.5 Other energy taxes than on CO₂ emissions. 2007 tax rates

Tax	Rate
General heating oil tax (NOK/liter)	0,429
Electricity tax (NOK øre/kWh)	
- General rate	10.23
- Low rate (industry etc.)	4.5
Gasoline tax (NOK/liter)	
- No-sulphur	4.17
- Low-sulphur	4.21
Autodiesel tax (NOK/liter)	
- No-sulphur	3.02
- Low-sulphur	3.07
CO ₂ tax on waste incineration (NOK/ton waste)*	59

*There is also a waste treatment tax, directed first and foremost at reducing methane emissions.
Source: Ministry of Finance

The waste treatment tax

A tax on the final treatment of waste, both for landfills and incineration was imposed in 1999. This tax is first and foremost directed at reducing methane emissions. For waste delivered for incineration, the tax rate is based on emissions to air of various harmful substances. For CO₂ the tax is NOK 59 per tonne waste delivered. Waste treatment plants that do not receive waste containing fossil substances are not subject to the CO₂-part of the tax.

Sweden

Energy and electricity tax

Energy tax differs between fuel types and fuel uses. The manufacturing industry pays no energy tax on their fuel consumption. Similarly, fuels used in heating and power plants are exempted from the energy tax. Instead, electricity consumption is subject to tax, with a general rate SEK 0.265 per kWh. However, the manufacturing industry, agriculture (greenhouses) and forestry have a lower rate, SEK 0.05 per kWh.

Carbon tax

The CO₂ tax was introduced in 1991. Prior to that, fossil fuels were subject to energy taxation only. As a response to the introduction of the carbon tax, energy taxes were somewhat reduced.

The general tax rate has increased from SEK 0.25/kg CO₂ in 1991 to SEK 0.93/kg CO₂ in 2007. However, manufacturing industry, agriculture, forestry and aquaculture are levied a lower rate, 21% of the general tax

rate. In addition, special regulations for reductions apply to energy intensive industry.²⁵

In 2000, a green tax reform was initiated: taxes on energy use were increased, while taxation on labour was reduced correspondingly. However, the focus was mainly on the service sectors' and households' use of fossil fuels and electricity, and industry was largely exempted from increased taxation. The green tax swap in 2005 focussed on transport-related fuel taxes.

In 2004, the carbon tax on heat produced in CHP plants was reduced to the same level as for the industry and the energy tax was removed in order to promote combined heat and power production. Heat-only plants, however, still pay the full tax.

Energy efficiency measures

In addition to taxes, the countries have used other measures to increase energy efficiency and reduce emissions. The MURE Odyssee database gives an overview over energy efficiency measures in the EU countries plus Norway since 1990. The tables below list the energy efficiency measures (apart from taxation and emission trading) that are used in the Nordic countries.

Table A.6 Policy measures for improved efficiency in industries

Country	Measure
Finland	Energy audit program (1994) Energy conservation agreement (1997)
Denmark	Agreement on energy savings measures (1996)
Norway	Industrial buildings (2002) Heating plants in industrial buildings (1997) Industrial energy efficiency network (1989)
Sweden	Program for more efficient energy use (2005)

²⁵ If the total amount of carbon dioxide tax exceeds 0.8% of the sales value the tax rate is reduced to 24% of the reduced rate. Until the end of 2005 the total carbon dioxide tax on producers of non-metal mineral products is limited to 1.2% of the sales value.

Table A.7 Policy measures for improved efficiency in households

Country	Measure
Finland	Energy conservation program for municipalities and non-profit housing properties (2002) Energy conservation program in oil-heated buildings (2002)
Denmark	Energy saving activities by electricity, nat.gas and DH companies (2001) Energy labelling of larger buildings (1997) Energy labelling of smaller buildings (1987) Energy labelling of electrical appliances (1993)
Norway	Grants to electricity savings in households (2003) Labelling and energy efficiency requirements on appliances (1996)
Sweden	Grant to convert from electric heating or fossil fuels to DH or heat pumps (2006) Information campaign (2006) Energy declarations (2006)

Voluntary agreements in Denmark

Energy intensive industry can obtain a substantially reduced CO₂ tax rate if they enter into a voluntary agreement with the Energy Agency which require them to carry out certain energy saving actions investments. By 2004, approximately 100 agreements with energy intensive industries had been entered into, covering almost half of the industrial energy consumption.

Voluntary agreements in Finland

The industry has been provided with an opportunity to entering into voluntary energy conservation agreements with the government. The energy audits related to these agreements include nowadays also renewable energy sources, and they form a part of conservation agreement activities. The scope of the energy conservation agreements has been extended and by the end of 2002 the effect of energy saving measures through these agreements was equal to a total of 4.1 TWh.

Voluntary agreements in Norway

Voluntary agreements have been used several times in the Norwegian climate change policy. The first agreement was signed in 1997 between Ministry of the Environment and the aluminium industry to reduce GHG emissions per tonne aluminium produced by 50% and 55% in 2000 and 2005 respectively, compared to 1990 level. According to Ot. prp. nr. 13 (2004-2005) emissions per tonne aluminium produced in 2000 were 53% lower than in 1990.

In March 2004, Ministry of the Environment and the Federation of Norwegian Process Industries signed a new agreement to reduce GHG emissions from the process industries by 20% in 2007 compared to 1990-level, implying a reduction from 16.8 to 13.5 mill. tonne CO₂-equivalents. The agreement covers process emissions from 60 plants in

the aluminium, ferroalloys, carbide, other metals and fertilizer industries as well as some other industries, but excludes refineries and oil/gas processing onshore. The agreement covers both the gases and emission sources that are included in the emissions trading system in 2005–2007 and those that are not.

Regulation in Sweden

The Environmental Code of 1999 that applies to commercial activities includes a number of principles that have an effect on the emissions of greenhouse gases. For instance, there is a requirement that plants should use the best possible technology and prefer renewable resources.

Investment subsidies through Local Investment Programmes for ecologically sustainable development (LIP) were available between 1998 and 2002. A total of SEK 6.2 billion was granted during that time period. The purpose of LIP was both improved environment and increased employment. A large share of the subsidies has gone to measures that aim at reducing GHG. LIP was replaced by Klimp, investment programmes with an explicit focus on climate measures. Approximately SEK 0.8 billion were available within the investment programmes for the years 2003–2004.

Support to renewables

In addition to taxes, voluntary agreements and other measures that aim to reduce CO₂ emissions directly, the Nordic countries seek to reduce emissions indirectly, by supporting renewable energy sources that have low or no emissions.

Denmark

Wind power, bio-fuels and decentralised CHP plants receive a subsidy. The subsidy scheme has been extremely complex, depending on fuel, size and age of the plant, among other things. Some of the subsidies are fixed production subsidies per kWh, others depend on market price (the subsidy level is reduced when the market price is high, hence guaranteeing the producer a minimum price level).

In 1990, the “Energy Policy 2000” strategic plan was introduced. According to this plan, the Danish Government proposed to increase the use of renewable energy by 12–14% in 2005, compared to the 1988 level. When the new tax reform introduced a combined energy and CO₂ tax in 1992, renewable energy was exempted from the tax. Subsidies were introduced to increase renewable energy production in order to follow up the targets.

1993 saw the introduction of the “Biomass Agreement”, a political agreement with the purpose of increasing the use of biomass considerably by the end of 2000. The goal was to use 1.4 tonnes of biomass in electricity supply (more specifically 1.2 tonnes of straw and 0.2 tonnes of wood chips). The Biomass Agreement was changed in 1997 to increase the flexibility between the use of straw and wood chips.

The *Energy 21* action plan, introduced by the Danish Government in 1996, proposed new initiatives in order to increase both onshore and offshore wind power capacity. The expansion of wind power capacity (onshore and off-shore) was outlined to be 1500 MW by 2005, corresponding to an annual production of 3.2 TWh. Already by the end of 1998 wind power capacity had reached 1467 MW, and by the end of 2005, wind power capacity was 3129 MW (423 MW off-shore).

A support scheme for replacing the old, small wind plants with new larger plants is also in place. When a small plant (<450 kW) is decommissioned, the owner receives a scrap certificate which can be used to receive an extra price mark-up in a new plant.

In 1999, the Electricity Reform proposed a market for renewable energy certificates (*VE bevis*), requiring 20% of total electricity consumption in 2003 to be produced by renewable energy sources. However, the Danish Government decided to postpone the certificate market in 2000, due to protests from renewable energy producers who argued that their conditions would deteriorate substantially compared to existing subsidy schemes. Instead, a subsidy of 0.1 DKK/kWh for a maximum of 20 years was introduced (capped so that if the total producer price (market price plus subsidy) exceed 0.36 DKK/kWh, the subsidy will be reduced).

Finland

The program for promoting renewable energy sources and energy conservation was implemented after the tax reform in 1997. From 2003 the support scheme has been expanded gradually and now nearly all renewable energy sources except large-scale hydropower (over 1 MVA) are eligible to subsidies (incl. different kind of wood fuels, recycled fuels, biogas, waste gases from metallurgical processes and reaction heat from chemical processes). There are three different subsidy levels, according to the energy source:

- Wind power and from wood chips: € 0.69/kWh
- Recycled fuels: € 0.25/kWh
- Others: € 0.42/kWh

Norway

During the 1990-ies, support for renewable energy sources was given in the form of investments subsidies. In 2002, Enova was established, a governmental agency that administers the support more efficient energy use and renewable energy. Enova also administers the support schemes to promote infrastructure for domestic supply of natural gas.

In the early 2000-ies, the government planned to establish a green certificate market jointly with Sweden. However, the negotiations were terminated in the beginning of 2006, just before the system was to be launched. In autumn 2006, a new support scheme for renewable electricity based on feed-in tariffs was announced, to come into force from January 1, 2008. The feed-in tariffs are differentiated between technologies:

- Bio fuelled CHP: 10 øre/kWh
- Wind power: 8 øre/kWh
- Small-scale hydro: 4 øre/kWh

The present goal for Norway is to achieve 12 TWh of energy conservation and energy production by new renewable energy within 2010. Of this, at least 4 TWh must be district heating based on new renewable energy sources, waste heat or heat pumps, and at least 3 TWh wind power.

Wind power was first introduced around 1990. The first projects were pilot projects, and the process to licence the first large projects commenced in 1997/98. By the end of 2005, wind power capacity had grown to 280 MW. A large number of projects, with a total capacity amounting to about 840 MW and annual production of more than 2.6 TWh, have been approved since 2000, but not been built yet. No new projects were realized in 2006 due to uncertainties about the future support scheme for renewables.

The registered use of biomass was 12.4 TWh in 2005. About 4.4 TWh was used in industry, the rest mainly for heating purposes in households. The pulp and paper industry uses waste products from production processes mainly for drying purposes. In households biomass is used for heating.

Hydropower has a substantial potential in Norway. Even though utilization of the remaining hydro resources is highly controversial due to nature conservation concerns, small-scale hydro (less than 10 MW) is considered a new renewable energy source. Special simplified concession rules apply to small-scale hydropower. In 2005, 34 small-scale hydropower stations with a total annual production of 490 GWh were licensed. Another 200 GWh was allowed built without concession.

Sweden

Prior to 1991 there was no support for renewables in Sweden. In 1991, several support schemes for renewable energy were introduced, including wind power, bio-fuelled power and solar heat. The support schemes were mainly designed as investment subsidies, e.g. 4,000 SEK/kW for bio fuelled power and 15% of total investment costs for wind power. In July 1994 an environmental bonus was added to the wind power subsidy. The bonus was designed as a production subsidy (per kWh) and it equalled the electricity consumption tax.

Within the Government's short program for the conversion of the energy system that took place in 1997–2002, the investment support for 1997–2001 to wind power and small hydro power was 15%, and for investments in bio-fuelled power plants 25%. This corresponded to SEK 4–5 öre/kWh for wind power, SEK 3–4 öre/kWh for small-scale hydropower and SEK 5–7 öre/kWh for investments in bio-fuelled power plants. For all small-scale wind or hydropower plants with an installed capacity less than 1.5 MW, there was also a specific subsidy at SEK 9 öre/kWh. In addition to this, wind power had an environmental bonus at SEK 18.1 öre/kWh. The total amount of subsidies to wind power was SEK 31–32 öre/kWh, to small hydro SEK 12–13 öre/kWh and to bio fuelled power plants SEK 5–7 öre/kWh. In 2002, the investment subsidies were reduced to 10 % for investments in wind power and in small-scale hydropower.

In 2003, it was time for the next major upgrading of the support system for renewable electricity. The old scheme was completely replaced by a electricity certificate market in May 2003. This scheme included all renewable electricity generation (new as well as existing). Demand for electricity certificates became mandatory through a quota obligation, i.e. a certain share of the electricity consumption (excluding industry) has to be supplied from "certified" generation. The quota obligation will be gradually increased to achieve the Swedish target of 10 TWh electricity from renewable energy sources in 2010. The environmental bonus for wind power was not removed, but will be gradually phased out within 2010. The electricity certificate scheme led to a significant increase in support for electricity based on bio-fuels.

Figure A.1 shows the development in support levels for bio-fuel and wind power since 1990. The figures are based on estimates of e.g. investment costs, economical life times, discount rates and annual utilization times.

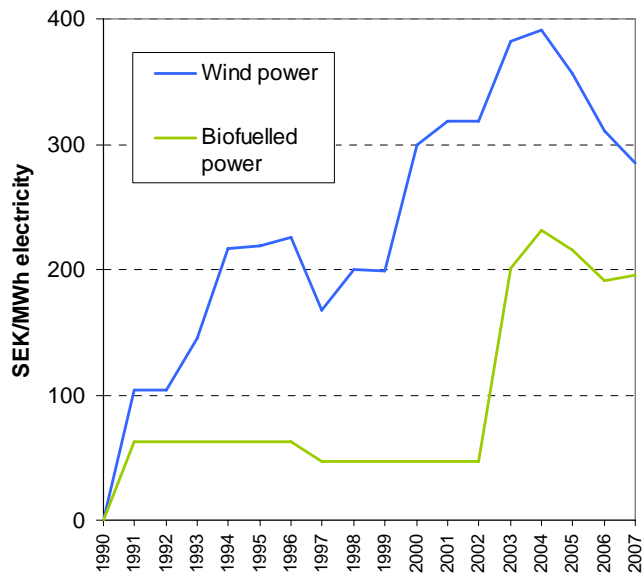


Figure A.1 Total estimated support in SEK/MWh for wind power and biofuelled power in Sweden since 1990.

Appendix 2: MARKAL-Nordic

The MARKAL (acronym for MARKet ALlocation) model was originally developed in the second half of the 1970s, and is an optimizing linear-programming model with perfect foresight (Fishbone and Abilock 1981). In simple terms, MARKAL satisfies, at the least possible cost²⁶, demand for energy through a complex combination of energy conversion modules, energy distribution chains and fuel-supply systems under a large number of constraints. Fuel switching, co-production of heat and power, and conservation and efficiency measures are considered, among other factors. Technologies for energy supply are included on both the demand side and the supply side. Thus, *e.g.* heating of single-family houses may be achieved with, among other things, heating pumps, oil- and bio fuelled furnaces or conservation measures. Correspondingly, on the supply side, *e.g.* district heating may be supplied by utilizing also heating pumps, oil- and bio fuelled furnaces, and so forth.

Using the MARKAL model implies that the energy system in focus is organized into a reference energy system (RES; Marcuse *et al.* 1996) as seen in Figure 1 below. The RES is a snap-shot of the energy system in focus. Energy demand (to the right in Figure 1) is governed by demand for commodities such as housing and industrial goods. *Useful* energy demand (or energy-service demand) is the demand for energy services such as heating and lighting.²⁷ *Final* energy demand, on the other hand, is defined as the demand for energy carriers such as electricity, fuel oil and district heating that satisfy the demand for useful energy. Generally, the energy demand in MARKAL models includes both useful and final energy demand, depending on the end-use sector and the model version used. Energy demand may also be defined as a function of energy prices by using special versions of the MARKAL model. This requires the use of end-use elasticities.

The figure below shows the reference energy system (RES) with its boundaries. For simplicity only three examples of energy demand have been included. In MARKAL modelling in general, significantly more energy-demand sectors are included. Energy demand may be expressed in terms of useful energy or final energy. This somewhat flexible definition of the demand boundary of the system is also shown in the figure.

²⁶ The objective function, which is to be minimized, is generally the total discounted system cost

²⁷ Useful energy demand may be the desire to have for example 20 °C in-doors or a demand expressed in tons of paper production. This means that useful energy demand does not necessarily have to be expressed in energy terms. However, in an energy systems model, such as the ones used here, useful energy demand is generally expressed in energy units. The demand for 20 °C may be expressed in, for example, W/m² given the insulation for a specific type of building.

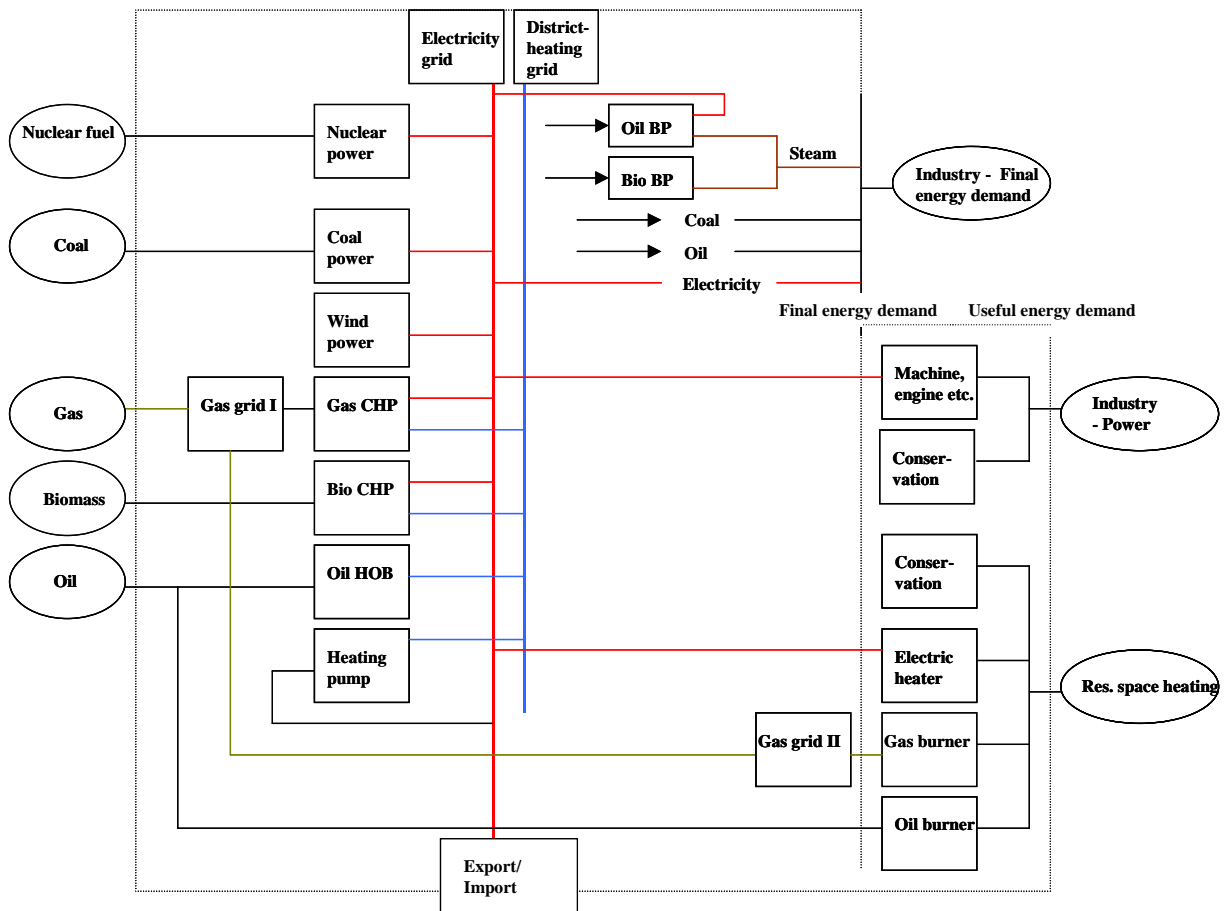


Figure 1: The reference energy system (RES) with its boundaries

Energy demand may be divided into an appropriate number of sub-sectors, for example demand for space heating or demand for electricity in industries. The division between sectors is based on nationality, sector (industry, residential housing and commerce etc.), and purpose of energy use (lighting, heating etc.). The annual load duration for electricity is divided into six periods, including diurnal representation of winter, summer and an intermediate season. The corresponding load duration for district heating is divided into only three periods, one for each season, while demand for all other energy carriers is expressed on an annual basis.

All technologies in the model are described in terms of technical efficiency, availability, investment costs, operation and maintenance costs, fuel delivery costs, and life lengths. For existing technologies, capital costs are considered as sunk costs, and the time dependence of the residual capacity is expressed as an “age curve” based on estimations of remaining technical lifetime (assumed identical to the economic lifetime). Investments are, thus, done endogenously in the model. The MARKAL model is dynamic in the sense that up to nine mutually interdependent time steps can be treated. Generally, the choice of time

horizon for studies using the MARKAL model generator is between 20 and 50 years.

A more thorough description of MARKAL modeling may be found in Loulou et al. (2004).

The MARKAL-NORDIC model

In MARKAL-NORDIC, roughly 80 energy-demand sub sectors are included covering the stationary energy systems (the stationary energy systems include all energy use but transports) of the four Nordic countries Sweden, Norway, Finland and Denmark.

The division between demand sectors is based on nationality, sector (industry, residential housing and commerce *etc.*), and purpose of energy use (lighting, heating *etc.*). Residential energy demand is, for example, divided into space heating and electric appliances. The energy-intensive industry, *e.g.* paper & pulp or iron & steel, is generally modeled with three different types of complementary inputs: “non-substitutable” fuels, process heat and electricity (see also Nyström 1995). Producing electricity and steam is, however, subject to different and substitutable options. A non-substitutable fuel in the model is, for instance, coke for the iron & steel industry, but also a significant share of the oil used in industry. The relation among the different non-substitutable fuels and process heat is fixed. The industrial demand for electricity is supplied from the combination of electricity and electricity conservation. It is assumed that there exists a limited substitutability between, on one hand, electricity (and electricity conservation) and, on the other hand, the group of non-substitutable fuels and process heat.

As mentioned above the transport system is excluded but may be indirectly included in a very simplified manner as a simple bulk emission of CO₂ based on projections.

A sample of typical technology inputs may be found in Table 1 below.

Table 1 A few examples on input assumptions in the model year 2002 for typical electricity and district-heat supply technologies in MARKAL-NORDIC.*

	Investment cost (SEK/kW) ²⁸	Fixed O&M (SEK/kW)	Variable O&M (SEK/M Wh)	Efficiency (%) ²⁹	Power-to- heat ratio	Availability (h) ³⁰
Coal PF	9330	170	35	45	–	8000
Gas NGCC	5000	100	15	58	–	8000
Nuclear	18000	360	16	– ³¹	–	7500
Biomass/coal convent. CHP (large) ³²	11000	220	35	30	0.52	7000
Biomass convent. CHP (small)	14500	310	40	30	0.50	7000
Biomass/coal CHP IGCC	16500→13200	410→330	40	44→47	1.0	7500
Gas NGCC CHP (large)	6000→5500	115	16	49→51	1.2	7500
Gas NGCC CHP (small)	7000→6500	140	18	45→47	1.05	7500
Gas fuel cell (PAFC) CHP ³³	31000→18000	470→270	7	36→48	2	7000
MSW CHP ³⁴	30800	1232	101	23	0.32	8000
Wind onshore (typical)	8000→6200	140→110	0	–	–	2000–2500
Wind offshore (typical)	14000→9900	300→250	0	–	–	3000–3500
PV	32000→15000	320→150	0	–	–	1110
Gas fuel cell (SOFC-GT) ³⁵	31000–18000	470→270	7	60→70	–	7000
Small-scale hydro (typical)	13200	390	0	–	–	3820
Biomass/coal HS	3000	60	15	88	–	8000
Gas/oil HS	1400	22	15	92	–	8000

* Costs are reduced between 2002 and 2023 for certain technologies due to technological learning, which is indicated with an arrow (1 € = 8.45 SEK in 2000).

²⁸ SEK/kW electric for electricity producing technologies, and SEK/kW heat for heat producing technologies

²⁹ Electricity efficiency for electricity producing technologies, thermal efficiency for heat-only producing technologies (HS)

³⁰ Should not be confused with utilization time, which is a model result. CHP has, generally, less utilization time than *e.g.* baseload condensing power stations. In excess of the availability the year is made up of outage for thermal plants. The yearly unavailability (8760-availability) is divided into two parts for thermal plants, scheduled (such as fuel reloading or maintenance) and unscheduled outage. The occurrence for the scheduled outage is chosen by the optimization.

³¹ Nuclear power is modelled with a hypothetical efficiency based on assumptions of the sum of variable and fuel costs corresponding to roughly 70–80 SEK/MWh electricity.

³² Certain multifuel technologies have different investment costs depending on fuel. These fuel-related differences are, however, assumed small compared to the bulk investment cost.

³³ PAFC (Phosphor acid fuel cell).

³⁴ MSW (Municipal solid waste).

³⁵ SOFC-GT (Solid oxide fuel cell integrated with gas turbine).

Fuels are associated with exogenously given costs and potentials. For fossil fuels, potentials are unlimited, mimicking global markets. Natural gas is, however, supplied through a transmission and distribution grid associated with investment and O&M costs. Domestic fuels such as bio fuels are divided into several cost classes yielding a supply curve. In addition, international trade of bio fuels can also be modelled by assuming exogenously given import prices and potentials (e.g. infinite import capabilities).

CO₂ emissions (which is the only environmental “pollutant” included in MARKAL-NORDIC so far) occur whenever fossil fuels are used. However, investments in carbon sequestration and disposal are optional for a selection of large-scale power schemes.

Several important energy and carbon taxes are included in the MARKAL-NORDIC model. This also applies to wind-power subsidies in the Nordic countries and the existing TGC scheme in Sweden.

In Figure 2, two typical MARKAL-NORDIC model output, are shown. The top diagram shows how the future Nordic electricity supply in the 2020 is affected by three different levels of EUA prices (European Union Allowances for emitting CO₂). Assuming a EUA price of 50 EUR/t, there is hardly any fossil-fueled electricity at all in the system. Gas power is not competitive due to relatively high gas prices assumed. The bottom diagram shows how final energy demand in the residential, service and commercial sectors aggregated over all four countries, develops over time for a given EUA price of 20 EUR/t. It may be seen that renewable fuel use and district heating are constantly increasing their share on the behalf of oil and electricity.

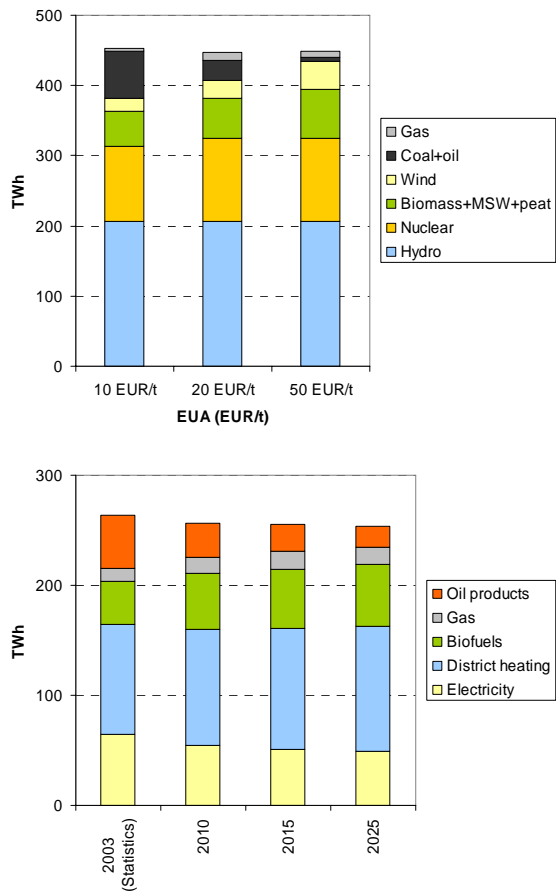


Figure 2 MARKAL-NORDIC model output samples.