SWEDEN'S NATIONAL

REPORT

UNDER THE UNITED NATIONS FRAMEWORK

CONVENTION ON CLIMATE CHANGE

Ministry of the Environment and Natural Resources
September 1994

Introduction

The United Nations Framework Convention on Climate Change was signed in Rio de Janeiro in June 1992. The Convention entered into force the 21st of March 1994. In September 1994 approximately 90 countries had ratified the Convention.

The United Nations Framework Convention on Climate Change (FCCC) forms the basis for further international cooperation in the field of global climate change. The ultimate objective of the Convention is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The Parties to The Convention should take precautionary measures to anticipate, prevent or minimize the causes of climate change, formulate national programmes containing measures to mitigate climate change in all relevant sectors, including all greenhouse gases and cooperate in preparing for adaptation to the impacts of climate change. The industrialized countries shall aim at returning by the end of the present decade to 1990 levels of anthropogenic emissions of carbon dioxide and other greenhouse gases. OECD-countries shall provide new and additional financial resources needed by the developing country Parties to meet their commitments.

According to Article 12 of the Convention, industrialized countries shall within six months of the entry into force of the Convention, communicate to the Secretariat a detailed description of adopted national policies and measures to mitigate climate change. The report shall also include an inventory and a projection of greenhouse gas emissions n. The report shall be communicated to the interim secretariat.

In accordance with the provisions in Article 12, Sweden has elaborated the present report which was adopted by the Swedish Government on the 15th of September 1994. National Swedish Environmental Protection Agency, Swedish National Board for Industrial and Technical Development, the Commission for Forecast and Development in the Transport Sector and the Commission for Climate Change have participated in the preparation of the report.

Contents

EXECUTIVE SUMMARY

BASIC DATA AND NATIONAL CIRCUMSTANCES

Sweden had 8.7 million inhabitants in 1993. Population growth is approximately 0.6 percent per year which is about the average for other industrialized countries. Approximately 85% of the inhabitants live in urban areas.

The total area of Sweden is 450,000 km^2. Compared to other OECD-countries, population density is low, on average 19 inhabitants per km^2. However, a large part of the population is concentrated in three major urban areas. Sweden has a long shoreline and a very large number of lakes. Transportation needs are high due to low population density and long travel distances.

Forest covers 62 % of the total land area. Forest is one of the most important natural resources in Sweden. The timber stock volume - i.e the carbon reservoir - has grown from 2100 million forest cubic meter (m^3sk) in 1920 to 2900 million m^3sk in 1990. Historically the forest industry, together with the iron and steel industry, has been the backbone of the Swedish economy.

Energy intensive industries are very important to the Swedish economy. As in other industrialized countries a decline in the importance of the industrial sector has taken place during the last decade. In 1992, Gross Domestic Product (GDP) per capita was SEK 165 700. Annual average real growth of the economy has been 1.8 per cent between 1975 and 1990. More recently Swedish economy has experienced a recession with low or negative growth in GDP.

The climate in Sweden is temperate, influenced by the Gulf Stream in the Atlantic ocean. The annual average temperature is only + 1.8 degrees Celsius(^{o}C), ranging from +7^{o}C in the south to -2^{o}C in the north. The heating requirement for homes and other premises are significant during the winter season.

Total final energy demand has been almost constant during the last 25 years, reaching 450 TWh/year. Hydro power has always played a major role in the total electricity production. Since the 1970's oil-crisis, the Swedish energy system has been significantly restructured. Expansion of nuclear power has reduced oil consumption. Also, different programmes for energy efficiency and oil substitution have had a considerable effect. The share of fossil fuels in total energy supply has dropped from 80% in 1970 to 50% in 1990. Nuclear and hydro today produce approximately 95% of the total electricity generated.

INVENTORY OF GREENHOUSE GASES

An inventory of greenhouse gas emissions and removals by sinks has been performed according to Intergovernmental Panel on Climate Change (IPCC) preliminary methodology and the decision made by Intergovernmental Negotiating Committee (INC). The inventory data are presented in Table 1 for the base year 1990. Gaps in inventory data are indicated in the figure below.

ESTIMATED UNCERTAINTITIES

Carbon dioxide	10%
Carbon sinks	10-25 %
Methane	10-25 %
Nitrous Oxides	>25 %
Nitrogen Oxides	10 %
Carbon monoxi-de	10-25 %
NMVOC	>25 %

Carbon dioxide accounts for most of the greenhouse gas emissions in Sweden. More than 80 % of total greenhouse gas emissions calculated as GWP-100 is attributed to carbon dioxide. Transportation is the most important sector accounting for 40% of the total carbon dioxide emissions. Since 1970, carbon dioxide emissions has declined considerably. (Figure 1) Since 1970 emissions have decreased approximately 40 per cent. While emissions from the energy sector and from manufacturing industry have steadily declined, emissions from the transportation sector have increased.

Table 1 shows that carbon dioxide emissions were 61.3 million tonnes in 1990. However, if emissions are adjusted for normal climatic conditions the emissions would have been 64 million tonnes.

The largest sources of methane emissions in Sweden are the agricultural sector and refuse disposal.

Nitrous oxide emissions are poorly monitored. Burning of fuels and releases from arable land are the most important sources.

The Swedish forest today constitutes a sink for carbon dioxide. The increment or annual growth of the forest is larger than the harvest. That leads to accumulation of carbon dioxide in the biomass. The net carbon dioxide accumulation in Swedish forests has been estimated to nearly 35 million tonnes per year. This is more than half of the annual emissions of fossil carbon dioxide emissions.

However, most of the increment are anthropogenic, due to forest management which raises the forest timber stock above the level of non-managed forest.

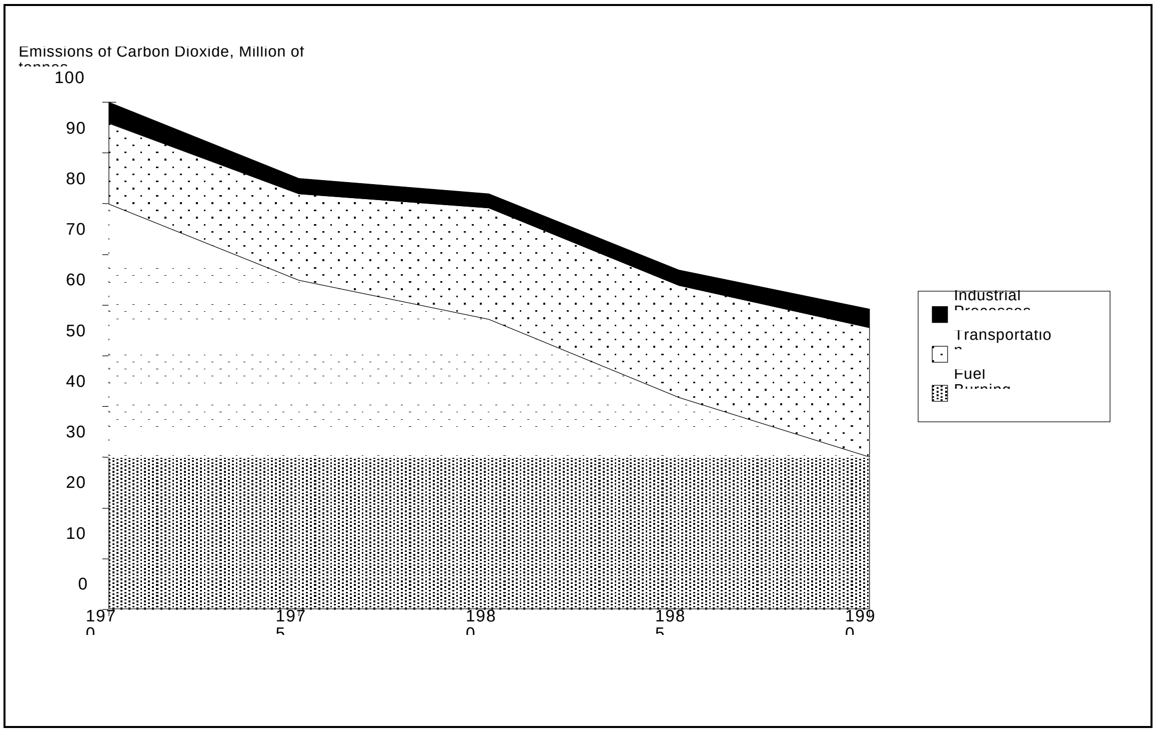

Table 1. Summary Report for 1990 National Greenhouse Gas Inventories (1000 tonnes).

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2[1]	CH_4	N_2O	NO_x	CO	NMVOC
TOTAL National Anthropogenic Emission	61256	329	15.2	373	1612	540
1 All Energy (Fuel Combustion + Fugitive)	55175	32.9	4.6	362	1606	375
A Fuel Combustion	55122	32.9	4.6	362	1606	357
Energy and Transformation Industries	7041	1.25	1.42	19.58	7.83	3.54
Transport[2]	23092	17	0.4	285	1503	201
Industries (ISIC)	13446	4.2	2.1	38.9	25.7	10.8
Commercial/Institutional	11543	10.4	0.7	19.0	69.3	141.2
Residential						
Agricultural/Forestry						
Other						
Biomass Burned for Energy	21737[3]	14.6[4]	1.3[4]	19[4]	84[4]	153[4]

[1]Total CO_2 according to IPCC methodology. Includes emitted CO_2 and oxidized carbon.

[2]Emissions from international aviation and marine bunker fuels not included.

[3]Not included in Total National Anthropogenic Emissions.

[4]Included in the Total National Anthropogenic Emissions, but also under the different sub-categories under Fuel Combustion.

B Fugitive Fuel Emission	53	0	0	0	-	17.8
Oil and Natural Gas Systems	53	0	0	0	0	17.8
Coal Mining	NO	NO	NO	NO	NO	NO
2 Industrial Processes	4972	NE	2.7	11	5.9	67
A Iron and Steel	1561	NE	0	1	2.2	2.2
B Non-Ferrous Metals	720	NE	0	1.3	0	NE
C Inorganic Chemicals	NE	NE	2.6	1.6	NE	0
D Organic Chemicals	16	0	NE	NE	NE	5.3
E Non-Metallic Minerals Products	2493	NE	0	7.2	0.16	0
F Other	182	NE	0.1	0	3.5	59
3 Solvent and Other Product Use	294	-	-	-	-	98
A Paint Application	120	-	-	-	-	40
B Degreasing and Dry Cleaning	45	-	-	-	-	15
C Chemical Products Manufacture/-Processing	21	-	-	-	-	7
D Other	108	-	-	-	-	36
GREENHOUSE GAS SOURCE AND SINK CATEGORIES (continued)	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**
4 Agriculture	540	196	7.9	-	-	-
A Enteric Fermentation	518	188	-	-	-	-
B Agricultural Wastes	22	8	-	-	-	-
C Agriculture Soils	-	-	7.9	-	-	-
D Rice Cultivation	-	NO	-	-	-	-
E Agriculture Waste Burning	NO	NO	NO	NO	NO	NO
F Savannah Burning	NO	NO	NO	NO	NO	NO
5 Land Use Change & Forestry	- 34368	-	-	-	-	-
A Forest clearing and On Site Burning of Cleared Forests	NO	NO	NO	NO	NO	NO
B Grassland Conversion	NO	-	-	-	-	-
C Abandonment of Managed Lands	NO	-	-	-	-	-
D Managed Forests	- 34638	-	-	-	-	-
6 Waste	275	100	-	-	-	-
A Landfills	275	100	-	-	-	-
B Wastewater	NE	NE	-	-	-	-
C Other	NO	NO	NO	NO	NO	NO
TOTAL NET National Emission (sum 1 through 6)	26888	329	15.2	373	1612	540
Emissions from international aviation and marine bunker fuels	*4190*	*1.3*	*0.04*	*60*	*44*	*15*

NE = not estimated NO = not occurring -not applicable
1 Total CO2, according to IPCC methodology. Includes emitted CO2 ans oxidized carbon
2 Emissions from inteernational aviation and marine bunker fuels not included

3 Not included in Total National Anthropogenic Emissions
4 Included in the Total National Anthropogenic Emissions, but also under the different categories under Fuel Combustion.

VULNERABILITY

Average temperatures in Sweden increased from the middle of 18th century through the 1930's. From 1940 to 1960 the average temperature decreased followed by a new period with raising temperature. Even if most winters in the beginning of the 1990's were unusually mild it is difficult to draw any definite conclusions from current trends.

Sub-arctic ecosystems' like those in Sweden are sensitive owing to long generation times, slow growth and irregular reproduction. Initially climate change is expected to affect higher mountain areas. The adaptability of these ecosystems is limited.

Another vulnerable area is the Baltic Sea. The Baltic Sea could be affected in three different ways; through sea level rise, through warmer temperature in the water body and finally through reduced salinity. Sea-level rise would cause serious erosion on the southern coasts of the Baltic. Flooded areas in coastal zones may increase the leakage of nitrogen to the sea. An increasing water temperature would generate certain physiological changes in marine organisms leading to modification in the fish population. The most probable development would be that catchments of cod, salmon and whitefish would decline, thus affecting fishery. The water exchange in the Baltic is mostly controlled by runoff of surface water from land areas and water exchange with the North Sea through the Belts and the Sound (Öresund). Climate models predict more precipitation in the winter, leading to an increase in runoff of surface water to the Baltic. In such a case the salinity in the Baltic sea could fall. If the interflow of oxygen-rich and saline water coming from the Atlantic into the Baltic would be affected, serious consequences could emerge.

Increasing air temperature and precipitation would result in more rapid growth of forests. However some species are adapted to cold winters and increasing temperature may enhance damage by insects and pests. Spruce forests are expected to be the most vulnerable to rapid changes in the climate. Obviously forestry must adapt its management practises to any changing situations.

Global warming could also have other adverse effects on the environment. Transport patterns for air pollutants from Europe to Scandinavia could be changed. Conditions for ground-level ozone formation would become more favourable. If the frequencies of mild and wet winters could increase, the amount if nitrogen reaching the sea would grow, other circumstances being unchanged. Thus, if the environmental goals for acidification, eutrophication and air quality may be met, more stringent measures will be required due to global warming.

POLICIES AND MEASURES

Overall policy context

Sweden has applied policies and measures for climate change since 1988, when the issue was discussed in the Riksdag (Parliament) for the first time. A more comprehensive programme was adopted by the Riksdag in May 1993 the Government Bill on action to limit climate change was adopted. The goal established by the Riksdag is that emissions of carbon dioxide from fossil fuels in the year 2000 shall, pursuant to the UN Framework Convention on Climate Change, be stabilised at the 1990 level and shall decline after that.

Furthermore emissions of methane from disposal of wastes shall be reduced by 30 percent between 1990 and 2000.

The main strategy for achieving the carbon dioxide goal is to limit the demand for fossil fuels, replacing them with renewable energy resources, along with improved energy management and more efficient use of energy. Measures to improve energy efficiency includes technology procurement and demonstration of electricity efficient products, processes and systems in homes, non-housing premises and industry. In contrast to other countries the possibility of reduction of greenhouse gases by changes in the electricity sector is very limited in Sweden. Today only five per cent of the electricity is based on fossil fuels.

In the climate debate one could argue that policies and measures should be concentrated to increase carbon storage in the forest. However, whereas an increment of carbon storage is just temporary, reductions in the use of fossil fuels gives permanent effects. If biomass is grown in a sustainable way its production and use cause no net build-up of carbon dioxide in the atmosphere. Carbon dioxide released in combustion is offset by reabsorption of carbon dioxide by the biomass culture during photosynthesis. This imply that one efficient way to reduce the atmospheric burden of fossil carbon dioxide in Sweden is to expand the use of biomass and use it to replace fossil fuels in the energy system.

In Sweden, economic instruments were introduced in environmental policy in the mid-1970's and their use has since increased and successively developed. In the field of climate change the government places great attention on carbon and other forms of energy taxes as means for limiting carbon dioxide emissions.

In Sweden marginal cost for further reduction of carbon dioxide emissions is high, compared to most OECD countries. As part of our national programme we have taken initiatives in the Baltic countries and Eastern Europe in order to finance measures in the field of renewable energy, energy management and certain supportive measures. The possibilities for joint implementation or similar policy measures are of great importance for Sweden.

SUMMARY OF THE ENERGY POLICY PROGRAMMES (million SEK)

	M SEK	time period
INVESTMENT PROGRAMMES		
CHP's biofuel	1000	1991-1996
Windpower	250	1991-1996
Solar-heating	57,5	1991-1996
District heating	50	1993-1994
DEMONSTRATION PROGRAMMES		
New technology	187	yearly
Biofuel technology	625	1991-1996
Transport technology	500	1991-1996
More efficient use of energy	1000	1991-1998

As from January 1991 a carbon dioxide tax is levied on fossil fuels. The introduction of the carbon dioxide tax coincided with a major tax reform with the aim to reduce taxes on income and capital and to increase environmental taxes. Value Added Tax (VAT) was from that date applied to all forms of energy (fuels, heat, electricity). The carbon dioxide tax was initially set at the level of SEK 250 per tonne carbon dioxide released. The existing rates of energy taxes were at the same time reduced by 50 per cent.

The carbon dioxide tax and the energy taxes work as excise duties levied on fossil fuels (oil, coal, natural gas and liquified petroleum gas) except fuels for electricity generation. The tax in SEK per unit of energy is calculated on the basis of the average carbon content of the fuels.

In 1993 the energy and the carbon dioxide taxation was changed in order to adjust the Swedish tax rates on sectors subject to international competition to those applied in other similar countries. The general carbon tax rate increased from SEK 250 to 320 per tonne of carbon dioxide. A lower tax rate of 80 SEK/tonne was introduced for manufacturing industry. At the same time energy taxes were abolished for manufacturing industry.

Up to 1993 an exemption system existed for mainly energy intensive industry providing possibilities for single enterprises to apply for tax reductions. This regulation implied that companies energy taxes were limited to a certain per cent of the value of the goods produced. A similar system, which is applied to a minor number of enterprises, is still in force until the end of 1995. From January 1996 all branches of the manufacturing industry will be subject to uniform carbon dioxide taxation.

The first of January 1994, energy and carbon taxes were increased by 4 per cent (adjusted for inflation).

In order to promote and stimulate the introduction of renewable energy sources and energy efficiency the Riksdag has decided on several programmes. These programmes include the programme for energy management and promotion of biofuels, wind power and solar energy. The National Board for Industrial and Technical Development (NUTEK) has the responsibilities for these programmes. The programmes started in 1991.

In order to limit emissions from the transport sector we have up till now introduced mainly two measures, higher taxation on fuels and research and development. During the last four years two broad R&D-programmes have been initiated, concerning the use of alternative fuels and hybrid and electrical vehicles.

Action taken in the Forestry and Agriculture sectors

Many actions that have been taken in the forestry sector since 1990 affect the carbon balance. Various measures are taken to reduce carbon releases from the soils, e.g. through restrictions on forest site preparation operations and drainage.

A new agricultural policy was adopted by the Riksdag in 1990. Some of the policies indirectly affect climate change. In general, these measures will lead to reduced emissions of greenhouse gases. These include reduced and better nitrogen application practices, replacements from arable land to grazing grounds or forests, and increased use of winter overgrown land. However, methane emissions are expected to increase due to changes in land use patterns.

PROJECTIONS AND EFFECTS OF MEASURES

Projection of greenhouse gas emissions until 2005

The projections of the carbon dioxide emissions are based on assumption of Swedish future energy demand and supply. Basic economic forecast is given in Appendix 2. The figure shows the key assumptions.

FORECAST KEY DATA ASSUMPTIONS

	1993	**2005**
World Oil Price	USD 17/bbl	USD 28/bbl
GDP Level	1.8% increase	
Population Level	0.4% increase	
Electricity Price Households	850 SEK/MWh	970 SEK/MWh
Electricity Price Heavy Industries	230 SEK/MWh	339 SEK/MWh
Specific Energy Use Industry	0.217 kWh/SEK	0.188 kWh/SEK
Industry Production billion 1985 SEK	658	859
Number of Dwellings	4 144 000	4 506 000

The total energy demand is expected to grow by 0,9 per cent per year during the years 1993-2005 compared to the expected GDP-growth of 1,8 per cent per year. There is consequently a considerable improvement in energy efficiency during the period. The analyses show that there are rather large uncertainties in the fuel demand for electricity production, the assessment of energy efficiency and fuel used in the transport sector. Increasing demand for electricity can raise emission of carbon dioxide up to four million tonnes per year

depending on fuel used and amount of electricity imported from neighbouring countries. We have assumed that further power demand comes from natural gas combi cycles.

Other projections about emissions from the transport sector predict a higher penetration of new technologies that lead to less fuel consumption. The sensitivity analysis show that influence of world oil price on carbon dioxide emissions is small. The most important factor with the respect of carbon dioxide emissions is the growth of the economy.

It is important to stress that emission levels for 1990 are based on actual emissions, not adjusted for temperature variation. This is however the case for the projected years 1995 - 2005. If this would be done for a climatic normal year, emissions in 1990 would have been at the same level as for the year 2000 - i.e 64 million tonnes. The projections show that carbon dioxide emissions will grow somewhat until the year 2005 (Table 3). The decline from 1990 adjusted level in 1995, could mainly be attributed to industry production level.

Methane and nitrous oxides emissions are expected to decrease 10% until the year 2000 from 1990 levels, while HFC's emissions are expected to increase. Forest growth is expected to increase in forthcoming years. Timber lodging is the greatest factor determining total net removal by sinks. Thus, industry demand is crucial for the forecast but also difficult to predict. Estimations done show an increasing demand of timber for the industry. The increase in forest growth cannot compensate the increase in timber consumption. Net removals of carbon dioxide by sinks will therefore decrease from 1990 levels. However, forest carbon reservoir is expected to increase.

Table 3. Carbon Dioxide Emissions and Removals 1990 - 2005 (million tonnes)

Source	1990	1995	2000	2005
Energy and Transformation Industries	7,0	9,2	10,9	13,7
Transportation	23,1	24,0	25,3	26,7
Industry	13,5	12,6	13,1	13,7
Residential, Commercial	11,5	9,5	8,4	7,7
Industrial processes and others	5	5	5	5
Other sources	1,2	1,2	1,1	1,1
TOTAL	**61,3 (64)[5]**	**61,5**	**63,8**	**67,9**
Net removal of carbon dioxide by sinks	**-34**	**-31**	**-29**	**-28**
Forerst carbon reservoir	**2679**	**2846**	**2996**	**3139**

Effects of the measures taken

[5] Adjusted for normal precipitation and temperature

The effects of the action taken to combat climate change is difficult to estimate. This is specially true for the programmes for research and development and the programmes for energy efficiency. Effects of these programmes can only be fully evaluated in the long term.

Estimations have been made using different methods. Analysis of the effects of taxation on fossil fuels, the investment-programmes and the programme for more efficient use of energy were made separately.

In addition, an energy-model called MARKAL was used to estimate the overall effects of the climate change programme on the energy supply-side. The model optimizes the energy supply - given different available technologies - at lowest possible cost. However, the model cannot predict the relationship between energy-demand and energy-prices.

Higher prices on gasoline will lead to less traffic and a shift to more efficient cars i.e limited fuel demand. The study shows that emissions from the transport sector would have been two million tonnes higher without changes in tax rates. The programme for energy efficiency will decrease electricity consumption. Electricity savings due to the efficiency programme are estimated to 8 TWh, compared to the present consumption of 145 TWh up to year 2000.

The MARKAL-model compared the energy taxation at the beginning of 1990 with present energy taxes and subsidies for bio-fuels, windpower and solar heating. The result shows that the 1994 measures reduce emissions of carbon dioxide at the year 2000 with about five million tonnes. In the future increased demand for electricity will make the differences larger.

In total we estimate that the effects of the measures taken decrease the carbon dioxide in the year 2000 with about 10 million tonnes i.e 16% reduction from projected levels.

REDUCTION OF CARBON DIOXIDE IN THE YEAR 2000 [million tonnes]

Carbon taxes - energy sector	5.3
Gasoline tax and carbon tax - transport sector	2.2
Efficiency Programme	2.1
Investment Programme - Biofuel	0.6
Others	0.2
Summary	10.4

Projected emission in 2000: 64 million tonnes

FINANCE AND TECHNOLOGY

SWEDISH CONTRIBUTION TO FINANCIAL ISSUES (million SEK)

GEF, TOTAL	646	1991-1997
Energy systems in the Baltic countries and eastern europe	227	1993-1995
Transportation systems in the Baltic countries	15	1992-1993
Climate and Africa	8	1993-1994

The Swedish government contributed SEK 196.07 million to the pilot phase programme of the GEF for the three years up to July 1994. For the first period of the permanent phase ending in June 1997, Sweden will contribute SEK 450.04 million. The contribution to the core fund can not be directed to a specific focal area but will cover projects in all four windows.

The Swedish Government has so far allocated SEK 227 million to be used for activities aiming at an environmentally adapted energy-system in the Baltic states and Eastern Europe in particular measures to reduce carbon dioxide emissions.

The overall goal is to promote cost-effective activities that have a sustainable influence on the emissions of carbon dioxide. Such activities may also simultaneously reduce acidifying substances. The programme will primarily target the Baltic rim area and areas where there exists established Swedish contacts in the energy sector have been established earlier. Financial resources will be used for capacity building and direct investments in conversion to renewable fuels and in equipment for improvement of energy efficiency. Now, about 30 projects have been initiated.

The Swedish Government does also support programmes in developing countries trying to meet their commitments under the Convention One example is the project Climate and Africa. The Stockholm Environment Institute (SEI) has got the assignment to support participation of countries in Africa in the global climate debate. African experts will carry out the major part of the work. The budget for the project is SEK 8 million.

RESEARCH, EDUCATION AND PUBLIC AWARENESS

The Swedish Government has set up a special committee to promote and coordinate research in the field of climate change (The Swedish Committee on Climate Change). Sweden has supported the IPCC assessments through the chairmanship of professor Bert Bolin. Sweden also supports contribution by other scientists in the different IPCC working groups. Swedish research on global change is coordinated in the international programmes - International Geosphere-biosphere Programme (IGBP) and World Climate Research Programme (WCRP).

RESEARCH IN SWEDEN RELATED TO CLIMATE CHANGE 1993/94 (million SEK)

Scientific issues	43
Energy supply and use	180
Transportation	52

The Swedish Environmental Protection Agency is financing research on the impacts of climate change on Nordic ecosystems. The programme is mainly focusing on the following areas;

- Emissions and removals of greenhouse gases
- Effects of global climate change on Nordic ecosystems

Technical research in climate change is mostly dealing with different measures. The Energy Research Programme and the Transportation research Programme concentrate on renewable energy sources. A large part of the programme concerns different measures to enhance energy efficiency. The transportation programme also involves demonstration a programme on alternative fuels and electric vehicles.

Information activities are conducted in connection with the different R&D programmes addressing public awareness. The National Environment Protection Agency has the responsibility for a special information campaign.

FUTURE WORK

The long term climate policy must, according to the decision by the Riksdag in 1993, be based on a firm scientific basis, be comprehensive and cover all sectors in the society. Through the complexity of the climate change problem and the near association to central economic and political questions, international cooperation in this field is essential.

The Riksdag has requested the Government to propose new targets for carbon dioxide and other greenhouse gases after the year 2000. The Riksdag has also asked the Government to review the energy tax-system. The purpose is to establish energy taxes that in the long term and clearly promote an efficient and environmental friendly energy use and production.

Several committees have been established to elaborate new measures to combat climate change.

A shift in taxation from private enterprises, labour and savings to a taxation of limited resources could be beneficial to the environment. A parliamentary committee will be looking into these issues.

Another parliamentary committee is focusing on the energy sector. The energy policy is based upon a parliamentary agreement from 1991. The aim of the measures decided upon is to secure the long and short term energy supply on economically competitive terms and on environmentally sustainable conditions. The committee shall review ongoing energy programmes and estimate the demand for changes. The committee will also follow the work with reformation of the electricity market. The committee shall after its analyze is completed, propose measures to secure an effi-

cient electricity supply. The commission shall also propose a scheduled programme on how to transform the energy system. The deliberation within the committee shall be done against, among other things, the need to limit climate change at a level that can be sustainable for the society and for ecosystems. The measures proposed should be cost effective.

A third committee is concerned with the transportation system. It will analyze economic instruments in order to promote more fuel efficient cars and alternatives to petroleum based fuels. It will also propose measures to promote public transport systems and consider the importance of physical planning.

Another important area is individual and private sector work in the context of climate change. How to strengthen these sectors will be addressed in conjunction with local follow-up of Agenda 21 and the decisions made during UNCED.

1. Basic Data, National Circumstances and Emission Inventory

1.1 Country description

1.1.1 Introduction

This section contains a description of Swedish conditions within several sectors of society. Some of these facts may also shed light on what factors may be of importance for the levels of emission and sequestering of climate gases. The greenhouse gas that is of most importance for the climate is carbon dioxide. Anthropogenic emissions in 1990 amounted to 61.3 million tonnes. The forecast, which is described in chapter 3, foresees some increase of Swedish emissions up to 2005, Table 3.7.
There are large land and water areas in Sweden that are heavily affected by anthropogenic emissions of greenhouse gases in other ways than through their greenhouse effect. One of the most serious problems is acidification of soil and bodies of water, which is caused by acidifying substances like nitrogen oxides (NO_x) emissions originating in both Sweden and other countries. Nitrogen emissions also affect the levels of nitrogen accessible for eutrophication of the ecosystems in inland waters, in the Baltic Sea and in the seas off the west coast of Sweden (the Skagerrak and the Kattegat)

1.1.2 Retrospect

As far as the greenhouse gases as such are concerned, the main object of interest to date has been reducing carbon dioxide emissions. The background is that emissions of carbon dioxide have been increasing ever since the start of industrialization in the 18th century. The rate of increase in these emissions accelerated after the Second World War. Most of today's carbon dioxide emissions, 80%, derive from combustion of fossil fuels.
The global net flux of carbon dioxide to the atmosphere is also influenced by the cultivation methods practised within agriculture and forestry. In previous centuries it was above all in the temperate regions of the world that the forested areas were decreasing, thereby contributing to the increase of carbon dioxide concentrations in the atmosphere. Nowadays it is the deforestation of the tropical rainforests that is of importance.
The use of fossil fuels in Sweden started to increase at the end of the 19th century as industrialization proceeded. From a level of about 10 million tonnes per year in 1900, carbon dioxide emissions increased to about 100 million tonnes per year by

the end of the 1970's. Since then a decrease in fossil fuel usage has taken place. It can also be noted that the rising trend was temporarily interrupted during the period of the two world wars, when the use of fossil fuels declined markedly.

Carbon dioxide emissions declined in Sweden between 1980 and 1990 from about 80 to about 60 million tonnes per year. This reduction was made possible by a shift in energy consumption from fossil fuels to other energy sources. Fuel oil has been replaced by nuclear power, and to a smaller extent by biofuels and gas. Some of the decline can also be attributed to energy-saving measures. Motor vehicle emissions increased sharply during the same ten-year period.

Sweden imposed a tax on emissions of carbon dioxide in 1991. It takes the form of a fuel tax on fossil fuels. The tax is intended to reduce the economic advantage which fossil fuels enjoy in relation to renewable fuels.

In the case of other climate gases that are not covered by the Montreal Protocol, it is mainly reasons other than climate change that have motivated efforts to reduce emissions. One example is the measures taken to mitigate both occupational hygiene and environmental problems associated with the use of solvent-based paints in industry. These measures have led to reduced emissions of VOCs (volatile organic compounds).

1.1.3 Geography and climate

Sweden has a temperate climate, due to the fact that the Gulf Stream in the Atlantic Ocean carries huge quantities of warm water on its way north from the Gulf of Mexico. The surface area of the country is 450,000 km^2. Its shape is long and narrow, stretching 1,572 kilometres north to south. The northernmost part lies north of the Arctic Circle, which means that, in spite of the temperate climate, winters in the north are severely cold with large heating requirements for housing and industry as a consequence.

The mean temperatures in southern, central and northern Sweden during the period 1961-1990 were 7.2 (Sturup), 6.6 (Stockholm) and -1.6 (Kiruna) degrees Celsius, respectively. The annual mean precipitation figures at the same locations during the same period are 677, 539 and 488 mm, respectively. The southwestern part of the country has annual precipitation in excess of 1,000 mm.

The vegetational zones vary from hardwood (broad-leaved) forests in the south to tundra in the north. A vast boreal belt of softwood (coniferous) forest covers most of central Sweden.

The land boundary in the west with Norway (1,619 km) runs through a mountain range. There is also a land boundary with Finland (586 km) in the northeast. In the east and south the country borders on the Baltic Sea and in the southwest on the Sound (Öresund) and the Kattegat.

Sweden is rich in lakes with some 29,400 km^2 of lakes and watercourses. The country has several large archipelago areas with tens of thousands of islands.

Administratively Sweden is divided into 24 counties and 286 municipalities.

1.1.4 Demographics

The population of Sweden has increased from around 1 million inhabitants at the beginning of the 17th century to 8,7 million inhabitants in 1993. The rate of increase was low up to about 1820, when the population was 1.4 million. With the age of industrialization, the population increased more rapidly. In 1992, the birth rate was 14.2 persons born per 1,000 inhabitants per year, while the death rate was 10.9 deaths per 1,000 inhabitants per year.

The population is concentrated to the central and southern parts of the country. Most of the people (85%) live in urban areas. Stockholm is the largest metropolitan area. Greater Stockholm, including its suburbs, is home to about 1.5 million people. Only three cities — Stockholm, Göteborg and Malmö — have a population in excess of 200,000 people. The population density in the two northernmost counties is very low, 3 and 5 inhabitants per km^2, respectively. The average population density in the country is 19 inhabitants per km^2, which makes Sweden as a whole a sparsely populated country.

1.1.5 Economy

The Swedish economy is open and the country is highly dependent on foreign trade. The current economic situation can be illustrated by a few key figures from 1992:

Gross domestic product per capita (current SEK):	165,700
National debt per capita (SEK):	110,517
Exports as share of GDP:	22.7%
Manufacturing share of GDP:	17.6%
Number of cars per capita:	0.41

In 1992, exports of goods from Sweden accounted for 82% of total export revenues. Half of the country's exports go to the EU region. Approximately 15% of the exports of goods go to Norway and Denmark. Compared with other industrial countries, basic industries account for a relatively large share of total exports.

During the period 1975-1990, GDP growth averaged 1.8% per year. If an index of 100 is assigned to the year 1985, the GDP has increased from 75.6 in 1970 to 108.2 in 1992.

Different industrial sectors' shares of GDP (1992) are:

Chemical industry	2.3%
Iron and steel industry	0.7%
Engineering industry	7.4%

Pulp and paper industry	2.3%
Construction industry	5.8%

The economy has been weakened over the past three years, and the GDP has declined between 1991-93. The inflation rate is currently about 3%. Unemployment was very low for a very long time in Sweden, but has risen since the most recent recession to a very high level by Swedish standards. At present about 13% of the working population are unemployed.

The competitiveness of industry has been strengthened since the Swedish currency was allowed to float freely. The krona has declined about 25% in value in relation to the US dollar. On top of this, extensive structural rationalization has been carried out within industry during the past few years. Exports have increased very sharply during the past year.

One problem that may have great future consequences is the large budget deficit in the public finances. The borrowing rate will continue to be high during the next few years, which may keep interest levels high.

1.1.6 Energy structure

Total per-capita energy consumption in Sweden in 1990 was 50 MWh. Sweden's total energy use has been relatively stable over the past 25 years and amounted to 447 TWh in 1990. However, Swedish energy system has been markedly restructured although the development appears to be rather stable. The oil portion has decreased from about 77% in 1970 to 44% in 1990 of total energy consumption. At the same time the production of electricity has doubled through increased use of hydro- and nuclear-power. Approximately 95% of the electricity consumption comes from hydro- and nuclear power. During the period the electricity portion have increased from 10% to 33% of the total energy requirement. Also biofuel and peat have increased their portion from 9% in 1970 to 15% in 1990. Almost all electricity production, 95%, derives from nuclear-power and hydropower.

Different energy carriers was in 1990 as follows:

oil	197 TWh
coal and coke	28 TWh
Electricity: hydro and nuclear	148 TWh
biofuels, peat, etc.	67 TWh

When it comes to total energy use the distribution between industrial, residential and commercial sectors has been rather stable. It is changes within different energy carriers that have taken place. The electricity consumption has increased with 3.5% per year since 1970. The greatest increase has occurred within the residential and commercial sectors. The consumption of electricity in

the manufacturing industry depends mainly on the production level but to some extent electricity has replaced oil consumption.

Biofuels are mainly used in three different areas; forest industry, district heating plants and space heating of family houses. Biofuel have mainly expanded within the forest-industry and for district heating.

Traditionally forest industry use by-products for production of steam and electricity. The production and use of black liquor within the pulp and paper industry was 28 TWh in 1990 and another 8 TWh was by-products. In total, sawmills used 6 TWh. A small increase during the past 15-year period of biofuel use is attributed primarily to more efficient use of various by-products (except liquors) within the pulp and paper industry and at sawmills.

Domestic fuels use, such as biofuels, in district heating plants has increased from 2 TWh in 1980, through 10 TWh in 1990 and 15 TWh in 1993. The potential for further use of biofuel is large.

Space heating of single-family homes by biufuels is currently about 10 TWh per year or 15% of total biofuel use.

Energy use in transport sector has increased from 12% in 1970 to slightly more than 20% of total energy demand in 1990. Oil consumption has increased in that sector in contrast to reduced consumption in other sectors.

1.1.7 Transportation structure

Every Swede travels an average of about 40 km per day. Most passenger travel takes place by car. Few population centres are big enough to provide a basis for an efficient and competitive public transport system. Added to this is the fact that Sweden has many small communities spread out over a large areas. The national government recently approved investments for expansions of the traffic systems in the big cities (roads and public transport).

The highway network is extensive. Decisions have recently been made on large new investments in the highway network. The winter climate sometimes creates difficulties for car traffic, as well as for pedestrian and bicycle traffic.

The railway network has been thinned out during the past fifty years and investments during this period have been small. Very recently, however, a number of investments in the railway system have been approved, both in track and in rolling stock.

Sweden carries on extensive foreign trade. Most goods are shipped by sea, but large volumes are also transported by rail and road. Freight carriage doubled during the 1960's. This development stagnated in the 1970's and has since then been highly cycle-dependent.

Figure 1.1 Breakdown between different transport modes, passengers
(not available electronically)

Figure 1.2 Breakdown between different transport modes, freight
(not available electronically)

Road traffic

The number of automobiles is on the same level as in other Northern European countries, 0.4 car per inhabitant. The Swedish vehicle stock contains a relatively large share of large, heavy and high-powered vehicles.

Car travel accounts for about 75% of all personal transports. The factors that affect car use the most are believed to be personal income, the price of petrol (gasoline) and public transport convenience.

In all, truck (lorry) haulage accounts for about 40% of the freight haulage volume. In short-distance haulage the truck has a dominant position over other modes of transport. In the market segments that are exposed to competition between different transport modes, about 55% of the haulage volume is performed by truck.

Air traffic

Air traffic has been deregulated during 1992. The domestic air traffic share of long-distance passenger travel in Sweden is about 9%. The industry is highly sensitive to cyclical swings.

Train traffic

Train traffic is to away large extent electrified.

Passenger travel by rail includes both short commutes and longer trips. Short trips by rail take place mainly in the big-city regions as a part of the public transport systems. Railways account for 15% of long-distance personal transports.

Freight haulage by rail take place almost exclusively over long distances. Rail accounts for about 25% of such domestic freight traffic. The railway's share of freight haulage has declined through the years. On those market segments that are exposed to competition between different transport modes, rail has one-third of the transport volume.

Shipping

Shipping accounts for a large portion of the transport of goods. For long-distance domestic goods transport on the market segments that are exposed to competition

between transport modes, shipping accounts for 12% of the transport volume. 40% of the total transport volume consists of long-distance international shipments. Shipping accounts for half of this transport volume.

Ferry traffic across the Baltic Sea has increased sharply during the 1980's. Fairway investments lie at a constant level.

1.1.8 Industrial structure

Sweden is an industrialized country with both exploitation of natural resources (mining, forestry, hydropower) and heavy industrial production (iron, steel and non-ferrous metals, petroleum refining, chemical and pulp manufacture). Furthermore, the country has large engineering and electronics industries whose production programmes include both cars and typical high-tech products.

The number of employees in the manufacturing industry is about 700,000, with the engineering industry accounting for about half. The engineering industry is also of great importance in terms of the total value added within the manufacturing industry: 45% of the total value of SEK 228 billion (1991).

The value added by manufacturing in 1991 within some industrial sectors is given below in SEK billion and in % of the total value added.

	SEK billion	%
Engineering industry	102	45
Pulp and paper industry	34	15
Timber products industry	14	6
Chemical industry	31	14
Iron and steel industry	11	5
Food industry	23	10
Mines	3	1

Conditions within the openly competitive basic industry are characterized by modern equipment and high efficiency. Technical development efforts have generally been focused on developing the processes. The products have not been developed to the same extent in recent years. The production processes cause disturbances in the environment. More stringent environmental standards may affect industrial development in this industrial segment.

The knowledge-intensive high-tech manufacturing industry has a high proportion of well educated employees. This sector is distinguished by rapid product development and market adaptation. Companies within this segment of Swedish industry are dependent on access to a qualified labour force and various market regulations for their development.

The more labour-intensive part of the manufacturing industry has been exposed to keen competition from low-wage countries for a number of years. The

Swedish textile and clothing industry, for example, has been put almost completely out of business over the past 30 years. The food and sawmill industries, on the other hand, still exhibit good profitability.

1.1.9 Agricultural structure

Agriculture in Sweden employed about 106,000 people in 1992, which is equivalent to 1.2% of the population. In 1992 there were approximately 97,000 farming enterprises in the country. The sector has diminished greatly over the past 50 years, in terms of number of persons engaged, number of agricultural units and area of land under tillage. The land area devoted to agriculture amounted to 28,000 km^2 in 1992. The reason for the decline is a structural transformation with increased demands on efficiency.

Approximately 20,000 farms are devoted primarily to plant husbandry, about 40,000 are devoted primarily to animal husbandry, and about 10,000 have mixed production. Most of the remaining approximately 30,000 units are small family holdings.

Animal husbandry is often mixed, but cattle dominate and are found on every other farm. The number of head of cattle in 1992 was about 1.7 million, of which one-third were kept for milk production. The number of other animals in 1992 was 0.2 million sheep, 2.2 million pigs, 6.7 million fowls and 0.16 million horses. All horses are not used within the agricultural sector, however.

The ongoing restructuring of the agricultural sector may mean for the period up to the turn of the century that about 5,000 km^2 of arable land are taken out of production and that the number of cows declines by about 50,000 head.

The agricultural sector has an impact on the environment. Traditionally it has been nonpoint-source discharges of nutrients to water that have received attention. Atmospheric emissions come mainly from the handling of manure. Ammonia emissions are not believed to have changed significantly during the past 50 years. Atmospheric emissions have been discussed intensively recently, especially now that climate issues have entered the picture.

1.1.10 Forestry structure

The forest is one of Sweden's most important natural resources and is the basis for forest industry. Approximately 30 000 people engaged in forestry. Forestland covers about 280,000 km^2, corresponding to 62% of the country's surface area. The predominant tree species are Norway spruce (45%), Scots pine (38%) and birch (10%). Other species include oak, beech and aspen.

Swedish forestry policy have during 1900th century been characterised by the demand for sustainable management of forest resources. Since 1920's when the country-wide national forest survey started, the annual forest growth has increased from 60 forest cubic meter (m^3sk) to almost 100 m^3sk. During the same

period the volume of standing timber has increased from 1,800 million m^3sk to 2,800 million m^3sk. This development have been able to take place at the same time as the yearly fellings have increased from 50 m^3sk to 65-70 m^3sk.

During the spring 1993, the Swedish Government (Riksdag) adopted a new forestry policy. Environmental goals are now equated with production goals. The environmental goal is that the natural carrying capacity of forest land is to be sustained and the biological and genetic diversity of the forest is to be safeguarded.

The size of the forested areas as well as forest density and vitality is of importance for the cycling of carbon dioxide in the atmosphere, since carbon dioxide is accumulated in the growing forest. Sweden's forest area has increased very little in the past few decades, and in those cases mainly to the withdrawal of cropland from farming and planting of forest on it. Continued acidification of forest soil will involve the risk of considerable damage in the form of timber losses. This can have a major economic impact on the forestry sector as well as the importance of forest acting as a sink of carbon dioxide. The risk is greatest in southern and central Sweden.

1.2 Emissions inventory for 1990

1.2.1 Total emissions

Sweden has previously presented atmospheric emissions inventories for 1990. In the Swedish Environmental Protection Agency's report 4186 "Strategies to prevent climate changes" (English version), an inventory was carried out for climate gases that in the main follows the IPCC's reporting format. In addition, Sweden participated in CORINAIR '90, carried out by the EU's European Environmental Agency, EEA. Furthermore, in June 1994 the Swedish Environmental Protection Agency reported atmospheric emissions and forecasts to the UN/ECE's convention on Long-Range Transboundary Air Pollution (LRTAP).

The present emissions inventory follows IPCC instructions. The full IPCC-formate is given in Appendix 6. The material has been gathered with the aid of official statistics. Energy statistics, industrial statistics, agricultural statistics and forestry statistics have been used. Statistics on industrial emissions have their origin in a) emissions figures in the annual environmental reports to the regulatory authorities, and b) calculations with the aid of activity data and emission factors.

However, official Swedish emissions statistics do not cover all parts of this inventory. Data on emissions of nitrous oxide, methane and carbon monoxide in particular are lacking. The amounts of the emissions are therefore uncertain in many cases. Despite these uncertainties, figures on emissions have been given.

The reader should always check the quality ratings, see below. Swedish statistics on fuel use also have certain shortcomings. It has therefore not been possible to distinguish between energy use in agriculture and forestry sectors between individual space heating in the residential commercial sectors, etc., sections 1A4, 1A5 and 1A6 in the inventory. They have instead been reported together under the "other" section 1A7. The relative proportions of fuels for space heating and for process purpose in industry are also uncertain. All energy use is reported, however, so that final total is correct.

The demands on reporting of quality emissions data for the different gases have increased with this inventory. The inventory material for 1990 was not originally collected for the degree of quality assurance stipulated by the IPCC. Some statistics, quality levels and emission factors have therefore been unavailable and have had to be estimated.

Previously collected and processed material in other inventories have been utilized to as great an extent as possible. This is particularly true with regard to the data on industrial, agricultural and forestry emissions. In conjunction with the forecasts that have been made (see chapter 3), NUTEK (the National Board for Industrial and Technical Development) and DPU (the Commission for Forecasts and Development in the Transport Sector) have jointly reviewed the fuel statistics and the traffic volume in the country for 1990 as well. Some revisions of the traffic volume in particular have been possible compared with previous emissions inventories. Some of the emissions figures therefore exhibit minor changes compared with previous emissions inventories.

An attempt has been made to quantify the margins of error in the emissions data by classification in one of three classes: H(igh), M(edium) and L(ow). High represents data with a margin of error $< \pm 10\%$, Medium between $\pm$ 10-25% and Low $> \pm 25\%$ The classifications are reported on special quality sheets with the IPCC's reporting format.

The error estimates are expert assessments.

Table 1.1 Emission inventory of greenhouse gases in 1990 (1 000 tonnes)

Pollutant/ Sector	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	FCs	SF_6
Fuel Combustion: Energy and Transformation	7041	1.3	1.4	19.6	7.8	3.5	--	--
Fuel Combustion: Industries	13446	4.2	2.1	38.9	25.7	10.8	--	--
Fuel Combustion: Transportation	23092	17	0.4	285	1503	201	--	--
Fuel Combustion: Others	11543	10.4	0.7	19	69	141	--	--
Industrial Processes	4972	0	2.7	11	5.9	67	350	900
Fugitive Fuel Emission	53	0	0	0	0	18	--	--
Solvents	294	--	--	--	--	98	--	--
Agriculture	540	196	7.9	--	--	--	--	--
Waste	275	100	--	--	--	--	--	--
Total anthropogenic emissions	**61256**	**329**	**15.2**	**374**	**1611**	**539**	**0.06**	**0.04**
Land Use Change and Forestry (total not removals)	-34368	--	--	--	--	--	--	--
Total Net Emissions	**26888**	**329**	**15.2**	**374**	**1611**	**539**	**0.06**	**0.04**

HFC's were not used in Sweden in 1990.

Table 1.2 Emissions from international shipping and aviation in 1990 [6] **(1 000 tonnes)**

Pollutant/ Sector	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	FCs	SF_6
International shipping and aviation	4190	1.3	0.04	60	44	15	--	--

Table 1.3 Anthropogenic emissions, kg per capita 1990:

Pollutant/ Sector	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	FCs	SF_6
Emissions per capita	7052	38	1.7	43	185	62	0.007	0.005

The annual variations of emissions are dependent on how much the temperature deviates from a normal year and how much precipitation has fallen compared with a normal year. 1990 was a warm year and a year with greater than normal precipitation. The unusually supply of hydro power in 1990 made it possible to replace a certain amount of fossil fuels with electricity. This, together with the higher temperature, enabled the use of fossil fuels to be reduced by a quantity equivalent to carbon dioxide emissions of 2.7 or about 3 million tonnes. In other words, if 1990 had been a normal year, carbon dioxide emissions would have been about 3 million tonnes higher. See Appendix 5 for more details.

1.2.2 Emissions of CO_2

Anthropogenic emissions of carbon dioxide are 61 million tonnes. This is roughly in agreement with previously reported figures. The net emission of carbon dioxide calculated according to the IPCC's methodology is 27 million tonnes. Carbon dioxide is formed in connection with all combustion. The major emission sources are therefore sectors such as power and heat generation, transportation and industrial combustion.

[6] Excluded in table 1.1

The quality of the emissions data for carbon dioxide may be regarded as good. The data can be regarded as lying within a margin of error of ± 10%. However, it is much more difficult to determine how much carbon dioxide is sequestered in growing forest. The net emission of 27 million tonnes may therefore not be accorded a better accuracy than ± 10-25%.

The emission factors for carbon dioxide are weighted when it comes to combustion of gas (1A) depending on how much LP gas, town gas and natural gas is included.

For activities related to combustion, emissions of carbon dioxide in inventory section 1A have been reported according to the IPCC methodology. This means that the total emissions that can be calculated if all component carbon compounds in the emissions are converted to carbon dioxide equivalent shall be reported. For the sake of clarity, the emissions have also be reported in the Table 1.1.

In 1990 the net removals by forest sinks was about 34 million tonnes.

1.2.3 Emissions of CH_4

The largest sources of methane emissions are to be found in agriculture and in waste disposal. Together they account for 90% of the total emissions. Difficulties are associated with determining the size of the emissions. This is mainly due to the fact that the methodology employing emission factor calculations has not been able to be verified by measurements to a sufficient extent. As far as emissions from waste landfills are concerned, the total emissions are not known. It can be assumed that the figure of 329,000 tones has a margin of error of ± 10-25%.

1.2.4 Emissions of N_2O

There is no tradition of measuring or calculating emissions of nitrous oxide in Sweden. The figure given of 16,000 tonnes may be considered to have a margin of error greater than ± 25%. The largest emissions come from agriculture and combustion. The emissions previously given in CORINAIR '90 are of the same order of magnitude as in this inventory.

1.2.5 Emissions of NO_x

Total emissions of nitrogen oxides amount to 374,000 tonnes. Transportation is responsible for the largest emissions. In this inventory the total emission figures are lower than previously presented (400,000 tonnes). The differences are primarily attributable to the fact that international traffic has been completely excluded. A revision of the method of calculating the traffic volume for different vehicle categories carried out for this emissions inventory is also of significance, as are certain shifts between combustion and process industry due to difficulties in clearly defining industrial process and space heating activities in different

inventories. The total of the emissions is the same, however, regardless of which sector they are assigned to.

It can be assumed that the emissions are accurate within a margin of error of less than ± 10%.

The emission factors for NO_x for combustion (inventory section 1A) are considered to be at the high end, which may mean that the reported emissions are slightly too high.

1.2.6 Emissions of CO

Emissions of carbon monoxide, 1,6 million tonnes, arise primarily in connection with combustion of fossil fuels within the transportation sector. Previous emissions inventories have suggested lower emissions than this figure, about 1,35 million tonnes in the LRTAP inventory and in CORINAIR '90. The differences are due to changes in the calculated transportation volume after the revision by NUTEK and DPU. It can be assumed that the emissions are accurate within a margin of error of ± 10-25%.

1.2.7 Emissions of NMVOCs

Emissions of non-methane volatile organic compounds amount to 539,000 tonnes. This figure is greater than the one given in SNV report 4312 "Atmospheric emissions of volatile organic compounds" (available in Swedish only). However, it is difficult to measure emissions of NMVOCs accurately. It cannot be assumed that the figures have an accuracy better than ± 25%. The largest contributions come from motor vehicle traffic and from wood-burning for space heating of single-family homes.

1.2.8 Emissions of FC's and SF_6

FC compounds are highly stable compounds with a long life in the atmosphere and a high GWP (Global Warming Potential). FC compounds are used within very specific areas of application such as within the electronics industry for plasma etching and vapour phase soldering and within the textile industry in the manufacture of modern outdoor wear. The emitted quantities of FC's are about 20 tonnes. The accuracy of the figures is no better than ± 50%.

FC's are also formed unintentionally during aluminium manufacture. These emissions amount to about 40 tonnes and the margin of error in the determination is > ± 25%.

SF_6 also has a high GWP. SF_6 is primarily used as an insulating gas in electrical equipment. Emissions amount to about 40 tonnes.

HFC's were not used in Sweden in 1990.

2. Evaluation of Vulnerability to Climate Change

2.1 Climate change in Sweden

The climate in Scandinavia is influenced greatly by activity along the polar front, the geographic situation of the region at the edge of a large continent, and the influence of the North Atlantic and its currents. These factors lie behind the highly varying character of the Nordic climate and local variations are great, especially in the mountain districts.

The temperature trend in Sweden over the past 130 years can be summarized as one of rising temperature from the middle of the 19th century until the end of the 1930's (Figure 2.1). The temperature then fell until the beginning of the 1960's, when a new rising trend set in (*Alexandersson and Dahlström, 1992*; *Alexandersson and Eriksson, 1989*). The occurrence of both very cold and very mild winters during the past 30 years makes it difficult to discern any clear temperature trend in Scandinavia during the period.

Uncertainty in the precipitation measurements, along with local variations in precipitation, are great. Nevertheless, a clear tendency has been that the mild winters, caused by heavy low-pressure activity and a high frequency of westerly winds, during the period 1988-1993 have led to a sharp increase in winter precipitation in the mountains.

The spatial resolution of the models and their ability to calculate details in weather events are still not good enough to produce credible regional future scenarios. The best (published) available estimates of a possible future climate in the Nordic region (*Rodhe, 1990)* are used in this evaluation of Sweden's vulnerability to a climate change. The winter temperature is assumed to increase by 3°C by the year 2030, and the summer temperature by 2°C. Precipitation is assumed to increase by 15 mm/month during the winter and by 10 mm/month during the summer, and southerly and southwesterly winds will blow more often during the winter. The sea level is expected to rise by 20 cm, but due to postglacial land uplift the net rise at many places will be less.

Figure 2.1 Annual temperatures 1860-1991 from five stations in northeastern Sweden (the northern region). The smoothed curve is based on data obtained from a Gaussian low pass filter with a standard deviation of 9 years (not available electronically)

It is possible that a change will lead to an increase or a decrease in the variability of the climate. When it comes to the consequences of climate change in particular, extreme weather situations may be of great importance. The climate-dependent economic sectors would, at least in a short time perspective, probably be affected more negatively by an increase in the variability of the climate and/or by an increase in the frequency of extreme weather situations than by a slow, limited rise in mean temperature or precipitation.

If climate change were to lead in the long run to a change in the heat transported by the ocean currents, the consequences of a subsequent drastic warming or cooling could be disastrous for all climate-dependent ecosystems and economic sectors in Scandinavia.

2.2 Impact on natural ecosystems

2.2.1 Forests

The natural range of the different tree species and the species composition of the forests in the forested regions change slowly as a function of the climate and soil conditions. In large parts of Sweden, human forestry activities have also been an important factor to changes during the past 200-300 years.

The southern broad-leaved, or hardwood, forest region, in which stands consist mainly of oak (*Quercus spp*.) and beech (*Fagus sylvatica*), comprises a northern offshoot of the vast western and central European *nemoral* region. Within this region we find most of Sweden's deciduous hardwood forests. The *boreo-nemoral* forest region, in which Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) dominate, is found further north. Birch (*Betula pendula*) and aspen (*Populus tremula*) are common broad-leaved species in the coniferous, or softwood, forest. The northern limit of stands of pedunculate oak (*Quercus robur*) roughly coincides with the *Limes norrlandicus* (Figure 2.2). The forest landscape contains fewer types of vegetation with fewer species in the *boreal* forest region. Besides Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), there are several broad-leaved species, of which three — downy birch (*Betula pubescens*), silver birch (*B. pensula*) and aspen (*Populus tremula*) — are stand-forming.

Towards the west and with increasing altitude the coniferous forest thins out at the same time as the presence of mountain birch increases. In northern Sweden the climatically determined coniferous forest limit consists of pine, while spruce is the dominant tree species further south. In the sub-alpine region, just above the

actual coniferous forest limit, birch forest dominates, but with occasional softwood trees in climatically favourable habitats.

In order to determine more exactly the climate sensitivity of a given species we need to know more about which climatic conditions and soil conditions control the ranges of the different species. The predictive climate models developed to date employ a limited number of climate parameters to describe the probable ranges of individual species under changed climatological conditions. Model results (*Prentice et al., 1991)* show that the boreo-nemoral forest region may be shifted northward if the temperature increases. In the southern parts of the region, the present-day dominance will shift from Norway spruce (*Picea abies*), which is expected to grow more poorly in a milder and more maritime winter climate, to mixed forest dominated by beech (*Fagus sylvatica*), oak (*Quercus spp.*) and Scots pine (*Pinus sylvestris*). The simulated changes may take place over a time period of up to about 200 years.

Figure 2.2 Forest regions in Sweden. *(not available electronically)*

2.2.2 Sub-arctic ecosystems

The climate models predict that the temperature increase will be greater at higher latitudes (*Mitchell et al., 1990*). Furthermore, species at higher altitudes and latitudes are sensitive to changes due to slow growth, long generation times, irregular reproduction and thereby incapacity for rapid adaptation *(Callaghan et al., 1993*). Furthermore, the Swedish mountains belong to those areas where early and rapid effects of a climate change can be expected. Studies of effects of climate change on the Swedish mountain ecosystems have recently been initiated (*Molau, 1993; SNV, 1993*), and as yet we have only preliminary results. In general it is assumed that the growth of sub-arctic vegetation will also increase with rising temperature and carbon dioxide concentration, but the effect is normally short-lived due to limits set by other environmental factors as well as internal physiological limitations (*Lemon, 1983)*.

The tree line, which has been monitored for a long period of time, has risen by more than 50 vertical metres since the 1930's in the northern part of the mountain chain, which seems to be linked to a particularly pronounced temperature increase during the 1930's (*Sonesson and Hoogesteger, 1983)*. In the middle and southern parts of the mountains, on the other hand, a retrogression has been noted (*Kullman, 1989; 1993*), which could be caused by falling temperatures since the 1930's. If the forest limit rises, some of the arctic-alpine species above the present-day tree line will presumably be displaced if they cannot expand upward. This applies above all to the flora on many low mountains, which would be completely covered by forest if the present-day tree line were to rise only a little.

Measures to prevent an elimination of competitively weak species in a natural environment are scarcely possible other than on a very limited scope and/or at great cost. Clearly endangered genotypes may perhaps be preserved through targeted rescue actions in the field, frozen storage of seeds, etc.

2.2.3 Wetlands

Wetlands include mires (bogs and fens) in depressions in the landscape as well as marshy areas along the shores of rivers, lakes and seas. Altogether 20% of Sweden's land area is covered by wetlands (*Löfroth, 1991)*. Due to their inaccessibility, wetlands are relatively unaffected by man and therefore comprise some of our remaining wilderness areas.

The hydrological conditions in wetlands, in combination with the temperature regime and nutrient supply, give rise to different types of mires, primarily bogs and fens. Bogs dominate the wetlands in southern Sweden, while fens are most common in the northern parts of the country. A mosaic of the two types occurs in

many mires in central and northern Sweden. Hydrologically the mires act as water reservoirs and thereby form part of the regulation of the water flows within different drainage basins. This is manifest, for example, in a fluctuating groundwater table; the water level is high in the spring and autumn in connection with the melting of the snow and autumn rains, and reaches a minimum during dry periods, especially in the late spring and high summer. The floral composition on a mire, and thereby peat formation, is dependent on the temperature and the supply of water and nutrients. The same applies to biogeochemical processes in the form of primary production, decomposition and accumulation. Due to their peat-forming ability, mires are one of the few ecosystems where carbon dioxide from the atmosphere is sequestered. On the other hand, methane (CH_4) is formed, and mires and other wetlands are believed to constitute the largest natural source of atmospheric methane (*Armentano and Menges, 1986; Gorham, 1991; Harriss et al., 1993; Svensson and Sundh, 1992*).

Owing to the interactive effect of increased precipitation and temperature it is difficult to give a clear-cut answer to how the hydrology of the wetlands will be affected by a changed climate. An increased supply of water can increase carbon dioxide formation. An increase in precipitation would probably also lead to a spreading of the wetlands and a change in the relative occurrence of different types of mires.

If the temperature increases, evapotranspiration also increases. If the temperature increase were to balance out or overcompensate for the effect of increased precipitation, this could lead to a shrinkage of wetlands and even a change in the distribution of different mire types. In both cases, changes in the composition of the flora are to be expected for both the mires and the shore wetlands. In the mires in particular, peat formation and the methane flux will change. An increase in temperature could cause an increase in the anaerobic decomposition of the submerged peat, and this should give rise to an increase in methane formation. With a smaller water supply, oxygenation of previously submerged peat would increase, causing some of the peat to decompose so that stored carbon is returned to the atmosphere as carbon dioxide. This process, which is accelerated by a rise in temperature, causes mineralization of the organic material, liberating nutrients. This provides added scope for afforestation and shrinkage of the wetland area (*Hånell, 1988; Silvola, 1986*).

In Sweden, peat is cut and utilized as an energy source and a soil conditioner. Peat-cutting contributes to the greenhouse effect by altering the environment in a complex manner with consequences for the yield of both carbon dioxide and methane (*Rodhe and Svensson, 1994)*. Before the peat is cut, the mire is drained. This leads to a reduction in methane emission, but also to an increased emission of carbon dioxide, due to increased decomposition of the organic material.

2.2.4 Soil water and groundwater

Soil water plays a key role in the hydrologic cycle, since it is in the unsaturated zone that it is determined whether the infiltrated water will return to the atmosphere as water vapour, or whether it will be transported further to the groundwater and thereby recharge the water resources.

Since higher precipitation promotes greater groundwater recharge while higher temperatures promote evaporation, it is difficult to predict whether the change in climate will lead to increased, decreased, or largely unchanged groundwater recharge and level. The increased amount of vegetation and extended growing period that is expected to result from increased temperature and precipitation may counteract increased groundwater recharge.

Simulations of the water balance *(Gärdenäs and Jansson, 1994*) show that the net effect of a climate change may result in a higher frequency of early summer drought, but that the water stress will probably not increase during the height of summer when the lowest soil water level is normally recorded. An increase in early summer drought can be particularly problematical for cultivation of light sandy soils, where there is already a large irrigation requirement today. The simultaneous increase of the carbon dioxide concentration in the atmosphere is expected to cause the plants to become more water-efficient, i.e. uptake of carbon per unit of water evaporated increases. This, along with the increased precipitation, reduces the risk of a soil water shortage. A climate change can also affect the chemical and biological processes that take place in the soil water zone and that are of great importance for nutrient cycling in the soil and for the transport of water-soluble substances.

The temperature rise causes a northward shift of the permafrost line, winter precipitation in the form of rain, and an extended vegetation period. These factors control the annual regimen of groundwater level fluctuations. The country can be divided into four regions with different groundwater regimes (Figure 2.3). In the event of a temperature rise of about 2-3°C, the groundwater regimes would move roughly one step to the north, which means that low and high groundwater levels would occur at different times during the year than today. A longer frost-free season and groundwater recharge all winter long could lead to greater leaching of nutrients from agricultural land further north (*Lundström and Öhman, 1990*). Higher temperatures and greater percolation promote weathering and could result in slightly higher salinities in the groundwater (*Sverdrup and Warfinge, 1993*).

To better be able to quantify the vulnerability of groundwater to a climate change, it is necessary to carry out model calculations with respect to the quantity and quality of the groundwater. No measures have been taken to adapt to the situation a climate change is expected to result in. However, climate change is one of the "threats" that will be monitored within the new national environmental monitoring programme for groundwater. Since precipitation is expected to increase, climate change is not expected to lead to any serious long-term threat to our water resources.

Figure 2.3 Groundwater regimes and groundwater levels
(not available electronically)

2.2.5 Lakes and watercourses

The majority of lakes in Sweden are so shallow that by far most of the water mass during the ice-free part of the year is well mixed. In these lakes an increase in the mean temperature of the air will be reflected in a higher water temperature for the water mass in the entire lake. In deeper lakes, if the summer temperature increases it is probable that only the surface water temperature will be affected. If the wind increases during the spring, the deep water (hypolimnion) in these lakes may also be warmed up. With a higher winter temperature, more lakes will be ice-free all winter long, and there will be a general shortening of the duration of the ice cover by perhaps more than a month on average.

The temperature changes will hardly be so great that the lethal limits for the majority of organisms present in the lakes and watercourses of Sweden will be exceeded. Compared with other large-scale impacts on lakes and watercourses in Sweden — such as acidification, eutrophication and water regulation — a moderate temperature increase is probably a minor threat. For organisms that are close to or even beyond their temperature limit due to their migrational history, even minor temperature changes may have major effects (*Firth and Fisher, 1992*).

In the long run, significant shifts in the composition of fish communities can be expected (*Carpenter et al., 1992*). With an increased hypolimnion temperature, the rate of oxygen consumption will increase, which may make the cold hypolimnion unhabitable for e.g. char and certain crustaceans. These species are already threatened in southern Sweden by acidification, eutrophication and the introduction of stronger rivals. On the other hand, more warm water-loving species, such as roach fishes and perch, will be able to migrate northward and higher up in the Swedish mountains.

An increase in precipitation will have the greatest effects in running water. However, communities of organisms here are adapted to strong fluctuations in stream discharge, so an increase in the water flow per se will scarcely have any dramatic effects. On the other hand, the transport of dissolved and particulate material is affected significantly by increased precipitation, especially during the winter season when the retention effect of the vegetation is minimal. If the increase in precipitation and runoff leads to increased eutrophication due to an increase in the transport of suspended matter, dissolved humic substances and plant nutrients (especially nitrogen and phosphorus) to lakes and watercourses, changes can be expected in the ecosystems (*Forsberg, 1992)*.

No measures have been taken to adapt to the effects of climate change on lakes and watercourses. Possible measures mainly have to do with the increased risk of flooding and burst dams, sizing of stormwater and sanitary sewers, etc.

2.2.6 Marine and coastal ecosystems

As a result of a rising sea level, an increase in the seawater temperature and changes in precipitation, winds and water circulation, the seas and their coasts may be affected by a climate change.

The Swedish coastline is characterized by different types of landscape such as archipelago coasts, rocky coasts, moraine coasts, sand and dune coasts, deltas and river mouths (*Sjöberg, 1992)*. The coastal areas, especially along the Baltic Sea, have undergone great changes since the most recent ice age. Postglacial land uplift is still in progress north of 57°N (*Voipo and Leinonen, 1984*).

The most striking result of a sea level rise would be flooding and increased erosion of the coasts. Low-lying urban areas may be in the risk zone (*Gustavsson, 1994; Hansson and Alm, 1992*), but in the event of a sea level rise of up to 50 cm it will probably be possible to protect important land areas with embankments and shore barriers. From an ecological viewpoint, nature will by and large have enough time to adapt to a water level rise of this magnitude. If the level rises further, heavy socio-economic costs and environmental destruction are expected to result (*Lindhagen, 1989)*.

Ecological disturbances of the plant and animal communities in the shore zone are likely in the event of sea level rise. The size and salinity of estuaries may increase, which may affect spawning and maturation areas for fish. Salt water intrusion into wetlands, as well as into water mains and wells, to become more common as a result of floods in conjunction with storms (*Warrick and Rahman, 1992)*. Leaching of flooded soil may exacerbate eutrophication problems.

A shift in the distribution and composition of species of marine organisms would probably follow from an increase in sea water temperature. Heat-tolerant animals would replace species that are sensitive to higher temperatures, and the growth and recruitment of commercially interesting molluscs, crustaceans and fishes would be affected. The increase in water temperature might also generate physiological changes in the marine organisms, which could affect all stages of the fish population. Effects on processes such as growth, maturation, nutrient uptake and range are probable (*Kennedy, 1990*).

Changes in precipitation and winds and water circulation affect not only the circulation pattern of the surface water and its mixing with deeper water layers (*Melillo et al., 1990)* but also salinity, water stratification and the transport of nutrients and toxic organic compounds to the seas (*Wulff and Niemi, 1992; Wulff et al., 1990). A*n increased runoff of humic substances and trace metals from acidified soil would favour blooms of toxic algae. A change in the cycling of nutrients would affect phytoplankton production. Phytoplankton take up carbon dioxide from the air so that the sea acts as a sink for greenhouse gases. The increased phytoplankton production that is expected to result from increased eutrophication could hypothetically increase the uptake of carbon dioxide.

Besides the fact that changes in ocean currents would have serious effects on the recruitment of bottom-dwelling animals and fishes to coastal areas, the consequences for the terrestrial climate would probably also be great.

2.2.7 Baltic Sea

The sand coasts around the southern part of the Baltic Sea would particularly be affected, while at higher latitudes the process of land uplift would compensate for sea level rise as long as the latter is limited. Shoreline erosion is already a problem in some areas, where the shoreline has on average retreated 1-2 m during the past 150 years. A combination of long-term geological processes and climate change, but also human intervention, are believed to be the cause (*Gustavsson, 1994; Lindhagen, 1989*).

Water exchange in the Baltic Sea takes place by inflow from land areas via rivers, precipitation on the surface of the sea and direct evaporation, as well as water flow through the Belts and the Sound (Öresund) (*Franck et al., 1987; Håkansson et al., 1993*). The inflow via rivers is well known today (*Bergström and Carlsson, 1993), b*ut variations between years are great (Figure 2.4).

Figure 2.4 Total annual inflow of fresh water from land to the Baltic Sea, the Sound, the Belts and the Kattegatt during the period 1921-1990.
(not available electronically)

Precipitation and air temperature are the most important meteorological factors controlling inflow from land to the Baltic Sea. Precipitation determines the amount of water available, while temperature affects snow accumulation and melting as well as evapotranspiration (*Lindström et al., 1994*). The annual dynamics of the rivers would be altered considerably by an average temperature change of +3°C (*Carlsson and Sanner, 1994*), for example the total inflow to the Gulf of Bothnia from Sweden would change by the order of 20%. Much more detailed regional interpretations of the climate scenarios than are available today are required as a basis for analyses of the effects of a climate change on the total inflow.

A change in the Baltic Sea's water balance can have serious consequences for the marine ecosystems. At irregular intervals, oxygen-rich salt water flows into the Baltic Sea and upholds the oxygen and salt concentrations in this manner. Small inflows are relatively common, while larger inflows may occur once every ten years under extreme weather conditions. In order to be able to analyze the effects of a climate change on the Baltic Sea's exchange of salt water, the frequency of extreme weather conditions must be accurately simulated. The global climate models that exist today are not capable of doing this.

Both the total inflow from land and the flows to rivers and streams from areas with a heavy pollution load and intensive agriculture are of importance for the water quality of the Baltic Sea. A higher winter temperature leads to greater inflow in the wintertime, and since the concentration of e.g. nitrates is higher during the winter than during the summer, the combined effect is a considerable increase in the pollution load (*SNV, 1990; Wulff and Niemi, 1992)*.

2.3 Impact on economic sectors

2.3.1 Agriculture

The crop-growing season in Sweden is limited by both temperature and insolation. An increased temperature in the spring means above all that the growing season may be longer in the spring. If cloudiness increases, a negative influence on growth could be obtained during the entire growing season. It will be possible to increase the harvests, and the cultivation limit for most types of crops may move northward if the growing season gets longer. An increased carbon dioxide concentration in the atmosphere, together with a temperature increase, results in increased growth for most agricultural crops (C3 plants). To be able to take advantage of this increased growth potential, the supply of water and nutrients must not be limited. The increased mineralization that follows from increased precipitation and raised soil temperature increases the risk of nitrogen leaching from agricultural land. To reduce this risk, the proportion of vegetation-covered land in the autumn and winter may be increased.

More precipitation-rich springs may lead to tillage problems, especially on stiffer soils, and greater quantities of rain during the summer and autumn may lead to harvesting problems. Occurrence of insects and fungi, increases with a warmer climate that may lead to an increased use of biocides. Animal husbandry will, on the other hand, be affected to a lesser extent by climate change.

Swedish agriculture is, and has always been, exposed to greater or lesser variations in climate and weather. Relatively great differences occur in the weather between different years, as far as both precipitation and temperature are concerned. This means that the prospects that Swedish agriculture will be able to adapt to a climate change ought to be good. To be able to benefit from the climate change in terms of production, however, farming practices must be adapted to the extended vegetation season.

2.3.2 Forestry

Higher temperatures and increased precipitation should result in general improvements in forest growth. However, an increased temperature can also have negative consequences. Milder and windier winters lead to a greater risk of

windthrow. The Scots pine's capacity for natural regeneration can also decrease, since this process requires cold winters. Norway spruce are also expected to grow less well in a milder and maritime-influenced winter climate. Furthermore, an increase in the temperature increases the risk of attacks by insects, fungi and other pests.

Model experiments (*Prentice et al., 1991*) show a possible shift in tree species composition towards a greater hardwood presence in large parts of the country and reduced spruce dominance in Southern Sweden.

Planted forests, with one or a few tree species and same-aged stands, are poorly suited to cope with different types of disturbances, including rapid climate changes (*Persson, 1985)*. Spruce forests of continental origin, with their low genetic variation, are judged to be the most vulnerable. Compared with agriculture, which has more species than the forestry and shorter rotation periods, forestry will have more difficulty adapting to climate change (*Linder, personal communication*). An adaptation will probably be necessary through, for example a different choice of tree species and provenance.

The Swedish forest contributes in two ways towards mitigating Sweden's net emission of carbon dioxide. The Swedish forest has during a longer period stored carbon in biomass and it produces bioenergy, which may replace fossil energy. Every combination of silviculture and cutting level results in a given average storage of carbon (*Eriksson, 1994)*. The climate, the carbon dioxide concentration in the air and different contaminants also affect the size of the carbon store. In the lay term the production of biofuel is of grater importance to reduce atmospheric carbon as the increase of timber stock volume is of anthropogenic character and thus can continue within given limits. In the future, forestry will have to adapt to a changed climate, also preserve or increase the amount of carbon stored in the forest without negatively affecting timber stock volume or biodiversity.

2.3.3 Reindeer herding

During mild winters, the most recent being 1988 and 1993, larger quantities of snow fall than normal in large parts of the reindeer grazing region. This has contributed to large energy losses among the reindeer. Winter temperatures above the freezing point give rise to formation of a layer of ice ("ice bark") covering the lichen which the reindeer depend on for food. Besides making the reindeer's search for food more difficult, this has also forced reindeer to a greater extent than normal out onto roads and railway tracks in large flocks, rendering them vulnerable to traffic death.

2.3.4 Fishing

The effects on open-sea populations of fish in the seas west of Sweden (Skagerrak and Kattegatt) are expected to be marginal, and both positive and negative effects are possible. As a result of a temperature increase, several fish species with a more southerly range today, such as sea bream and sea perch, may become more common. On the Swedish west coast, cold-water species such as cod and flat-fish dominate even in shallow water. Here eel is probably the only warm-water fish which, like lobster, can be expected to be favoured by a temperature increase. Coastal fishing may also be affected by changes in the behaviour of the fish, for example the fact that cod and herring keep further out to sea at higher water temperatures in coastal waters. In the event of a temperature increase, the most probable development for the Baltic Sea will be that cold-water species such as cod, salmon and whitefish will decrease in importance. The littoral fish community, with primarily stationary warm-water species such as perch and roach, should instead increase its range. In the Baltic Sea it is difficult to judge the effects of a temperature increase owing to the fact that the salinity, whose development is difficult to predict, may change. Intrusion of salt water oxygenates the deep basins of the Baltic Sea and creates the conditions necessary for bottom-dwelling animal communities and fishes, including the commercially important cod. Here there is a mixture of marine and fresh water species, but the number of species is relatively small due to the low salinity.

Because coastal fishing in the Baltic Sea is based on many species, of both limnic and marine origin, and on both warm- and cold-water species, the fishing is relatively flexible, which increases its chances of adapting to a climate change. More storm days would reduce the opportunities for fishing, but a higher water temperature would lead to reduced ice formation on the Baltic Sea, which would increase the number of fishing days. If commercially important fish stocks decline, however, the open-sea fishing fleet may have problems with overcapacity and adaptation.

2.3.5 Effects on Hydro Power

Analyses of the effects of climate change on hydropower production also require detailed regional climate interpretations. Hydropower production is heavily dependent on whether the precipitation falls in the lowland or high up in the mountains. During the mild winters of the past few years, snow accumulation has been very heavy in the mountains, resulting in record-level hydropower production. An accurate assessment of how dam safety would be affected by a climate change is extremely difficult to make, since extreme flows are primarily dependent on predictions of extreme precipitation on a regional scale, something which is not generated from today's models.

2.4 Health

In a global perspective, the negative health effects of increased emissions of greenhouse gases can be great. The changes in temperature and precipitation that could occur in Scandinavia are not, on the other hand, likely to have any direct effects on the state of health of the population. On the other hand, human health could be affected indirectly via an increase in other environmental problems that affect health.

Intensive insolation and high temperatures are believed to increase the formation of ground-level ozone, which at high concentrations is not only irritating to the respiratory passages but also causes damage to crops and other vegetation. An increased temperature during the vegetation season increases the risk of attacks by microorganisms, fungi and insects. This could lead to an increased usage of chemical pesticides in agriculture, which in turn could result in increased pesticide residues in foods. If climate change exacerbates the acidification situation, concentrations of metals in drinking water could increase, which means a greater risk of exposure to e.g. cadmium and mercury.

2.5 Impact of climate on other environmental problems

A change in the climate could have significant effects on emissions, transport and deposition of air pollutants. A temperature change, as well as a change in humidity and cloudiness, could affect the chemical reactions in the atmosphere which create or transform photochemical oxidants and other pollutants. A higher temperature, for example, will probably stimulate the production of ground-level ozone. How large the load will be is also dependent on air circulation and the presence of other pollutants.

The predicted increase in the frequency of winds from the south and southwest in the wintertime may increase the pollution load, since the pollution levels in the air are elevated in Sweden when the wind is southeasterly to southwesterly. Changes in precipitation patterns influence both the relative proportions of dry and wet deposition and the total deposition of pollutants. Pollution levels in precipitation are also generally highest when the air has been brought here from directions between east and southwest.

The relationship between air pollution and forest damages is complicated. Unfavourable circumstances may force the trees. to be more susceptible to air pollutants.

If the winters are mild with lots of precipitation, so that mineralization is permitted to proceed during a longer period in the autumn, and even to a limited extent in the winter, leaching of nutrients from soil to water will increase, which will result in increased eutrophication. On the other hand, the vegetation season will expand, which enable plants to take up more nutrients. A warmer and moister climate would, on the other hand, probably have a rather limited effect on

the acidification status of lakes and watercourses, compared with long-term changes in the quantity of sulphur deposition.

The intensification of other pollution problems which a climate change could conceivably lead to will perhaps cause the most noticeable effects in the near future. The future environmental work will have to include an integrated risk assessment. Interaction of different environmental problems and the consequences of different measures will have to be analyzed in a coordinated and cohesive fashion.

3. Measures, Forecasts and Effects

3.1 Measures for limiting emissions of greenhouse gases

Sweden's current energy policy stems from the 1991 Government bill on energy policy[7]. This bill stated that the goal of energy policy is to secure short- and long-term supplies of electricity and other energy on internationally competitive terms. Energy policy must further be based on what nature and the environment are able to bear.

From the climate viewpoint it was considered urgent to avoid burning fossil fuels wherever possible. According to the bill, this shall be accomplished by means of active energy conservation and by utilizing renewable energy sources.

The question of when the phase-out of nuclear power can be commenced and the pace at which it should proceed will be decided by the success of electricity conservation efforts, the availability of electricity from environmentally acceptable power sources and the ability to maintain internationally competitive prices. The statement of the *Riksdag* (Swedish parliament) from 1980 stipulating 2010 as the year when the last nuclear power reactor in Sweden is to be shut down, has not been subject to reconsideration.

The Government Bill on Actions to Counteract Climate Change of 1993[8] set forth a more concrete strategy for Swedish climate policy according to which Sweden shall, in accordance with the climate convention, stabilize its emissions of carbon dioxide at the 1990 level by the year 2000. After that the level shall be reduced. The strategy covers all greenhouse gases, but pending new knowledge no targets are set for other greenhouse gases than carbon dioxide. The exception is leakage of methane from waste landfills, for which the target is a reduction of emissions by 30% by the year 2000.

The main thrust of the strategy is to limit emissions of carbon dioxide. The development of sinks is viewed as a complement.

Swedish climate policy puts an emphasis on cost effectiveness and states that Sweden should take action both nationally and internationally. Since Sweden is only marginally able to influence global emissions, it is stressed that Sweden shall be a driving force in the international work of limiting greenhouse gas emissions.[9]

Swedish marginal cost for reducing carbon dioxide is high compared to many OECD-countries. Sweden has, as a part of the national climate change policy, started

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[7] Gov. Bill 1990/91:88.

[8] Gov. Bill 1992/93:179.

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to make an active contribution to reduce carbon dioxide emission in the Baltic countries and Eastern Europe.

The Riksdag approved the Government Bill on a reform of Swedish Electricity Market[10]. The new legislation will be in force from 1 January 1995.

The objective of this reform is to achieve more rational utilisation of the production and distribution resources and to ensure that customers enjoy both flexible conditions and the most possible prices, on the basis of increased competitive strength. Questions concerning transfer of electricity is subject to government supervision even in the future.

3.1.1 Energy and environmental taxation

The use of energy in Sweden has long been subject to excise taxes (general energy tax and special tax on petroleum products, coal and nuclear electricity). In conjunction with the big tax reform of 1990, VAT (value-added tax) was imposed on energy. VAT was imposed on top of existing excise taxes. For the purpose of obtaining a price structure consistent with the political goals, a number of supplementary environmental taxes were introduced. Such a tax is the tax on emissions of carbon dioxide which, when introduced in 1991, was equal to SEK 250 per tonne of carbon dioxide[11]. For petrol (gasoline), the tax was introduced at the beginning of 1990. When the carbon dioxide tax was introduced, the energy taxes were reduced by 50%.

The carbon dioxide tax and the energy tax were levied up to 1993 on all use of fuel with the exception of fuel for power production. The energy-intensive industrial sector was able to obtain a tax abatement, however, whereby companies did not have to pay energy and carbon dioxide tax in excess of 1.7% of the sales value of their production.

Energy and environmental taxation was changed once again in 1993. After this change, industry and other users are taxed differently. Manufacturing industry now pays no general energy tax on fuels and electricity and only 25% of the carbon dioxide tax. The previous rules for abatement of the energy taxes for industry are to be abolished, but transitional rules apply up to 1995 according to a decision by the Riksdag in the spring of 1994. At the same time the general carbon dioxide tax was increased to SEK 320 per tonnes.

For other users, a general energy tax is payable on coal, oils, natural gas, LP (liquefied petroleum) gas and electricity. No tax is payable for biofuels and peat, on

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[10]Gov. Bill 1993/94:162

[11] A sulphur tax was also introduced in 1991. A carbon dioxide charge was introduced in 1992 for certain plants. Boilers or gas turbines that produce warm water, hot water, steam or hot oil for space heating of buildings, for production of electricity or for use in certain industrial processes are covered by the system. The charge covers about 120 plants with around 200 boilers. The paid-in charge is repaid to the plants in proportion to the particular plant's production.

the other hand[12]. The tax on diesel fuel is differentiated with respect to environmental properties into environmental classes. The tax on electricity is also differentiated in that consumers in northern Sweden pay a lower rate than those in the rest of the country.

The carbon dioxide tax is levied on heating and fuel oils and motor fuels, including aviation fuel for domestic flights, coal, natural gas and LP gas. Pending an international coordination of taxation, electricity production has been exempted from carbon dioxide taxation. A unilateral carbon dioxide taxation within electricity production in Sweden could raise the total cost in Swedish electricity generation and electricity-intensive industry. Furthermore, problems would arise with the Nordic power exchange. Condensing plants abroad could be used in preference to CHP in Sweden, which would lead to increased carbon dioxide emissions globally.

The energy and carbon dioxide taxes are index-adjusted for the period 1994-1998 so that the taxes will not be undermined by inflation. An increase of these taxes by 4% therefore entered into effect as of 1 January 1994. The carbon dioxide tax for industry is currently SEK 83.2 per tonnes of carbon dioxide and SEK 322.8 per tonnes for other users.

During the spring of 1994 the Riksdag decided on certain changes in the energy and environmental taxation. An energy tax on fuels used in co-generation, i.e. combined heat and power production (CHP), will be reinstated at half the rate from 1 July 1994 and remain in force until the CHP taxation has been fully investigated. In the new system, biofuels used in CHP plants for deliveries of heat to industry receive a compensation of SEK 90 per MWh of heat delivered, but crude tall oil is exempted.

Furthermore, it has been decided that as of 1 July 1994, wind power shall receive a special environmental bonus equivalent to the tax on the electricity delivered to households, at present SEK 88 per MWh in southern Sweden. The bonus shall be paid to the distributor and passed on to the producer.

It has been decided to broaden the system of charges on emissions of nitrogen oxides. Plants that produce at least 25 GWh shall be included in the charge system. The broadening will take place gradually so that boilers that produce at least 40 GWh are included as of 1 January 1995 and boilers that produce at least 25 GWh are included from 1 January 1996.

Tables 3.1 and 3.2 present the energy and environmental taxation as it was before the changes of 1 July 1994 entered into force. The reason for this is that the forecast of carbon dioxide emissions that is presented in this chapter was made before these changes were decided on. VAT, currently 25%, is also levied on top of these taxes.

[12] By “biofuels” is meant biomass fuels such as wood fuels, agricultural products, biogas and certain types of waste.

Table 3.1 General energy and environmental taxes 1994

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Total Tax, SEK/MWh
Light Fuel oil, SEK/m³ (less than 0.1% sulphur)					
environmental class 1	5	957	-	962	97
environmental class 2	302	957	-	1259	127
environmental class 3	562	957	-	1519	154
Heavy Fuel oil, SEK/m³ (0.4% sulphur)	562	957	108	1627	150
Coal, SEK/t (0.5% sulphur)	239	832	150	1221	162
LP gas, SEK/5	109	998	-	1107	86
Natural gas, SEK/1000 m³	182	707	-	889	82
Peat, SEK/t (0.2% sulphur)	-	-	60	60	20
Petrol, leaded, SEK/l		3.65[1]	0.77	-	4.42
Petrol, unleaded, SEK/l		3.14[1]	0.77	-	3.91
Diesel, environmental class 2, SEK/l		1.60[2]	0.96	-	2.56
Electricity, other, SEK/MWh	88	-	-	88	88
Electricity, northern Sweden, SEK/MWh	36	-	-	36	36
Electricity, district heating producers, SEK/MWh	66	-	-	66	66
Northern Sweden, SEK/MWh	36	-	-	36	36

1) Petrol tax
2) Energy tax SEK 0.30/l plus diesel tax SEK 1.30/l (replaced km tax)
Note: Taxes do not include VAT and are given in 1994 prices.

Table 3.2 Industry's energy and environmental taxes 1994

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Total Tax, SEK/MWh
Fuel oil 1, SEK/m³	0	239	-	239	24
Fuel oil 5, SEK/m³	0	239	108	347	32
Coal, SEK/t	0	208	150	358	47
LP gas, SEK/t	0	250	-	250	20
Natural gas, SEK/1000 m³	0	177	-	177	10

Note: Taxes do not include VAT and are given in 1994 prices.

The general energy and environmental taxation and the broadening of VAT to include the transport sector as well has largely led to a gradual increase in the taxation of transportation during the period 1990-1994. However, the abolition of the kilometre tax in October 1993, which was then replaced by an increase in the diesel tax, has led to some tax reduction for heavy vehicles and vehicle combinations. The reduction of VAT for transport services during 1993 from 25% to 12% has also led to some relaxation of the generally increasing taxation of transportation.

The sharpest increase of taxation can be noted for petrol (gasoline). The imposed carbon dioxide tax amounts to SEK 0.77/litre. Furthermore, the petrol tax has been raised a number of times during the period 1989-1994, and VAT (currently 25%) has been imposed on petrol. Altogether, these tax changes amount to an increase of nearly 30% in the price of petrol, see Table 3.3.

Table 3.3 Price of petrol 1989-1993, SEK per litre, 1993 prices

	Unleaded		**Leaded**	
	Incl. tax	Excl. tax	Incl. tax	Excl. tax
1989	593	253	618	252
1993	767	226	802	227

Source: SPI and own calculations.

For industry, the changes in taxation have entailed a lower energy price. During the period 1990-1993 the price of heavy fuel oil has fallen substantially by more than 10%.

For other users (non-industry), taxation has increased since 1989. This is especially true for households, who pay VAT. The price of fuel oil for space heating has risen since 1989 by more than 16% in real terms (including the introduction of VAT).

3.1.2 National energy and climate programmes

Through the 1991 energy policy bill, Sweden's energy policy was allocated additional resources to ease the transformation of the energy system to nuclear power phase-out and improved environment. The programmes that were introduced were investment support to biofuel-based power production, investment support to wind power, investment support to solar heating, additional resources to the Energy Technology Fund, support programme for biofuel-based electricity production, the programme for more efficient use of energy and support to ethanol production.

Table 3.4 Energy programmes, SEK million

	Budget	Programme period
Investment support		
CHP, bio	1,000	1991-1996
Wind power	250	1991-1996
Solar heating	57.5	1991-1996
District heating	50.0	1993-1994
Development and demonstration		
Energy Technology Fund	187 per year	
FABEL	625	1991-1996
Supply of alternative motor fuels		
More efficient use of energy	1,000	1991-1998
Transportation		
Development and demonstration	500	1993-1996

The 1993 climate policy bill added support for construction of district heating systems. Furthermore, funds were allocated for investments in biofuels and energy efficiency improvements in the Baltic states and the Eastern European near region[13].

The most important programmes, their budgets and timetables are shown in Table 3.4.

Investment support

Investment support to CHP production with biofuel is payable at a maximum rate of SEK 4,000 per kW of electric output capacity. The CHP plants commit themselves to using biofuel for five years.

Support can be given to *investments in wind power plants* amounting to up to 35% of the cost. To obtain support, the plant must have an output of at least 60 kW.

Support to investments in large solar heating plants (plants that are connected to the district heating system or that heat commercial premises) is given at up to 25% of the initial cost. Support at up to 35% of the initial cost is given for small residential plants.

Support to district heating construction is aimed at reducing energy use for space heating by replacing small oil-fired boilers with district heating. Grants of 15% of the initial cost are given for the actual piping network. An increased number of loads connected to the district heating networks will increase the load base for a future expansion of CHP.

[13] See chapter 4.

Operating support

After 1 July 1994, wind power production will, as previously mentioned, receive an *environmental bonus* equivalent to the excise tax on electricity. In southern and central Sweden, this amounts to SEK 88 per MWh. In northern Sweden the bonus is SEK 36 per MWh.

Support to development and demonstration

The *Energy Technology Fund* was created in 1988 for the purpose of coordinating the state support measures for development of environmentally-friendly technology. Support shall be made available to the development, or preparation for the commercial introduction, of new energy technology, to CHP plants with good environmental performance, to wind power plants of various size classes, to small-scale hydropower plants and to solar energy. Priority is also given to replacement of electricity with other heating systems. The 1991 energy policy bill changed the rules for the fund so that support could also be given to programme-oriented research and so-called collective research. This has assumed great importance for the fund's direction. Investments in research have increased greatly, while investments in demonstration plants have been reduced. So far 220 projects have been granted support, normally in the form of grants or loans of between 25 and 40% of the project costs, amounting to more than SEK 460 million in granted funds.

A programme for the promotion of biofuel for electricity generation — FABEL — was established as a result of the 1991 energy policy bill. The main thrust of the programme is support to development of technology for electricity generation from biomass. Support can also be obtained for demonstration plants for the production of ethanol from cellulose-rich raw materials. FABEL is a complement to other existing forms of support and can be combined, for example, with investment support to CHP. The programme aims at increasing the efficiency and improving the environmental performance of biofuel-based electricity generation technology. An interim goal is that such technology shall become commercially available in the 1990's.

Within the framework of the Energy Technology Fund, support is provided for development of new technology for ethanol production in the amount of SEK 4 million per year. The research programme for alternative fuels was strengthened in 1993/94 with SEK 15 million per year during three years, to support the development of new technologies so that they can be operated commercially. The funds shall mainly be used to support laboratories and pilot plants for production of ethanol from cellulose. Preliminary planning and design of full-scale plants can also receive support.

Programme for more efficient energy use

The programme for more efficient energy use and replacement of electricity was strengthened and broadened by the 1991 energy policy bill. The technology procurement programme was given additional resources and expanded to encompass the full range of energy use. The emphasis in the programme lies on the efficiency-improvement programme being conducted by NUTEK (the National Board for Industrial and Technical Development)[14]. The programme is based on technology procurement, framework agreements, and programme requirements. By augmenting technology procurement with demand-boosting measures (framework agreements and programme requirements), the procured technology will hopefully become more widespread. The programme also includes support for demonstration of energy-efficient technology in housing, commercial/institutional premises and industry, plus backing in the form of energy labelling, product testing and information[15].

Altogether, the programme for more efficient energy use has at its disposal a funding frame of nearly SEK 1 billion for a seven-year period.

National energy and climate programmes — transport sector

The programmes within the transport sector include *support to development and demonstration* and *support to measures to promote a more energy-efficient and climate-friendly transport structure*. Regular subsidies for investment or operation with known technology, e.g. investment support similar to that given to biofuel-fired CHP plants, have not yet begun to be applied.

Investments in development and demonstration must be coordinated between technical systems, vehicles, engines/propulsion and fuels in order to be effective. For this reason, activities in the various functional parts of the total system are coordinated.

The total resources spent on programmes that can be directly or indirectly classified as climate-related support for development and demonstration within the transport sector excluding research amount to about SEK 500 million for the period 1993-1996.

Support to development and demonstration

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[14] Several authorities are involved in the programme for more efficient energy use (NUTEK, the National Board of Housing, Building and Planning, the Swedish Transport and Communications Research Board, the Council for Building Research, the National Board for Consumer Policies and the Swedish Environmental Protection Agency).

[15] The demonstration programmes within industry, housing and commercial/institutional premises are funded via the Energy Technology Fund.

Support to demonstration and fleet trials with alternative fuels is a central part of the programme within the sector. The Swedish Transport and Communications Research Board, KFB, has an allocation of SEK 120 million for four years for co-funding of projects within this field, which means that the total allocation can be estimated to be SEK 240 million. Trials to date have mainly involved alcohol- and biogas- or natural gas-powered buses and also include studies of the infrastructure for fuel supply. Projects to develop engines for heavy traffic that are optimized for a given fuel are also being pursued within the programme. This development work is not expected to yield concrete results for many years. Low admixture of alcohols, which does not require engine modifications, is also being tried.

The demonstration programme for electric and electric hybrid vehicles is a four-year programme with a funding frame of SEK 120 million whose primary aim is co-funding of demonstration programmes for electric hybrid vehicles. The total funding can thereby be estimated at SEK 240 million. Evaluation and analysis of suitable societal policy instruments will take place continuously. The programme started only recently and the appropriation for the current year is SEK 9 million.

Government committee appointed to propose measures to mitigate emissions of climate gases from the transport sector

In April 1993 the Government appointed a committee with the assignment of coming up with a proposal for measures to reduce emissions of climate gases from motor vehicle traffic. In an initial report in June 1994, this committee, the Traffic and Climate Committee, proposed principles for the choice of policy instruments to limit vehicular emissions of carbon dioxide and other climate gases. In the committee's final report, which is due no later than 31 May 1995, the proposals shall be concretized and broadened to encompass the environmental impact of motor vehicle traffic in a broader sense.

3.1.3 Measures within agriculture

As yet, no measures have been taken within agriculture for the express purpose of reducing the production of climate gases. Some of the measures that have been adopted for other purposes have had an effect against climate gases as well, however. Examples are measures against nitrogen leaching.

Carbon dioxide

Oxidation of organic matter in arable soil results in carbon dioxide formation. It is primarily in connection with drainage and tillage of organogenic soils that a net loss of carbon dioxide from the cropland is obtained. In mineral soils, an equilibrium has normally been established between the accumulation of carbon in the soil via plants and the loss of carbon via oxidation.
Possible and partly adopted measures:
- Intensively tilled organogenic soils are turned over to extensive grazing or afforestation. This results in a slower loss of CO_2.
- Restoration of wetlands on organogenic soils means that carbon dioxide loss is reduced, but methane emission increases at the same time.
- Increased cultivation of energy crops such as Salix reduces the amount of carbon dioxide emitted compared with the use of fossil fuels. Salix also increase soil carbon content.

Methane

Microorganisms in the gastrointestinal tracts of ruminants in particular form methane when they digest the fodder. The lower the quality of the fodder, the more methane is formed. The formation of methane is reduced when cattle are raised mainly on grain.
Adopted measures:
- Constant efforts to increase the yield from animal husbandry are reducing the amount of methane emitted per quantity of meat and milk produced.
- Measures adopted to reduce ammonia emission from manure storage result in a higher ammonia content of the manure, which inhibits methane formation.

Nitrous oxide

Nitrous oxide is formed by denitirification in the soil. A smaller quantity of easily soluble nitrogen in the soil reduces the risk of increased emission of nitrous oxide. The action programme that has been adopted to reduce the leaching of plant nutrients from agriculture therefore also affects this emission of nitrous oxide.
Adopted measures:

- Limitation of number of animals per hectare
- Increased storage capacity for manure
- Increased proportion of autumn- and winter-planted land
- Ban on fertilizer spreading at unsuitable times
- etc.

With today's knowledge it is difficult to say how much these measures will affect the emission of climate gases from Swedish agriculture. In earlier evaluations these measures are estimated to lead to a reduction of nitrogen leaching by about 50% when they have reached full effect. Assuming that the measures have the same percentage effect on the emission of nitrous oxide as on nitrogen leaching, this should also be reduced by about 50%.

3.1.4 Measures within forestry

Measures in forestry affect the emission of greenhouse gases. The predominant flux in the Swedish forest is carbon dioxide, but emissions of methane and nitrous oxide also have a certain influence on the balance of greenhouse gases from the forest. Annual emissions of other volatile organic compounds (NMVOCs) from the trees in the forest are considerable but comprise a natural source for the most part.

Carbon dioxide

Forest felling

Decomposition of forest residues from different types of clearing, thinning and final felling operations releases greenhouse gases mainly in the form of carbon dioxide.

The forest, including the humus in the forest soil and timber products, constitutes a carbon reservoir. Large quantities of carbon circulate annually in the forest ecosystem. The standing timber constitutes a large portion of the carbon reservoir and changes in the standing timber affect the carbon balance.

The timber balance for the Swedish forest is strongly positive, as is evident from Table 3.5. Increment (annual growth) exceeded felling by 35.5 million forest cubic metres (whole trees with bark) in 1990, measured as an annual average for the period 1988 — 1992. This is equivalent to an annual carbon sink of the order of 34 million tonnes of carbon dioxide in the form of forest biomass (stemwood, branches, stumps and large roots).

Carbon storage in the fine roots of the trees, the humus in the forest soil and in other vegetation is not long-ranging; a better balance probably prevails here between storage and decomposition. On the other hand, the aggregate carbon reservoir in the forest soil in boreal forests can be up to twice as large as that in the forest trees, roughly speaking.

Table 3.5 Sweden's timber balance 1990 (average for the period 1988 — 1992

	Total, million m^3 (whole trees with bark)	Per hectare, million m^3 (whole trees with bark)
Timber volume	2797	116
Increment	97.6	4.2
Felling (incl. clearing, thinning and final felling)	62.1	2,6

The Swedish forest's aggregate carbon reservoir in trees, other vegetation and forest soil could thereby amount to 8,000 million tonnes of carbon dioxide, of which 5,000 million tonnes is stored in the forest soil.

With today's forestry methods, the growing forest comprises a net sink for carbon dioxide. It has been estimated that the increase of the forest biomass could continue for another few decades. There is uncertainty as to whether soil-bound carbon is still accumulating or is approaching a balance point. The portion of this carbon reservoir that sediments in lakes and the coastal sea via runoff and transport has probably been reduced in recent years as a consequence of reduced land drainage, which diminishes the size of this sink.

Soil scarification

The practice of soil scarification (cultivation prior to planting) causes the soil carbon to be cycled and emitted faster in the form of carbon dioxide than in untouched forest soil. The area of forestland scarified annually in Sweden was relatively constant during the 1980's. Between 1990 and 1992 the scarified area decreased from just over 170,000 hectares to about 125,000 hectares. A conversion to more gentle measures, is expected to reduce emissions of carbon dioxide caused by soil scarification up to the turn of the century.

Land drainage

Forest drainage increase mineralization of the soil carbon, which in turn increases emissions of carbon dioxide. According to Nature Conservation Act, prohibition against land drainage is in force since 1 January 1994 in a number of counties and municipalities in Southern and Central Sweden. Land drainage in other parts of the country requires a permit. Protective drainage requires notification under the Forest Conservation Act. State grants on forest drainage schemes has been abolished. Only about 2,000 hectares of forestland are included in forest drainage schemes, compared to about 7,000 hectares in 1990. Protective drainage has previously (1986) been

estimated by the county forestry boards to cover about 15,000 hectares per year. There is reason to assume that some reduction has taken place in recent years, among other things due to the aforementioned notification requirement, but also as a consequence of increased adaptation of silvicultural methods to nature conservation considerations. Reduced land drainage is believed to have reduced carbon dioxide emissions from forest drainage considerably since 1990.

Fertilization and liming of forestland

The ongoing atmospheric deposition of nitrogen compounds from anthropogenic sources is currently causing a fertilization effect that is increasing biomass production in the forests, mainly in Southern and Central Sweden. The deposition of airborne substances is also contributing to soil acidification and forest damages. Furthermore, these processes have increased in recent years. A loss of vitality in the forest leads to a diminished ability to sequester carbon dioxide. There is a risk that certain types of spruce forests in southwest Sweden may now be close to the limit where growth is reduced and reversed to timber loss.

Direct nitrogen fertilization of forestland has been reduced since 1990 from 70,000 hectares (about 10,000 t N) to less than 30,000 hectares (about 4,000 t N) in 1993. The aggregate effect of nitrogen fertilization of forestland in Sweden is judged to lead to an insignificant reduction of emissions of greenhouse gases.

Liming and vitalizing fertilization are currently being conducted on a trial basis in the most severely acidified forests in southern Sweden. Besides the fact that the cycling of lime in the soil leads to a limited direct production of carbon dioxide, liming can also entail some increased mineralization of organic matter, which in turn leads to a reduction of the soil's stored-up carbon.

Transition to sustainable silvicultural methods and increased life of forest products

Changes in forestry practices since 1990 that affect emissions of greenhouse gases:

- reduced size of clear-felled areas, reduced cleaning of clear-felled areas and increased use of shelterwood all lead to improved soil husbandry, which sustains the soil carbon better than before.
- natural regeneration decrease greenhouse gas emissions since nursery activities and planting is not needed.
- soil scarification is done with more gentle measures.
- afforestation of arable land is contributing to an increase in the size of the carbon dioxide sink. The scope of these measures, which have been conducted since 1990 within the framework of the agriculture realignment programme, has so far been limited, however. According to the Agricultural Register, more than 14,000 hectares of cropland was afforested between 1990 and 1993, and the contribution made by this to the carbon dioxide sink is insignificant.

- a transition to wood products with a longer life and increased recycling of paper products can reduce carbon dioxide emissions in the short run. The recycled fibres are an important raw material today for the pulp industry and cover about 10% of the annual requirement. At the same time as this leads to an increase in the carbon dioxide sink in the forest, the replacement of fossil fuel with old paper in heat production can also contribute to reducing carbon dioxide emissions.
- forest fuel as a substitute for fossil fuels.

Methane and nitrous oxide

The emissions of nitrous oxide affected by forestry have probably declined since 1990. The large uncertainties inherent in previous estimates make it impossible at present to specify values for this reduction. Ongoing acidification and future liming of forestland may lead to an increase of these emissions.

3.2 Future emissions of carbon dioxide

In this section we shall present a forecast of future carbon dioxide emissions from the energy system. The forecast results are contingent on assumptions regarding e.g. economic growth, energy prices and technical progress. It should be noted that the forecast is based on political decisions made to date, as described in section 3.1. If taxation or the national energy programmes are changed in terms of content, the forecast must be adjusted.

We have not included the changes in energy taxation that went into effect on 1 July 1994, since they were decided on after the forecasts had been made.

3.2.1 Forecast premises[16]

Economic performance

Predictions regarding Sweden's future economic performance are necessarily associated with a high degree of uncertainty. This uncertainty is more pronounced today than before. The deep recession with high unemployment and a decline in the value of the total production of goods and services (GDP) three years in succession is unique in Sweden's postwar history. Opinions are divided as to how quickly and to what extent the economy will recover.

Table 3.6 summarizes our assumptions concerning Sweden's economic performance for the period 1994-2005. Figures for the 1980's are shown for comparison.

Table 3.6 Forecast premises for the period 1993-2005, percent per year

	1980-1990	1990-1993	1994-2005
GDP	1.8	-1.7	1.8
Private consumption	1.8	-1.6	2.0
Industrial production	1.9	-2.1	2.6

Prices of energy

[16] Our fundamental assumptions regarding economic performance and the price of energy are described in this section. More sector-specific assumptions, for example how the composition of production will develop and technological developments, are presented in Appendix 2.

Our assumptions regarding fuel prices and the value of the dollar are presented in Table 3.7. The price of crude oil is projected to be 28 dollars a barrel in 2005, which is on a par with the EU Commission's estimate but two dollars lower than the IEA's estimate.

Table 3.7 Prices of crude oil and coal and dollar exchange rate, 1993 values[17]

	1990	1993	2005
Crude oil, USD/barrel	19	17.0	28.0
Coal USD/tonne	47	41.0	52.0
SEK/US dollar	5.8	7.8	7.0

Based on our assumptions regarding the development of the international fuel markets, energy taxation and profit margins, and on price-setting on the Swedish fuel markets, we predict that the prices of petroleum products will increase more rapidly than the price of coal. It is predicted that the prices of forest fuels will decline slightly up to the year 2005. For large users — heating plants — the oil price will rise in real terms by 1-2% per annum, depending on the type of customer in question, while the coal price will only rise by around 0.3% annually. For industrial customers, the oil price will rise by 2-3% per annum depending on the type of customer and the petroleum product.

For residential customers, the price increase for light fuel oil will be just over 1% per annum and for heavy fuel oil around 1.5% per annum.

Estimates of the future price of electricity are associated with great uncertainty due to the impending reform of the electricity market, among other factors. The introduction of competition in electric power production and sales will change the incentive forces for the players on the market. The profit motive will determine their behaviour more than before. The electricity market reform is creating new opportunities for international trade with electricity. This will enable an increased demand for electricity in Sweden to be met by production outside the country, and vice versa. Further down the road, the impending phase-out of nuclear power will alter the structure on the Swedish electricity market.

In our judgement, the price of crude power will increase substantially by more than 3% per annum to around SEK 320 per MWh in 2005[18].

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[17] The prices for 1993 are based on an average for the period Feb.-Oct. 1993.

[18] By crude power price is meant the price of electricity on the trunkline system level. This price reflects in principle the costs of electricity production and transmission on the national grid. The price of electricity to electricity-intensive industry is expected to rise by 3% annually, to 33 öre per kWh. The corresponding price for medium-sized industry is projected to be 38 öre per kWh, which entails an annual increase of about 2.6%. The price to electric heating customers will increase according to our forecast by 1.7% and to household customers by 1.1% per annum.

Our assumptions and estimates indicate that the price of electricity will rise relative to the cost of fossil fuels. These changes of price structures can be expected to affect the structure of energy usage in the long run. This is particularly true in activities where different fuels can be exchanged for each other, for example within heat and electricity production.

3.2.2 Emissions of carbon dioxide 1990-2005

The energy system[19]

Domestic energy use is projected to increase by an average of 0.9% annually during the period 1993-2005. This is a considerably weaker growth than the GDP growth of 1.8% per annum. The forecast thus presumes considerable energy savings and structural changes towards a less energy-intensive economy.

Industry

Industrial production is assumed to grow at an average rate of 2.6% annually until the year 2005. The engineering and chemical industries are expected to grow the fastest. The energy-intensive sectors pulp and paper and iron and steel are expected to grow at a slower pace than average for industry. As a consequence of these assumptions of a transformation of industry towards a less energy-intensive structure in terms of operations and products and more efficient energy use, it is estimated that energy use in industry will increase at an average rate of 1.4% annually.

In view of the assumed restructuring within industry and the price trend for the different energy sources, it is expected that coal, petroleum products and electricity will increase their shares of total energy use within industry. The increase in oil use is also a result of the assumption that electricity deliveries to interruptible boilers within industry will decrease.

Transportation

Passenger travel by automobile is projected to grow more slowly than GDP, and in a longer time perspective also slightly more slowly than private consumption. This projected trend entails something of a reversal of the trend during the past three decades. Perhaps the single most important factor behind this trend is the fact that car ownership per capita is tending to approach the saturation level[20]. Air traffic, on

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[19] A detailed account of forecast results for the energy system, assumptions and method is given in Appendix 2.

[20] A given forecast trend of total fuel consumption can be realized by many alternative combinations of trends for the underlying variables. A forecast for the underlying variables that is consistent with the

the other hand, is expected to increase more rapidly than the GDP after a slump in the early 1990's. Rail transportation is also expected to increase more rapidly than GDP. Bus traffic is expected to increase more slowly than GDP.

Goods transportation, both domestic and international, with all modes of transport is expected to grow very slowly up to the year 2000, owing to the deep economic recession during the early 1990's. Between 1990 and 1993, the total transport volume by both road and rail declined by five percent each. The trend for domestic transportation will be particularly weak.

Growth of domestic shipping is expected to be weak due to the nature of the goods carried in domestic shipping, which is such that the structural changes occurring in domestic industry do not favour this transport mode.

In a longer perspective, however, freight carriage volume in vehicle-kilometres is expected to grow at the same or a faster rate than GDP, although growth in tonnes will be slower. According to the forecast, growth is expected to be roughly equally strong for transport by road and rail. Even faster growth is expected for international shipping, whereas domestic shipping is expected to grow much more slowly than other transport modes in the future as well.

It is estimated that energy consumption in domestic transportation will grow by an average of 1.6% annually during the period 1993-2000. This growth in consumption will consist for the most part of petroleum products.

Housing and services etc.

New construction of commercial/institutional premises and housing during the period 1993-2005 is projected to be small in scope. Furthermore, some technological development is assumed within space heating. Total temperature-corrected energy use within the sector *housing and services etc.* will therefore decline by an estimated 1.4 TWh or 0.1% per annum up to 2005[21]. This trend is explained to a large extent by reduced energy use for space heating and hot water as a consequence of assumed higher efficiencies and conversion from oil to electric heating and district heating. Such a changeover results in an increase in electricity use but a decrease in oil use. Total energy consumption will be reduced due to the replacement of a less-efficient system with a more-efficient system.

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forecast annual increase in the level of petrol consumption between 1990 and 2000 of 1% is shown in the following table. DPU's (Commission for Forecasts and Development in the Transport Sector) transport forecast gives slightly different values for these variables.

Percentage change 1990-2000:			
Population			+0.4
Number of cars/capita		+0.6	
Average distance driven per car		+0.3	
Average fuel consumption per km	-0.3		
Rate of change of total fuel cons.	+1.0		

[21] Based on actual energy use in 1993, the increase in use will be 0.2% per annum.

Energy supply

Only minor structural changes are expected up to the year 2005 on the *supply side*. In 2005, it is expected that fuels will account for 69% of the energy supply as compared with 67% in 1990. Petroleum products are projected to dominate the energy supply in 2005, although the oil share is expected to have declined slightly. Fuels that will increase their market shares are biofuels, peat, etc., which are projected to account for nearly 18% of the total supply of energy in 2005. The corresponding share in 1990 was 15%. The natural gas share is also expected to grow.

Our forecasts of electricity use indicate that demand will exceed production by 3.2 TWh in the year 2000 and 5.5 TWh in 2005. With increased opportunities for trade in electricity due to the reform of the Swedish electricity market, it cannot be taken for granted that the increased demand will be covered by new power production in Sweden. Opportunities for power imports are increasing due to the reform of the electricity market. Furthermore, it is possible that Swedish companies will invest in new generating capacity abroad for sale to Sweden. This will happen if the conditions for power production differ greatly between different countries.

Emissions of carbon dioxide

A forecast of carbon dioxide emissions and sinks is presented in Table 3.8. The forecast is based on the projection of energy use presented above. Emissions in 1990 refer to actual emissions in 1990, while the forecast for other years assumes that these years are normal with respect to e.g. temperature and supply of hydropower.

Total emissions of carbon dioxide (not including international transportation) are projected to increase slightly between 1990 and 2000. 1990 was a mild year with abundant precipitation, with consequential low use of fossil fuels. Emissions would have been nearly 3 Mt higher if it had been a normal year. If such a correction is made, it is found that the forecast for emissions in 2000 is on the same level as a hypothetical normal year's corrected emissions in 1990. The sink in the forest is projected to decrease slowly.

The increase is greatest within the transport sector. Emissions also increase from plants for the production of electricity and district heating. Here it should be noted that the change in emissions is dependent on how the additional electricity that is projected to be needed is generated. This electric power can be generated from biofuel, natural gas, oil or coal, or be imported, but the probable result is a mix of these forms. In the forecast we have assumed that the emission factor on average is equivalent to the emissions for natural gas combi-cycle plants. If it is assumed that all additional power is imported or produced with biofuel, emissions are 1.1 million tonnes lower in 2000 and 1.8 million tonnes lower in 2005. If it is instead assumed

that electricity is generated in coal-fired condensing plants, emissions are 1.4 million tonnes higher in 2000 and 2.5 million tonnes higher in 2005.

Table 3.8 Forecast of carbon dioxide emissions and removals by sinks (million tonnes)

	1990	1995	2000	2005
Fuel Combustion: Power and heating plants	7.0	9.2	10.9	13.7
Fuel Combustion: Industry	13.5	12.6	13.1	13.7
Fuel Combustion: Housing and services	11.5	9.5	8.4	7.7
Fuel Combustion: Domestic transportation	23.1	24.0	25.3	26.7
Fugitive Fuel Emissions	0.1	0.1	0.1	0.1
Industrial Processes	5.0	5.0	5.0	5.0
Solvents	0.3	0.2	0.2	0.2
Agriculture	0.5	0.6	0.6	0.6
Waste	0.3	0.3	0.2	0.2
Total emissions	**61.3**	**61.5**	**63.8**	**67.9**
Land Use Change and Forestry	-34	-31	-29	-28
Net emissions (total net removals)	27	30	35	42
Total carbon reservoir	2,679	2,846	2,996	3,139
International transportation	4.2	4.8	5.2	5.6

Emissions from housing and services decline. It should be noted that these changes are in part a shift of emissions as a consequence of the changeover from individual to collective space heating.

It is projected that emissions will increase more rapidly after the turn of the century, mainly as a consequence of a continued growth in traffic, but also due to the

growth of fossil-fuel-based electricity production. In the forecast we have not assumed any commenced phase-out of nuclear power during the forecast period. If such a phase-out is begun, emissions from power production will increase considerably compared with the values given in Table 3.8.

The total net storage of carbon dioxide in the forest amounts to about 34 Mt per year. This includes stemwood as well as branches, stumps and roots. According to estimates from the Swedish University of Forestry and Agricultural Sciences' National Forest Survey (AVB92), forest growth is expected to increase during recent years. In Table 3.8 shows an estimation of net removals by sinks to year 2005. Forest growth in Sweden has for a long period exceeded yearly fellings. Up to the year 2005 the difference is estimated to decrease mostly due to increasing fellings of timber. Since forest growth is expected to exceed yearly fellings, timber volume will still grow. In long term forest management is a prerequisite to maintain a high level of forest growth and a large timber volume. When timber volume, i.e. carbon store, approaches maximum practically level, forest growth will be balanced by fellings and decomposition. The realignment of agriculture has not led to any major afforestation of arable
land. Ongoing deposition of airborne pollution which causes damages to the forest comprises an uncertainty factor. Similarly, a reduction of nitrogen deposition can eventually bring the forest growth rate back to a more natural level.

Uncertainty

As we have pointed out above, the forecast of future carbon dioxide emissions is contingent on the assumptions that are made regarding e.g. energy policy, economic growth and technological development. The most important determining factors for the results of the forecast are the assumptions regarding economic performance (GDP growth, growth and composition of industrial production) and the assumption regarding when the phase-out of nuclear power will take place. Assuming a more rapid economic growth and a structural transformation towards heavier industry would give a more rapid growth in the demand for energy than we have calculated on. Additional factors of great importance for the transportation requirement are the geographic structure of production and consumption and the product and country structure of foreign trade.

Changes in prices on the international fuel markets have only a limited effect on energy consumption in Sweden nowadays. This is explained by the fact that the impact of wholesale prices on the consumer price of petroleum products and coal is small due to the high tax component. The exceptions are energy use in industry and fuel use in electricity production, for which the tax share is lower.

As long as no quantum leaps in technology are assumed, the results of the forecast are not affected to any appreciable extent by other assumptions regarding technological development than those we have made here. This is largely a result of

the relatively short time horizon in this study. It is presumed that alternative fuels will not become available on a large scale during this period.

3.2.3 Emissions of other greenhouse gases

A forecast of emissions of other greenhouse gases is presented in Table 3.9. The table is based on the forecast of energy use presented previously. A breakdown of the emissions among different sectors is given in Appendix 1.

Table 3.9 Emissions of other greenhouse gases (1000 tonnes)

	1990	1995	2000	2005
Methane	329	335	300	295
Nitrous oxide	15.2	14	13	12
Nitrogen oxides	373	310	248	232
Carbon monoxide	1612	1100	700	550
NMVOCs	540	436	331	276
HFCs	0	0.8	2.0	2.0
FCs	0.06	0.07	0.07	0.07
SF_6	0.04	0.04	0.04	0.04

3.2.4 Total emissions of greenhouse gases

The aggregate impact of different greenhouse gases can be calculated with the aid of GWPs (Global Warming Potentials). Greenhouse gases can have a direct and an indirect effect. In the IPCC's most recent evaluation (1992), it is stated that it is difficult to give exact values for the indirect component, so only a value for the direct component is given. In the draft of a new IPCC report in 1994, weighted and updated values are given. Nitrogen oxides, carbon monoxide and NMVOCs have only indirect effects.

Table 3.10 GWPs (100 year time horizon) for greenhouse gases

	IPCC (1992)	IPCC draft (1994)
Carbon dioxide	1	1
Methane	11	24.5
Nitrous oxide	270	330
HFC 134a	1200	1300
CF_4	5100	6300
SF_6	20000	24900

Total emissions of greenhouse gases expressed in carbon dioxide equivalent (as million tonnes of carbon dioxide) converted using the IPCC's GWP values are given in Tables 3.11 and 3.12.

Table 3.11 Total emissions of greenhouse gases in million tonnes CO_2 equivalent, GWPs as per IPCC 1992

	1990	1995	2000	2005
Carbon dioxide	61.3	61.5	63.8	67.9
Methane	3.6	3.7	3.3	3.2
Nitrous oxide	4.0	3.8	3.5	3.2
HFCs	0	1.0	2.4	2.4
FCs	0.3	0.4	0.4	0.4
SF_6	0.8	0.8	0.8	0.8
Total	**70**	**71**	**74**	**78**

Table 3.12 Total emissions of greenhouse gases in million tonnes CO_2 equivalent, GWPs as per IPCC draft 1994

	1990	**1995**	**2000**	**2005**
Carbon dioxide	61.3	61.5	63.8	67.9
Methane	8.1	8.2	7.4	7.2
Nitrous oxide	5.0	4.6	4.3	4.0
HFCs	0	1.0	2.6	2.6
FCs	0.4	0.4	0.4	0.4
SF_6	1.0	1.0	1.0	1.0
Total	**76**	**77**	**80**	**83**

3.3 Effects

3.3.1 Overview

In the preceding section we presented a forecast of Swedish carbon dioxide emissions. It showed that annual emissions may increase by 3 million tonnes up to the year 2000, despite the policy instruments that have been decided on during the period 1990-1994.

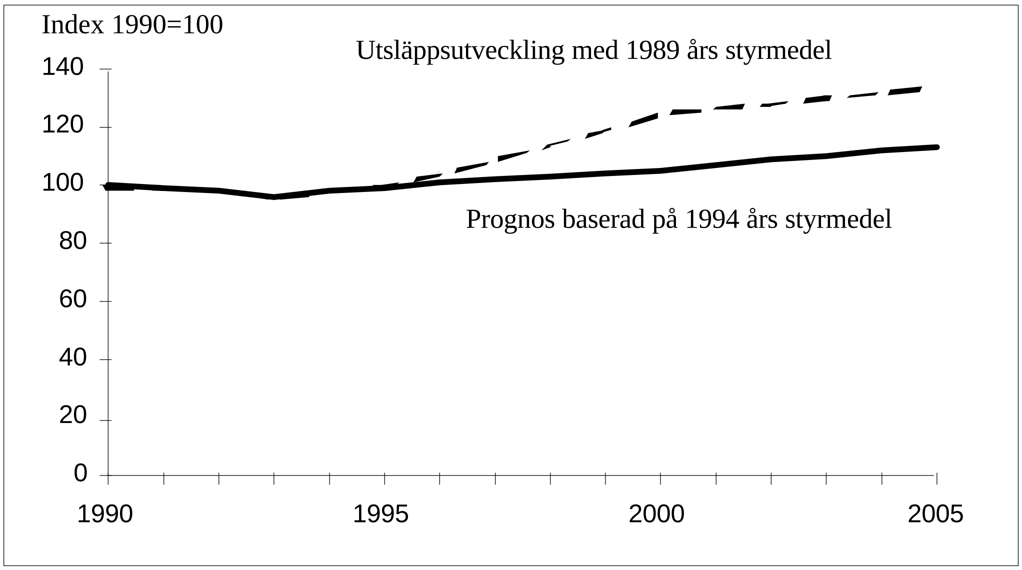
In this section we will try to determine how emissions would have developed if no additional policy instruments had been adopted during the period 1990-1994 to limit emissions. In other words, we will try to calculate the effects of the instruments that have been adopted and will exert an influence during the period.

Considerable difficulties arise when such a quantification is attempted. A fundamental difficulty is trying to describe the hypothetical alternative course of events that the measures are to be evaluated against. How would energy price and demand have developed in a situation where the energy policy measures had not been adopted? Would other rules have governed the energy markets? Since these questions cannot be answered, certain more or less uncertain assumptions must be made.[22]. The following quantification of the effects of public policy on carbon dioxide emissions must thereby be interpreted as rough estimates.

[22] We have assumed in this analysis that economic growth, industrial production and energy prices are not affected by the policy instruments adopted.

The *forecast* emissions trend, based on the adopted policy instruments, and the *calculated* emissions trend if no additional policy instruments had been adopted are shown in Figure 3.1.

Figure 3.1 Emissions trend with and without policy instruments adopted after 1989, million tonnes of carbon dioxide.



B

The difference between the forecast trend and the hypothetical trend without the policy instruments adopted between 1990 and 1994 to mitigate carbon dioxide emissions is estimated to amount to about 10 million tonnes in the year 2000.

The instruments included in our analysis are energy and environmental taxation (including VAT and other fiscal taxation), the programme for more efficient energy use, investment support to biofuel-based CHP, wind power and solar heating. The operating subsidy to wind power is also included.

In the relatively short time horizon covered in this study, the shortcoming that possible effects of research and development are not included in the analysis can be regarded as of little consequence. In longer term perspective, the technology development may be of great importance.

Table 3.13 presents a more detailed description of the projected effects of adopted policy instruments. According to the above calculations, carbon dioxide emissions in the year 2000 would have been around 10 million tonnes higher if additional policy measures had not been adopted. The achieved limitation of carbon dioxide emissions indicated by the above calculations is explained to a large extent by the fact that with 1994's taxation (carbon dioxide tax) and support, biofuels are used to a greater extent.

As a consequence of 1994's taxation, biofuel use within industry will decline compared with 1990's taxation. This effect will be offset by increased biofuel use in other parts of the system, especially district heating.

The 1994 tax system will also lead to substitution of electricity and district heating for a large portion of the oil use for space heating.

Due to the imposition of VAT on energy, energy-saving measures will be adopted on a larger scale by households. Heat pumps will be used to a greater extent.

Table 3.13 Effects in 2000 of policy instruments adopted from 1990, millions of tonnes of carbon dioxide[23]

Sector	Reduction	Measure	Reduction
District Heating[24]	-4,9	Carbon tax Energy sector	-5,3
Industry[25]	+1,9	Gasoline- and Carbon tax Transportation	-2,2
Residential Commercial[26]	-5,2	Energy Efficiency Programme	-2,1
Transportation -passenger cars	-2,0	Investment Programme biofuels	-0,6
-others	-0,2	Other investment Programmes	-0,2
TOTAL	**-10,4**	**TOTAL**	**-10,4**

Source: Evaluation of policy instruments and support for limitation of carbon dioxide emissions in Sweden — calculations with the MARKAL model, NUTEK R 1994:48, calculations performed by NUTEK *Analys* and DPU.

[23] The effects of the energy and environmental taxation, the investment support and the operating subsidy to wind power have been calculated with the aid of the energy system model MARKAL. The programme for more efficient energy use is analyzed separately. Similarly, the effects of measures within the transport sector (mainly fuel taxation) are analyzed on their own.

[24] Including electricity production in CHP plants

[25] The changed taxation is projected to lead to an increase in emissions from industry by 2.2 million tonnes. At the same time, the programme for more efficient energy use is assumed to reduce emissions by 0.3 million tonnes. It has been assumed that the saved electricity would have been produced in natural gas combi-cycle plants.

[26] Of which 1.8 million tonnes can be attributed to the programme for more efficient energy use.

The 1994 tax system and investment support increase the incentives for building wind and solar power capacity compared with 1990's taxation. However, neither of these technologies are adopted on any significant scale during the studied period. CHP becomes less attractive with the 1994 tax system.

In the following we examine the calculated effects of the more powerful policy instruments.

3.3.2 Energy and environmental taxation

Of the calculated reduction of emissions in 2000, approximately 70% or 7.5 million tonnes can be attributed to changed taxation of energy and fuels (including imposition of VAT on energy). It is worth noting that the taxation of energy use within industry has reduced the energy price paid by industry, which is why carbon dioxide emissions from this sector increase as a result of the changed taxation. At the same time, emissions in other sectors decrease as a consequence of the changed taxation, mainly heat production (4.1 million tonnes), housing and services etc. (3.4 million tonnes) and transportation (about 2.2 million tonnes).

The modelling runs performed for the transport sector show that adopted taxation measures can be estimated to have a considerable effect on automobile traffic in particular, but also on specific fuel consumption by the different transport modes.

The effects of the taxation measures are estimated to result in a reduction of carbon dioxide emissions from automobile traffic by 2.0 million tonnes in the year 2000 and about 2.4 million tonnes in 2005. Compared with the alternative "with 1990-1994 taxation rules", an alternative without these measures would, according to the calculations, mean that the volume of automobile traffic would be about 11% higher in the year 2000 - the traffic volume would be about 73 billion vehicle-kilometres instead of about 66 billion.

Present tax system is expected to change the average fuel consumption of the passenger car fleet. Table 3.14 shows how much greater the average fuel consumption of the car fleet would be if the taxation measures had not been adopted.

Table 3.14 Estimated increase of average fuel consumption for petrol-engined automobiles in the Swedish car fleet litre/100 km

Year	With 1990-1994 measures	Without 1990-1994 measures
1990	9.4	9.4
2000	8.9	9.3
2005	8.8	9.4

Average weighted fuel consumption for new passenger cars has dropped from 9.3 litre per 100 km in 1978 to 8.3 litre per 100 km in 1987 and have not changed since.

Average kerb weight for new passenger cars have increased. Taxation system for official or company cars favour large vehicles. The depression has led to less sales of new cars, especially within private households. This development also explains why the portion of larger cars in the Swedish car fleet have grown.

The adopted taxation measures can thus be projected to be a driving force for changes in the vehicle fleet, especially outside company cars fleet, and its use, leading to reductions in average fuel consumption. Without these measures, the "autonomous" trend towards declining average consumption could be interrupted and an increase could occur between 2000 and 2005. Despite the positve trends to more efficent carfleet, total emissions of carbon dioxide from the traffic sector can not be stabilized in the year 2000.

The small effects for other sub-sectors than automobile traffic are due to low price elasticities for transport services per se, and the fact that fuel price comprises a small portion of the cost of the transport service. They are also due to the fact that the taxation measures adopted for commercial traffic are considerably weaker than for automobile traffic.

3.3.3 Investment support to biofuel-based CHP

The investment support to biofuel-based CHP has been estimated to lead to a reduction of carbon dioxide emissions by 0.56 million tonnes, see Appendix 3, providing that it is natural gas-based electricity production that is being replaced. In addition support to expansion of district heating plant give a reduced emission of 0.2 million tonnes.

3.3.4 Programme for more efficient energy use

The Energy Use Council says that there is a savings potential within several studied use sectors of 8 TWh of electricity, of which 1.6 TWh is electric heating[27]. If we assume that this entire potential is realized by the year 2000 as a consequence of the programme for more efficient energy use and that the saved electricity is not sold anywhere else, i.e. that the production of electricity is reduced to a corresponding degree, the effects of the programme on carbon dioxide emissions (excluding electric heating) can be estimated to be a decline of 0.2 — 5.0 million tonnes of carbon dioxide, depending on how the electricity that is saved would have been generated[28]. If we assume that a natural gas combi-cycle plant would have been built, the reduction of carbon dioxide emissions is about 2.7 million tonnes. In the MARKAL model the effect of savings potential for electric heating have been included as a condition.

[27] Report of Energy Use Council 1993/94.

[28] See Appendix 3.

4. Financial Support and Contribution to the Financial Mechanism

4.1 Contribution to the financial mechanism

Swedish contribution to the interim financial mechanism under the UN framework Convention on Climate Change - Global Environmental Facility (GEF) - was SEK 196.07 million up to 1 July 1994.

For the period 1 July 1994 — 30 June 1997, which is the first phase of the permanent GEF, it amounts to a total of SEK 450.04 million, which is paid in the form of promissory notes and is therefore difficult to specify on an annual basis. The amount is a total amount to the GEF. No earmarked resources are distributed and the Swedish contribution constitutes a part of the core fund, which is used to finance projects within all four focal areas. The contribution shares are negotiated but are based on a key which in itself contains a burden sharing feature. It appears likely that the Swedish contribution will increase as the GEF increases in size.

4.2 Other sources of financing, for example to implement Article 11.5

Within the framework of bilateral assistance, activities can be sponsored in, for example, the energy field that can be said to make a direct or indirect contribution towards the goals of the climate convention. An example of this type of project is the skills- and knowledge-building support that is given through Swedish Agency for Research Cooperation with Developing Countries (SAREC) to the African Energy Policy Research Network. This project, which had a total budget of SEK 32 million, was initiated before the convention was finally negotiated, but can in some respects have effects that contribute towards the goals of the convention. They are, however, often difficult to measure in detail.

Within the framework of measures aimed at Eastern Europe, some can be defined as measures in projects that have direct effects when it comes to climate impact. Such measures include, for example, the resources that are allocated for projects to increase energy efficiency in the Baltic states and Eastern Europe. For this purpose, in the context of the two climate bills, SEK 15 million has been channelled to the Baltic Sea cooperation in the transport and environmental sector, and in total 1992/93--1994/95 SEK 227 million to energy efficiency improvement measures and increased utilization of renewable energy sources in the Baltic states and Eastern Europe.

Climate-related projects may be undertaken within the framework of the Swedish Board for Investment and Technical Support (BITS) programme for knowledge

transfer to support the political and economic reform process and measures to improve the environment, particularly in the Baltic Sea. This cannot be specified at the present time, however. Similarly, efforts in the area of nuclear safety may have secondary effects in a positive direction when it comes to the climate, but this cannot be defined in greater detail at present either.

4.3 Other information of importance

In 1993, the Stockholm Environment Institute (SEI) received an appropriation of SEK 8 million for a project directly related to the climate convention, "Climate and Africa — An Assessment of African Policy Options and responses".

The work was begun during the autumn of 1993 and the project aims at assisting African countries with the development of climate strategies and with their national and regional policies to better be able to meet the requirements made in the convention. This requires improvement of the data on greenhouse gases in the African countries and a strategic analysis of how African development goals and options should be viewed in a climate perspective. The question is how the economic and social development of Africa may be affected by the global climate issues and which policy alternatives can be developed. The project is intended to serve as input at the first meeting of the parties in Berlin in April 1995.

To coordinate the work on the project, SEI has established a secretariat at the African Centre for Technology Studies (ACTS) in Nairobi under which a network of researchers operates. Case studies that will serve as a basis for a broader analysis on a regional and finally a continental level are being done for Morocco, Algeria, Cameroon, Ghana, Uganda, the Seychelles, Zimbabwe and South Africa. Furthermore, special analyses are being made of issues such as joint implementation, technology transfer etc. The intention is to focus on the most important issues that will influence the African attitude towards the global climate issues and towards the negotiations within the INC.

Four regional seminars have already been arranged to follow up and coordinate the development of the project. Three publications with the most important results are planned. Interest in and knowledge of these matters are very low in Africa. ACTS has therefore helped arrange political gatherings and is furnishing information during the course of the work.

The project is being concluded according to plan with a major conference in Nairobi on 5-8 December 1994. Several governments and a number of international organizations have expressed an interest in participating. The United Nations Environment Programme (UNEP) has offered to host the conference, which is also supported by the World Meteorological Organization (WMO). The intention is to start a debate, based on the work within the project, on the impact of climate issues on African politics and to discuss and prepare documentation for the work of negotiation. One possible result of the conference may therefore be an African

statement on the climate convention. The debate will continue to be followed until the first meeting of the parties to the climate convention.

4.4 An estimate of future contributions to the convention

An estimate of future contributions to the convention is very difficult to make. It can be regarded as certain that the contributions to the financial mechanism, GEF, will continue to be made. Estimating the value of direct bilateral or multilateral actions is much trickier, however. Nevertheless, some form of follow-up of successful projects is desirable — especially for countries where the domestic capacity is still uncertain.

4.5 International cooperation

The climate convention states that the parties can implement national policies and adopt appropriate measures to counteract climate change jointly with other parties — known as joint implementation.

By joint implementation of measures against climate change is normally meant that a party invests in emission-reducing measures in another country for the purpose of wholly or partially crediting the emissions reduction towards its own quantified target. It should be emphasized that no such right to crediting is expressly mentioned in the climate convention.

The need for joint implementation arises from the fact that the cost of achieving national emissions targets varies from country to country. In the absence of general policy instruments such as taxes and emission rights, joint implementation can be a means to increase the emission-reducing effect in relation to the resource input by means of a transfer of resources between countries.

The National Board for Industrial and Technical Development, NUTEK, has a Government mandate to make investments in biofuels and energy-efficiency improvements in the Baltic states and the nearby Eastern European region, particularly northern Poland, Kaliningrad and the St. Petersburg area. Priority is given to the space heating sector in this context. The programme also includes contributing to increased use of renewable energy resources. A total of SEK 227 million has been appropriated within the energy sector for the budget years 1992/93, 1993/94 and 1994/95. The frame for the current budget year amounts to SEK 87 million. A brief description of this programme and what effects conversion can be expected to have on carbon dioxide emissions is given in the following. It should be noted that this programme is not joint implementation in the sense the expression has assumed in the climate discussion. The existing programme thus makes no demands that parts or all of the achieved emissions reduction should be credited to Sweden.

Even if the programme is not to be regarded as joint implementation according to the above description, it will provide experience that can be valuable when devising a possible future system for joint implementation. This is particularly true of

experience relating to the feasibility and difficulties of conducting project activities in the Baltic states and Eastern Europe. Furthermore, contacts are being established with the appropriate parties in the recipient countries. Today's programme also contains elements of development activities within which information and training are being provided. In the light of the shortages in institutional capacity which plague these countries, such knowledge transfer will constitute an important step in building up the regulatory and watchdog agencies that a system for joint implementation will make high demands on.

NUTEK's programme started in the spring of 1993 and currently comprises some 30-odd ongoing projects, the majority of which will be completed by the autumn of 1994. Besides these, three boiler conversion projects have been carried out, one in each of the Baltic states. The boiler conversion programme is being concentrated on plants of 3-10 MW. Heating plants of this size are common in small and medium-sized towns. It has been found that these plants are generally too small to fit into the financing systems which, for example, the World Bank and the European Investment Bank have so far been able to offer.

Projects included in the programme strive for cost efficiency and demands are made on the participation of those who own the plants in all stages of the project. The projects are financed with loans to the plant owner from NUTEK. The terms of the loans largely coincide with those attached to loans procured through the World Bank. The repayment period is set at a maximum of ten years, with the first two years generally being instalment-free. The selection of projects is made in consultation with the energy ministry or equivalent in the particular country and taking into account what measures are being taken or planned by various international agencies. The projects are normally profitable with short pay-off periods.

Measurements made in connection with the three completed conversions of heating plants show that carbon dioxide emissions are reduced by more than 0.026 million tonnes per year[29]. Emissions of other pollutants are also reduced. For example, it is estimated that emissions of sulphur are reduced by more than 150 tonnes. The cost of these three conversion projects amounts to SEK 11.1 million. It is estimated that the 10 boiler conversions that are in progress will further reduce annual emissions by about 0.075 million tonnes of carbon dioxide, calculated on the basis of reported oil and coal consumption to date.

[29] Approximately 9,000 tonnes of oil and 5,500 tonnes of carbon are replaced by woodchips.

5. Overview of Swedish Climate-Related Research

The Swedish Riksdag (parliament) has dealt with the question of research and development as an integral part of its continued strategies against climate change. The Government Bill on research and development[30] emphasizes the importance of stepped-up research on the consequences of climate change for the Nordic ecosystems. Greater weight is to be given to the application of the research. Furthermore, the importance of supporting and developing research on the socio-economic impact of climate change is also emphasized. Economic analyses and evaluations of effects of climate change and effective countermeasures are of particular importance here. In conjunction with the processing of the Government's Bill on action to counteract climate change[31] it was decided to form a special scientific joint consultation group, the Commission for Climate Questions. The Commission has been given the assignment of coordinating and tying together climate-related research efforts within different fields.

5.1 Scientific climate-related research

5.1.1 Allocation of funds to scientific climate research

The scientific research on global climate change is being coordinated through two international programmes: the International Geosphere-Biosphere Programme (IGBP), and the World Climate Research Programme (WCRP). The IGBP is mainly concerned with biological and chemical processes, while the WCRP focuses on physical processes related to climate change. In Sweden the research is coordinated by the Swedish National Committee for the IGBP and the WCRP. Funding is provided mainly via the Natural Science Research Council (NFR), the Swedish Environmental Protection Agency (SNV), the Swedish Council for Forestry and Agricultural Research (SJFR) and the National Board for Industrial and Technical Development (NUTEK). Research is conducted primarily at the universities and at the Swedish Meteorological and Hydrological Institute (SMHI), which is responsible for climate data.

Table 5.1 shows the allocation of funds to scientific climate research in Sweden. The projects have been distributed as far as possible among the different fields of

[30] Government Bill 1992/93:171

[31] Government Bill 1992/93:179

research within the IGBP and the WCRP. In addition to these funds, grants are awarded via the Nordic Council of Ministers and the EU's Environment Programme. Approximately SEK 10 million was distributed last year to projects with Swedish participation in the Nordic Council of Minister's Climate Research Programme. In the projects with Swedish participation within the Environment Programme, approximately SEK 7 million has gone to studies of the effects of climate change and about SEK 3 million to studies of sources and sinks for greenhouse gases.

Table 5. Overview of funding of scientific climate-related research in Sweden 1993/94, SEK million

Project	NFR	NUTEK	SJFR	SNV	*Total*
International Global Atmospheric Chemistry Project, IGAC	1.3	1.6		1.5	4.4
Joint Global Ocean Flux Study, JGOFS	0.6				0.6
Land-Ocean Interactions in the Coastal Zone, LOICZ	0.2			0.6	0.8
Biosphere Aspects of the Hydrological Cycle,BAHC	1.3		4.6	0.4	6.2
Global Change and Terrestrial Ecosystems,GCTE	0.2	1.6	15.5	2.1	19.4
Past Global Changes, PAGES	4.6				4.6
World Climate Research Programme, WCRP	0.4				0.4
World Ocean Circulation Experiment, WOCE	0.5				0.5
Stratospheric Processes and their Role in the Climate, SPARC	0.1				0.1

Other		0.4	1.0	3.7	1.3	6.4
Total	0.6	4.2	23.6		5.9	43.4

5.1.2 Climate change

IGBP-related research

Within the IGAC (International Global Atmospheric Chemistry Project), Sweden has especially emphasized projects that have to do with the exchange of greenhouse gases and other trace gases between the biosphere and the atmosphere. The studies are concerned with ecosystems both at northern latitudes and in the tropics.

Swedish participation plays a central role in the European project GLOMAC (Global Modelling of Atmospheric Chemistry). The core is a climate model which includes chemical substances and chemical conversion processes. The Swedish contribution is focused on simulations of the global sulphur cycle, and especially aerosol formation from anthropogenic sulphur emissions and the climatic impact of the aerosol particles.

Swedish researchers are collaborating with researchers from other Nordic countries in JGOFS (Joint Global Ocean Flux Study). The ongoing Nordic project on studies of the fluxes of CO_2 between the atmosphere and the Norwegian Sea is related to JGOFS. Swedish researchers are working with a high-resolution regional atmosphere model for this region. A measurement station on Spitsbergen performs high-quality measurements of CO_2 and other atmosphere components.

During the past few decades, Swedish researchers have devoted great interest to integrated ecological and hydrological studies in the Baltic Sea. This research has been able to be used within LOICZ (Land-Ocean Interactions in the Coastal Zone). Special studies have been conducted of the cycling of organic carbon in the coastal zone and the function of the coastal zone as a source of nutrients, as well as of the biological feedback mechanisms in the Baltic Sea.

Sweden is participating in BAHC (Biosphere Aspects of the Hydrological Cycle) with a project called NOPEX (Northern Hemisphere Climate Processes Land Surface Experiment). The project aims at increasing our understanding of the hydrological and meteorological factors that control the processes of energy, water and carbon exchange in the ground-vegetation-atmosphere interface.

Swedish research is making substantial contributions within two of the focal areas within GCTE (Global Change and Terrestrial Ecosystems). The first is "Ecosystem physiology", where field experiments on the ecosystems of the boreal forest are being conducted. These studies are being complemented by studies of trace gases and by hydrological studies within BAHC.

The second prioritized area for Swedish research activities within GCTE is modelling of structural changes of ecosystems on a regional, continental and global level as a result of climate change. This research has established close connections with the paleoclimatological research within PAGES (Past Global Changes) and is particularly concentrating on a global approach for developing dynamic models for determining the climatic conditions that set limits for the Earth's biota, both today and in the past.

The Swedish activities within PAGES are focused on changes during the past 20,000 years. Swedish research is also being conducted in the Arctic and the Antarctic through the Swedish Polar Research committee.

WCRP-related research

Swedish research priorities within WCRP-related research are described in a new proposal entitled *A Proposal for Strengthening Climate Modelling in Sweden* (KVA, Documenta No. 59, 1994). Following is a description of the most important Swedish climate-related research efforts within the framework of the WCRP.

GEWEX (the Global Energy and Water Cycle Experiment) is a combination of field experiment and theoretical modelling which is focused on studying hydrology and energy fluxes in the climate system.

One programme within GEWEX which is of particular Swedish interest i BALTEX (the Baltic Sea Experiment). The most important scientific goals of BALTEX are to determine the variability of the fluxes of energy and water over time and space within the Baltic Sea's drainage basin and to link them to the global circulation systems in the atmosphere and the seas. BALTEX, which is intended to be carried out jointly by the Baltic Sea states, is now concluding its planning phase. Sweden has an important role in the execution of the project, and a special Swedish committee has been set up.

NOCLIMP (Nordic Climate Modelling Project) is a joint Nordic project financed by the Nordic Council of Ministers. The project has relevance for GEWEX since one of the objectives is to study the sensitivity of large climate models, GCMs (General Circulation Models) to moisture-cloud-radiation processes. The influence of these processes on low-frequency atmospheric variability is also being investigated. A large-scale global model is being used by Swedish researchers in this work. This latter task lies within the objective of the WCRP project CLIVAR (Climate Predictability and Variability).

The work of collecting and analyzing data also falls within CLIVAR. Databases with meteorological, hydrological and oceanographic data are necessary to understand variations in the climate system. SMHI is working to create such databases. In the same way, collection of paleoclimatic data is essential for understanding climatic variations in a longer time perspective.

A third major WCRP project aside from GEWEX and CLIVAR is WOCE (World Ocean Circulation Experiment). Swedish contributions are being made here in Nordic cooperation concentrated on the exchange of surface and benthic water in the North Atlantic over the ridge between Greenland and Scotland.

Recently a proposal was put forth to create a Swedish capacity for climate modelling (KVA Documenta No. 59, 1994; L. Bengtsson: Proposal for Action Programme for SMHI, SMHI, 1994). Complete general circulation models (GCMs) only exist at a few places in the world. The idea is not to create a unique Swedish model, but to cooperate with some foreign modelling centre.

5.1.3 Sources and sinks for greenhouse gases

The Swedish Environmental Protection Agency is funding research work on the consequences of climate change for Nordic ecosystems. The research programme *Climate change and UV-B radiation* has the following topics on its programme:

- Emission and uptake of greenhouse gases
- Effects of global climate change on northern terrestrial ecosystems
- Effects of increased UV-B radiation on northern ecosystems

Priority questions are how climate change affects the decomposition and cycling of organic material and how nitrogen regulates carbon cycling. Changes in the water balance and soil climate in coniferous forest ecosystems are being simulated for different climate scenarios. Similarly, attempts are being made to estimate nitrogen mineralization and the climate dependency of nitrification. Attempts are also being made to explain the regulation of emissions of N_2O from forest soil by means of process studies. Knowledge of how the flux of greenhouse gases from organogenic arable soils is affected by changed land use is also of great importance for future strategic land-use decisions. Studies of how emissions of N_2O from farmyard manure can be reduced are also being conducted.

Special efforts are being made to estimate the methane flux from Swedish wetlands for the purpose of predicting how the decomposition of organic material in mires will be affected by climate change and increased loads of sulphur and nitrogen.

Research on fluxes of greenhouse gases with an emphasis on how human activities affect them is being conducted within NUTEK's programme *Bioenergy/climate*, *Forest ecosystems* and within the project area *Fuel technology*, see below under 6.2.1.

5.1.4 Effects of climate change

Within SNV's R&D programme *Climate change and UV-B radiation*, priority is being given to studies of effects of global climate change on plant communities and populations in the mountain region. Studies of the effects of increased temperature, elevated CO_2 concentration and increased UV-B radiation on arctic heath vegetation are being conducted at the Abisko Scientific Station in Lapland. The results will offer future possibilities to predict the effects of a simultaneous elevated temperature and CO_2 concentration and possible feedbacks to the atmosphere.

The reproduction of selected plant species is being followed during a period of several years within climate change experiments. The study is a more in-depth extension of ITEX (International Tundra Experiment), within which increased temperature is being simulated with the aid of open-top chambers and six selected circumpolar species are being studied.

A better understanding of how rapidly a natural forest adapts to climate change is needed as a basis for estimates of how great the effects of climate change may be on the forest. This process is being studied through modelling of the spatial dynamics of

natural hardwood (broad-leaved), mixed and softwood (coniferous) forests. Paleodata are being used to validate the model results.

Data for a model of climate-related expansion dynamics for the northern limit of the boreal coniferous forest are being gathered through studies of the age structures of different marginal tree populations. These data are being compared with the independent climate reconstructions that have been done based on annual ring studies.

A big effort has been put into studies of effects of elevated CO_2 concentration, elevated temperature and changed nutrient input on the forest. Models have also been developed where the reaction of the biosphere to an elevated atmospheric CO_2 concentration has been simulated.

A large project is being conducted in the Baltic Sea concerning cod reproduction and its dependence on environmental factors, including changes in the climate.

5.2 Technical and socio-economic research

Swedish climate-related technical and socio-economic research is integrated with long-standing research efforts within the energy and transportation sectors. Besides the climate aspect, these efforts have other goals as well, such as increased energy efficiency, reduced oil dependence, reduced emissions of acidifying and toxic substances, etc. The most important R&D projects within the energy and transportation sectors are described below, with a special emphasis on areas with more direct climate aspects. Besides these efforts, research and development is also being pursued within the power industry, the transportation industry, etc. Support to technical development work, introduction support for new energy technology and different types of demonstration programmes for new technology are described in chapter 3 above.

5.2.1 Energy research

Research at NUTEK of relevance to the climate issue

The National Board for Industrial and Technical Development research with relevance to the climate issue consists for the most part of so-called response option research.

Within the field of inventorying sources and sinks for greenhouse gases, NUTEK funds research that is above all concerned with the topic of energy-related land use. Within the project field of Fuel Technology, funds are allocated to research concerning methane fluxes from peatlands and how the net emission of climate-affecting gases is affected by land drainage, peat cutting and peat burning.

The research programme Bioenergy/Climate that started this year is inventorying the flux of carbon dioxide to and from forestland at different intensities of silviculture. An overall objective of the programme is also to develop system

solutions for how increased biofuel usage can be utilized in the most cost-effective manner from a socio-economic viewpoint to reduce net emissions of climate-affecting gases.

Emissions from waste landfills are the most important anthropogenic source in Sweden of methane emissions to the atmosphere. Since 1988, NUTEK, together with the waste management industry, has funded a research, development and demonstration programme concerned with optimal design of landfill cells and gas collection systems for recovering landfill gas (methane) for energy purposes.

The energy research programme is primarily focused on renewable energy sources, and a large portion of the programme is concerned with efforts to reduce the use of fossil fuels. A selection of the research programmes and project fields presented in Table 6.2 below is presented in the following.

The research programme General Energy System Studies is supposed to support research for adaptation of the Swedish energy system to increased demands on consideration for the environment and climate change. Research in this field is mainly focused on questions related to the changeover to an energy system with greater use of sustainable and domestic energy sources, for example how new energy technology can be introduced, what obstacles exist and how they can be eliminated. Furthermore, effects of various control instruments are studied. The technical optimization model MARKAL has been developed to provide guidance for decision-makers in finding the most suitable energy mix under given conditions and with given environmental restrictions. The MARKAL model has been expanded with a macroeconomic growth model, MACRO.

Research within the field of fuel technology is concerned with, among other things, how biofuels can be produced in a sustainable and environmentally sound fashion. In the programme Forest Ecosystems, the environmental consequences of fuel withdrawal from the forest are studied, along with what compensatory measures may be required in the form of vitalizing fertilization or recycling of biofuel ashes. Research on the use of biofuels dominates within the programmes Combustion/Gasification and Small-scale Combustion of Biofuels and the projects within the project field Combustion and Gasification. The research within the project field Power/Heat is largely concerned with renewable energy sources and with the development of technologies and processes whereby heat and electricity can be produced with high efficiency while emissions are effectively controlled. The activities include R&D concerning CHP (combined heat and power) processes adapted for biofuels, advanced cycles for CHP production, wind power, solar power, solar cells, fuel cells, district heating, heat pumps and geothermy.

Research within the project field Energy-Intensive Industry is mainly concerned with energy efficiency improvements within the iron and steel industry, the paper and pulp industry, the chemical industry and the food industry.

Sweden is participating in a large number of international research projects in the fields presented above as well as within the framework of different EU programmes such as Joule, Drive, Brite-EuRam, AIR, etc., and within the framework of the IEA's research cooperation in the energy field. One of the IEA's projects is the

Greenhouse Gas Research and Development Programme, whose purpose is to clarify the conditions for separation, handling and storage/disposal of carbon dioxide from fossil-fuelled combustion plants, as well as the programme GREENTIE (Greenhouse Gases Technology Information Exchange), whose purpose is to spread knowledge internationally, especially to non-OECD countries, about energy technologies and systems that can reduce emissions of climate-affecting gases.

Table 5.2 NUTEK's grants to energy research 1993/94 (million SEK)

programmes:	
Fluid mechanics	10
General energy system studies	9
Power electronics	2
Energy-related material development	4
Fuel cells / Solar cells	3
Combustion / Gasification	12
Thermal electricity production	2
Heating technology	5
Wind power	5
Hydropower / Environmental effects	0.6
Energy forest cultivation	12
Forest ecosystems	4
System studies — bioenergy	3
Forest fuel technology	2
Bioenergy / Climate	3
Small-scale combustion	10
project fields:	
Energy-related basic technologies	8
Power / Heat supply	8
Energy-intensive industry	13
Fuel technology	10
Industrial research	15
Total	141

Swedish Council for Building Research

The sphere of operations of the Swedish Council for Building Research (BFR) is defined as follows:
"Research, development and experimentation concerning changes in and design of the building environment with the aid of planning, building and management. The Council's sphere of responsibility also includes research, development and experimentation concerning energy conservation and new energy technology for buildings."

In the long run, changes in buildings and the transportation infrastructure can have significant effects. Through a strategic planning of buildings and traffic systems, municipalities and regions can contribute towards reducing energy use. Together with the Swedish Transport and Communications Research Board and the Swedish Association of Local Authorities, BFR has built up researcher environments around the relationships between buildings and infrastructure. Among other things, a model

for planning of buildings taking into account energy, transportation and environmental factors has been developed, as well as a compilation of ecological principles for planning and building.

Experimental building projects have shown that technology is available today for reducing energy use in single-family homes by up to 50% with an unchanged or even improved indoor climate. More or less the same applies to multi-family apartment buildings.

Solar heating research has focused on big systems for the production of heat with the aid of solar collectors. Sweden is the world leader within this field today. However, solar heating is still not economically competitive on the market, other than in exceptional cases. Progress has also been made in the development of simulation programs that permit more reliable sizing of large solar collector fields.

Due to extensive R&D efforts and a previously extensive experimental building programme, Sweden was long in the front line when it comes to large and medium-sized heat-pump systems. Today's heat-pump research is more long-range and is primarily being pursued within framework programmes at universities. It is primarily concerned with new refrigerants and more efficient systems. However, Sweden still has a leading role within the IEA and is an operating agent within several areas.

Sweden occupies an internationally leading position within the energy storage field as well. Certain technologies are already competitive, for example short-term storage of various kinds, storage in steel tanks and in certain aquifers. Others stand on the threshold of commercial introduction, e.g. aquifer storage, borehole storage and pit storage.

Table 5.3 BFR's grants to energy research 1993/94 (SEK million)

Programmes	total	of which energy R&D
Energy research	25	25
solar heating		
heat pumps		
energy stores		
energy systems		
energy-efficient buildings and installations		
information and documentation		
Building research		
1. Building research	167	8
buildings and infrastructure		
energy-efficient buildings		
information and documentation		
2. Experimental construction	10	5
3. Building and property research	9	2
Total	211	40

5.2.2 Transportation research

KFB's contributions to climate-related research

The Swedish Transport and Communications Research Board's contributions to climate-related research are limited to the field of transportation-related research. KFB has several programmes concerned with research, development and demonstration in the field of energy and the environment. Climate impact is usually dealt with as one aspect in a larger perspective in these projects.

KFB has a special research programme for energy-related transportation research. The appropriation for 1993/94 amounted to SEK 5.5 million. The purpose of this research is, firstly, to reduce environmental problems in the form of harmful air emissions and carbon dioxide; secondly, to increase energy efficiency; and thirdly, to study control instruments for switching to biobased fuels.

KFB's regular research grants fund projects involving basic research knowledge-building at universities and colleges. Examples of such research are the theme programmes "Man and means of transportation" and "Cars and society", both of

which study life-styles and behaviours of importance for transportation and the environment.

NUTEK's contributions to climate-related transportation research

Within the framework of the research field of energy technology, NUTEK is in charge of research and development concerning engines and propulsion systems. The purpose of the research is to develop less polluting and more efficient engines and to learn more about the combustion of alternative fuels. For example, development of storage batteries is being supported within the framework of the programme Electric and Hybrid Vehicles.

Within the framework of energy-related transportation research, mention should also be made of the special programme that has been created within the energy technology fund for Environmentally Sound Vehicles. This programme is intended to include development of vehicles, engines and propulsion systems as well as biobased fuels, electric hybrid systems, etc. Projects within the programme are being carried out in collaboration between the vehicles industry, subcontractors and, where appropriate, public transport companies.

The special Ethanol Development Programme is planned for a three-year period, the purpose being to develop new technology for the production of ethanol from cellulose-rich raw materials. The programme is a complement to the research programme Alternative Fuels already in progress. The development work can be intensified as a result of the new programme, and the goal is that the new technologies can begin to be applied for commercial production of ethanol from cellulose-rich raw materials and thereby enable fossil fuels to be replaced within the transportation sector on a larger scale.

Table 5.4 NUTEK's grants to transportation research 1993/94 (SEK million)

Programmes:	
Engine-related combustion	10
Electric and hybrid vehicles	8
Ethanol development	15
Alternative fuels	4
Environment-friendly vehicles	15
Total	52

5.2.3 Socio-economic climate research

Socio-economic and humanistic environmental research became established in earnest during the 1970's and 1980's. Environmentally-oriented studies have become fairly well-established within such fields as economics, political science, sociology, cultural geography, psychology and history. The total support targeted to socio-economic research within the environmental field is still relatively small.

Socio-economic research concerning global environmental change is supported by the Human Dimensions of Global Environmental Change Programme (HDP). According to calculations by the Swedish Human Dimensions Committee, total support to socio-economic environmental research in 1993/94 amounted to about SEK 40 million. The biggest single funding organization was the Council for Planning and Coordination of Research (FRN). Support to direct climate-related socio-economic environmental research was estimated at about SEK 10 million.

The Foundation for Strategic Environmental Research (MISTRA) was created in January 1994. Starting in a year or so, MISTRA is expected to allocate about SEK 250 million annually to research for sustainable development. MISTRA has expressed an ambition to strengthen socio-economic environmental research as well. What form this research will take has not yet been decided.

Only a few research projects and research groups within the field of socio-economic and humanistic research have expressly taken up questions such as how the greenhouse effect can be mitigated. Of direct relevance to the climate issue is the research, mainly in the field of political science, that focuses on the role of government institutions in the implementation of environmental policy decisions, as well as the analyses that are being made of the function of the international environmental negotiating system (governance studies). Other important projects

have examined people's choice of energy source for residential heating and the environmental effects of urbanization and infrastructure investments.

Within the field of environmental economics and economic instruments, in addition to the work described above under energy research, research is also being conducted by the Swedish Environmental Protection Agency, among others. Questions being studied include the effectiveness of different instruments and the costs they entail for society.

5.3 Education and raising of public awareness

In 1993 the Riksdag (Swedish parliament) allocated SEK 5 million for climate-related information and education etc. The purpose is to increase the level of knowledge among the general public concerning the effects of climate change as well as preventive measures and the importance of individual behaviour.

The Swedish Environmental Protection Agency plans to support information activities with two target groups. The recipients of the first information activity are teachers, politicians, local authorities, non-governmental organizations, etc.

The second information activity is targeted at motor vehicle traffic and emissions in connection with transports of goods and people. Examples of recipients of information are transport companies, driving school instructors and auto service shops.

Another activity that has been going on for a number of years is the information that is conveyed within the framework of the Energy Efficiency Programme, whose secretariat is situated at NUTEK.

The information strategy is to show that it is possible to improve energy efficiency by means of good examples. The information is spread via targeted actions among networks of persons who work for the common goal: better technology for more efficient energy use. There are networks for large property management companies, energy service companies, environmentally sound offices, lighting, windows, the engineering industry and electric cars. There are international networks within the IEA, Nordeff, the EU and the USA.

The programme works via traditional communication fora: seminars, education, brochures, newsletters, fairs and exhibitions, publication series, etc. A campaign was held to promote energy-efficient household appliances, but instead of being sent directly to households the information was sent to those utilities who so desired. So far the campaign has reached around 800,000 electricity consumers. The idea is now to extend the information to all domestic appliance dealers in the country.

The programme cooperates in information matters with other public authorities, such as the National Board for Consumer Policies when it comes to domestic appliances and the Transport and Communications Research Board when it comes to electric cars.

Appendix 1

Emissions of other greenhouse gases

Methane

Emissions of methane in Gg (1000 tonnes)

	1990	1995	2000	2005
Fuel Combustion: Energy and Transformation	1	2	2	3
Fuel Combustion: Industries	4	5	5	5
Fuel Combustion: Others	10	10	9	8
Industrial Processes	NE	NE	NE	NE
Domestic transportation	17	14	10	7
Agriculture	196	205	205	205
Waste	100	97	67	67
TOTAL	**330**	**335**	**300**	**295**
International transportation	1	1	1	1

NE = not estimated

Nitrous oxide

Emissions of nitrous oxide in Gg (1000 tonnes)

	1990	1995	2000	2005
Fuel Combustion: Energy and Transformation	1.4	1.6	1.7	2.0
Fuel Combustion: Industries	2.0	2.0	2.1	2.2
Fuel Combustion: Others	0.7	0.7	0.6	0.5
Fuel Combustion: Domestic transportation	0.4	0.5	1.3	1.3
Industrial processes	2.7	2.5	2.5	2.5
Agriculture	7.9	6.5	5.0	5.0
TOTAL	**15**	**14**	**13**	**12**
International transpor-tation	0.1	0.1	0.1	0.1

Nitrogen oxides

Emissions of nitrogen oxides in Gg (1000 tonnes)

	1990	1995	2000	2005
Fuel Combustion: Energy and Transformation	20	18	16	19
Fuel Combustion: Industries	39	28	25	25
Fuel Combustion: Others	19	12	9	8
Fuel Combustion: Domestic transportation	285	242	188	170
Industrial processes	11	10	10	10
TOTAL	**374**	**310**	**248**	**232**
International transportation	60	62	65	78

Carbon monoxide

Emissions of carbon monoxide in Gg (1000 tonnes)

	1990	1995	2000	2005
Fuel Combustion: Energy and Transformation	8	12	10	12
Fuel Combustion: Industries	26	27	29	30
Fuel Combustion: Others	69	65	44	31
Fuel Combustion: Domestic transportation	1500	1000	600	475
Industrial processes	6	6	6	6
TOTAL	**1600**	**1100**	**700**	**550**
International transportation	44	46	48	57

Emissions of non-methane volatile organic compounds (NMVOCs)

Emissions of NMVOCs in Gg (1000 tonnes)

	1990	1995	2000	2005
Fuel Combustion: Energy and Transformation	4	6	5	6
Fuel Combustion: Industries	19	19	19	19
Fuel Combustion: Others	141	140	111	80
Fuel Combustion: Domestic transportation	201	130	76	51
Industrial processes	67	64	60	60
Fugitive Fuel Emission	18	10	10	10
Solvents	98	67	50	50
TOTAL	**548**	**436**	**331**	**276**
International transportation	15	16	17	20

Emissions of HFCs, FCs and SF_6

Emissions of these gases are estimated as follows, assuming that no new restrictions are introduced.

Estimated quantity of HFCs, Gg (1000 tonnes) in bulk and in imported products

	1990	1995	2000	2005
Refrigerants	0	0.5	1.3	1.3
Foam plastics	0	0.3	0.6	0.6
Aerosols	0	0.02	0.04	0.06
Other	0	0	0.01	0.01
TOTAL	**0**	**0.8**	**2.0**	**2.0**

Estimated emissions of FCs in Gg (1000 tonnes)

	1990	1995	2000	2005
Products	0.02	0.03	0.03	0.03
Industrial processes	0.04	0.04	0.04	0.04
TOTAL	**0.06**	**0.07**	**0.07**	**0.07**

Estimated emissions of SF_6 in Gg (1000 tonnes)

	1990	1995	2000	2005
Total	**0.04**	**0.04**	**0.04**	**0.04**

Appendix 2

Forecast premises, methodology and forecast results

A.2.1 Assumptions

Price assumptions

The following prices are expressed at the 1993 price level.

Table 1 Fuel prices for large heating plants, SEK per MWh

	Central heating plants		Local heating plants	
	1993	**2005**	**1993**	**2005**
Light Fuel Oil	274	313	294	344
Heavy Fuel Oil	217	268	237	288
LP gas	202	244	246	306
Coal	208	215	219	226
Biofuel	108	100	108	108

Note: Including excise taxes but excluding VAT.

Table 2 Fuel prices for large and small industries, SEK per MWh

	Large industry		Small industry	
	1993	**2005**	**1993**	**2005**
Light Fuel Oil	151	189	169	220
Heavy Fuel Oil	104	155	124	175
LP gas	137	179	182	242
Coal	97	104	107	114

Note: Including excise taxes but excluding VAT.

Table 3 Fuel prices for residential properties, SEK per MWh, including taxes and VAT

	Residential buildings		Single-family homes	
	1993	**2005**	**1993**	**2005**
Light Fuel Oil	267	431	396	455
Heavy Fuel Oil	297	361		
LP gas	308	383		
Coal	274	282		

Table 4 Motor fuel prices, SEK per litre, including taxes

	1990	**1993**	**2005**
Petrol, premium[1)]	6.57	8.18	9.01
Diesel[2)]	2.88	5.16	6.95

1) Including VAT. 2) Excluding VAT. As from 1993 special diesel oil tax.

Table 5 Electricity prices for different customer types including excise taxes and VAT, SELK per MWh

	Elect.-intensive industry[1)]	**Medium-sized industry[2)]**	**Electric heating[3)]**	**Household electricity[4)]**
1990				
Electricity price	190	230		
Excise tax				
Elect. price incl. excise tax and VAT[5)]	190	230		
1993				
Electricity price	230	280	400	590
Excise tax	0	0	85	85
Elect. price incl. excise tax and VAT[5)]	230	280	600	850
2005				
Electricity price	330	380	500	600
Elect. price incl. excise tax and VAT[5)]	33	38	730	970

1) Annual consumption 140 GWh and subscribed demand MW. 2) Annual consumption 50 GWh and subscribed demand 10 MW. 3) Annual consumption 25 MWh. 4) Annual consumption 2 MWh. 5) VAT relates to other energy users.

Source: Prices for electricity-intensive industry are taken from Vattenfall and prices for electric heating and household electricity from SCB (Statistics Sweden).

A.2.2 Sector-specific assumptions, method and results

Industry

The forecast model for industry's energy consumption is based on assumptions concerning production in the different sectors and how specific energy use (kWh/production value) in each sector will develop. The latter factor is based on knowledge/projections concerning e.g. technological development and renewal of capital equipment.

A sector's energy demand consists of the products' production value x specific energy use. Industry's aggregate demand is the sum of the demands of the different sectors.

The consumption of different fuels is given by the assumed fuel prices and assumptions regarding the ability of different sectors to change fuel, which is dependent on the type of production and the capital equipment.

Table 6 Industry's production values in 1990, 1993, 1995, 2000 and 2005, SEK billion, 1985 prices.

Sector	**1990**	**% per annum**	**2000% per annum**	**2005**		
Pulp and paper industry		57.6	2.2	71.6	1.6	77.5
Chemical industry etc.		51.4	4.4	79.0	3.0	91.6
Iron and steel, nonferrous metals		47.0	-0.3	45.6	0.4	46.5
Engineering industry		262.3	2.8	346.2	3.0	400.2
Other		240.7	-0.2	237.9	0.4	242.8
Industry total		**659.0**	**1.7**	**780.3**	**1.9**	**858.6**

Source: SCB and own calculations.

Table 7 Average specific energy use, kWh per production krona

SNI		**1990**	**2000**	**2005**
341	Pulp, paper industry	1.079	0.971	0.951
341,2,6	Chemical industry etc.	0.189	0.139	0.132
371,2	Iron and steel, nonferrous metals	0.555	0.601	0.596
38	Engineering industry	0.058	0.052	0.051
	Other	0.146	0.139	0.142
	Total	**0.215**	**0.195**	**0.188**

The forecast for industry's energy use is presented in Tables 8 and 9.

Table 8 Industry's energy use 1990-2005, TWh

Energy source	**1990**	**% p.a.**	**1993**	**% p.a.**	**1995**	**% p.a.**	**2000**	**% p.a.**	**2005**
Steam coal	7.1	-9.3	5.3	1.6	5.5	2.0	6.0	2.0	6.7
Coke	9.8	2.0	10.4	0.3	10.5	0.0	10.5	0.1	10.5
Biofuels, peat etc.	42.8	2.3	45.8	1.6	47.3	1.4	50.6	1.3	53.9
Natural gas	3.1	0.0	3.1	2.6	3.3	1.9	3.6	2.0	4.0
Diesel oil	1.9	-2.3	1.7	1.7	1.8	0.9	1.9	0.8	2.0
Fuel oil 1	3.8	-9.2	2.9	6.9	3.3	1.8	3.6	1.6	3.9
Fuel oil 2-5	11.6	-5.5	9.8	0.8	10.0	1.5	10.7	1.5	11.6
LP gas	4.1	1.0	4.2	2.4	4.4	1.0	4.6	1.1	4.9
Town gas	0.1	27.6	0.1	10.6	0.2	1.2	0.2	0.6	0.2
District heating	2.6	4.2	4.1	6.2	4.5	1.7	4.9	1.6	5.3
Electricity, primary	50.4	-2.3	46.9	3.5	50.3	1.5	54.1	1.2	57.4
Interruptable electric boilers	2.6	-8.4	2.0	-0.7	2.0	-17.8	0.8	-17.9	0.3
Total	**140.9**	**-1.1**	**136.4**	**2.3**	**142.9**	**1.2**	**151.4**	**1.2**	**160.5**

Source: SCB and own calculations. Note: Exclusive of petroleum refineries. Biofuels also include waste liquors from the pulp and paper industry. Coke also includes coke and blast-furnace gas. Rounding errors occur.

Table 9a Industry's energy use 1990 per sector, TWh

Sector	Coal, coke	Bio-gas	Nat. gas	Oils	LP gas	Dist. heat.	Elec-tricity	Total
Pulp and paper industry	0.8	35.7	0.3	4.7	0.3	0.3	20.0	62.2
Chemical industry etc.	0.3	0.5	0.7	1.0	0.1	0.8	6.2	9.7
Iron and steel, nonferrous metals	11.0	..	0.3	2.0	1.8	0.1	7.5	22.7
Engineering industry	0.2		0.3	2.5	0.5	1.1	7.2	11.8
Other	4.6	6.4	1.5	7.4	1.3	1.1	12.8	35.1
Industry, total	**16.9**	**42.6**	**3.1**	**17.6**	**4.0**	**3.4**	**53.7**	**141.9**

Table 9b Industry's energy use 1995 per sector, TWh

Sector	Coal, coke	Bio-gas	Nat. gas	Oils	LP gas	Dist. heat.	Elec-tricity	Total
Pulp and paper industry	0.6	39.4	0.5	3.9	0.4	0.8	19.7	65.4
Chemical industry etc.	0.1	0.5	0.7	1.6	0.1	1.0	6.0	10.1
Iron and steel, nonferrous metals	12.2		0.2	2.0	1.8	0.2	7.4	23.8
Engineering industry	0.1	..	0.3	2.5	0.6	1.6	7.5	12.8
Other	2.8	7.3	1.7	5.4	1.4	0.7	12.1	31.4
Industry, total	**15.8**	**47.2**	**3.4**	**15.4**	**4.3**	**4.3**	**52.7**	**143.5**

Table 9c Industry's energy use 2000 per sector, TWh

Sector	Coal, coke	Bio-gas	Nat. gas	Oils	LP gas	Dist. heat.	Elec-tricity	Total
Pulp and paper industry	0.8	42.5	0.5	4.1	0.4	0.9	20.3	69.5
Chemical industry etc.	0.2	0.5	0.9	1.6	0.1	1.0	6.6	10.9
Iron and steel, nonferrous metals	12.2		0.2	2.0	1.9	0.1	7.5	23.9
Engineering industry	0.2	..	0.5	3.1	0.7	1.9	8.4	14.8
Other	3.1	7.5	1.7	5.5	1.5	0.6	12.7	32.6
Industry, total	**16.5**	**50.6**	**3.8**	**16.3**	**4.6**	**4.5**	**55.5**	**151.7**

Table 9d Industry's energy use 2005 per sector, TWh

Sector	Coal, coke	Bio-gas	Nat. gas	Oils	LP gas	Dist. heat.	Elec-tricity	Total
Pulp and paper industry	1.1	45.5	0.5	4.3	0.4	1.0	21.0	73.8
Chemical industry etc.	0.4	0.6	1.1	1.6	0.2	1.1	7.1	12.1
Iron and steel, nonferrous metals	12.2		0.2	2.1	2.0	0.1	7.6	24.2
Engineering industry	0.2	..	0.6	3.8	0.8	2.2	9.3	16.9
Other	3.4	7.7	1.7	5.7	1.5	0.6	13.2	33.8
Industry, total	**17.3**	**53.8**	**4.1**	**17.5**	**4.9**	**5.0**	**58.2**	**160.8**

Note: Biofuels, peat etc. also include waste liquors from the pulp and paper industry. Coke also includes coke and blast-furnace gas. Natural gas also includes 167 GWh from town gas.
.. Values less than 100 GWh. Rounding errors occur.

Transportation

The forecast for the level of energy use in the transport sector is based on simple elasticity models for the fuel in question. The forecast for aviation fuel use is based

on the Civil Aviation Administration's traffic forecast. DPU's forecasts for traffic and transport volume within the transport sector are used for breakdown of future fuel consumption among traffic modes and for calculation of emissions of other climate gases than carbon dioxide. The minor differences that exist in forecast premises between the two forecasts are not deemed to give rise to any appreciable distortion of the forecast of the transport sector's carbon dioxide emissions.

The elasticity models for petrol and diesel are specified in the following manner:

$$Bt = Bb \times ((dP \times Ep + dY \times Ey - T)/100 + 1)$$

$$Dt = Db \times ((dI \times Ei - T)/100 + 1)$$

E = price/income elasticity
t = forecast year
b = base year

The models for forecasting of the level of use of petrol and diesel contain a trend component (T), which can be considered to represent an ongoing technical/economical efficiency improvement process over time. The specific assumptions concerning the trend component (T) that are made in the forecasts for the level of fuel consumption are as follows:

Average fuel consumption per kilometre for automobiles during the period 1993-2000 is assumed to decrease by 0.3% per annum. For the period 2000-2005 it is assumed to decrease by 0.7% per annum.

For diesel-engined vehicles we make the assumption that the average consumption per kilometre decreases by 0.5% per annum during the period 1993-2005.

The transport forecast model (DPU) consists of a set of interlinked models. For *passenger transport*, a traditional four-step model is used (traffic generation, traffic breakdown, travel mode breakdown and network layout) with relatively detailed zonal resolution and network information. The three first elements consist of structured logit models and the fourth of a network model, which is sequentially tied to the other steps. For *goods transport*, data on the national industrial structure is combined with data on regional breakdown in a model system where the future goods transport pattern (broken down into traffic modes and relations) is forecast with the aid of an entropy model, where regional values for production, international trade and consumption constitute limitations.

The forecast for the transport sector is presented in Table 10a.

Table 10a Energy use in the transport sector 1990-2005

Energy source	**1990**	**% p.a.**	**1993**	**% p.a.**	**1995**	**% p.a.**	**2000**	**% p.a.**	**2005**
Petrol, 1000 m^3	5589	0.0	5588	1.9	5800	1.3	6190	1.3	6600
Diesel, 1000 m^3	2052	2.5	2009	2.9	2340	1.0	2465	1.1	2600
Light Fuel Oil, 1000 m^3	96	-22.3	45	10.6	55	2.4	62	2.5	70
Heavy Fuel Oil, 1000 m^3	64	-24.1	28	19.5	40	2.4	45	2.1	50
Aviation fuel, 1000 m^3	1086	-2.1	1019	2.9	1080	2.6	1230	2.6	1400
LP gas, 1000 tonnes	0								
Natural gas, mill. m^3*	2	-100.0 4							
Ethanol etc., 1000 m^3*	-	-	-						
Electricity, GWh	2475	-0.3	2452	0.2	2460	1.3	2420	1.3	2800
Total, TWh	83.5	0.0	83.4	2.3	87.4	1.4	93.7	1.4	100.6
International shipping									
Diesel	7	58.7	28	6.9	32	59.4	52	9.4	80
Light Fuel Oil, 1000 m^3	172	1.0	177	8.9	210	9.5	230	1.7	250
Heavy Fuel Oil, 1000 m^3	568	12.2	802	1.7	830	2.4	850	0.5	870
Total, TWh	7.9	10.6	10.7	3.1	11.4	1.1	12.0	1.1	12.7

*Used as alternative fuel to diesel within public transport. Ethanol deliveries are not reported in SCB's statistics. Since statistical records of different alternative motor fuels are not comprehensive, and the volumes are marginal in relation to the total consumption, we refrain from making any forecasts for these fuels.

Source: SCB and own calculations

Table 10b Forecast of future passenger transport volume. Index 1990 = 100

	1990	1995	2000	2005
Automobile (vehicle-km)	100	111	117	150
Bus (vehicle-km)	100	113	117	121
Air (passenger-km)				
Domestic routes	100	151	151	185
International routes	100	132	181	230
International charter	100	93	107	176
Total air	100	125	151	202
Rail	100	127	152	185
Shipping	(Forecast not available)			

Table 10c Forecast of future goods transport volume. Index 1990 = 100

	1990	1995	2000	2005
Road traffic (vehicle-km)				
Heavy trucks	100	109	126	173
of which foreign	100	108	127	179
Light trucks	100	109	125	163
Shipping				
Domestic traffic (tonnes-km)	100	98	115	135
Int. traffic (tonnes-km, SCB def)	100	105	126	183
Int. traffic (index for tonnes)	100	99	117	140
Rail (tonnes-km)	100	109	129	171
Air	(Transport volume included in passenger travel by air)			

Housing and services etc.

The forecast for the sector housing, services etc. is based on assumptions concerning the future heating requirement (area to heat/efficiencies), appliance stock, specific energy consumption and operating time.

Space heating

Et = At/et, where

E = energy use for heating in year t
At = area to heat in year t
et = efficiency in year t

Operating electricity

Ot = A x Z, where

Ot = operating electricity in year t
At = area in year t
Zt = specific energy consumption in year t

Fuel consumption is determined by the assumed price structure and the freedom to switch fuels.

Table 11 Population and building stock

	1993	% p.a.	2005
Population, thousands	8,719	0.4	9,135
Number of dwelling units, thousands			
single-family homes	1,924	0.7	2,092
apartment buildings	2,220	0.7	2,414
Heated area in commercial and institutional premises, mill. m^2	155	0.8	171

1) 1993 value based on statistics for 1992.
Source: SCB, National Board of Housing, Building and Planning and own calculations.

Table 12 Annual mean efficiencies for existing and newly built single-family homes, 1993 and forecast for 2005

	Existing stock		New production	
	1993	2005	1993	2005
Electric heating	0.84	0.88	0.88	0.90
District heating	0.90	0.92	0.93	0.95
Oil	0.68	0.73	0.77	0.82
Natural gas	0.76	0.78	0.80	0.86
Fuelwood	0.56	0.65	0.70	0.74

Note: Efficiencies for different energy sources are calculated as annual means and include all boilers that use the type of energy source in question. The efficiency of electric heating, for example, includes all electric combi-boilers, electric boilers and direct electric heating.

Table 13 Annual mean efficiencies for existing and newly built apartment buildings and commercial/institutional premises, 1993 and forecast for 2005

	Existing stock		New production	
	1993	2005	1993	2005
Electric heating	0.80	0.84	0.88	0.89
District heating	0.74	0.78	0.81	0.86
Oil	0.62	0.68	0.74	0.81
Natural gas	0.68	0.72	0.76	0.84

Table 14 Total energy use in the residential sector 1990 — 2005, TWh

	1990 corrected	1993 corrected	1995	2000	2005
Coal	0.6	0.1	0.1	0.1	0.2
Wood fuel	12.6	12.2	11.5	10.2	9.0
Oils[1)]	45.2	35.3	33.6	29.5	25.9
Gas[2]	1.5	1.7	1.7	1.7	1.7
District heating	34.5	36.4	36.5	37.0	37.4
Electricity	67.9	72.2	74.0	78.2	82.3
of which electric heating	*26.6*	*28.9*	*30.0*	*32.4*	*35.0*
Total	162.2	157.9	157.3	156.7	156.5

1) Incl. LP gas. 2) Town gas and natural gas

Forecast results — energy system

Table 15 Energy balance, 1990-1993 and forecasts for 1995, 2000 and 2005, TWh

	1990	1991	1992	1993	1995	2000	2005
Use							
Industry	141	136	133	136	143	151	161
Transportation	83	81	82	84	87	94	101
Housing, services etc.	150	152	152	154	157	157	157
Domestic energy use	374	369	367	374	388	402	418
International shipping, conversion and distribution losses, non-energy purposes	73	65	69	67	72	76	83
Total energy use	447	434	436	441	460	478	500
Supply							
Oils[1)]	197	181	186	184	193	210	212
Natural gas	7	7	8	9	10	11	13
Coal and coke	28	28	27	28	28	29	30
Biofuels, peat etc.	67	70	71	76	79	84	89
Hydropower, nuclear power, waste heat and heat-pump heat plus net electricity trade etc.[2]	148	148	144	144	151	153	155[3)]
Total supply	**447**	**434**	**436**	**441**	**460**	**478**	**500**

1) Including LP gas. 2) Electricity input excluded. 3) This includes the additional power requirement described in section 3.

Table 16 Electricity balances 1990-1993 and 1995-2005, TWh

	1990	1991	1992	1993	1995	2000	2005
Total net electricity use	140.0	141.2	139.5	140.4	146.9	151.0	157.83
of which interruptable electric boilers	9.6	8.3	8.4	7.2	7.0	2.6	1.0
Electricity supply							
Hydropower[1)]	71.5	62.3	73.2	73.3	67.0	64.2	64.2
Nuclear power	65.2	73.5	60.8	58.9	69.0	72.0	72.0
CHP in industry	2.6	3.1	3.3	3.8	3.9	4.0	4.2
CHP in district heating	2.2	3.2	3.5	4.2	4.5	6.5	9.3
Oil-fired condensing	0.2	0.3	0.6	0.5	0.5	1.0	2.4
Gas turbines, other	0.0	0.1	0.1	0.1	0.1	0.1	0.1
Net production	141.7	142.6	141.6	140.8	145.0	147.8	152.2
Net trade/additional power requirement	-1.8	-1.4	-2.1	-0.4	1.9	3.2	5.5
Total electricity supply	**140.0**	**141.2**	**139.5**	**140.4**	**146.9**	**151.0**	**157.8**

1) Including wind power: 31 GWh in 1992, 48 GWh in 1993 and 200 GWh in 2005.

Table 17 Fuel input for electricity production 1990-1993 and 1995-2005, TWh

	1990	1991	1992	1993	1995	2000	2005
Oils	1.5	2.5	3.7	4.1	5.2	6.9	11.5
LP gas	0.3	0.0	0.1	0.1	0.1	0.1	0.1
Natural gas	0.5	0.5	0.8	1.0	0.9	1.8	2.8
Biofuels, peat etc.	2.5	2.6	2.7	2.9	3.4	4.8	6.6
Coal, blast-furnace gas	2.4	3.1	3.3	3.6	.31	3.1	3.2
Total fuel input	**7.1**	**8.8**	**10.6**	**11.6**	**12.6**	**16.7**	**24.1**

Note: Due to rounding-off, the total figures may not agree.

Table 18 Fuel supply in district heat production, TWh

Supply	**1990**	**1993**	**1995**	**2000**	**2005**
Fuel input					
Coal	7.5	5.3	5.8	6.2	6.5
Biofuels, peat etc.					
Light Fuel Oil	0.4	0.6	0.7	0.8	0.8
Heavy Fuels Oils	3.2	4.8	5.1	5.2	5.2
LP gas	0.5	0.7	0.8	0.9	0.9
Natural gas	2.0	3.2	3.4	4.1	4.6
Blast-furnace gases	0.8	0.8	793	799	805
Total	24.7	30.8	33.5	36.5	38.6
Electric boilers	6.3	5.0	4.9	1.9	0.7
Heat pumps	7.1	7.0	6.8	7.0	7.2
Of which electricity input	2.1	2.4	2.3	2.3	2.4
Waste heat etc.[1)]	3.0	3.4	3.4	3.7	4.0
Total supply	41.1	46.2	48.6	49.1	50.5
Own consumption of electricity[2)]	1.2	1.4	1.6	1.6	1.7

1) Heat received from industry and sector housing, services etc. 2) Including own consumption of electricity in gas and coking plants.

Table 19 Final energy use including electricity and district heat input per energy source

	1990	% p.a.	1993	% p.a.	1995	% p.a.	2000	% p.a.	2005
Steam coal, 1,000 t	2,306	-6.4	1,888	0.5	1,908	1.4	2,044	1.3	2,179
Coke, coke gas, 1,000 t	1,261	2.0	1,337	0.3	1,344	0.0	1,345	0.1	1,350
Biofuels, peat etc., ktoe	5,740	4.3	6,518	2.1	6,788	1.3	7,243	1.2	7,676
Petrol, 1,000 m³	5,629	-0.2	5,588	1.9	5,800	1.3	6,190	1.3	6,600
Light distillates, 1,000 m³	1,090	-2.2	1,020	2.9	1,080	2.6	1,230	2.6	1,400
Diesel oil, 1,000 m³	2,962	1.0	3,048	1.6	3,144	0.5	3,220	0.6	3,323
Light Fuel Oil, 1,000 m³	3,629	-5.7	3,044	1.3	3,121	-1.5	3,887	-1.5	2,678
Heavy Fuel Oils, 1,000 m³	2,548	4.0	2,866	2.9	3,037	1.4	3,261	2.8	3,752
LP gas, 1,000 t	404	0.8	413	2.8	436	1.2	462	1.2	490
Town gas, mill. m³	75	5.5	88	2.8	93	-0.8	89	-1.0	85
Natural gas, mill. m³	611	9.6	805	2.3	843	3.7	1,011	3.3	1,191
Blast-furnace gas, DH, ktoe	66	0.3	66	1.3	68	0.1	69	0.1	69
District heating, GWh	34,288	4.5	39,101	2.3	40,952	0.4	41,850	0.4	42,703
Electricity, GWh	130,798	0.3	132,053	2.2	138,057	0.6	142,080	0.9	148,349

Appendix 3

Effect assessments

Some partial calculations of the effects of different measures on carbon dioxide emissions are presented below. The assessment included in the quantification of the effects presented in chapter 3 is firstly the effects of the programme for more efficient energy use, and secondly the effects of the investment supports.

A.3.1 Effects of investment supports

In the calculations of the effects of the investment supports on carbon dioxide emissions, we have assumed that:

- Coal condensation plants in the year 2000 have an efficiency of 42%. Carbon dioxide emissions per TWh of electricity generated are thereby 0.78 million tonnes (0.3276/0.42).

- Natural gas combi cycles have an efficiency of 60%. Carbon dioxide emissions per TWh of electricity are thereby 0.335 million tonnes (0.201/0.6).

- Electricity generation in the year 2000 gives rise on average to 0.031 million tonnes of carbon dioxide per TWh of electricity (4.9/157.8). The calculation is made exclusive of the additional power requirement described in chapter 3.

Investment support to biofuel-based CHP

The allocated resources of SEK 1,000 million are projected in Energy Report 1994 to generate an annual production of about 1.7 TWh of electricity. This calculation is based on an assumption of an average operating time of 5,000 hours per annum.

In our calculations we have assumed that without the investment support, the heating demand would have been met by biofuel-based heat production. The effect the support has on carbon dioxide emissions is thereby limited to the fossil-based electricity production which the 1.7 TWh of electricity can be assumed to replace.

We further assume that the CHP plants that have received support use biofuel even after the initial five years.

Based on these assumptions, the effects of the support on carbon dioxide emissions (millions of tonnes) can be estimated at -0.153 (average production mix in 2000), -0.57 (natural gas combi cycles), -1,326 (coal-fired condensing).

Investment support to wind power

Through 1994, the support is estimated to have given rise to a production of 0.057 TWh of electricity[32]. Applications equivalent to 0.003 TWh await decisions. Wind power capacity of 200 GWh is projected to have been built by the year 2000. This is assumed to be primarily an effect of the investment and operating subsidies.

The effects of the support on emissions of carbon dioxide (millions of tonnes) can be estimated to be -0.002 (average production structure in 2000), -0.067 (natural gas combicycles) and -0.156 (coal-fired condensing).

Support to district heating

According to the applications, it is projected that the support will reduce carbon dioxide emissions by 0.19 million tonne.

A.3.3 Programme for more efficient energy use

The Energy Use Council says that there is a savings potential within a number of studied sectors of 8 TWh of electricity, of which 1.6 TWh comprises electric heating[33]. If this entire potential is realized by the year 2000 and we assume that the saved electricity is not sold anywhere else, the effects of the programme on carbon dioxide emissions can be calculated to be:

-0.248 million tonnes (production structure in 2000)
-2.68 million tonnes (natural gas combi)
-6.288 million tonnes (coal-fired condensing)

[32] Energy Report

[33] NUTEK Council of Energy Report 1993/94

Appendix 4

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Appendix 5

Variations of greenhouse gas emission

Background

A variety of different factors influence energy supply and demand. The need for heating is greater in a year that is colder and windier than a normal year. The amount and distribution of precipitation determines the runoff in various parts of the country and thereby the availability of hydropower. In dry years, the reduced availability of hydropower is compensated for by the use of other kinds of power.

Energy use is also influenced by the state of the economy. This aspect is not dealt with in the report.

Hydropower production

The production capacity of hydropower is determined primarily by water levels in watercourses and reservoirs. Normal-year-corrected hydropower production is based on current production capacity and an average of the production conditions during a 30-year period. This measurement period is changed every ten years. A period from 1950 to 1980 was used during the 1980's.

It is now time to update the measurement period. This will mean that the normal-year-corrected production will rise slightly due to the high precipitation during the 1980's.

The normal-year production of hydropower in 1990 was 63.2 TWh. The range of variation around the normal-year production can be estimated at around 20% or about 10 TWh. Thus production can decrease to around 53 TWh or increase to around 73 TWh in extreme years.

Electricity in Sweden is mainly generated in nuclear power plants and hydroelectric power points. In normal years, only a small fraction of the electricity is generated by combustion of fuels. In years with little runoff, so-called dry years, fuel-based electricity production may have to be used to a greater extent.

In a wet year, electricity production from hydropower may increase up to 73 TWh. Since fuel-based electricity production is relatively small even in a normal year, an increase in hydropower production does not lead to any significant reduction in fuel-based electricity production. In the present-day electricity system, nuclear power

production is reduced to some extent in such years. The strong electricity balance is exploited for greater use of electric boilers and increased exports.

Temperature correction

The heating demand of a building is dependent on the outdoor temperature. There are several different ways to correct the energy demand in relation to the outdoor temperature. The usual way is to calculate so-called degree-days. The number of degree days is basically the sum of the temperature difference between the indoor and outdoor temperatures for all the days the outdoor temperature is lower than the indoor temperature, with some compensation for waste heat production and solar in-radiation. These data can be summarized in a degree-day index for a given locality or weighted for the country as a whole. Such indexes have been developed for different purposes by SMHI (the Swedish Meterological and Hydrological Institute). SCB (Statistics Sweden), ÖEF (the Swedish Board of Economic Defence), CDL (the Swedish Central Power Supply Board) and the National Energy Administration. The question has been dealt with by the National Energy Administration in a report (1).

Since only a portion of household energy use goes into space heating, degree-day indexes cannot be used to correct the entire energy demand. The portion used for heating hot water, for example, is not dependent on the temperature. The portion of energy used for purposes other than heating has increased in recent years due to energy conservation.

This means that it is first necessary to choose a suitable degree-day index and then decide to what extent this should be used to correct energy use data.

Correction for carbon dioxide emissions

The variations for different climate factors impact energy use and thereby also emissions of carbon dioxide and other greenhouse gases. However, the impact on emissions of carbon dioxide is not directly proportional to the change in energy use.

Electricity production in Sweden consists primarily of hydropower and nuclear power. The electricity balance has been strong during the 1980's. This has meant that the system has been able to accommodate a lower availability of hydropower and an increase demand for electric heating during cold years without more than relatively marginal increases in fuel-based electricity production. During years when hydropower has been plentiful, the production of nuclear power has been phased down. The good availability of electricity during such years has also permitted the operation of electric boilers, which has reduced the need for combustion within the heating sector.

There is thus no direct connection between electricity demand, availability of different production factors etc and carbon dioxide emissions. This connection has so far been weak due to the good electricity balance. If the demand for electricity should increase sharply, this will change, since any electricity demand in excess of the production capacity of hydropower and nuclear power must be met primarily by fuel-based electricity production.

Demand for district heating varies with the temperature. In the last few years actual deliveries have varied around the estimated normal-year deliveries by 10-15% according to the following (data from the Swedish Heating Plants´ Association and STEV/NUTEK´s data differ slightly):

Table 1 Delivery of district heating TWh

Year	Actual	Normal year	Index, %
1981	26.9	25.5	105.5
1982	27.0	27.7	97.5
1983	27.5	29.4	93.5
1984	28.9	30.5	94.8
1985	35.9	32.6	110.1
1986	35.2	34.5	102.0
1987	37.8	35.0	108.0
1988	35.0	36.2	96.7
1989	32.1	37.0	86.8
1990	32.9	37.8	87.0

District heating is produced with a variety of different fuels. Base-load production mainly utilizes solid fuels, heat pumps and waste heat. Oil is normally used for peakload production. This means that the temperature variation is chiefly taken up by more or less oil operation.

In years with a good electricity balance, interruptible electric boilers can be used for district heating. This naturally reduces the need for fuels.

The demand for heating not provided by district heating varies in the same way with the temperature. A special problem within this area is the large number of combination boilers that can switch directly between electricity, oil and, in some cases, firewood. Some form of index for the price relation between different optional fuels is thus required to calculate temperature-corrected consumption for this sector.

The following factors, among others, must be taken into consideration when designers a model for correction of carbon dioxide emissions for climate factors:

- hydropower production capacity and water runoff
- nuclear power production capacity and availability
- electricity consumption
- correction of temperature according to some index
- optimal production of district heating (varies with production units and fuel price relations)
- optimal production for other heating (varies with production units and fuel prices relations)

Designing such a model is a very big job. The model should also be revised from year to year, since several of the above factors change constantly. The amount of work involved is out of proportion to the benefit derived from such calculations. Efforts should instead be concentrated on more qualitative assessments.

Correction of 1990 emissions

KVM (the Joint Committee of Swedish Power and Heat Producers on Environmental Issues) has estimated how the carbon dioxide emissions from electricity production are affected by different climate factors.

To illustrate the importance of different climate factors, KVM has estimated the emissions form electricity production - based on 1990´s electricity production system - for a normal year, a cold year, a dry year etc.

Type of year	**CO_2 emissions (Mt)**
Normal year	1.5
Cold year	1.5
Dry year	2.3
Severe year (cold and dry)	3.8
Warm year	1.5
Wet year	1.5

1990 was both a warm year and a wet year. This did not alter the emissions from electricity production compared to a normal year. But it did increase the supply of electricity, which reduced the use of fossil fuels for heating.

In the district heating sector, less district heat was delivered than the value for a normal year, 1990. In addition, electric boilers were used to a greater extent. A rough estimate would be an increased use of fossil fuels in a normal year equivalent to 5 TWh, which is equivalent to an increase of carbon dioxide emissions by about 1.5 Mt.

Within housing and services, NUTEK makes the following estimate of actual and temperature-corrected energy use for 1990 (table 2).

Table 2 Actual and temperature-corrected energy use 1990

Kind of energy	Actual use (TWh)	Normal-year use (TWh)	Difference (TWh)
Electricity, excl. electric heating	40.6	40.6	0
Electric heating	22.7	25.4	2.7
District heating	30.0	33.7	3.7
Fuels	49.4	54.9	5.5
Total	**142.7**	**154.6**	**11.9**

85% of the fuels used were of fossil origin. It can be assumed that about 4.5 TWh more fossil fuels would have been used within this sector if 1990 had been a normal year. This is equivalent to about 1.2 Mt of carbon dioxide emissions.

The differences if 1990 had been a normal year with regard to water runoff and temperature can be summarized as follows for different sectors (table 3).

Table 3Change of carbon dioxide emissions in a normal year compared to the actual year 1990

Electricity production	0
District heating	+ 1.5 Mt
Housing/services	+ 1.2 Mt
Total	**+ 2.7 Mt**

Thus, carbon dioxide emissions would have been about 3 Mt higher if 1990 had been a normal year from a climatic point of view.

Sources:

1. Statistikrapport: Bebyggelsens energiförsörjning, ("Statistics report: Energy supply for buildings"), May 1986, National Energy Administration. (In Swedish only).
2. Växthusgaser & Energiproduktion. Åtgärder mot klimatförändringar ("Greenhouse gases & Energy Production. Responses to climate changes"), KVM Bulletin, November 1991. (In Swedish only)
3. Energirapport 1991 ("Energy Report 1991), R 1991:1, NUTEK . (In Swedish only)
4. Korttidsprognos ("Short-term Forecast"), August 1991, NUTEK. (In Swedish only)

Appendix 6

IPPC Minimum Data Tables

(not available electronically)