NOTE:

Chapters 1 and 3 of the First National Communication of Denmark to the Framework Convention on Climate Change are available electronically. The remaining chapters and figures are not available in electronic format, and readers wishing to refer to these should obtain a copy of the printed version, or the Executive Summary.

Climate Protection in Denmark

National report of the Danish Government in accordance with article 12 of the United Nations Framework Convention on Climate Change

Introduction

At the United Nations Conference on Environment and Development in Rio de Janeiro in June 1992 more than 150 countries signed the UN Framework Convention on Climate Change. According to the Convention text the Convention enters into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification which happened on 21 December 1993. Denmark deposited her instrument the same date. Accordingly, the Convention has entered into force on 21 March 1994.

According to article 12 of the Convention each developed country Party shall within six months after the Convention takes effect communicate to the Convention secretariat its first national report presenting inter alia inventories of emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol; a general description of steps taken or envisaged by the Parties to implement the Convention, and other information that the Parties consider relevant to the achievement of the objective of the Convention.

Further, under the Convention the developed countries shall in their communications incorporate detailed descriptions of measures adopted to implement commitments under article 4, paragraph 2(a) and (b), and an estimate of the effects of such measures on anthropogenic emissions.

This report presents the Danish programmes and measures taken to observe the commitments under the Climate Convention. The Danish Government acknowledges the Guidelines for Communication of Information Under the Framework Convention on Climate Change prepared by the OECD/IEA and approved by the INC 9 in February 1994. However, work on this communication was initiated in spring 1993 and consequently differences between the format and content of the communication and the guidelines are inevitable. Background material and data underlying the calculations in the report, as well as information lacking, are available upon request to the Danish Environmental Protection Agency.

In preparing the report, it has been the intention to the extent possible to incorporate in the estimates, e.g. on the impacts of climate changes, relevant material that has been analyzed and assessed in other contexts. Material of this nature could not be provided from the North Atlantic parts of the Kingdom of Denmark, i.e. the Faroe Islands and Greenland, and in view of the limited number of inhabitants, approx. 50.000 in each area, it was decided to issue the first report without information on the North Atlantic areas.

Chapter 2 of the report contains a large number of reference data on Denmark, i.a. on geography, population, coasts, climate, and the consumption of primary energy sources, both for energy and for transport purposes.

Chapter 3 gives an inventory of emissions of greenhouse gases, and describes the scope for restricting emissions and increasing sinks within the forest and agricultural sectors. The chapter also includes the prognosis for the future development in the GHG emissions.

Chapter 4 gives an account of the impact of expected climate changes in Denmark, and the scenarios available for adaptation to the climate changes. Since Denmark is a low laying country with many small islands special attention is given to the impact of sea level rise in the coastal zone.

Chapter 5 gives an account of the action plans which have been drawn up for the energy, transport and waste sectors, and which will contribute significantly to restricting emissions of greenhouse gases. A very comprehensive and thorough description is given of the programmes and plans for the energy sector with additional information presented in Annex 1 and 2. The twofold purpose is to give a detailed documentation of how Denmark will meet the ambitious target to reduce the emission of CO_2 with 20% by the year 2005 compared to 1988 and to inspire other Parties to the Convention in controlling their present as well as their future emissions of the most important greenhouse gas.

Chapter 6 deals with Danish research activities carried out in support of climate research, both at national and at international level.

Finally, international cooperation in the field of finance is described in chapter 7.

The following institutions have made contributions to the national report: the Danish Coastal Authority, the Danish Energy Agency, the Danish Meteorological Institute, the Ministry of Agriculture, the Ministry of Foreign Affairs, the Ministry of Transport, the National Environmental Research Institute, the National Forest and Nature Agency, the National Statistical Office of Denmark and Risø National Laboratory.

1 Summary

Basic data

In 1990 the population of Denmark amounted to 5.2 mill. inhabitants and with a total area of 43.000 km^2 the population density corresponds to approximately 120 inh./km^2. Only a very slight increase in the population is envisaged.

Denmark is situated at about 55° Northern latitude and about 10° Eastern longitude. Due to the continental landmass and the warm Gulf stream, the temperature in Denmark is, especially during the winter, relatively high. The weather can in general terms be described as temperate west coast climate with mild winters and cool summers. The average temperature is 8 °C and the ground surface receives yearly between 500 and 900 mm of precipitation.

2/3 or 64% of the area is cultivated agricultural land, approximately 15% is classified as built-up areas and forests account for 10%. Natural areas like moorland, marshland and lakes make up the remaining 10%. The dominating agricultural crop, grain, covers approximately 15,000 km^2 of the Danish landscape.

The service sector, market and Government, contributes approximately 70% of the Gross National Product - amounting to US$ 129,000 billion in 1990 or US$ 25,000 per capita. In 1990 the GNP increased by 63% compared with 1970.

Primary energy consumption increased rapidly in the 60'ies but has essentially been stabilized at a level of 750 PJ from 1972 to 1992 as a result of the saturation effect, the two oil crises and the implementation of rigorous energy political instruments during the last 15 years.

Oil was replaced by coal, especially for power production and the oil consumption was reduced significantly due to energy savings and changes in consumption and supply system, e.g. introduction of combined heat and power.

In 1990 the distribution on energy sources of the total primary energy consumption of 768 PJ was Coal: 41%, Natural Gas:11%, Oil products: 41% and Renewable: 7%.

Energy taxes have been implemented on fossil fuels and electricity, especially in the household sector, and the ensuing energy savings in this sector is a strong indication of the efficiency of high energy prices as an instrument to lower the energy consumption.

After a recent energy taxation reform, a rather elaborate system of taxes has been replaced by a combined energy and CO_2-tax, with a level for private households of US$ 16 per tonne of CO_2, or approximately US$ 6 per GJ. Industry and service only pay CO_2 tax at a level which is half of the tax for households. Renewable energy is not taxed.

The number of passenger cars has increased by 48% in the period 1970 to 1990, and accordingly the road transport for cars shows a growth rate of 73%

from 29.8 billion person-km to 51.5 billion person-km. The transport of goods shows also a slightly lesser increase of 30% for the period from 8.2 billion transport-km to 10.7 billion transport-km.

According to traffic prognoses the authorities envisage an increase by the year 2010 of 40% and 60% for passenger and goods transport respectively compared with 1990.

Emissions and uptake

The basis of the calculation of emissions of greenhouse gases from the energy sector is primary energy consumption and emission factors. For the other sectors activity data and estimated national emission factors are used. The tables are produced in accordance with the latest version of the IPCC manual for emission inventories, and the figures are aggregated in categories consistent with the manual.

Carbondioxide

Since the Second World War the development in the emission of CO_2 is showing a very significant trend. In the period from 1945 to 1960 with a rather slow economic development the emission increased from 12 mill. tonnes to 26 mill tonnes, or approximately 1 mill. tonnes per year. From 1960 to 1972, a period with full steam on the economy, the emission was growing from 26 mill. t. to 62 mill. t., corresponding to a growth rate of 3 mill. tonnes per year.

After the so called energy crisis in 1973 and up to present the emission of CO_2 has due to an active energy management been levelling around 60 mill. tonnes despite a constant economic development. In the same period the GNP increased by approximately 60%. The variation from year to year is mainly caused by import/export of electricity from the two other Scandinavian countries.

The main sources for CO_2 emissions are power plants and transport, with a share of 50% and 20% respectively.

The Danish Parliament has decided that during a period of rotation, e.g. 80 - 100 years, the forest area should be doubled. This decision implies an afforestation rate of about 40 km^2/year, corresponding - at its highest level - to a CO_2 fixation rate of approximately 1 mill. tonnes C per year or 5% of the yearly CO_2-emission.

Since no common international agreement has been reached on the methodology on determination of the CO_2-uptake in afforestation programmes the uptake has not been included in the Danish emission inventory but is listed separately.

Methane

The yearly anthropogenic emission of methane amounts to about 406,000 tonnes and has not changed through the last decade. Most important is the agricultural sector - enteric fermentation and animal waste - with 262,000 tonnes corresponding to 65%. Second are emissions from landfills with 120,000 tonnes (30%).

Nitrous oxide

The sources to the anthropogenic emission of nitrous oxide are almost completely dominated by the agricultural sector, which accounts for more than 75% of a yearly emission of 11,000 tonnes. The emission rate depends on a complex array of factors like soil structure, pH, temperature, type of crop,

water saturation and nitrogen fertilizer. The models for determining the emission are very simplified and their results are encumbered with great uncertainty.

Other GHG

The emission of two of three precursors for ozone - NO_x and NMVOC -is regulated within the Geneva-Convention, and for 1990 the emission was estimated at 293 ktonnes and 165 ktonnes respectively. The emission of the third precursor, CO, amounted to 771 ktonnes in 1990.

With the aim of phasing out the use of CFC's as fast as possible - at an even faster rate than prescribed by the Montreal-Protocol - the Danish environmental authorities accept HFC's to be used to replace CFC's in some areas. The areas in question are primarily the production of some types of refrigerators and freezers where the assessment of risks and the regulation by the authorities is excluding the use of other substances. In 1990 the use of HFC's was marginal but it has increased to approximately 300 tonnes in 1993.

Vulnerability

With a global reduction of the emission of greenhouse gases the development can be slowed down and possibly a new climate equilibrium can be obtained, but it is hardly probable that climate changes can be totally avoided. Without a global effort the climate may change further, but evaluations beyond a century are at present considered almost worthless.

It is possible to foresee a series of impacts of climate changes, but it is difficult to estimate their magnitude; sometimes, it may even be impossible to indicate whether they are an advantage or a drawback.

If the human influence on the atmosphere proceeds unchanged it may result in climate changes, for Denmark comprising a temperature rise, which by the end of the next century will be about 3°C as a yearly average. It is envisaged that the increase of summer temperature will be a little smaller than the winter temperature, 1-3°C and 2-5°C respectively. At the same time precipitation may increase by up to 10% and the relative sea level rise between 30 and 50 cm.

However, it must be assumed that generally the immediate consequences for Denmark in inter alia the agricultural sector, and the management of forests and coast protection within the next century only will be so modest that they can be managed through planned adjustment supported by an expected technological development.

A possible exception is the present natural ecosystem where climate changes may be too rapid for some animal and plant species; this may cause temporary instability and in the long run change the composition of species.

Denmark is however - ecologically as well as politically and economically - a small open system. The importance of climate changes and sea level rise for the development in the rest of the world may therefore most likely be decisive. The change of climate and the rise of sea level could lead to global economic and political instability.

National programmes

Danish policies regarding limitation of climate relevant gases, are rooted in many years of active national policies on energy and environment.

The first national energy plan of 1976 together with further development of the policies during the 1980'ies resulted in a major restructuring of the energy system in Denmark

As a result, the total primary energy consumption has essentially been stabilized, despite substantial growth in all economic sectors. In parallel, the environmental impact from the use of energy has been substantially reduced in the same period, as a direct result of the changes in the energy system, as well as introduction of emission standards, emission quotas and other regulations.

In the late 80'ies, focus was gradually shifted from considerations of security of supply, minimization of energy service costs, and local environmental effects, to wider environmental considerations, notably the goal of achieving long term sustainable developments, on a national as well as on a global level. I 1988, the Danish Government presented its plan of action on environment and development, as a follow up of the recommendations set out in the report from the World Commission on Environment and Development, the Brundtland Report.

In 1990 two action plans, relating to energy and transport, were presented to the Parliament. In these plans, limitations of greenhouse gas emissions, notably carbon dioxide, were introduced as explicit targets.

In 1992 the objectives of the Danish waste policy were described in the Danish Government's Action Plan for Waste and Recycling 1993-97. Among the objectives of the plan was minimization of deposition of organic material in landfills and energy saving through recycling. A consequence of the plan will be a reduction of the emission of methane from landfill sites.

In the Energy Action Plan, the Government listed a number of new initiatives to be implemented, with the expected result of achieving a reduction in CO_2 emissions of 28% in 2005 compared to 1988 levels, for the whole energy sector excluding transport. The Plan was dealt with in the Parliament and there was broad political backing for it.

Strategically speaking, the action plan emphasized efficiency improvements in end use, especially in the use of electricity, and increased efficiency of the energy supply systems, notably increased use of combined heat and power, as the most important areas of intervention.

The transport action plan, adopted in May 1990 by the Government, had as targets for the CO_2 emissions of the sector, to achieve a stabilization in 2005, and to achieve a 25% reduction by 2030 compared to 1988.

The combined effects of the two action plans were foreseen to be more than a 20% reduction in 2005, compared to the base year of the plans (1988). This target was subsequently approved by the Parliament.

Apart from this national CO_2 reduction target Denmark has committed itself to stabilize emissions at the 1990 level in 2000 within the framework of the Climate Convention, as well as to achieve a 5% reduction in 2000 compared to 1990, as a contribution to the overall stabilization by the year 2000 for the countries of the European Union (EU).

In 1993, the present Government has undertaken a major follow-up of the two action plans, in order to guarantee the achievement of the above targets.

In the recent action plan (Follow up on Energy 2000) a revised base scenario for the development of demand and supply, for the energy sector exclusive of transport, has been set up. This base scenario describes the expected development resulting from all measures which will be implemented as a result of implemented policies in place.

The analysis shows that the national CO_2 reduction targets would not be met in the base scenario, but fall short by several million t CO_2 in relation to the reduction target of 20% in year 2005.

In order to bridge this gap, the Government has launched a packet of initiatives in its action plan "Follow up on Energy 2000", which was published in November 1993.

The initiatives are to be implemented through legislation, administrative decisions or negotiations. The content of the packet is a result of extensive screening of a large number of potential options, based on economic and political considerations, and has been thoroughly politically negotiated, to ascertain the necessary parliamentary majority where this is needed.

Further more, it is the intention of the Government to increase the use of "green taxes" (taxes on energy, CO_2, water, waste etc.) in all sectors of the economy.

As a logical extension of this, Denmark is actively working for the introduction of a combined energy and CO_2 tax within the EU, as well as Community standards for electrical appliances.

With the plan in place, a CO_2-reduction of about 23% compared to 1988 levels can be achieved for the energy sector excluding transport. This corresponds to about 18% of the total CO_2 from energy and transport. Hence additional measures are needed to reach a 20% reduction.

In the year 2000, however, the expected reduction will be sufficient to guarantee the fulfilment of a 5% reduction in relation to 1990.

The Danish Government intends to review the results of the current plan as well as future initiatives and developments on the international scene on a periodic basis, next time in 1995. Present plans foresee that this revision should include a renewed analysis of the long term options, to update the analysis of the Energy 2000 Plan.

The main aim of sustainable transport policy is to promote an efficient transport system for the benefit of the general public and industry, to ensure that the damaging effects of traffic, e.g. pollution and accidents, can be reduced to a minimum in accordance with specified objectives.

The target for CO_2 emissions in the transport sector should be seen in relation to the considerable importance attached to helping to solve local environmental problems, which to some extent entails measures which can actually increase CO_2 emissions, e.g. replacing diesel by petrol.

The main objectives in the field of waste and recycling are to reduce the quantity of waste arisings, to minimize the environmental impact of waste disposal, and to make use of the resources contained in waste.

Today total waste arisings amount to about 10 million tonnes per annum. The objective is that about 50% of the total amount of wastes generated in the year 2000 should be recycled. The remainder should primarily be incinerated and landfilling should be minimized. One of the expected effects of the Plan is a reduction of methane emissions from landfilling.

The aim is to incinerate all combustible wastes which is not to be recycled, and which does not present particular incineration problems. By incinerating the energy content in the waste will be used to replace fossil fuels.

In connection with incineration, the energy content of non-recyclable wastes should be used effectively like other biofuels, since most of the waste is CO_2-neutral and therefore causes lower CO_2 emissions than burning of fossil fuels.

R & D and systematic observations

Denmark contributes actively to international climate research programmes including the World Climate Programme. A main area is the numerical models of the atmosphere. Efforts are directed towards harmonization of the models for weather and climate calculations in order to achieve a uniform model for all problems with a view to enhancing the exploitation of new results of research.

The work on climate models includes the study of selected physical processes on the climate and studying the extra-tropical northern hemisphere climate variability. Another important project is the development of a regional model using a high resolution model nested into the global climate model in order to assess regional climate changes caused by an increased greenhouse effect.

Climate observations from several Danish stations back to 1872 are available on electronic media, while sea level data are available back to 1890, and sea temperatures back to 1930. A serie of data from lighthouses and ships log books from 1675 to 1715 is also included in the data base.

The Danish Meteorological Institute (DMI) has been selected as a focal point for a Nordic climate modelling research effort and is collaborating with 11 other European institutes within the European Climate Support Network (ECSN) to promote more effective collaboration in the field of climate monitoring research and prediction. DMI also contributes to climate monitoring within the WMO-coordinated observation programmes(World Weather Watch and World Climate Data Programme).

Danish research institutes are heavily involved in the special area of climate research on palaeo-climate, and Denmark has contributed significantly to the European deep drilling project - GRIP - on the summit of the Greenland Ice Sheet. Analyses of the GRIP ice core reveal that climate in Greenland during the last interglacial period was characterized be a series of several cold periods, which began extremely rapidly and lasted for decades to centuries.

International cooperation

As a consequence of the global nature of environmental problems Denmark has over the past years intensified action at international level in order to meet the global challenges.

The climate problem is to be seen in the context of a broader global challenge. Growing numbers of people have been using up the Earth's store of natural resources. Curbing these trends will require a coordinated international strategy.

The awareness of this global challenge and the transboundary nature of the environmental problems were translated into the Danish Government's action plan for sustainable development of 1988, and as a consequence environmental strategies in several sectors have been developed. Plans and strategies will naturally be adjusted in light of the results of UNCED, particularly the Convention on Climate Change, in order to honour the specific obligations.

To follow up on UNCED the Danish Government has decided to establish an international environment and emergency fund the Danish Cooperation for Environmental and Development - DANCED, with the objective of strengthening efforts towards global environmental problems.

The United Nations target of 0.7 per cent of GNP in ODA has been reached for many years and the Danish ODA amounts to 1 per cent of GNP by the end of 1993.

Denmark wants the GEF to be the financial mechanism for the Convention on Climate Change on a permanent basis, on the condition that GEF is properly restructured.

Denmark would have liked to see a threefold increase of the GEF. A replenishment of US$ 2 billion is not sufficient. Denmark will contribute its fair share of GEF 2, but will in addition to that enter into cofinancing arrangements with the implementing agencies.

Denmark has since the beginning of the negotiation process contributed to the INC/FCCC special voluntary fund for the participation of developing countries and has been one of the major donor countries to activities in relation to the Convention on Climate Change.

Denmark has likewise supported activities in relation to the IPCC Trust Fund.

The new strategy under DANCED extends the possibilities of Danish assistance both in general terms to address the comprehensive approach under the Convention, and more specifically to fund country studies pursuant to Art. 12 of the Convention.

3. Inventories of anthropogenic emissions by sources, reservoirs and removals by sinks

This section shows the historical data for the years 1990-1992 and in addition the projected emissions for the years 1995, 2000 and 2005.

The emission projections are based on the most recent forecast for each of the sectors, for the expected development resulting from measures in place. Only measures that have been implemented or adopted are included.

For the energy sector excluding transport, the forecast is based on the action-plan scenario of the Energy 2000 Follow-Up from November 1993, with the minor revisions made in 1994 by the Danish Energy Agency. Annex I contains a comprehensive list of initiatives of the Energy 2000 Follow-Up, as well as earlier initiatives, and chapter 5.1.1 contains an estimate of the expected impact of the new initiatives of the Follow-Up. Initiatives, which have not been quantified (i.a. the Act on Integrated Resource Planning for the power-sector), or which are still in negotiation (i.a. voluntary agreements with the oil and gas sector), have not been included.

For the transport sector, the forecast are those of the base scenario in the white paper of Transport, TP2005, from November 1993 (see chapter 5.1.2), as the new measures towards the target of stabilisation by 2005, which are described in the white paper, have not yet been implemented or adopted.

The projected energy-balances resulting for the energy-sector are shown in annex II and summarized in table 3.1.

Based on the energy or activity forecasts, emissions have been projected based on estimates of the development in emission-factors implied by the Danish declaration to the ECE-protocols on NO_x (30% reduction in 1998 compared to 1986), the protocol on SO_2 signed in Oslo in June 1994 (emissions must be reduced to 90,000 tonnes of SO_2 in 2000) and the protocol on VOC (30% reduction in 1999 compared to 1985). The projected emission factors are shown in the table in Annex III.

3.1 Emission inventory

Tables 3.2, 3.3 and 3.4 give an overview of the Danish emissions of the main primary greenhouse gasses: carbon dioxide, methane, and nitrous oxide. Further tables 3.5, 3.6 and 3.7 show emissions of the secondary gases carbon monoxide, nitrogen oxides and non methane hydrocarbons (NMVOC). The ozone-layer depletion substances, CFC's etc., regulated by the Montreal - protocol are not included in this communication. Only anthropogenic emissions are included. The 1990 emissions are commented in the text.

The tables comprise some of the final results from calculations done at Risø National Laboratory for the Danish Agency for Environmental Protection in July 1994. The emissions are disaggregated into a number of sectors

consistent with the IPCC format given in the IPCC Draft Guidelines for National Greenhouse Gas Inventories. Table 6A: "Summary report for National Greenhouse Gas Inventories" in the Guidelines has been used as the format for tables 3.1 - 3.7 in this report. An additional line 1A8 has been added to the tables in order to correct for electricity imports/exports. Emissions from international transports (air bunkers and sea bunkers) are not included in the total national emissions but showed separately below the line at the bottom of the tables. Further background information and tables including disaggregation in relation to sectors and fuels can be found in "Inventory of Emissions to the Air from Danish Sources 1972-1992", Risø National Laboratory, 1994.

All emissions from energy combustion is based on the energy statistics from the Danish Energy Agency summarized in table 3.1 and the emission factors in Annex III. The primary energy consumption in 1990 includes 6.1 PJ of wind- and hydro-power.

Primary energy consumption	*1990*	*1991*	*1992*	*1995*	*2000*	*2005*
A Fuel Combustion	685,00	809,02	749,85	788,93	788,71	791,20
1 Energy & Transformation Industries	328,56	431,83	384,24	431,53	440,02	444,41
2 Industry	85,85	90,97	84,55	86,41	81,95	77,49
3 Transport	152,75	160,50	160,99	156,14	160,25	169,62
4 Commercial/Institutional	21,70	23,70	22,80	21,56	20,10	19,00
5 Residential	85,23	91,13	86,36	82,33	75,31	69,47
6. Agriculture/Forestry	10,90	10,90	10,90	10,95	11,08	11,21
7 Other						
International transport	66,40	60,17	62,62	67,12	75,36	84,65
A Air bunkers	26,60	24,63	25,48	27,70	31,85	36,61
B Sea bunkers	39,80	35,54	37,14	39,41	43,52	48,04

Table 3.1. Primary energy consumption in Denmark 1990 - 2005. Unit: PJ.

The sector 1A1: "Energy & Transformation Industries" includes public and industrial power plants, district heating plants and energy consumption from own-energy use at refineries and oil/gas extraction (including flaring). The emissions from power plants varies from year to year because Denmark some years has a large electricity import. Therefore a correction is done in the emission tables in an additional line in the emission tables 1A8: "Electricity import correction", where an emission is calculated as if the net import of electricity was produced at average conditions on Danish power plants.

Sector 1A2: "Industry" includes industrial combustion and the industrial off-roaders. In the Danish statistics energy consumption in agriculture and fishery is included in this sector - called "process. But here energy consumption for off-roaders in agriculture has been transferred to the sector 1A6: " Agriculture/ Forestry" and fishery to domestic transport.

Sector 1A3: "Domestic transport" includes road-, rail-, air- and sea transport (including fishery). The small amount of energy used in military transport is also included. The energy consumption is defined as the amount of fuel sold

inside Denmark. For air- and sea transport international bunkers are not included but shown separately below the double line.

The emission factors for road transport are based on calculations with the COPERT-model for the transport sector which is a background model for the CORINAIR work. The domestic emissions of CO_2 from air transport are based on the energy sold to this sector according to the statistics in the Danish Energy Agency whereas the emissions of the other pollutants from domestic air transport are based on fuel used in the landing/take-off cycles (LTO-cycles) from Danish statistics for type of air crafts and their engine characteristics. This fuel consumption is then subtracted from the total amount of jet-fuel sold in Danish airports in order get the fuel consumption used by international air transport.

In the Danish energy statistics commercial energy consumption is grouped with the residential sector. The emissions in the sector 1A4: "Commercial/Institutional" are calculated with the assumption that this sector consumes 8%, 20%, 33% of the coal, oil, gas respectively of the energy consumption in the residential & commercial sector of the Danish statistics. The rest is allocated to the sector 1A5: "Residential" which includes room heating in agriculture.

3.1.1 Carbon dioxide

Carbon dioxide is the most important anthropogenic greenhouse gas. The total national emissions are shown in table 3.2. The 1990 emissions were 58.4 million tonnes of CO_2. The annual emission from the energy sector (including flaring) in 1990 was 57.2 million tonnes. This includes an electricity import correction of 6.3 million tonnes, since the net electricity import this year was very large (23 % of the consumption). The projection is based on the assumption of zero net electricity import.

Emissions from combustion of refuse like other biomass are not included. The import correction is made by assuming that the imported electricity would have been produced with the current fuels. As recommended in the guidelines the CO_2 emission factors used are based on the assumption that all carbon is oxidised during fuel combustion and released as CO_2.

	1990	1991	1992	1995	2000	2005
Total National Emission of CO_2 in kilo tons	**58353**	**61144**	**60156**	**58765**	**53753**	**52051**
1 All Energy (Fuel Combustion and+ Fugitive)	*57187*	*59785*	*58752*	*57361*	*52349*	*50647*
A Fuel Combustion	57187	59785	58752	57361	52349	50647
1 Energy & Transformation Industries	26435	35596	30505	32974	28523	26783
2 Industry	5964	6380	5878	6185	5962	5746
3 Domestic transport	11241	11812	11846	11491	11785	12474
4 Commercial/Institutional	1465	1584	1509	1413	1298	1214
5 Residential	5022	5327	4950	4488	3960	3600
6 Agriculture/Forestry	807	807	807	810	820	829
7 Other						
8 Electricity import correction	6253	-1721	3257	0	0	0
B Fugitive Fuel Emission						
1 Oil and Natural Gas Systems						
2 Coal mining						
2 Industrial Processes	*1166*	*1359*	*1404*	*1404*	*1404*	*1404*
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals						
D Organic Chemicals						
E Non-Metallic Mineral products	1166	1359	1404	1404	1404	1404
F Other						
3 Solvent Use						
A Paint Application						
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing						
D Other						
4 Agriculture						
A Enteric Fermentation						
B Animal Wastes						
C Rice Cultivation						
D Agricultural Soils						
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste						
A Landfills						
B Wastewater						
C Other						
International transport	4975	4497	4667	5000	5611	6300
A Air bunkers	1915	1773	1835	1995	2293	2636
B Sea bunkers	3059	2724	2832	3006	3319	3664
Increased forest area	-2600	-2600	-2600	-2600	-2600	-2600

***Table 3.2**. Emissions of CO_2 by sector 1990 - 2005. Unit: Kilo tonnes per year.*

	1990	1991	1992	1995	2000	2005
Total National Emission of CH_4 in kilo tons	**406,3**	**408,3**	**408,2**	**381,6**	**354,2**	**353,5**
1 All Energy (Fuel Combustion and+ Fugitive)	*22,7*	*24,7*	*24,6*	*25,7*	*26,0*	*25,3*
A Fuel Combustion	11,5	12,8	12,8	13,9	14,2	13,5
1 Energy & Transformation Industries	1,8	2,8	2,8	3,2	4,0	4,1
2 Industry	0,6	0,7	0,6	0,7	0,6	0,6
3 Transport	2,7	2,7	2,7	2,7	2,3	2,0
4 Commercial/Institutional	0,0	0,0	0,0	0,0	0,0	0,0
5 Residential	6,1	6,6	6,6	7,3	7,1	6,7
6 Agriculture/Forestry	0,1	0,1	0,1	0,1	0,1	0,1
7 Other						
8 Electricity import correction	0,1	0,0	0,1	0,0	0,0	0,0
B Fugitive Fuel Emission	11,2	11,9	11,8	11,8	11,8	11,8
1 Oil and Natural Gas Systems	8,5	8,5	8,5	8,5	8,5	8,5
2 Coal mining	2,7	3,4	3,3	3,3	3,3	3,3
2 Industrial Processes						
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals						
D Organic Chemicals						
E Non-Metallic Mineral products						
F Other						
3 Solvent Use						
A Paint Application						
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing						
D Other						
4 Agriculture	262,0	262,0	262,0	262,0	262,0	262,0
A Enteric Fermentation	137,0	137,0	137,0	137,0	137,0	137,0
B Animal Wastes	125,0	125,0	125,0	125,0	125,0	125,0
C Rice Cultivation						
D Agricultural Soils						
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste	*121,6*	*121,6*	*121,6*	*93,9*	*66,2*	*66,2*
A Landfills	120,0	120,0	120,0	92,3	64,6	64,6
B Wastewater	1,6	1,6	1,6	1,6	1,6	1,6
C Other						
International transport	0,1	0,1	0,1	0,1	0,1	0,1
A Air bunkers	0,0	0,0	0,0	0,0	0,0	0,0
B Sea bunkers	0,1	0,1	0,1	0,1	0,1	0,1

***Table 3.3**. Emissions of CH_4 by sector 1990 - 2005. Unit: Kilo tonnes per year.*

	1990	1991	1992	1995	2000	2005
Total National Emission of N_2O in kilo tons	**10,5**	**10,6**	**10,7**	**11,0**	**11,5**	**12,1**
1 All Energy (Fuel Combustion and+ Fugitive)	*1,9*	*2,0*	*2,1*	*2,4*	*2,9*	*3,5*
A Fuel Combustion	1,9	2,0	2,1	2,4	2,9	3,5
1 Energy & Transformation Industries	0,9	1,2	1,0	1,1	1,0	0,9
2 Industry	0,2	0,2	0,2	0,2	0,2	0,2
3 Transport	0,4	0,5	0,6	0,9	1,5	2,3
4 Commercial/Institutional	0,0	0,0	0,0	0,0	0,0	0,0
5 Residential	0,2	0,2	0,2	0,2	0,1	0,1
6 Agriculture/Forestry	0,0	0,0	0,0	0,0	0,0	0,0
7 Other						
8 Electricity import correction	0,2	-0,1	0,1	0,0	0,0	0,0
B Fugitive Fuel Emission						
1 Oil and Natural Gas Systems						
2 Coal mining						
2 Industrial Processes						
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals						
D Organic Chemicals						
E Non-Metallic Mineral products						
F Other						
3 Solvent Use						
A Paint Application						
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing						
D Other						
4 Agriculture	*8,5*	*8,5*	*8,5*	*8,5*	*8,5*	*8,5*
A Enteric Fermentation						
B Animal Wastes						
C Rice Cultivation						
D Agricultural Soils	8,5	8,5	8,5	8,5	8,5	8,5
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste						
A Landfills						
B Wastewater						
C Other						
International transport	0,2	0,1	0,2	0,2	0,2	0,2
A Air bunkers	0,0	0,0	0,0	0,0	0,1	0,1
B Sea bunkers	0,1	0,1	0,1	0,1	0,1	0,1

Table 3.4 *Emissions of N_2O by sector 1990 - 2005. Unit: Kilo tonnes per year.*

	1990	1991	1992	1995	2000	2005
Total National Emission of CO in kilo tons	**771,0**	**823,8**	**812,5**	**727,0**	**646,6**	**562,3**
1 All Energy (Fuel Combustion and+ Fugitive)	*771,0*	*823,8*	*812,5*	*727,0*	*646,6*	*562,3*
A Fuel Combustion	737,7	781,3	771,4	685,9	605,5	521,2
1 Energy & Transformation Industries	39,0	42,0	46,0	24,9	26,3	26,9
2 Industry	5,8	6,0	5,6	5,8	5,9	6,0
3 Transport	547,2	576,7	563,0	480,1	399,9	325,6
4 Commercial/Institutional	0,5	0,5	0,5	0,5	0,5	0,4
5 Residential	139,4	151,0	150,9	169,6	167,7	157,0
6 Agriculture/Forestry	5,1	5,1	5,1	5,1	5,2	5,2
7 Other						
8 Electricity import correction	0,7	-0,2	0,4	0,0	0,0	0,0
B Fugitive Fuel Emission	33,3	42,5	41,1	41,1	41,1	41,1
1 Oil and Natural Gas Systems						
2 Coal mining	33,3	42,5	41,1	41,1	41,1	41,1
2 Industrial Processes						
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals						
D Organic Chemicals						
E Non-Metallic Mineral products						
F Other						
3 Solvent Use						
A Paint Application						
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing						
D Other						
4 Agriculture						
A Enteric Fermentation						
B Animal Wastes						
C Rice Cultivation						
D Agricultural Soils						
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste						
A Landfills						
B Wastewater						
C Other						
International transport	17,3	15,6	16,4	17,4	19,2	21,2
A Air bunkers	0,7	0,7	0,7	0,7	0,8	1,0
B Sea bunkers	16,6	14,9	15,7	16,6	18,4	20,3

Table 3.5 *Emissions of CO by sector 1990 - 2005. Unit: Kilo tonnes per year.*

	1990	1991	1992	1995	2000	2005
Total National Emission of NO_x in kilo tons	**293,3**	**313,6**	**285,1**	**254,0**	**202,6**	**191,5**
1 All Energy (Fuel Combustion and+ Fugitive)	*292,5*	*312,8*	*284,5*	*253,4*	*202,0*	*190,9*
A Fuel Combustion	292,5	312,8	284,5	253,4	202,0	190,9
1 Energy & Transformation Industries	95,9	139,1	98,0	99,1	75,6	77,4
2 Industry	16,6	17,4	16,4	16,6	16,6	16,6
3 Transport	137,5	142,3	140,5	119,5	92,0	79,3
4 Commercial/Institutional	1,1	1,2	1,2	1,1	1,0	1,0
5 Residential	4,6	5,0	4,6	4,3	3,9	3,5
6 Agriculture/Forestry	12,8	12,8	12,8	12,8	13,0	13,1
7 Other						
8 Electricity import correction	24,0	-5,0	11,0	0,0	0,0	0,0
B Fugitive Fuel Emission						
1 Oil and Natural Gas Systems						
2 Coal mining						
2 Industrial Processes	0,8	0,8	0,6	0,6	0,6	0,6
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals	0,8	0,8	0,6	0,6	0,6	0,6
D Organic Chemicals						
E Non-Metallic Mineral products						
F Other						
3 Solvent Use						
A Paint Application						
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing						
D Other						
4 Agriculture						
A Enteric Fermentation						
B Animal Wastes						
C Rice Cultivation						
D Agricultural Soils						
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste						
A Landfills						
B Wastewater						
C Other						
International transport	71,3	63,4	64,2	68,3	75,5	83,6
A Air bunkers	5,1	4,8	4,7	5,5	55,8	6,7
B Sea bunkers	66,1	58,2	59,5	63,1	69,7	76,9

Table 3.6 *Emissions of NO_x by sector 1990 - 2005. Unit: Kilo tonnes per year.*

	1990	1991	1992	1995	2000	2005
Total National Emission of NMVOC in kilo tons	**165,1**	**167,6**	**165,6**	**162,8**	**139,8**	**119,0**
1 All Energy (Fuel Combustion and+ Fugitive)	*129,2*	*131,7*	*129,8*	*126,9*	*104,0*	*83,1*
A Fuel Combustion	119,5	122,5	121,2	118,4	95,4	74,5
1 Energy & Transformation Industries	1,6	2,2	2,3	2,9	4,6	4,6
2 Industry	1,5	1,6	1,5	1,5	1,5	1,6
3 Transport	105,6	107,4	106,1	101,6	77,0	56,7
4 Commercial/Institutional	0,1	0,1	0,1	0,1	0,1	0,1
5 Residential	8,5	9,2	9,2	10,3	10,2	9,6
6 Agriculture/Forestry	1,9	1,9	1,9	1,9	2,0	2,0
7 Other						
8 Electricity import correction	0,1	0,0	0,1	0,0	0,0	0,0
B Fugitive Fuel Emission	9,8	9,2	8,6	8,6	8,6	8,6
1 Oil and Natural Gas Systems	9,8	9,2	8,6	8,6	8,6	8,6
2 Coal mining						
2 Industrial Processes						
A Iron and Steel						
B Non-Ferrous Metals						
C Inorganic Chemicals						
D Organic Chemicals						
E Non-Metallic Mineral products						
F Other						
3 Solvent Use	33,8	33,8	33,8	33,8	33,8	33,8
A Paint Application	25,5	25,5	25,5	25,5	25,5	25,5
B Degreasing and Dry Cleaning						
C Chemical Products Manufacture/Processing	1,7	1,7	1,7	1,7	1,7	1,7
D Other	6,6	6,6	6,6	6,6	6,6	6,6
4 Agriculture	*2,0*	*2,0*	*2,0*	*2,0*	*2,0*	*2,0*
A Enteric Fermentation						
B Animal Wastes						
C Rice Cultivation						
D Agricultural Soils	2,0	2,0	2,0	2,0	2,0	2,0
E Agricultural Waste Burning						
F Savannah Burning						
5 Land Use Change & Forestry						
A Forest Clearing						
B Grassland Conversion						
C Abandonment of Managed Lands						
D Managed Forests						
6 Waste						
A Landfills						
B Wastewater						
C Other						
International transport	2,7	2,4	2,5	2,7	2,9	3,2
A Air bunkers	0,2	0,1	0,1	0,2	0,2	0,2
B Sea bunkers	2,5	2,3	2,4	2,5	2,8	3,0

Table 3.7 *Emissions of NMVOCs by sector 1990 - 2005. Unit: Kilo tonnes per year.*

Recent years have seen a nearly constant emission from the energy sector, with the largest contribution from the power plants. The development in the emission of CO_2 since the Second World War is illustrated in fig 3.1. The figure shows clearly the significant increase from the late 1950'ies to the early 1970'ies and the stagnation thereafter. The perturbations during the last twenty years originates from import/export of electricity between Denmark and Norway/Sweden.

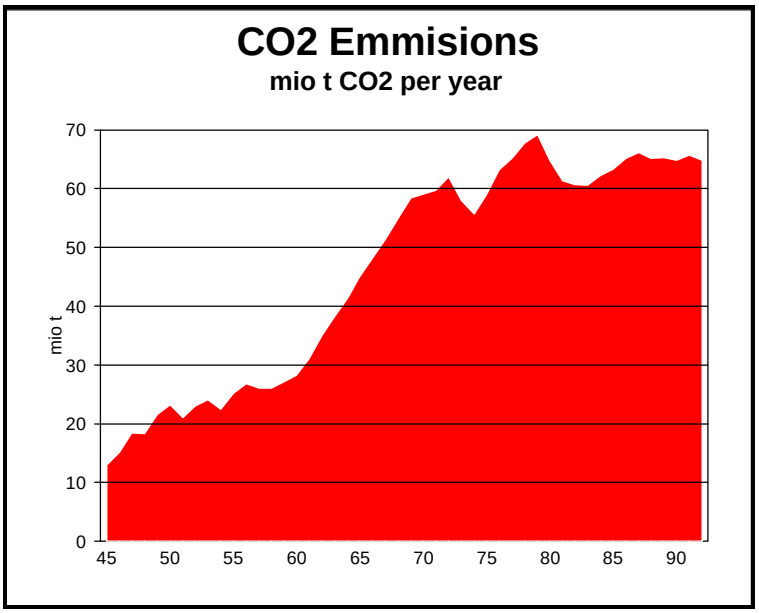

Fig 3.1 *CO_2 emissions from energy consumption, 1945 - 1992. Unit: mill. t CO_2 per year.*

The carbon dioxide emissions from industrial processes were 1.1 million tonnes (Mt) of CO_2 in 1990 dominated by the cement production with a contribution of 1.0 Mt. The rest of the emission from industrial processes originated from the production of burned lime (0.1 Mt) and an insignificant emission from the production of yellow bricks.

Biogenic sinks

The biogenic sources and sinks of carbon dioxide are not so easily accounted for, since they involve the entire biomass with photosynthesis and organic degradation. The changes induced by human activities, however appear to be modest. 2.6 Mt of CO_2 is bound annually in the forests according to the national strategy of doubling the forest area. This sink of CO_2 is not included in the national total but show below the line in table 3.2.

3.1.2 Methane

The anthropogenic emissions of CH_4 is shown in table 3.3. The total emission in 1990 was **406.3 kilo tonnes of CH_4**. Only a minor part (11.5 kt) originate from combustion of fossil fuels. A fugitive emission (section 1B of table 3.3) of similar size (11.2 kt) originates from leakages in the natural gas network (8.5 kt) and from coal storage (2.7 kt). The major part of the emissions comes from agriculture (262 kt) and from waste (121.6 kt).

Gas networks

The emission from leakage of CH_4 from the Danish natural gas network was estimated in "Danish Budget for Greenhouse Gases" from to be 7.9 kt. For the town gas network in Copenhagen the emission was 0.6 kt. Thus the total leakage for gas networks were 8.5 kt of CH_4. These numbers have not been updated and these results are therefore used here for the whole period.

Coal storage

Taking into account the origin of the coal used in Denmark, it was calculated that 40% of the coal originate from underground mining and 60% from

surface mining. Assuming that 50% of the emissions under transport and storage is emitted in Denmark, the "Danish part" of the emission from underground mined coal is 0.55 kg CH_4/t coal and for surface mined coal 0.09 kg CH_4/t coal. With the above mentioned underground/surface fractions the average emission factor is 0.27 kg CH_4 per tonne of coal. This emission factor has been used for the period 1990 - 1992, since there have been only minor changes in the distribution of coal import by countries in this period. In table 3.8 the total emissions are calculated based on the coal import data from the Danish Energy Agency. The coal import is not corrected for electricity import. The 1992 value was used for the projection to 2005. This is an overestimation since the projection used result in a 44% reduction in the coal consumption by 2005 compared to 1992.

Year	*Coal import, mill. tonnes*	*CH4 emissions, ktCH4*
1990	9,8	2,7
1991	12,5	3,4
1992	12,1	3,3

Table 3.8 *CH_4 emissions from coal storage in Denmark 1990-1992.*

Agriculture

The emissions from agriculture related activities were estimated in "Danish Budget for Greenhouse Gases" sources to bee due to enteric fermentation (137 kt) and digestion (125 kt). Some reduction will follow automatically by the current reduction in livestock (6 kt), but the possibilities of biogas production from manure should be investigated. This will at the same time produce energy and convert methane to the weaker greenhouse gas carbon dioxide. However due to the large uncertainty in these numbers they were kept constant for the whole period.

Landfills

Methane emission from landfills is estimated to 120 kt in 1990 by an emission factor of 29 kg CH_4 per ton waste and an amount of landfilled waste of 4.1 million tons. The projection was based on the Danish Government's Action Plan for Waste and Recycling mentioned in chapter 5.1.3., where the percentage of waste landfilled will be reduced from 39% now to 21% in 2000.

Wastewater

In "Danish Budget for Greenhouse Gases" a tentative estimate of 1.6 kt of CH_4 emissions from wastewater was given. The emission factor used was 0.8 kg CH_4 per tonne of waste water. These numbers have not been updated and are therefore used here for the whole period.

3.1.3 Nitrous oxide

The total anthropogenic emissions in 1990 was 10.5 kt N_2O, where 8.5 kt originate from land use and 2.1 kt from energy combustion (including an electricity import correction of 0.2 kt).

Agriculture

Only the anthropogenic emissions are included, defined as emissions from cultivated land, the total is 8.5 kt as shown in table 3.9. The emission factors used is based on the recommended IPCC value where 1% of the nitrogen in the used fertilizer is emitted in the form of N_2O. The unit is kt of N_2O. The understanding of the relation between the use of various nitrogen fertilizers and formation of nitrous oxide is however, modest. Further research is needed, especially to establish the importance of anhydrous ammonia.

	Area	*Emissions factor kg N2O per ha.*	*Emissions kt N2O*
Cultivated land	*2.227.000,00*	*3.049,00*	*6,80*
Fertilized grassland	*328.000,00*	*4.714,00*	*1,50*
Other grassland	*219.000,00*	*0,93*	*0,20*
Total			*8,50*

Table 3.9 *Annual anthropogenic N_2O emissions from agriculture.*

3.1.4 Other emissions

In principle almost all emissions to the atmosphere can influence the greenhouse effect via chemical reactions in the atmosphere, but three deserves a closer attention:

- Carbon monoxide reacts with hydroxyl radicals and thereby prevents the oxidation of methane,
- Nitrogen oxides, which together with
- Volatile Hydrocarbons and sunlight produce the greenhouse gas Ozone.

Carbon monoxide

Carbon monoxide is produced by incomplete combustion. The total emission in 1990 was 771.0 kt of CO (see table 3.5). The major part originate from fuel combustion (737.7 kt), where transport is responsible for the major part of the emission (547.2 kt). The introduction of 3-way catalytic converters is the measure responsible for the major part of the reduction to 325.6 kt in 2005. Residential burners are the second major emitter with 139.4 kt . Table 3.5 also includes an CO emission from coal storage of 33.3 kt.

Coal storage

Under coal storage some of carbon is partially oxidized to CO by the oxygen in the atmosphere. An estimated loss of 0.18 % in calorific value of the coal by storage can be attributed to this process - corresponding to an emission factor of 3.4 kg CO per tonne of coal. The 1992 value is used for the projection.

Year	*Coal import mill. tonnes*	*CO emissions kt CO*
1990	9,8	33,3
1991	12,5	42,5
1992	12,1	41,1

Table 3.10 *CO emissions from coal storage in Denmark.*

Nitrogen oxides

The total emission in 1990 was 293.3 kt of NO_x (see table 3.6). The emissions of nitrogen oxides are closely related to the use of fossil fuels in the energy and transport sectors. The total emission from fuel combustion was 292.5 kt. The electricity import correction in 1990 was 24 kt. The only other source of NO_x is nitric acid production, which in 1990 contributed with 0.8 kt falling to 0.6 kt in 1992. This value was used for the projection.

NMVOC

The emissions of non methane volatile organic compounds (NMVOC) from anthropogenic sources is estimated to be 165.1 kt (see table 3.7) with major contributions from transport (105.6 kt). The introduction of 3-way catalytic converters is the main measure reducing this part to 56.7 kt in 2005. Solvent evaporation is estimated to contribute with 33.8 kt.

The ECE Convention

Denmark is in accordance with the ECE-protocol to the 1979 Convention on long-range transboundary air pollution concerning the control of emissions of VOC or their transboundary fluxes committed to reduce the emissions of

VOC to 112 k. ton before the year 2000. The projections shown in table 3.7 must be seen as a baseline scenario only.

HFC's

With the aim of phasing out the use of CFC's as fast as possible - at an even faster rate than prescribed by the Montreal-Protocol - the Danish environmental authorities accept HFC's to be used to replace CFC's in some areas. The areas in question are primarily the production of some types of refrigerators and freezers where the assessment of risks and the regulation by the authorities is excluding the use of other substances. In 1990 the use of HFC's was marginal but it has increased to approximately 300 tonnes in 1993.

3.2 Inventories of reservoirs and sinks

3.2.1 Forest sector

The forest area is here defined as the area covered with trees. This mean, that open areas within the forest are not included.

The prognosis in figure 3.2 is made under the following assumptions. Air pollution, fires, diseases of trees will not reduce the area, but the wood species may change. The strategy of doubling the forest area within a forest rotation period will be followed. Afforestation will gradually reach 40 km^2/year as the interest in private afforestation increases and as the appropriations for national afforestation assumably rises. The maximal afforestation rate will be reached around year 2020.

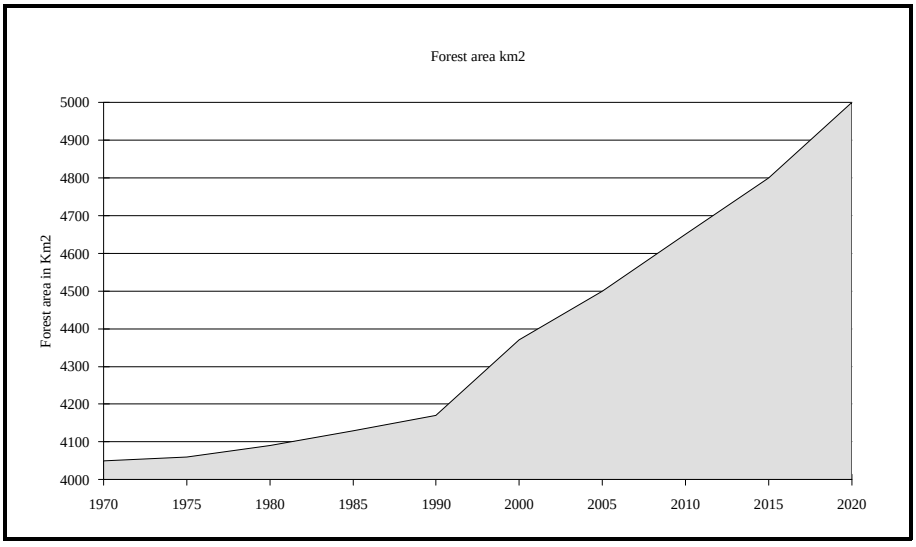

Fig. 3.1. *Forest area, historic and future development, 1970 - 2020. Unit km^2 (the years 1980 and 1985 are not measured but interpolated).*

Present levels of carbon

The growing stock volume has been measured in differently in 1977 and in 1990. The 1990 inventory on growing stock volume is not compatible with previous inventories due to a change in method for assessing the total volume. The estimate from 1990 is based on standard production levels on different kinds of soil. This method gives a total volume of 55,154,000 m^3. There is no inventory of the increase in the volume of standing stock in the period 1975-1990.

The average volume per km^2 is 13,200 m^3/km^2 in 1990. Conversion factor: 1 m^3 broadleaf species equals 0.30 t C, and 1 m^3 conifers equals 0.19 t C.

Carbon levels

The following assumptions are made as a basis for the calculation of C fixed per ha . The total volume of broadleaf species in 1990 is 23,917,000 m^3 and 31,237,000 m^3 conifers. This gives an average of 0.24 t C/m^3 and round 3,000 t C/km^2.

The annual increment in the period 1990 to 2000 is estimated to be on an average 3,753,000 m^3/year and round 800 - 900 m^3/km^2/year. This equals 180 - 210 t C/km^2/year (factor 0.24 t C/m^3).

Annual fellings/removals based on 1990 are 480 m^3/km^2/year and 110 t C/km^2/year.

Net change in growing stock

It is not possible to determine the net change based on the available data but there has been a net accumulation of biomass.

	t C/km²
Biomass in growing stock above ground	3,000
Biomass below ground	3,000
Total	6,000

***Table 3.11**. Biomass above/below ground, 1990:*

In connection with afforestation the fixation in the growing stock is round twice as big as in the rest of the biomass. In old growth forest the fixation is assumed to be the same both in growing stock and in foliage, brushwood and humus.

Options to increase carbon fixation in forests

Increased afforestation

The annual afforestation rate has been round 8 km^2/year by the national authorities. The private afforestation with subsidies has been about 1 km^2/-year, and the private afforestation without any subsidies is estimated to be round 10 km^2/year. These levels include both areas covered with trees and open areas in the forest. In connection with carbon fixation the area covered with trees is the interesting factor. Therefore the annual afforestation rate is estimated between 10 and 15 km^2/year. It is expected that the rate will rise gradually, as it is still the aim to double the forest area i Denmark within a tree rotation. This means round 4000 km^2 over 80-100 years and about 40 km^2 per year.

On the basis of the assumption of doubling the forest area within the next 80-100 years the following binding of CO_2 can be expected. Within the next 30 years the binding will be small. After 70-120 years after the forest is planted the binding will reach its highest level corresponding to a annual fixation of approximately 3.5 mill. tons of CO_2 or approximately 5% of present annual manmade emissions in Denmark.

Extension of rotation period

Increasing the forest biomass by extension of the rotation periods will not in the long turn maximize the binding of carbon. A middleaged forest in good growth is fixing more carbon.

Extension of rotation periods will give additional time to solve the problems about emissions but it does not give permanent additional binding of carbon. Even though afforestation does give additional binding of carbon it does not solve the increasing emission problems but it gives some time to find solutions.

Options of wood/timber utilization

	m^3/year
Fuelwood	305,500
Industrial wood and residues	937,400
Trunk wood	775,100
Total amount used	2,018,000

***Table 3.12**. Utilization of wood and timber, 1990.*

Concerning a prognosis for the next decades, Denmark is supposed to deliver an estimate (UN Timber Committee, European Timber Trend Study V), but the data are not available yet. Within the next 10-20 years the amount of wood for energy purposes will rise and the amount of wood for pulp and paper will fall. The quality of the trunk wood on some of the existing forest area is low and in connection with demands from the industries for better qualities the amount of wood sold as trunk wood will decrease in the future.

3.2.2 Agricultural sector.

Land used agriculturally

In 1992 the total arable area made up 27,600 km^2, which is about 65% of the total area of Denmark. The distribution of agricultural area by type of crop is given in table 3.13.

Since the 1930's the arable area has decreased by about 10 %. Part of this land is used for infrastructure and municipal development. During the later years agricultural land has also decreased due to afforestation and environmental measures.

Also permanent grassland has decreased by about 10% during this period, whereas annual crops have increased.

Due to the Agricultural Policy reform of the European Union 2000 km^2 of arable land has been set aside every year in order to reduce the production. This land may be used for non-food production.

According to the Action Plan for Sustainable Development in Agriculture arable land is expected to decrease further, by between 2,500 and 4,500 km^2 within the next 15 years. Land needed for municipal development and infrastructure, and will still be marginal land will be set aside or taken out for other environmental reasons. It is not expected that the use of the arable land will change considerably.

Biomass in agricultural ecosystems

During the last 30 years, there has been a considerably increase in the production of biomass in the agricultural ecosystem, due to a change in

agricultural practice and with that an increase in the use of fertilizer, especially nitrogen as shown in fig 2.4 at page 19.

It is difficult to give an exact measure of the production in the agricultural ecosystem, as it is closely related to climate conditions. In table 3.13 an average for the crop production for the last four years is given.

Crop	*Fresh weight*	*Dry matter*	*Dry matter in %*
Cereals	8,647	7,350	85
Rape	645	587	91
Pulses	437	371	85
Straw	3,535	3,005	85
Roots	10,854	2,388	22
Tops	2,258	339	15
Grass and green fodder	15,328	3,066	20
Total	41,704	17,106	

Table 3.13. *Crop production in Denmark taken as an average for the last four years, 1989-1992. Unit: 1000 tons.*

On the basis of the figures the total dry matter crop production in Denmark is about 17 mill. t.

It is supposed that root, straw etc. (left in field) make up at least 1/3 of the crop production. With this added to crop production it gives an approximate estimate of biomass in the Danish agricultural ecosystem of 23 mill. t which correspond to 820 t/km^2.

Possibilities in the agricultural sector to store CO_2 and reduce other greenhouse gases

Carbon dioxide, CO_2

In the cultivated soils humus masses makes up 2-5% of the top soil, depending on the type of soil and crop. The humus mass in soil seems fairly constant, though it has been slightly reduced by intensive farming during the last 30-40 years.

There might be a few possibilities to increase the humus mass slightly in some fields, though an increase will be very slow, and only be within the limits of the natural capacity of the soil. The most important factor for an increase is a constant high input of organic material.

It is not likely that a possible change in humus mass can be of such dimension that it is significant to storing CO_2.

Nitrous oxide, N_2O

The emission rate of nitrous oxide from cultivated soil depends on a complex array of factors like soil structure, pH, climate, crops, C content of the soil, water status, and amount and kind of N fertilizer.
The possible impact on emissions by changing these factors is not well known.

Possibly the most effective way to influence emissions is a general low nitrogen input to the soil and better use and handling of fertilizer, especially manure.

In Denmark several measures have been taken to improve handling and utilization of manure and to decrease the total nitrogen input to the soil. Certain rules for application of manure and the utilization of nitrogen in the manure are established. Standards for nitrogen need for the different crops are defined and the total application of nitrogen is not allowed to exceed the calculated need based of these standards, also taking into account that the nitrogen in manure shall be utilized to a certain minimum.
The total amount of N fertilizer used has decreased by about 8% from 1989 to 1992.

Methane, CH_4

In the agricultural sector methane is produced by enteric fermentation in the digestive tract of ruminants. The methane production is dependent on the amount and quality of the ingested diet and the weight of the animal. Methane emission from cattle, can be reduced by increasing digestibility of the diet. But the diet of a Danish dairy cow usually has a high digestibility.

Methane emission can also be reduced by reducing the number of cattle. During the last 10 years the number of cattle has been reduced by 24% and a further reduction is expected.

In Denmark sheep are of no importance in relation to the methane emission as their number is very small.

Manure

Manure from livestock also contributes to methane emissions especially when kept under anaerobic conditions in e.q. liquid manure tanks. About 75% of the manure from Danish farms is stored in that way. Further research is needed to explore the possibilities to reduce the emission.

3.2.3 Agricultural fuel production

Agriculturally produced raw material for energy purposes is expected to be an important potential for the future. But further investigations, research and development is needed, before this potential can be determined and exploited fully.

It is presently estimated that the cost of substituting one ton of CO_2 emission from energy production from fossil fuel is in the range of 300-400 DKK.

The full utilization of the potential are closely related to existing agricultural and energy policies. It is presently not attractive for farmers to engage in production solely for energy purposes due to existing price levels on products for other purposes and taxation on energy produced from this resource. The production for energy purposes has, however, been made more attractive to farmers under the EU set aside scheme.

The technological and economic issues are presently being reviewed by a joint task force from the Ministry of Energy, the Ministry of Environment and the Ministry of Agriculture.