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NATURAL RESOURCES AND THE ENVIRONMENT 1989

STATISTISK SENTRALBYRÅ
CENTRAL BUREAU OF STATISTICS OF NORWAY

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NATURAL RESOURCES AND THE ENVIRONMENT 1989

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ANDRE EMNEORD
Forurensning
Naturmiljø
Miljø-økonomi
Utslipp

P R E F A C E

The Central Bureau of Statistics elaborates environmental statistics and accounts for selected natural resources. The Central Bureau of Statistics also develops methods and models to analyse the interrelationship between socio-economic development, resource use and pollution. The publication *Natural Resources and the Environment* gives an annual survey of this work. This report is a complete translation of the annual publication for 1989.

Natural Resources and the Environment 1989 presents updated resource accounts for energy and fish and accounts for emissions to air, in addition to summaries of analyses based on these accounts. The report also contains analyses of agricultural pollution and forest damage.

The Central Bureau of Statistics wishes to thank those institutions which have contributed in the collection of data to Natural Resources and the Environment 1989.

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Senior executive officer Frode Brunvoll and junior executive officer Anne Strandli have been responsible for editing the publication.

Central Bureau of Statistics, Oslo 18. April 1990.

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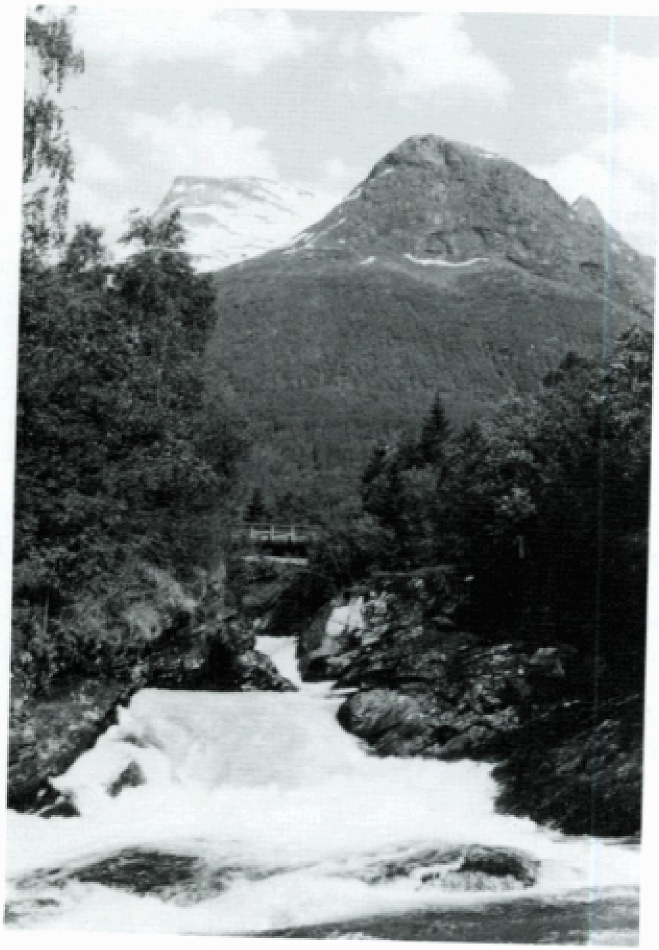

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Explanation of symbols in tables:

. Category not applicable
.. Data not available
- Nil
0 Less than 0.5 of unit employed
* Provisional or preliminary figure

The denomination **ton** in this publication is equivalent to metric tons (tonnes).

Institutions referred to in this report:

BP British Petroleum Company
ECE Economic Commision for Europe
FAO Food and Agriculture Organization (UN)
IIASA International Institute for Applied Systems Analysis
ICES International Council for the Exploration of the Sea
IEA International Energy Agency
MD Ministry of the Environment
NIJOS Norwegian Institute of Land Inventory
NILU Norwegian Institute for Air Research
NISK Norwegian Institute for Forest Research
NLH Norwegian Agricultural University
NPI Norwegian Petroleum Institute
OD Petroleum Directorate
OECD Organisation for Economic Co-operation and Development
OED Ministry of Oil and Energy
OPEC Organization of Petroleum Exporting Countries
SAF Center for Applied Research
SEFO Center for Commissioned Research
SFT The State Pollution Control Authority
SSB Central Bureau of Statistics
TØI Institute of Transport Economics

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1. INTRODUCTION AND SUMMARY

The Central Bureau of Statistics has elaborated accounts for selected natural resources and provided analyses of resource- and environmental issues since 1978. The natural resource accounts give an overview of the resource base, extraction and use of various resources. In addition to providing a status, the accounts form the basis for analyses and evaluations of present and possible future management of natural resources. The Central Bureau of Statistics also provides information and analyses of pollution resulting from economic activities.

Some of the greatest environmental challenges are global or international in character, such as the problem of greenhouse gases, the depletion of the stratospheric ozone layer, acid precipitation and pollution of the sea. In these areas, Norway can only contribute to the solutions by international cooperation. Norway has taken an active part in establishing international agreements, e.g. on reductions of emissions of sulphur dioxide, nitrogen oxides and CFCs (chlorofluorocarbons) and through conventions of the sea.

Other resource and environmental problems are national or local in character, and we shall have to solve these ourselves. It is easy to point to Norwegian resource and environmental problems which have been managed with poor insight and a certain lack of foresight. Candidates for criticism are both the management of Norwegian natural resources such as fish and hydropower, and of pollution from agriculture, manufacturing industries and transport. This does not mean, however, that Norwegian policies have been inferior to the policies of other countries. The examples below are not selected to draw a sinister picture of Norwegian resource- and environmental policies, but to indicate that prudent environmental policies might also lead to efficiency gains in the Norwegian economy.

Several economically important fish stocks in Norwegian waters are seriously diminished. With extensive use of modern technology, the catch has to be regulated to avoid overharvesting. However, a rich resource base, combined with regulations, should make it possible to provide a relatively stable long term yield in the industry, although natural variations in the various stocks will always give some fluctuations in profitability. Instead of providing a rent, the industry has gradually become heavily subsidized. This unfortunate situation is a result of several factors. The resource base has fluctuated and researchers have for some years based their recommended catch quotas on too optimistic stock assessments. The management of fish resources has to a large extent been based on partial assessments of single species, without due attention to the ecological interrelationship between species. Unregistered catch might also have led to statistics on delivered quantities which have given false information on actual take. The authorities have tried to pursue other goals than efficient management of fish resources, and have contributed to the problems by subsidizing an overcapacity in the fishing fleet.

The present utilization of Norwegian hydropower resources is not in accordance with theoretical principles. The "mismangement" is in this case related to wrong investment and pricing policies. The long term marginal cost of expanding hydropower capacity has not been compared with the willingness to pay, and the result is that the capacity has been expanded too rapidly. In 1989, the price of electricity varied between 4 and 60 øre for different consumer groups. Electricity is not a homogeneous product, since costs of transmission and distribution and user time vary between consumers. The differences in purchaser prices are far higher, however, than the differences in costs due to differences in transmission, distribution and user time. Large price differences within the same group of end users do not indicate an efficient utilization of the resource.

Air pollution is highly correlated with consumption of fossil fuels (coal, oil and gas). Environmental policies must therefore be concerned with management of energy consumption or reductions of emissions, directly or through the price mechanism. Last year, prices of fossil fuels were low compared with prices of electricity, making it profitable for many consumer groups to use oil instead of electricity for heating purposes and in industrial processes. At the same time, water supply equivalent to 6 TWh passed the production system, although turbines and idle transmission capacities were available.

In the agricultural sector, intensive and specialized production have led to an increased pressure on the environment. Specialized production and "cheap" fertilizers have resulted in eutrophication of inland waters and estuaries. Agriculture has (together with sewage) contributed to excess runoff of nutrients to the North Sea. As in the examples above, it is likely to be much cheaper to envisage and prevent problems than to repair the damage afterwards. The mismanagement in the agricultural sector can be modified by pricing inputs "correctly", to internalize environmental costs. Clean up projects have so far incurred costs amounting to billions of NOK.

The petroleum resources on the Norwegian continental shelf were discovered relatively recently, which has made it possible to draw on the experience of others. The dimensions of the petroleum resources are large compared with the size of the Norwegian economy. It has therefore never been regarded as a viable policy option to leave the exploitation to the market, or to be satisfied with marginal regulations. The authorities have regulated the production level by licensing and own investments, and have collected a major part of the revenues via ownership or taxation. The prices to different consumers have been decided by prices in international markets for oil and gas. The disputes have been on the escalation and level of production, on the intertemporal decoupling of fluctuating incomes and income spending and on the priorities chosen in the use of incomes.

The exploitation of natural resources differs from ordinary production. The resource might be depletable, the sustainable yield might be dependent on the annual take, there might be economies of scale in exploiting the resource or negative externalities such as pollution or amenity degradation connected to extraction or use of the resource. Such considerations are the reasons why the exploitation of natural resources cannot efficiently be left to an unregulated market, but it is not always easy to specify the regulations or other market interventions which are most appropriate. The challenges vary by resource category, and theories cannot always give simple and robust answers to how problems should be solved. This report discusses some of the issues raised above.

Summary

Chapter 2 presents an overview of Norwegian energy reserves, and of domestic extractions and use of energy. Changes in energy consumption are discussed in the light of macro-economic developments, changes in the price of electricity and oil products, and changes in the industrial structure. Developments on the international oil market are described briefly. This chapter also raises the question of how to estimate petroleum wealth, and discusses different principles for managing oil and gas resources. The fall in oil prices in 1986 showed that previous expectations of incomes and estimates of petroleum wealth had been far too optimistic. Income spendings linked more directly to the estimated petroleum wealth would have created serious imbalances in the Norwegian economy. The calculations illustrate that one should be extremely cautious in basing the management of petroleum resources on undifferentiated calculations of wealth and return based on expectations reflecting simple trends in observed market prices.

Hydropower production was record high in

1989, reaching 119 TWh. A large share of the power, 15 TWh, was exported. In addition, water equivalent to 6 TWh passed outside the production system. There was a large increase in oil and gas production in 1989 to 106 million tons oil equivalents; an increase of 23.5 per cent compared with 1988. Together with increased oil prices, this led to a strong increase in revenues from petroleum activities. During the period 1976-1987, total energy consumption in Norway, excluding the energy sector and ocean transport, increased by an average of 2.1 per cent per year. During the period 1987-1989, however, consumption dropped by an average of 1.9 per cent per year. According to preliminary figures, total domestic energy consumption was 743 PJ in 1989, which represents a decrease of 1.1 per cent in relation to 1988.

Chapter 3 presents the resource account for fish, including information on changes in fish stocks, quotas and the size of the catch in 1989, as well as figures for exports of fish products and reared salmon. In 1988 and 1989 the spawning stock of Norwegian spring spawning herring was larger than for many years, but is totally dominated by one specific year class. The capelin stock in the Barents Sea is increasing slightly, but still does not justify fishing. The cod stock is now assessed as very low, and the quota for 1990 is record low. The total catch in Norwegian fisheries was slightly higher in 1989 than in 1988, but the first-hand value has decreased by about 6 per cent. The export value of fish products increased by about 3 per cent from 1988 to just over NOK 11 billion. The exported quantity of reared salmon increased by 45 per cent in relation to 1988, but the export value increased by only 13 per cent.

Capital 4 describes the status of Norwegian forest, and more or less corresponding calculations for the Federal Republic of Germany. The forest status has changed only slightly since 1988. A slight decrease has been observed in the average defoliation. In 1988, the average defoliation was 16.4 per cent for both spruce and pine. In 1989, the defoliation had decreased to 14.9 per cent for spruce and to 14.3 per cent for pine.

Chapter 5 starts with a discussion of agricultural land and land resources. It also discusses agricultural pollution, with emphasis on nutrients. New figures from the State Pollution Control Authority indicate that agriculture is responsible for about 50 per cent of nitrogen emissions and 27 per cent of phosphorus emissions from Norway to the North Sea. The effects of various pollution control measures, such as reducing the fertilization intensity, introducing a minimum area requirement for spread of manure, and cultivation of meadow in areas with high erosion hazard are discussed on the basis of results from the simulation model SIMJAR. The calculations show that a 30 per cent reduction of nitrogen fertilization would reduce nitrogen runoff from grain areas by 30 per cent and from meadows by 45 per cent. This would reduce the crop by about 10 per cent in the short term. The farms that will be most affected by the introduction of a minimum spreading area of 4 decares per animal manure unit, as now decided, are pig and poultry farms. Changing from open grain area to meadows can reduce phosphorus runoff by up to 40 per cent in areas with high erosion hazard.

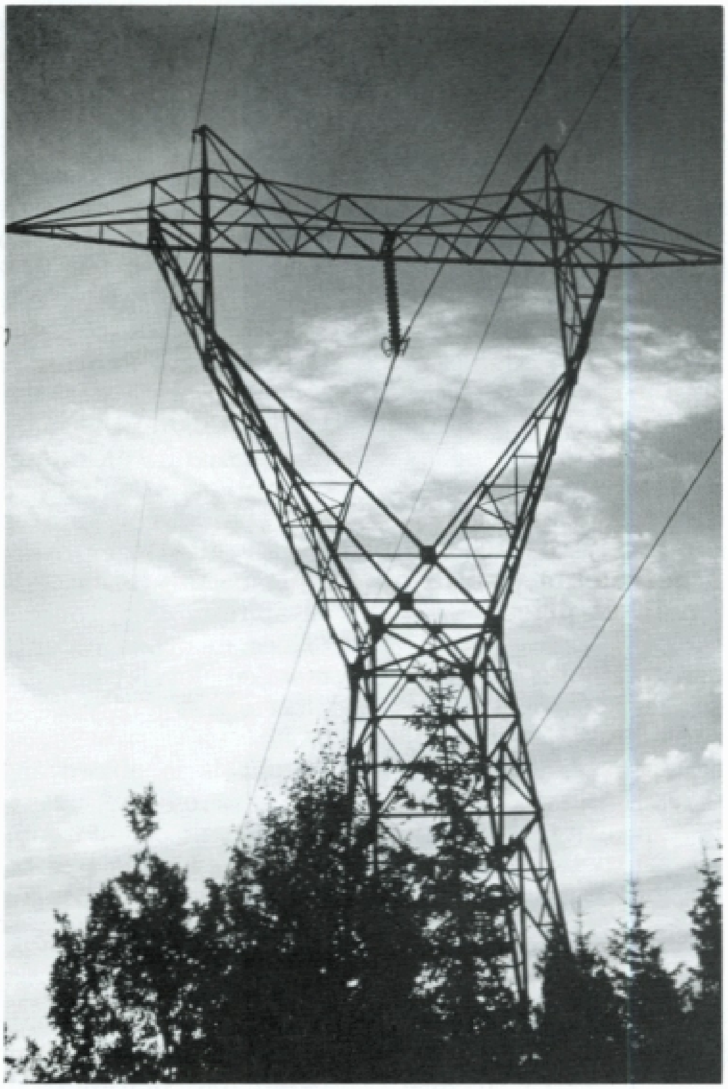
Chapter 6 discusses how economic activities influence emissions to air and the quality of the air. It presents an overview of trends in emissions to air of a number of pollutants in Norway as a whole over time.

Mild winters and a relatively low level of economic activity in the last few years has helped to stop the increase in emissions to air. Sulphur dioxide emissions and concentrations of sulphur dioxide in urban air are the lowest since the 1970s. The increase in nitrogen oxides and carbon dioxide emissions has stagnated in recent years. In spite of this, concentrations of nitrogen oxides in urban air still exceed the recommended levels for air quality in many places.

Emphasis is placed on studying the effect of taxes on the use of fossil fuel as an instrument of environmental policy. In one alternative the level of the tax is decided on the basis of calculations of the negative impacts of the emissions (health injuries, corrosion, acidification, etc.). In another alternative the tax is fixed so as to achieve the objective of stabilizing CO_2-emissions. The introduction of an environmental tax based on marginal damage implies an average increase of 75 per cent in the price of oil products by the year 2000. The calculations show that such a tax would give a 25 per cent reduction in SO_2-emissions and a 23 per cent reduction in CO_2-emissions by the year 2000. At the same time, the consequent reduction in environmental costs will give a gain of more than NOK 10 billion a year (1986 kroner). This gain would compensate for some of the loss in gross domestic product, estimated at NOK 14 billion.

Introduction of a tax with the objective of stabilizing CO_2-emissions after the turn of the century will imply that the oil price in year 2010 will be about twice as high as in a development path without the upper limit on CO_2-emissions. Such a tax will cause changes in energy consumption and the production structure. It is calculated that the value of the environmental improvements will amount to nearly NOK 20 billion (1986 kroner) in the year 2010. This goes a long way to compensate for the loss in production, which is estimated at NOK 27 billion.

The chapter presents projections of emissions to air in Europe. Calculations of how transferring funds to Poland and the German Democratic Republic to clean the emissions would affect sulphur depositions in the Nordic countries indicate that it is much more cost-effective to clean in Eastern Europe than in the Nordic countries. The chapter concludes with a section on the greenhouse effect, with emphasis on the contributions made by the different gases to this global environmental problem.



2. ENERGY

Hydropower production was all time high in 1989, as much as 119 TWh. At the same time the domestic demand for energy stagnated, mainly due to a mild winter. Excess domestic supply of 15 TWh was exported at low prices. In addition, water corresponding to 6 TWh passed outside the production system. Energy-intensive industry is offered long-term contracts for electricity at prices far below the cost of developing new power, but the price of electricity for regular domestic consumption has not been reduced.

Norwegian oil production increased sharply in 1989. Total production of oil and gas reached 106 million tons of oil equivalents. Crude oil prices increased, and contributed to an increase in the revenues from petroleum activities. The oil rent, which is a measure of the excess return on production of oil and gas, increased from about NOK 900 million in 1988 to just over NOK 20 billion in 1989.

An important element in the management of oil and gas resources is the estimated value of the Norwegian petroleum wealth. This term is discussed and analyzed in a special section of this chapter. The analyses point out, inter alia, that, taking into account the generally expectations of high oil prices during the 1970s and at the beginning of the 1980s, there is little reason to assert that the country used too much of the petroleum revenues. However, the fall of oil prices in 1986 indicated that the expected revenues and the estimates of the petroleum wealth had been far too optimistic. If the use of revenues had been more directly linked to the (high) estimates of the petroleum wealth, this would have created serious imbalances in the Norwegian economy. This chapter devotes particular attention to the (proposed) rule of management based on using the annual real return on the petroleum wealth for domestic consumption. It shows how, during the 1980s, this would have led to a serious deterioration of the Norwegian balance of trade and debt status. The analysis shows that one should be very careful to base the management of the petroleum wealth on simple estimations of wealth and return based on observed market prices.

2.1. Hydropower

Hydropower reserves

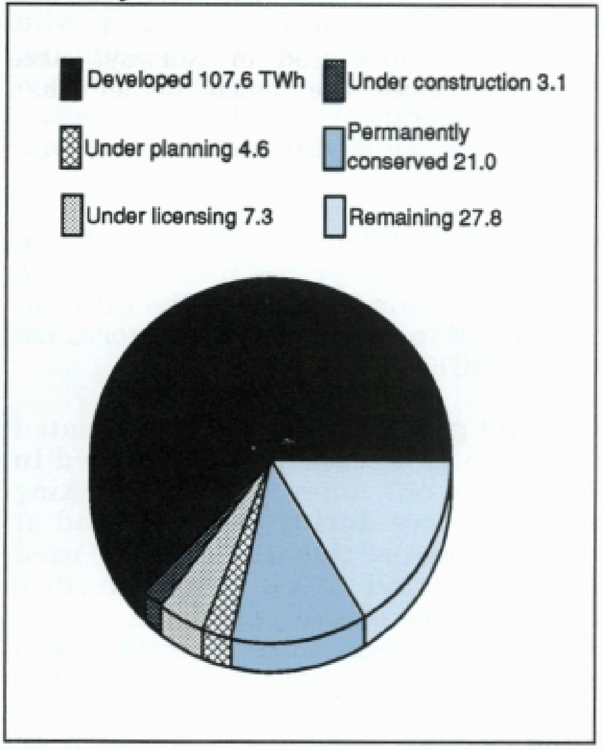
The hydropower reserves can be placed into four groups:

- Watercourses that have been developed for hydropower.
- Watercourses that are under construction or are under licensing
- Remaining watercourses in the "Master Plan for Water Resources"
- Protected watercourses.

Figure 2.1 shows that, per 1 January 1990, Norway's total economically exploitable hydropower resources amounted to 171.4 TWh. This figure includes permanently protected watercourses with a power potential of 21.0 TWh. Per 1 January 1990, hydropower resources had been developed with an average power potential of 107.6

TWh. This is 2.2 TWh higher than at the turn of the year 1988/89. The average production potential expresses the production capacity of the power plants in a year with normal precipitation. Undeveloped hydropower resources, excluding permanently protected watercourses, accounted for 42.8 TWh per 1 January 1990. Of this amount, about 15 TWh was under construction, under licensing, or under planning.

Figure 2.1. Potential hydropower reserves. 1 January 1990. TWh



At the turn of the year, the total reservoir capacity in the Norwegian hydropower system was just less than 79 TWh. For most of the year the reservoirs were filled to a far higher level than the average for the last ten years. The reason was heavy precipitation. In April the reservoirs were filled to about 50-55 per cent capacity, while the normal is about 30 per cent. Towards the end of the year the percentage filled capacity was still slightly above normal. At the turn of the year 1989/90 the reservoir holding was 59 TWh, which corresponds to a percentage filled capacity of about 75 per cent.

Hydropower production and the energy market

In 1989, the production of electricity (hydropower and thermal power) was 119.2 TWh. Therefore a new production record could be noted for the second year running, since production was as much as 9.2 TWh higher than in 1988. This was the third year running with a large increase in electricity production, after a decline in production from 1984 to 1986, see table 2.17 (in appendix of tables).

Gross domestic consumption of electricity was about 104 TWh in 1989; about 30 TWh firm power to energy-intensive industry, 59 TWh firm power to regular consumption and 4.5 TWh surplus power to electric boilers and pumping plants. About 10 TWh was lost in the transmission and distribution network, and 15.2 TWh was exported. Of this amount, 11.2 TWh was exported to Sweden, 3.8 TWh to Denmark and 0.2 TWh to Finland. In 1989, about 0.3 TWh was imported from Sweden. The main reason for the huge excess domestic supply electricity in 1989 was good flow of water to the reservoirs throughout 1989. Another, but less important reason, was lower demand because of high temperatures. In 1989, the export value of the electricity was about NOK 900 million. The import value was NOK 37 million.

In 1989, the Norwegian hydropower system had the capacity to produce about 104 TWh firm power at normal precipitation. Adjusted for temperature, the consumption of firm power was about 101 TWh. That is, in a year with normal temperatures the consumption would have been about 3 TWh higher than the actual consumption in 1989. If the temperature-adjusted firm power consumption is compared with the firm power production capacity, there is a certain surplus on the market at present prices. The surplus of 3 TWh covers two years gross increase in consumption, given the same rate of increase as in recent years.

Use of surplus power

In 1989, water equivalent to 6 TWh passed outside free production capacity. There were also surplus transmission capacity. The main reason for this waste of resources is the inflexibility of prices in the Norwegian electricity market. Electricity in excess of firm power is sold on the market for surplus power. However, only a small share of Norwegian consumers have access to this market. In spite of the surplus electricity, the purchasing price of firm power for regular consumption increased by an average of 3.5 per cent from 1988 to 1989.

Table 2.1. Electricity balance[1] 1989. Change 1975 - 1989

	1989 TWh	Average annual percentage change 1975-1988	1988-1989
Production	119.2	2.7	8.4
+Imports	0.32	4.4	-82.4
-Exports	15.2	2.0	105.4
=Gross dom. prod.	104.3	2.9	-0.1
-Consumption in pumping plants	0.5	19.4	-50.0
-Surplus power	5.0	2.7	11.1
-Losses in exports and surplus power	1.4	0.0	75.0
=Gross firm power consumption	97.4	2.9	-0.7
Energy int. ind.	31.2	0.9	2.6
Regular consumpt.[2]	66.2	4.0	-2.2
-Losses in the transmission lines, cons. in the power stations, stat. diff.	8.9	2.9	-2.2
=Net firm power consumption	88.6	2.9	-0.4
Energy int. ind.	30.3	0.9	2.4
Regular cons.[2]	58.3	4.1	-1.9
Regular cons., temperature adjusted	61.5	4.0	2.2

1) The definitions in the table follow the definitions of the Electricity Statistics. The figures are preliminary.
2) Firm power consumption outside energy intensive industries.

Electricity can to a large extent replace oil on the Norwegian market in the short term, and if the price of firm power had been lower, sales could have been increased in 1989. Production costs for the 6 TWh that passed outside the production capacity in 1989 would have been very low. Given a more flexible electricity market, this surplus electricity could have been offered to consumers at low prices.

The average price of exported electricity was 6 øre/kWh. With more flexible prices for electricity on the domestic market, more of the electricity that was exported in 1989 could have been used in Norway, since domestic prices are much higher than export prices. This would have improved the use of Norwegian resources, given lower oil consumption and less pollution.

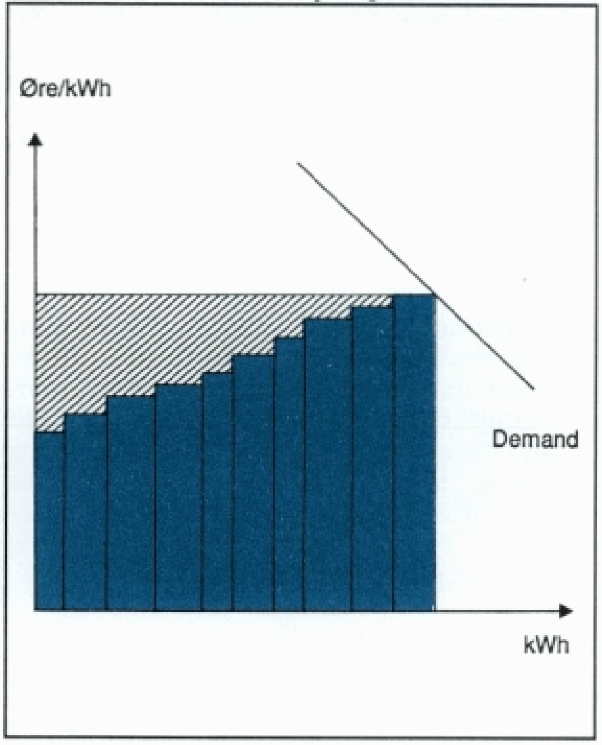
Table 2.1 shows the electricity balance. The estimated losses in the transmission network are uncertain, and therefore also the estimates of net consumption of firm power.

Hydropower rent

Different hydropower plants can be ranked by increasing costs per kWh. When market prices increase, plants with low costs will have a surplus return. This surplus return, the hydro power rent, is due to a scarcity of hydropower projects that are cheap to construct. If the market price of electricity is high, and the cost per kWh at the plant is low, the rent will be high. In the case of marginal plants the costs will be almost the same as the income, and the rent will be low.

The term rent is illustrated in figure 2.2, which shows different hydropower projects and market price. The height of the columns corresponds to the average costs at the hydropower plant, while the breadth shows production capacity. The average cost includes both capital costs (normal return on capital and capital depreciation) and running costs. The figure shows that, in hydropower production, the return decreases. The rent corresponds to the shaded area in the figure.

Figure 2.2. Rent in a hydropower market



The rent is a theoretical term. In order to realize the rent indicated in figure 2.2, the capacity of the electricity supply system has to be correctly dimensioned (price equal to long-term marginal cost) and the price in the market must be in equilibrium. If one or more of these conditions is not fulfilled, part of the rent will be lost. The potential rent that the electricity sector could have obtained can be calculated by assuming that all users have to pay the same cost-adjusted price and that the demand is so high that this price equals the long-term marginal cost.

In the National Accounts and in the Electricity Statistics, the electricity sector consists of production, transmission and distribution of electricity. Ideally, transmission and distribution should be excluded when calculating the rent in hydropower production. When calculating the rent for the electricity production sector, it can be assumed that the costs of transmission and distribution in the electricity sector are covered.

The Norwegian Water Resources and Energy Administration (NVE) (1988) presents the long-term marginal costs per 1 January 1988. The long-term marginal costs in 1989 have been calculated by price-adjusting NVE's figures with the increase in the consumer price index. The long-term marginal cost for supply of electricity for regular consumption in 1989 was 44.5 øre/kWh. In energy-intensive industry, the utilization time is longer, transmission costs are lower and there are no distribution costs. The calculated long-term marginal cost of supplying electricity to these sectors is 31.0 øre/kWh.

Given these prices of electricity, and the same total sold quantity as in 1989, the operating surplus in the electricity sector could be NOK 24.7 billion. This gives a rent of NOK 10.8 billion, assuming a 7 per cent return on capital. This is an illustration of the long-term annual potential rent in the electricity sector at present capacity, assuming that the market is in equilibrium. Provisional estimates for 1989 give an operating surplus of about NOK 11.0 billion in the electricity supply. With a real capital of NOK 199 billion, this gives a return on capital of about 5.6 per cent in the sector. Thus the electricity sector gave no rent in 1989.

2.2. Oil and gas

Reserves of oil and natural gas

The part of the total proven resources that can be extracted at today's prices and by known technology is called reserves. If prices rise, or better production technologies are developed, the share of profitable resources (reserves) will increase. In the case of oil, the reserve share of the proven resources averages about 1/3. To these proven resources must be added the potential resources in unexplored parts of the continental shelf. The Petroleum Directorate (1989) estimates a resource potential of 5 200 million tons oil equivalents (mtoe) south of Stad per 1 January 1989. Of this amount, 4 400 mtoe have been discovered. It has been decided to develop 2 910 mtoe, and just less than 23 per cent of this amount has been extracted. In addition to the reserves south of Stad, proven resources are estimated to be 480 mtoe on the Haltenbank and 270 mtoe on the Tromsøflak.

Tables 2.14 and 2.15 (appendix) show the time development for reserves in developed fields and in fields to be developed for the ten-year period 1979-1989. In 1988 the oil reserves in these fields increased, partly due to reevaluation of the stocks in "old" fields, partly because of decisions to develop new fields. These increases exceeded the extraction. No decision was taken to develop new fields in 1989. Reevaluations have not yet been undertaken for 1989.

At the present rate of extraction, the oil reserves in developed fields and in fields to be developed will last about 12 years time, and the gas reserves about 41 years. If the reserves in fields where no decision has been taken concerning development are added, the oil reserves will last for 20 years and the gas reserves for 91 years. The strong reduction in the lifetime of remaining oil reserves in relation to previous estimates is due to the strong increase in oil production.

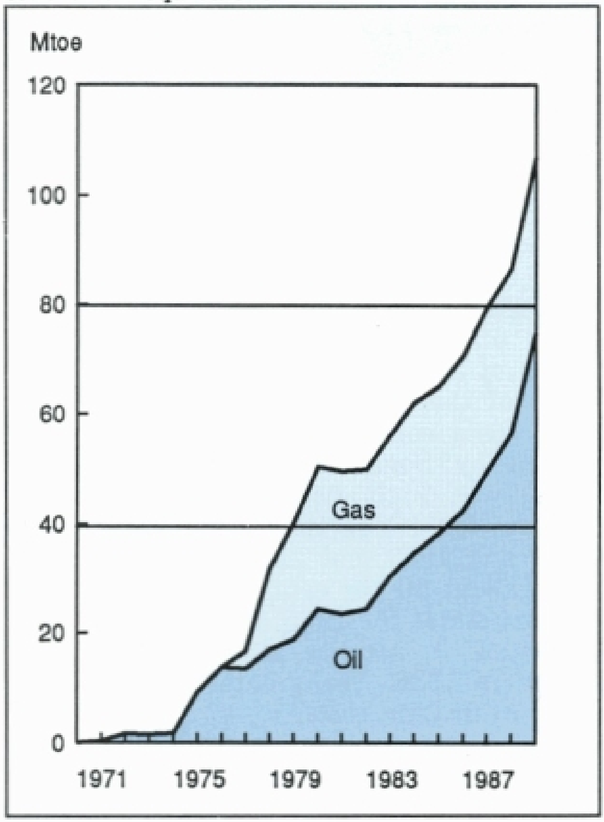
Oil and gas extraction in 1989

Norwegian oil and gas production in 1989 amounted to 106.8 million tons oil equivalents, an increase of 23.5 per cent in relation to 1988. Oil production increased by about 32 per cent from 56.7 million tons in 1988 to 74.9 million tons in 1989. The main cause of the total increase was higher production from the Oseberg, Gullfaks and Ekofisk fields. Throughout the whole year, Norwegian oil production was 7.5 per cent below capacity. The reason for limiting production is that this should help to stabilize the price of oil at a reasonably high level. Production of natural gas increased by about 7 per cent in 1989 in relation to 1988.

In 1989, the production increased most on the Oseberg field. Production started in December 1988, and because a large number of production wells had been drilled already before production start, it increased quickly. In 1989 the field produced 11.6 million tons. This accounted for more than 15 per cent of the total Norwegian oil production.

There was also a strong increase in production on the Gullfaks field, amounting to 13.9 million tons in 1989. This represents an increase of 80 per cent in relation to 1988. The field produced almost 19 per cent of all Norwegian crude oil in 1989, in spite of the fact that Gullfaks takes the combined production cut for the Gullfaks and Statfjord field. In mid-December 1989, production started on the third Gullfaks platform (Gullfaks C), which means that production from this field will continue to increase substantially.

Figure 2.3. Oil and gas production on the Norwegian continental shelf. 1971-1989. Million tons of oil equivalents



Production from Norway's largest oil field, the Statfjord field, has passed its peak, and was reduced by 2 per cent in 1989 compared with 1988. Some years ago this field accounted for about 70 per cent of Norwegian oil production, but in the 4th quarter of 1989, production from Statfjord accounted for "only" about a third of the total.

Norwegian *gas production* is still dominated by the Ekofisk and Frigg fields. The combined production from the two fields accounted for just over 65 per cent of the total gas production in 1989. Each of the two fields produced about the same quantity in 1989, but while production from the Ekofisk field increased by just over 10 per cent compared with the year before, gas production in the Frigg area was reduced by 1.5 per cent.

Oil investments in 1989

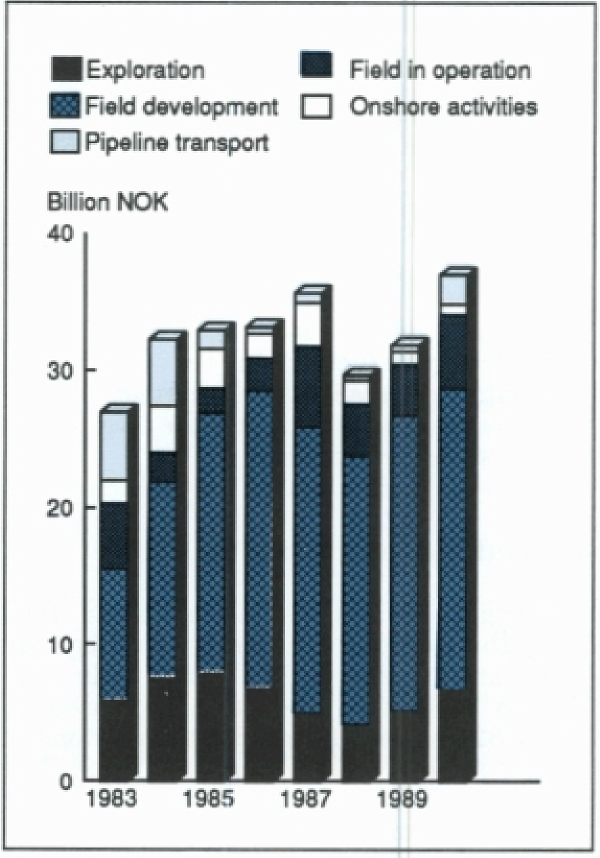
According to the investments survey undertaken by the Central Bureau of Statistics in the 4th quarter of 1989, accrued investment costs for production and pipeline transport of oil and gas are estimated at about NOK 31.8 billion in 1989. This is about a fifth of the total Norwegian gross investments. The estimate implies an increase in value of 7.4 per cent in relation to 1988. Accrued investment costs are a measure of activity expressing the current use of resources in different investment projects.

Accrued *exploration costs* are estimated at NOK 5.1 billion in 1989, an increase in value of 23 per cent in relation to 1988. Most of this increase is due to extremely high costs connected to a particular well drilled by Saga near to Ekofisk, where there was high risk of an uncontrolled blowout for a long time. The estimates for 1988 and 1989 (not including Saga's well) were about 50 per cent below the value of the estimates for 1985, indicating a strong reduction in activity after the fall in oil prices in 1986. The greatest decrease has been in drilling costs.

Accrued investment costs in *field development* are estimated at NOK 21.7 billion in 1989, an increase of 10.2 per cent from the year before. The investment costs in field development account for almost 70 per cent of the total costs in the production sector. The higher total figure conceals a strong shift in the ratio between goods and services; from 1988 to 1989, costs of goods increased by almost 40 per cent, while costs of services decreased by 7 per cent in value.

Accrued investment costs in *fields in production* are estimated at NOK 3.7 billion in 1989, a slight decrease in value from 1988. Normally, production drilling accounts for the greater part of the investments costs for fields in operation, and the costs of production drilling have increased substantially in recent years. In the years 1985 to 1987, these costs amounted to NOK 1.1 billion per year, in 1988 they were doubled and in 1989 increased to NOK 2.5 billion.

Figure 2.4. Accrued investment costs in the petroleum sector. 1983-1990. Billion kroner

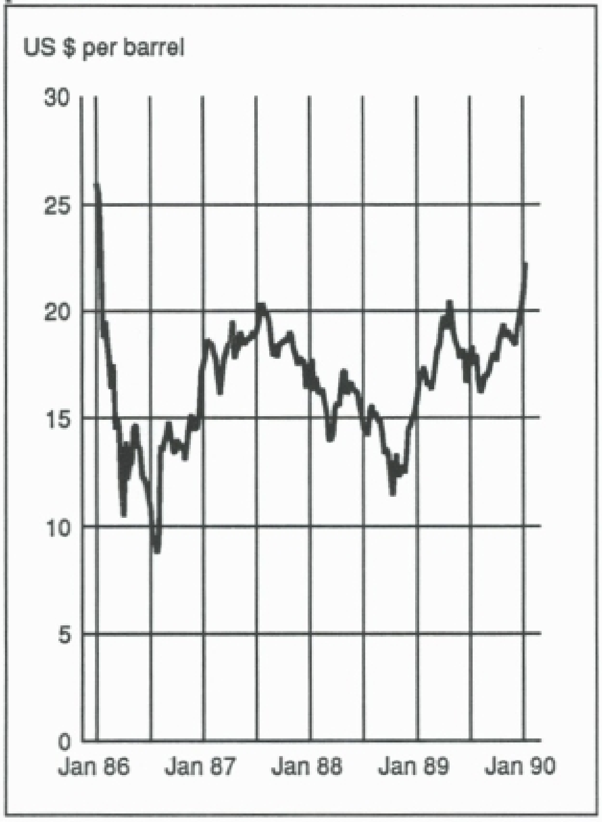


The estimate for accrued investment costs in *pipeline transport* are estimated at just short of NOK 0.5 billion in 1989. The estimate of NOK 2.2 billion for 1990 is the first signal that investments in pipeline transport will be high during construction of the Zeepipe pipeline from Troll/Sleipner.

The oil market in 1989

The oil market remained relatively stable throughout 1989. The spot price of North Sea oil varied between US$ 16 and 20 per barrel in 1989, with an average of just over US$ 18 per barrel. Steadily increasing overproduction by OPEC countries was to a large extent counteracted by a fairly strong increase in the demand for oil products. This situation led to a relatively stable and high spot price for oil for immediate delivery, while for forward contracts for future delivery the prices were lower for most of the year.

Figure 2.5. Spot price of Brent Blend. US $ per barrel

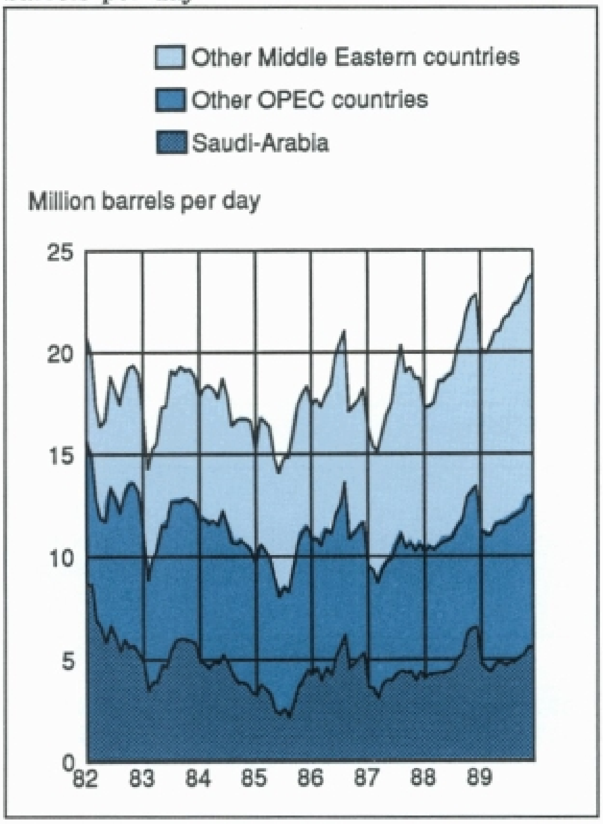


Source: Petroleum Intelligence Weekly.

At the start of 1989, the spot price of crude oil was about US$ 16 per barrel, after having been much lower before the OPEC meeting at the end of 1988. The price then increased slowly to the beginning of the 2nd quarter, when it reached more than US$ 20 per barrel. Afterwards, the spot price started to fall, and declined during the whole of the 2nd quarter and up to the beginning of August, by which time it had again fallen to about US$ 16 a barrel. So far, this development had been much the same as in 1988, but in 1989 the oil price increased again during the autumn, and at times the spot price of crude oil was about 50 per cent higher than at the same time in 1988.

OPEC's increased production through the year followed the pattern as in the previous 2-3 years; OPEC holds its ordinary meeting of Oil Ministers in November, reaches some sort of agreement, and manages to reduce combined production from December to January. Afterwards, production rises again throughout the rest of the year. In 1989, OPEC increased its production quota on several occasions; from 18.5 million barrels a day (mbd) in the first six months to 19.5 mbd in the 3rd quarter and to 20.5 mbd during the last quarter. Production always exceeded the quota and, on average, the OPEC countries produced just less than 22 mbd. The United Arab Republics and Kuwait were the countries which exceeded their production quota most.

Figure 2.6. OPEC oil production. Million barrels per day



Source: Petroleum Intelligence Weekly.

The consumption of oil products has increased quite considerably after the drop in oil prices in 1986, and consumption in the OECD area and in developing countries increased by about 5 mbd from 1985 to 1989. This increase in consumption is declining, however, and according to IEA estimates, the increase in oil consumption in OECD countries was less than 1.5 per cent in 1989, compared with 1988. Oil consumption in developing countries is estimated to have increased by 4 per cent in 1989.

Petroleum revenues - the oil rent

Norway's petroleum revenues can be calculated as the value of the gross product in all oil companies operating on the Norwegian continental shelf, minus dividends on share capital which foreign companies take out of the country. The revenues from oil and gas production in the North Sea increased substantially up to 1985, when the gross product in the production sector, amounted to almost NOK 90 billion (see table 2.2). Due to the strong fall in oil prices, the gross product decreased to just over NOK 50 billion in 1986. The decrease continued in 1988 due to the low prices of oil and gas throughout the year. Increasing oil production was not enough to compensate for the low prices. In 1989, higher prices and production led to a strong increase in the gross product.

Table 2.2. Petroleum income and oil rent. 1977-1989

Year	Value added in petroleum extraction	Oil rent	Oil rent as a share of gross domestic product
	Billion kroner		Per cent
1977 . .	7.4	2.8	1.5
1978 . .	12.8	7.0	3.3
1979 . .	20.8	13.7	5.7
1980 . .	41.0	31.8	11.2
1981 . .	51.0	36.4	11.1
1982 . .	55.3	37.8	10.4
1983 . .	66.9	48.0	11.9
1984 . .	83.4	59.5	13.1
1985 . .	89.7	62.3	12.4
1986 . .	51.0	18.3	3.6
1987 . .	51.1	13.2	2.3
1988 . .	44.2	0.9	0.2
1989* .	69.6	20.1	3.1

The excess return from oil and gas production, as compared with other production, is often called the oil rent. This can be calculated as the part of the total income from production of petroleum and gas which is achieved when current production costs and a normal return on invested capital are deducted. The method of calculation ignores the fact that several of the input factors used in oil and gas extraction are probably paid more than in other industry. Therefore they can be said to be paid part of the oil rent.

If the normal return on invested capital is fixed at 7 per cent, which is about equivalent to the average rate of return in industry during the last ten years, preliminary calculations show that the oil rent was just over NOK 20 billion in 1989. This is a substantial increase from 1988, when the oil rent was less than NOK 1 billion, but is still only about the same level as in the "crisis year" 1986. In 1989, the oil rent amounted to 3.1 per cent of the gross domestic product. This means that, in the course of four years, Norway's excess return from petroleum and gas activities decreased from NOK 15 000 per capita to about a third of this figure in nominal prices. The oil rent decreases quicker than the gross product because the capital to be serviced by the total operating surplus becomes steadily bigger as more fields are developed.

2.3. Extraction and use of energy goods

Up to the beginning of the 1970s, hydropower accounted for the greater part of the production of energy goods in Norway. After production of crude oil, and afterwards natural gas, was started in the mid-1970s, these energy goods have taken over a steadily increasing share of the total energy production. Table 2.3 shows how extraction of energy goods has developed since 1930 up to today. Coal production in Svalbard remained at about the same level from 1950 to 1987. In recent years, coal extraction has been somewhat less, due to a halt in operations at the mines in Svea. Fire in one of the two other mines gave an especially low production figure in 1988. Extraction of the other energy goods shows a general increase. During the 1980s, there has been a marked increase in production of crude oil, but in the case of natural gas, production has tended to increase only slightly since 1980. In 1989, the total extraction of energy goods was twice the extraction in 1980, and more 20 times higher than in 1970.

Table 2.3. Extraction of energy goods in Norway. 1930 - 1989. PJ

Year	Total	Hydro power	Crude oil	Natural gas	Coal
1930 .	37	31	-	-	6
1939 .	47	39	-	-	8
1950 .	82	61			11
1960 .	122	111	-	-	11
1970 .	220	206	-	-	14
1972 .	324	243	68	-	14
1974 .	362	276	72	-	14
1976 .	904	295	584	10	14
1978 .	1 562	291	718	541	11
1980 .	2 289	301	1 034	944	8
1981 .	2 291	336	992	952	11
1982 .	2 412	334	1 036	1 029	12
1983 .	2 717	382	1 289	1 032	14
1984 .	2 959	383	1 467	1 096	13
1985 .	3 096	371	1 622	1 089	14
1986 .	3 282	349	1 799	1 122	12
1987 .	3 676	374	2 098	1 193	11
1988*	4 013	394	2 400	1 212	7
1989*	4 898	427	3 171	1 291	9

The energy accounts follow the energy goods from extraction via conversion to use within the different production sectors and private households. In the accounts, the energy sectors consists partly of extraction sectors, partly of conversion sectors. The extraction sectors are coal mining, hydropower plants and extraction of crude oil and natural gas. The conversion sectors include coke plants, oil refineries, thermal power stations and district heating plants. So far, energy accounts have been prepared for the years 1976 to 1988. Table 2.16 gives the preliminary accounts for 1988, see section 2.11, appendix of tables.

Figures from the energy accounts show a total production of energy in Norway of 4 013 PJ in 1988. The primary supply, that is to say the gross supply of energy for use in Norway, is 917 PJ. This comprises 22.9 per cent of the total production. Norway is net importer of coal and coke and net exporter of oil, gas and hydropower.

In 1988, consumption of petroleum products in sectors other than the energy sectors was 472 PJ. This comprises 52.8 per cent of the total use of energy in these sectors. Domestic use of petroleum products decreased by 5.5 per cent from 1987 to 1988. The greatest decrease was for oil other than oil for transportation, where a tendency for decreased consumption over many years continued after a temporary increase in 1985 and 1986, see table 2.18, section 2.11, appendix of tables.

There was a slight decline from 1987 to 1988 in consumption of electricity and solid fuels. Electricity accounted for 37.4 per cent and solid fuels for 9.5 per cent of the total energy consumption outside the energy sectors.

Table 2.4. Use of energy goods[1] outside the energy sectors by industry. 1988*. Change 1976 - 1988[2]

Industry	1988 PJ	Average annual percentage change 1976-87	1987-88
Total	894	-0.7	2.4
Ocean transport .	143	-10.0	41.6
Domestic use . . .	751	2.1	-2.7
Agriculture and forestry	32	0.3	3.2
Energy intensive industry	206	2.3	-0.5
Other manufacturing and mining .	108	-0.8	-5.3
Other industries .	197	3.1	-4.8
Private households	208	3.0	-1.9

1) Includes use of energy goods as raw materials.
2) From 1987 district heating is included in the figures.

In 1988 the energy used outside the energy sectors was 894 PJ, see table 2.4. This implies an increase of 2.4 per cent from 1987 to 1988. The increase is due to an increase in ocean transportation (foreign trade), with a far higher tonnage registered in NIS (The Norwegian International Ships Register). Domestic use of energy decreased slightly in 1988 in relation to 1987, to about the same level as in 1985 and 1986. Energy-intensive industry used about the same amount of energy in 1988 as in 1987, but the energy used in other industry decreased by about 5.3 per cent. Private households used 1.9 per cent less energy in 1988 than in the year before. The total use of energy in other sectors decreased by 4.2 per cent. Preliminary figures for 1989 indicate that domestic use of energy decreased from 751 PJ in 1988 to 743 PJ in 1989.

Table 2.5. Use of energy goods outside the energy sectors, by energy source. 1989. Change 1976 - 1989

Energy source	1989 PJ	Average annual percentage change 1976-87	1987-89
Total	743	2.1	-1.9
Electricity	337	3.0	0.3
Firm power . . .	319	3.0	-0.3
Regular consumption. . . .	210	4.2	-1.8
Energy intensive industries	109	0.8	2.4
Surplus power .	18	4.8	9.5
Oil total	319	1.0	-4.3
Oil other than transportation .	65	-5.7	-12.0
Oil for transportation	201	3.2	-1.7
Liquefied gas . .	53	44.2	-2.7
District heating . .	3	.	0.0
Solid fuels	84	2.6	-1.2
Coal, coke	48	0.7	-3.0
Fuelwood. paper waste, other solid waste . . .	36	6.2	1.4

In the period 1987-1989, the total use of energy outside the energy sectors and excluding ocean transport decreased by 1.9 per cent per year, see table 2.5. 1988, and 1989 especially, were very warm years in large parts of Norway. This explains the decrease in the use of energy for heating. Use of firm power for regular consumption shows an average decrease of 1.8 per cent during the last two years. Energy consumption has increased in energy-intensive industry, due to an upward economic trend abroad. A lot of rain and high temperatures led to low prices for surplus power, and strong increases in consumption during the period 1987-1989. The average annual decrease in the use of oil products other than oil for transportation was as much as 12.0 per cent for the last two years. This is perhaps because oil consumption for purposes other than transportation reacts more strongly than the electricity consumption does to fluctuations in temperature. Oil consumption for transportation also declined during the same period - by an average of 1.7 per cent per year. This decline is connected to the slowdown in economic activity in Norway in the period 1987 to 1989.

Table 2.6. Average prices[1] of electricity[2] and selected petroleum products. Delivered energy. 1989. Change 1988 - 1989

Energy source	1989	Percentage change 1988-1989
Heating products : Price øre/kWh		
Electricity[3]	43.0 (38.6)	3.1 (3.8)
Heating kerosene . .	28.3	10.1
Fuel oil no. 1	21.6	9.6
Fuel oil no. 2	20.7	10.1
Heavy fuel oil	14.7	25.6
Transportation products : Price øre/liter		
Super gasoline . . .	578.5	7.9
Unleaded gasoline .	540.5	7.5
Auto diesel	233.0	8.9

1) All taxes included.
2) Households and agriculture.
3) The figures in parentheses comprise the variable part of the price (the energy part of the H4-tariff).

Table 2.6 shows the price of electricity to private households and agriculture, and the prices of some selected petroleum products.

2.4. Development of energy consumption 1973-1988

Introduction

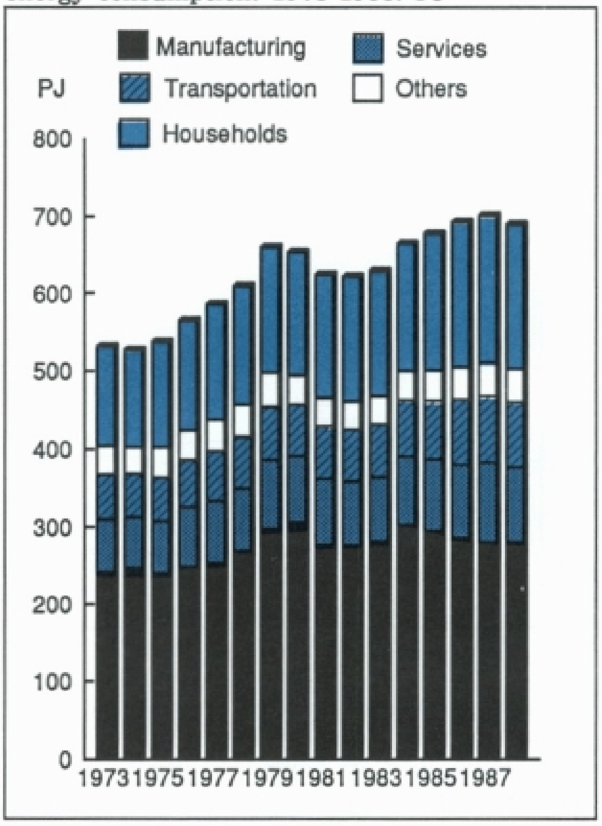
For many years, interest in the development of energy consumption in Norway was connected to the wish to chart the need for further hydropower development. Increasing focus on environmental problems connected to the use of energy makes it necessary to consider the whole of the Norwegian energy market combined, that is to say, to take a closer look at oil consumption as well. This approach becomes even more relevant since production of thermal power is the most probable alternative to hydropower. Thermal power production leads to large emissions of CO_2, and some emissions of NO_x.

The most important driving forces behind changes in energy consumption are economic growth, developments in the real price of energy, the industrial structure and technological, possibly also organizational, changes. The effects of these factors are interdependent. Changed prices of energy may accelerate both technological progress and changes in the industrial structure. There are indications that rapid fluctuations in the price of crude oil on the world market have strongly influenced the world economy during the last 15-20 years. A fully satisfactory analysis of developments in the use of energy in Norway requires an economic model that takes these connections into account. However, the review of the data on the development of energy consumption presented here can help to sort out the most important factors behind changes in the level and composition of the energy consumption.

Main features in the development of energy consumption

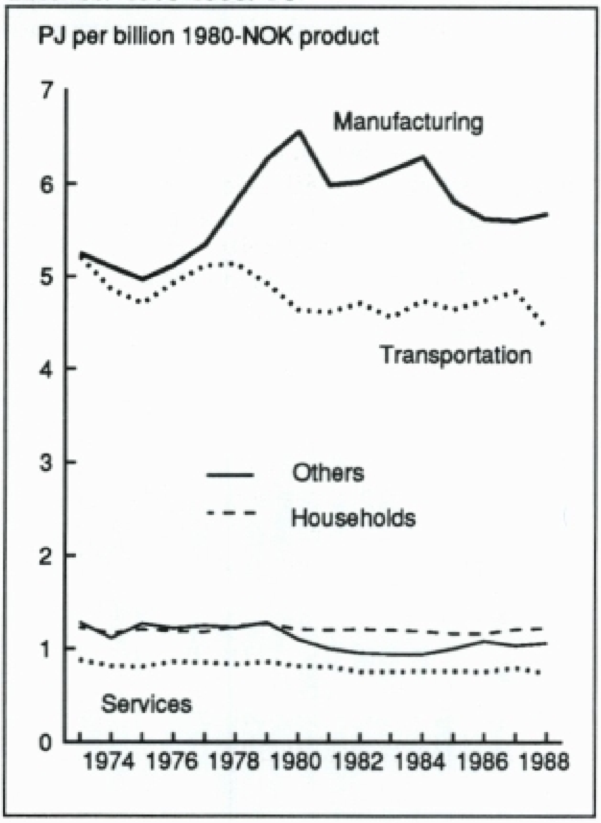
Figure 2.7 shows the development of the total domestic energy consumption in Norway distributed between five sectors: manufacturing, services, transportation, other industries and households. Transportation, as defined, consists of enterprises providing transport services, i.e. goods transport companies, bus companies, etc. The part of the total work of transportation that occurs in the other sectors (for example, private cars used by households) has not been separated out as "transportation", that is to say, gasoline consumption by private cars is registered in the household sector. Ocean transport (shipping engaged in foreign trade) has also been excluded. "Other industries" include the building and construction sector and the agriculture, forestry and fishing sectors.

Figure 2.7. Time development of total domestic energy consumption. 1973-1988. PJ



After the oil crisis in 1973 - 1974, energy consumption tended to level off, but increased strongly and steadily towards the end of the 1970s. After the sudden increase in the price of oil in 1979/80 consumption decreased, only to rise again slightly from 1982 to 1987. There was another decrease in total domestic energy consumption from 1987 to 1988. The main cause of the relatively large fluctuations in energy consumption in manufacturing is economic fluctuations within energy-intensive industry, which in 1987 accounted for about 65 per cent of the industrial consumption of energy. Energy consumption in the other sectors is less dependent on fluctuations of the market. As for the transportation sector, the increase in energy consumption was somewhat higher in this sector since 1973 than in the other sectors.

Figure 2.8. Energy intensities in various industries. 1973-1988. PJ

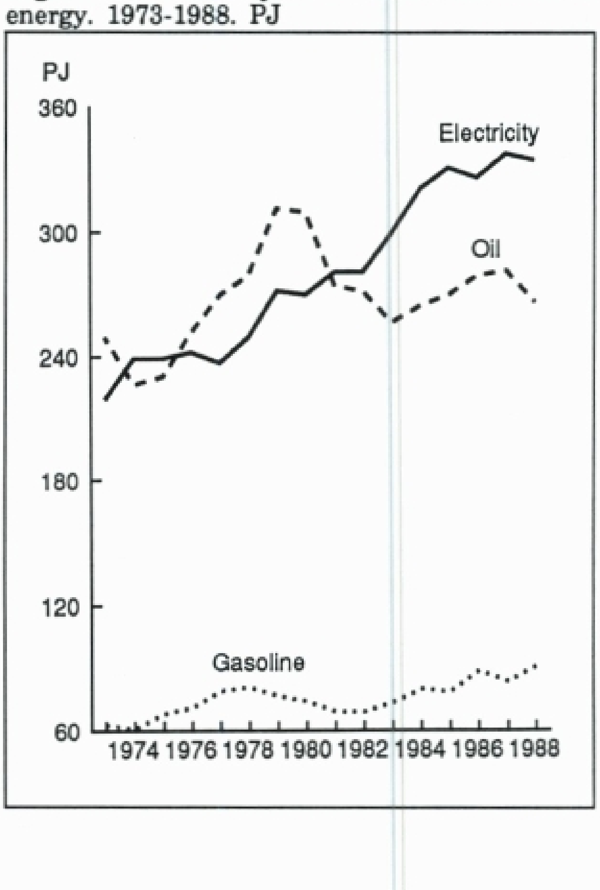


The energy intensities are defined as energy consumption per unit produced or consumed (calculated in terms of constant prices). Figure 2.8 shows the development in energy intensities in the 5 different sectors for the period 1973 to 1988.

The variations that can be observed in the total energy consumption in manufacturing correlate with the intensities. As mentioned above, the main reasons for the variations are economic fluctuations, particularly in export-oriented energy-intensive industry. As in manufacturing, transportation has a high consumption of energy per produced unit. The energy intensity decreased substantially at the end of the 1970s, since when it has remained fairly stable. At the same time, the extent, or level of production of the transportation sector has increased, and this has led to a rise in the total energy consumption. A reduction of the energy intensity can also be registered within the building and construction, agriculture, forestry and fishing sectors, which make up the greater part of the sector "other industries". There has been little change in the energy intensities of either the service sector or households during the period.

The increase in energy consumption is distributed differently between oil and electricity. Figure 2.9 shows domestic consumption of the different energy carriers during the period 1973-1988. The oil crisis in 1973-74 led to a reduction in the use of oil products and an increase in electricity consumption. However, consumption of oil products soon picked up, but declined yet again when the price of crude oil took a new leap in 1979-80. Since 1981, the consumption of heating oils has remained more or less stable, but the consumption of gasoline and electricity increased up to 1985.

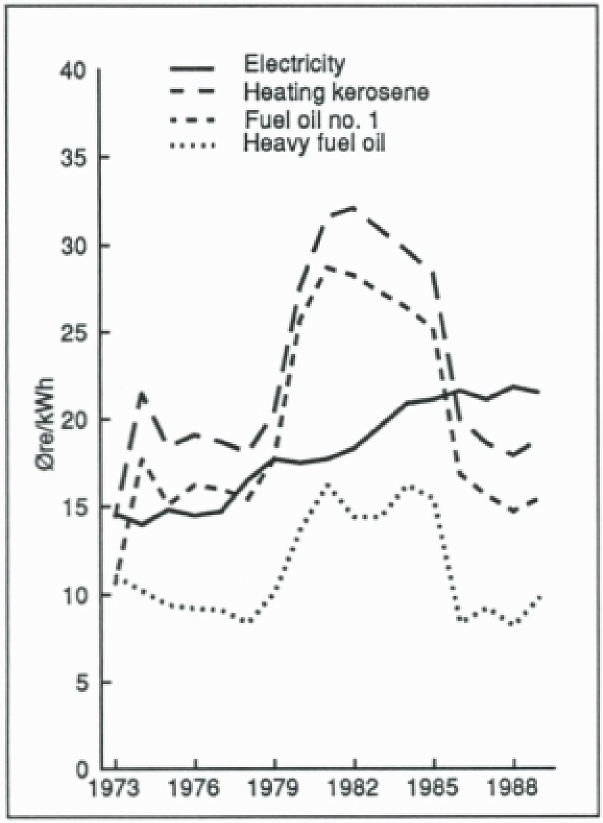
Figure 2.9. Consumption of individual forms of energy. 1973-1988. PJ



Changes in energy prices

A main reason for the differences in the increase in consumption of electricity and oil is the difference in the price development of these different forms of energy. In periods when the price of one energy carrier rises, the consumer can shift to a different energy carrier. However, the possibilities of substituting one carrier for another will depend on the purpose for which the energy is used. In some cases it is quite easy to change the form of energy, for example by substituting oil heating by heating with electricity. In other cases such substitution is more difficult, as when a large proportion of the energy is used for transportation.

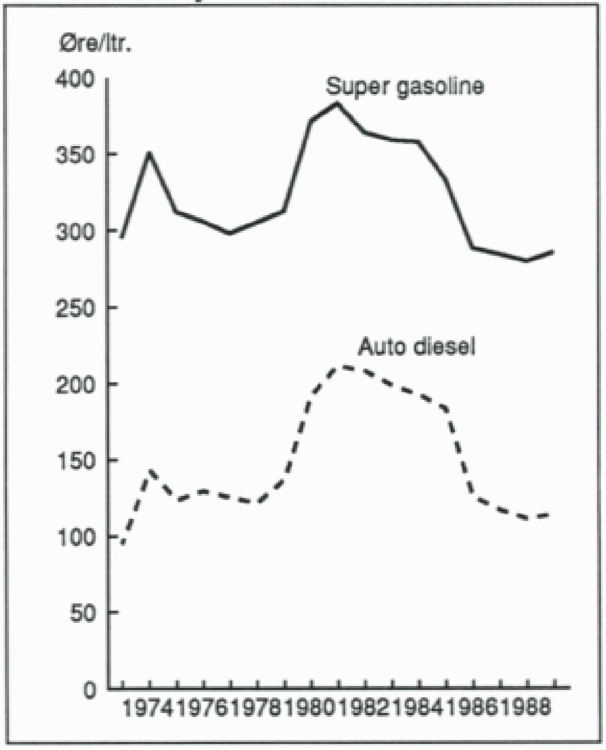
Figure 2.10. Estimated prices of utilized energy. 1973-1988. Constant 1980-prices. Øre/kWh. All taxes included



The possibilities of substituting one energy carrier for another vary between the different sectors. In transportation and in "other industries", a large part of the energy consumption refers to oils for transportation. These sectors have few opportunities of substituting oil by electricity if the price of oil rises. Thus, reducing the consumption per produced unit of each energy carrier depends on introducing new technology, such as vehicles which use less fuel per kilometer. In the service industries and in households, much of the energy consumption goes to heating, where substitution is easy. In these industries, changes in relative energy prices can quickly lead to one energy carrier being substituted by another.

Figure 2.10 shows the prices of electricity and oil products per unit of energy (converted into utilized energy), measured in terms of constant 1980 prices. Figure 2.11 shows the development of the price of fuel oils. The price of electricity, measured in constant 1980 kroner, has risen steadily by an average of 2.9 per cent per year during the period. In contrast, the prices of oil products have fluctuated strongly. These changes in prices are chiefly due to variations in the price of crude oil on the world market. The average price of light heating oil and autodiesel has risen slightly during the period, but there is a slight tendency towards lower prices for heavy heating oils and gasoline.

Figure 2.11. Prices of fuel oils. 1973-1989. Constant 1980-prices. Øre/liter



A comparison of the price *levels* of the different energy carriers, see figure 2.10, shows that, in the 1970s, it was almost just as expensive to heat with kerosene as with electricity. This situation was clearly changed by the marked increase in the price of oil in 1979/80 (OPEC II). However, since the fall in the price of oil in 1986, it has become cheaper to heat with oil than with electricity.

During the periods with a marked rise in the price of oil in relation to the price of electricity, this seems to have resulted in a clear shift from oil to electricity. So far, the substantial reduction in the price of oil products in 1986-87 does not seem to have produced the opposite effect. Consumption of petroleum products other than gasoline has in fact decreased, while gasoline and electricity consumption have remained almost constant. A possible explanation is that changing from one energy carrier to another requires *investment*, for example, in a heating equipment. Because of these capital costs, *expectations* as to how energy prices will develop in the future will be of major importance when choosing the form of energy to be used. Thus, the fact that the composition of the energy consumption has changed so little in recent years in spite of drastic changes in the prices of energy may indicate that consumers expect oil prices to rise again.

Energy consumption and the industrial structure

Changes in the total energy consumption and the energy intensity (amount of energy per unit GDP) are caused partly by changes in the industrial structure. For example, the energy intensity for the country as a whole will rise if the growth of production is stronger in energy-intensive industries than in other sectors, because the energy consumption of this sector will have greater weight in the calculations of energy intensity. Figure 2.12 shows how the total energy consumption would have developed under the assumption of an unchanged industrial structure during the period 1976-1987. More precisely, this calculation is based on identical growth of production in all sectors (equal growth in GDP), at the same time as the development of the energy intensity is equal to the actual development in each sector. The figure shows that changes in the industrial structure have helped to reduce energy consumption in Norway during the period.

Calculations of energy consumption adjusted for changes in the industrial structure will depend on the extent of detail in splitting up the economy. The curve in figure 2.12 is based on dividing industry into 35 production activities, plus a household sector. Changes may have occurred within these production activities which either intensify or neutralize the effect observed in figure 2.12. Therefore, a different and more detailed division into activities might produce quite another picture. One cause of changes in the industrial structure may be factors which also directly influence the demand for goods and services. Different income elasticities will have a marked effect on the industrial structure during a process of growth. Changes in energy prices may also be important. For example, an higher price of oil may lead to higher prices for road and sea transport, which may in turn shift the demand over to the railways.

Figure 2.12. Energy consumption adjusted for changes in industry structure. 1976-1987. PJ

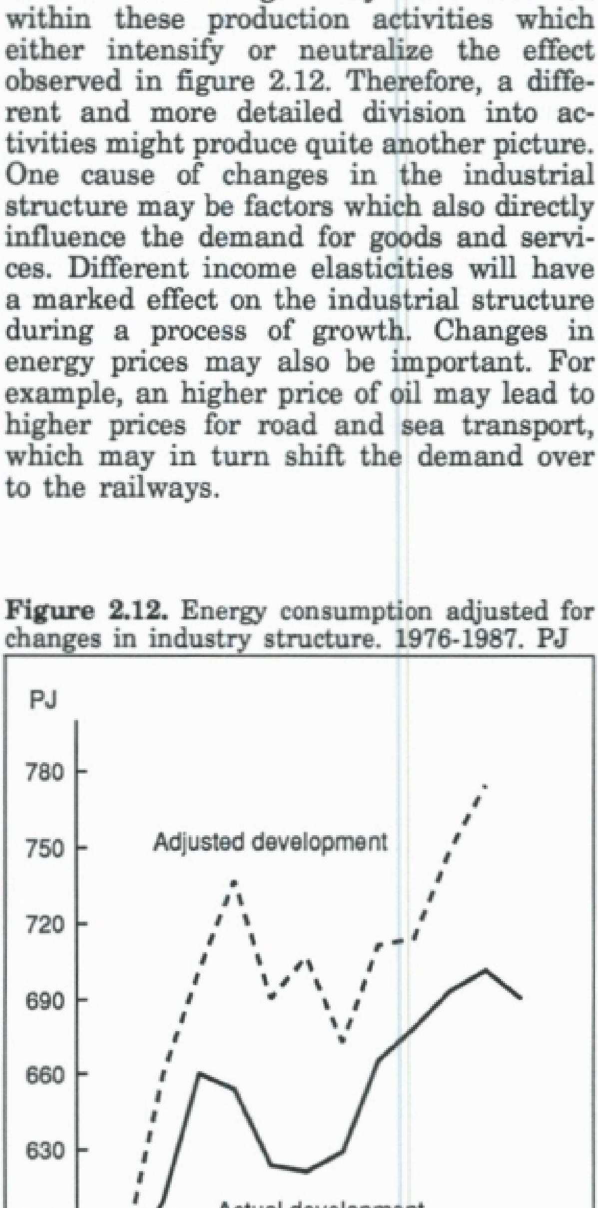
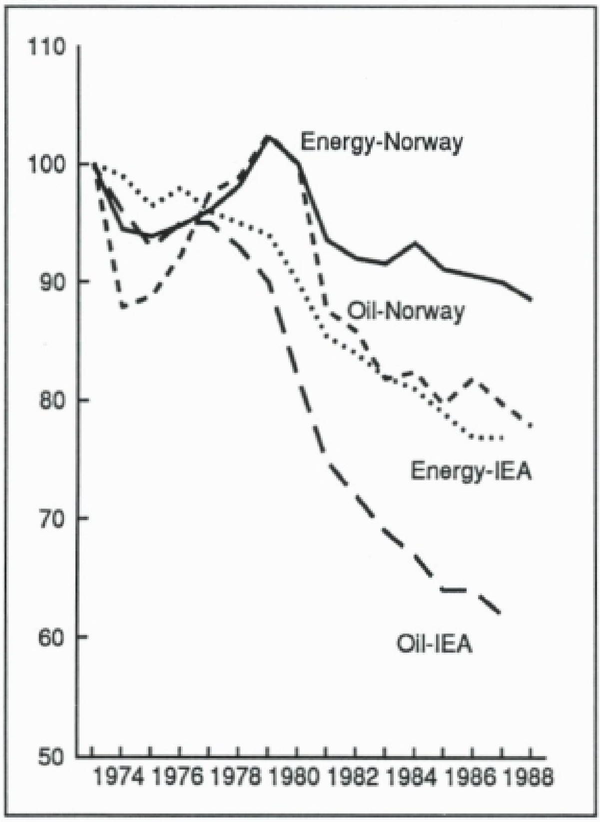


Figure 2.13. Index for energy - and oil intensities in Norway and in the IEA countries. 1973-1988



Concluding remarks

This section has dealt with how changes in respectively the price of energy and the industrial structure affect changes in energy consumption. Common to the factors mentioned above is that they point towards a reduction in sector-wise and total energy intensities over the period under consideration. The fact that it has been possible to introduce more energy-effective equipment has had the same effect. However, in spite of rising prices for energy from 1973 to 1985, an industrial structure that requires less energy now than it did 15 years ago, and technological progress, no marked reduction is observed in the energy intensities. The total energy intensity has not been reduced in Norway to the same extent as in other IEA countries, see figure 2.13. An important reason is the composition of the energy consumption in Norway, with a larger share of electricity in the consumption than in other countries. This means that Norwegian households and enterprises were not affected to the same degree as consumers in several other industrial countries by the high rise in prices of oil in the 1970s. However, the oil intensities have also only fallen moderately in Norway in relation to other IEA countries. This cannot be explained without undertaking a more detailed analysis than presented here.

2.5. Energy policy

Several important issues of energy policy relating to various aspects of the management of the country's hydropower resources were discussed in the Norwegian national assembly (The Storting) in 1989. The fundamental principles for an economically effective use of these resources are well known: The price of electricity should be fixed so as to fully exploit, at least as far as possible, the available production capacity. All purchasers should have to pay the same cost-adjusted price for electricity. No further development of the electricity system should take place unless the consumers are willing to pay the costs of new hydropower development. The way in which the Norwegian electricity market functions does not by any means satisfy the requirement for effective use of resources. The prices paid for electricity vary considerably between different groups of consumers and far too much capacity has been developed over the years, partly because too little importance has been attached to the consumers' willingness to pay when deciding to invest. This is probably the main reason for the situation on today's electricity market, with widespread sales of cheap electricity, both to certain sectors of Norwegian industry and to other countries. The following sections describe the main content of two propositions and one report on the domestic electricity market, presented to the Storting in 1989. The concluding remarks discuss whether these reports can be said to give due regard to the principles described above.

New Energy Act

A proposal for a new Energy Act was submitted to the Storting in Proposition no. 73 (1988-89) to the Odelsting (one of the chambers of the Norwegian Storting), dated 28 April 1989. The proposed Energy Act was to replace a whole series of Acts which at present apply to the energy sector. At the request of the Standing Committee on Energy and Industry, the Odelsting decided not to consider the proposition, due to lack of time during the spring session. The Act was submitted for consideration a second time on 29 September 1989. This proposition was withdrawn when the Government was replaced by a new one during autumn. A new proposal for an Energy Act is expected to be presented to the Storting in spring 1990.

The Proposition no. 73 to the Odelsting on a new Energy Act advocated larger sales of electricity at market prices. This would help to level out the price of electricity, and would thus be an economically sound exploitation of energy resources. The committee appointed to review energy legislation stated in its report, Norwegian Official Report no. 1985:9, that a major weakness of the organization of the power sector is the large number of smaller units selling power. The Proposition on a new Energy Act includes a proposal for a new licensing system for sales of electricity. The new system would reduce the number of small suppliers on the power market. Furthermore, such a licensing system would enable the authorities to control the 30-35 major suppliers of most of the electricity available on the market.

The proposed licensing system would apply to distribution plants, wholesale companies and others who participate in the market by further distributing electricity, and industry which produces electricity itself for further sale to regular consumption. If the proposal is followed, all participants who can be said to have a monopoly will be required to have a licence. The licence will apply to the right to sell, and will not be connected to specific contracts for the supply of electricity. When granting the licence, it will be possible to impose the condition that those granted a licence must combine into larger units or integrate other power plants into their own organization. This can be regarded as a threat to companies who oppose the authorities' recommendations to form larger and more effective units for sale of electricity - they can risk not being granted a licence. Another proposal was that it should be possible, when a licence expires, to expropriate plants that produce, transmit or distribute electricity, to the benefit of other power plants or the State.

New power contracts

In April, the Government presented Proposition no. 79 (1988-89) to the Storting on measures to promote industrial activity and a more flexible power market. The Government asked the Storting for authority to allocate electricity to energy-intensive industry and the pulp and paper industry at a 1976 contract price up to a limit of 2 TWh per year.

For energy-intensive industry, the assumed price in the new 1976-contracts is 15.73 øre/kWh delivered to the enterprise, including electricity tax. For the pulp and paper industry, the price is fixed at 16.53 øre/kWh delivered to a central location. The prices are 6-7 øre/kWh (34 per cent) cheaper than the 1983-contracts. It is assumed that the power will be used for new industrial projects.

The Report on Energy Conservation

The Government presented Report no. 61 (1988-89) on "Energy Conservation and Energy Research" to the Storting on 26 May 1989. This was the third report on energy conservation during the last 10 years. According to the Government, the main reason for the new report was "the new environmental requirements for the energy policy, connected to the use of fossil fuels". The report points out that "it is also a major challenge to the energy policy that the purely economic benefits of a more effective use of energy seem to be considerable".

The report presents calculations of energy conservation potential for different industries. These calculations are based on the alternative cost, as defined by the cost of developing new hydropower, to the extent the purpose is to save electricity, and by the world market price of oil, Norwegian taxes included, to the extent the purpose is to save oil. The calculations should probably be interpreted as an estimate of the long-term potential for reducing energy consumption. In the short term it is obviously unrealistic to assume that the alternative cost for all users is the long-term marginal cost of hydropower. One of the reasons is that the fundamental premises for energy-intensive industry (the users of one third of all the electricity) include much lower prices, and another is that the Norwegian power market has a lot of surplus electricity.

In the report, the calculations of energy conservation potential for dwellings and service buildings include a curve showing the correlation between a possible energy conservation potential and the price of energy. The curve shows that, in these sectors, a large potential can be realized at extremely low cost. The report does not include a similar curve for the correlation between energy conservation potential and costs for manufacturing industry.

Summary

The Norwegian hydropower market today is characterized by different prices for different consumers. For large groups of consumers the price is lower than the cost of producing energy in new hydropower plants. In spite of this fact, new plants are still being built. This shows that the participants in the power market lack the necessary incentives to make the adjustments that would lead to an economically effective use of energy resources. The power market is characterized, on the other hand, by numerous licencing systems, laws, regulations and institutional constraints.

The new power contracts, based on 1976-terms, will imply that companies who achieve such low-price contracts will have a clear advantage over other industry. This conforms with the general economic principle that an effort should be made to sell all available power during a year with surplus power, if necessary at very low prices. The measures proposed in Proposition no. 79 (1988-89), however, imply that industries that already pay too little for power will be offered new long-term contracts for large quantities of power at prices which will not, in the long term, cover the costs of development. It is stated quite clearly in the proposition that Statkraft (Norwegian State Power Board) can be expected to make a loss over the contract period as a whole. This loss must be borne by the rest of the community.

With more market-oriented pricing on the power market, there should be a potential for much more effective use of energy in the Norwegian community. An alternative to developing new sources of power is to invest in new, more energy-effective technology. With large differences in prices, users of cheap power will not be motivated to save energy. On the other hand, users of high price power might invest too much in reducing energy consumption. A discussion of how to make the use of energy more effective must be based on how the energy is actually used. In such a survey it is also important to clarify the fundamental premises for each user, and to consider why the potential for energy conservation is not realized. Is this due to lack of information among the users of the power, or is it because they have no incentives for optimal adjustment? With sales of electricity based to a larger extent on market prices, the equilibrium price in the medium term will lie far below the cost of developing new power. This equilibrium price is the relevant alternative cost for calculation of a possible energy conservation potential in the short term. This means that a large share of the energy conservation potential is lost. In the long term, on the other hand, the relevant alternative cost is the cost of developing new power.

2.6. Analysis: Thermal power - or investment in hydropower?

Introduction

The profitability of a thermal power plant as compared with a hydropower plant depends on a number of variables which are to a large degree uncertain. This analysis emphasizes two sources of uncertainty. In the first place, the future demand for electricity is uncertain, because of temperature variations and uncertainty about general economic developments. In the second place, the price of gas delivered to thermal power plants is uncertain, because of uncertainty about future export contracts for natural gas. A third element in an analysis of the uncertainty is uncertainty about hydropower production, due to variations in rainfall. This third element is disregarded in the present reasoning. The following analysis is based on an article by Kobila (1990).

The choice between hydropower and thermal power can be regarded as a choice between two different investment projects. A comparison of the profitability of thermal power versus hydropower implies examining the total costs, since the income per produced unit (i.e. the price of electricity) is the same.

The costs of production of hydropower consist almost entirely of capital costs, and are in this connection regarded as relatively certain. The importance of the price of gas for a decision to invest depends on whether the gas can be used in other ways. Profitability assessments of thermal power plants in Norway have assumed that thermal power is based on so-called associated gas, which as yet cannot be used for other purposes. In this analysis it is assumed that the gas can alternatively be exported, so that the willingness to pay for gas on the export market determines the price the thermal power plant has to pay. Fluctuations in the export price of gas will then express the uncertainty in the cost of producing thermal power. In practice, a large share of the total costs of a thermal power plant will consist of variable costs, i.e. costs of purchasing gas.

Uncertainty concerning gas prices and the demand for electricity are far more important for choosing hydropower capacity, considering that the investments are irreversible. In other words, the capacity cannot be reduced once the investments have been made. If the uncertain variables had been known with complete certainty, irreversible investments could be made at the most favourable time. In a situation of uncertainty, there is more chance of making a wrong investment when the capacity cannot be reduced. This is why the importance of uncertainty is analyzed in connection with irreversible investments in hydropower.

As explained above, the assumption that hydropower investments are irreversible is important when analyzing the importance of uncertainty for future income and costs. As far as hydropower investments are concerned, it is also natural to consider another form of irreversibility, namely that it is impossible to repair encroachments in nature. This analysis does not explicitly take into account damage to nature and the environment. However, the analysis can be extended to include environmental costs. It is possible, to some extent, to quantify the damage caused to the environment, and the loss of opportunities for recreation caused by the hydropower development, and make these an additional cost in the long-term marginal cost for hydropower. In the same way, the environmental damage caused by a thermal power plant may advocate an additional tax to the price of the gas. This will not change the following analysis qualitatively. If the environmental costs are taken into account, the total energy production will be reduced in relation to a situation without negative environmental impacts.

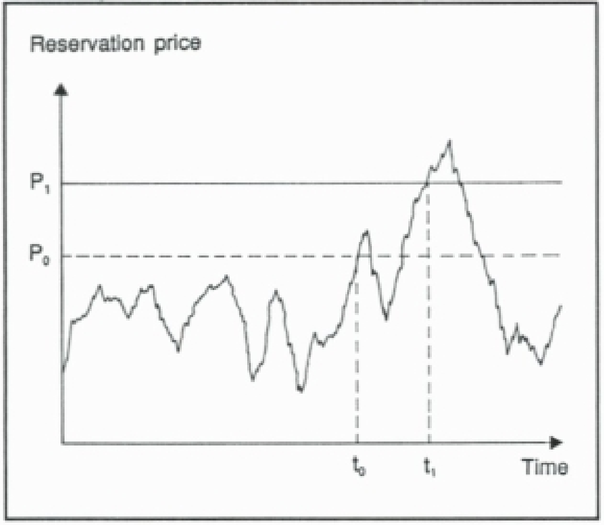
The main conclusion of the following analysis is intuitively reasonable: Unlike a situation with complete certainty about future income and costs, if either the price of gas is uncertain, or the demand for electricity is uncertain, and investments in hydropower are irreversible, it could pay substantially to delay the further development of hydropower.

Uncertain price of gas

The analysis in this section concerns the choice between hydropower and thermal power to cover a certain level of demand, disregarding uncertainties in the future demand for electricity. This analysis is concerned solely with the uncertainty of the price of gas. The problem is to find the most profitable time to undertake further development of hydropower. In principle, this would have been an easy decision to take if the future development of the price of gas had been known with complete certainty; the development should take place at a time when the present value of future costs of gas purchases equal the costs of developing the hydropower. The solution can be expressed by the term *reservation price*, which is a critical value for profitable development. As long as the price of gas is lower than the long-term marginal cost of hydropower (the interest rate), it will pay to postpone the development of hydropower. Investments in hydropower should be undertaken as soon as the price of gas exceeds the reservation price (in this case the long-term marginal cost of hydropower).

It can be shown that if the gas price is uncertain, a decision on the time to develop should be based on a corresponding rule of decision, i.e. the development of hydropower should be postponed until the time when the price of gas is so high that it exceeds the reservation price. However, this price is higher than when there is full certainty about the development of the price of gas, see figure 2.14. This figure illustrates a numerical example which does not necessarily reflect the actual conditions of cost and demand. The same applies to figure 2.15.

Figure 2.14. Uncertain gas price and reservation price under uncertainty, P_1 (solid line), and full certainty, P_0 (dashed line). The time for investment in hydropower is t_0 under full certainty and t_1 under uncertainty

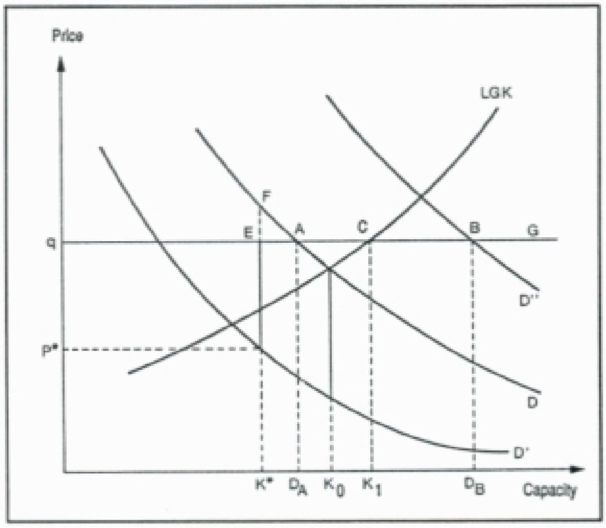


The reason why the reservation price is higher under uncertainty is that, given an uncertain price of gas, an increase and a decrease in the price of gas will not have a symmetric effect on the decision concerning hydropower development. It pays to postpone the development of hydropower, even if the price of gas is slightly higher than the long-term marginal cost of hydropower. If the gas price is much higher, the higher costs can be avoided by developing hydropower. On the other hand, if the gas price were to fall, it is still possible to produce electricity in the cheapest way. Therefore, the difference between the reservation price under uncertainty and under full certainty represents a safety margin against too rapid hydropower development. Since investments in hydropower development are irreversible, it pays to postpone further development for a time, even if such a postponement is not indicated by simple considerations of present costs.

Uncertain demand for electricity

A comparison of the profitability of hydropower versus thermal power becomes much more complicated when one takes into account the uncertainty in the future demand for electricity. How large a development of hydropower would be profitable in this case depends both on the uncertain demand and upon the amount of hydropower capacity already developed. This reasoning disregards the uncertainty of the price of gas, since it is impossible to carry out this analysis with two uncertain variables simultaneously. It is assumed, furthermore, that the gas price is constant over time.

Figure 2.15. Desired hydropower capacity and production of hydropower and thermal power when demand is uncertain



In figure 2.15, the curve D shows the demand for electricity at a specific time.

The uncertainty of the demand is illustrated by the fact that, in the next period, the curve D can move down to D' or up to D". The gas price is constant at q. This implies that electricity from a thermal power plant can be delivered at a constant unit price q. In hydropower production the long-term marginal cost (LGK) increases. The supply curve for electricity depends on the amount of hydropower capacity already developed. When the hydropower capacity is K*, the supply curve for electricity in the short term is shown by the kinked line K*EG. At all times the price of electricity will be adjusted to ensure full utilization of the hydropower capacity. When the demand is less than K* at price q, the total demand for electricity is covered by hydropower. When the demand is higher than K* at price q, adjustment takes place on the horizontal part of the supply curve. This means that part of the demand is covered by thermal power with a constant unit price q. Therefore the price of gas acts as a ceiling for the price of electricity.

It is assumed that the developed hydropower capacity is K*, and the demand is expressed by curve D. In a situation with uncertain future demand, it does not pay to extend the capacity right up to K_0, that is to say, where the curve for long-term marginal cost intersects the demand curve. It is true that an extension of capacity would increase the consumer surplus in the short term. The shaded area shows the loss in consumer surplus during the period in question by retaining capacity K* and not extending to K_0. However, the main point in this analysis is that hydropower capacity cannot be reduced if the future demand decreases. If the demand falls to level D', and the capacity is K_0, the loss in terms of less consumer surplus will correspond to the double-shaded area. The loss represented by the triangle to the left of the double-shaded area has already been accrued, and is therefore of no importance for a comparison of K* and K_0. Not extending the hydropower capacity at the present time insures against being saddled with irreversible excess capacity during the next period. Thus, the possibility of covering part of the demand for electricity by thermal power is an insurance against less demand for electricity in the future.

Therefore the adjustment, given an initial capacity of K*, initial demand D and uncertain future demand, is that the consumers pay the price q for the electricity, and demand a quantity D_A. This implies that the excess demand D_A-K* will be covered by thermal power.

If the demand during the next period drops to D', the price of electricity P* will ensure that the hydropower capacity is fully utilized. In this situation, thermal power will not be used. If the demand rises to D", the consumers will pay the price q for the electricity. At this price, the demand for electricity will be D_B. It will then pay to extend hydropower capacity up to K_1, the maximum level for development of hydropower, since all demand over and above this level can be covered by cheaper thermal power. It can be demonstrated that when the demand is uncertain, the maximum hydropower capacity should be K_1, minus a safety margin. Therefore the conclusion is that, given a demand curve D", hydropower capacity should be increased up to K_1, i.e. K_1 minus a safety margin, and the rest of the demand should be covered by thermal power.

2.7. Analysis: Cost structure in energy-intensive industry

There are marked differences in prices in the Norwegian power market. Because of their long-term contracts, energy-intensive industry and the pulp and paper industry pay far less for power than is paid by users in the regular consumption. This is not an economically optimal use of resources. It is very important to examine the consequences for energy-intensive industry and the pulp and paper industry of gradually making power prices more equal. Some understanding of the situation can be obtained by studying the cost structure and elucidating the potential for greater effectiveness in these sectors. This is analysed by comparing the different enterprises' technology and the best practice technology in the industry concerned.

The aluminium industry

The Centre for Applied Research and the Central Bureau of Statistics (Bye and Førsund (1989a)), have carried out a study of the cost structure in the Norwegian aluminium industry, based on data from individual companies. This study shows, inter alia, that the costs at the different aluminium plants vary considerably, in spite of the fact that these companies produce fairly homogeneous products.

There are large differences in energy consumption per produced unit in the aluminium industry. In 1989, the most effective enterprises used 30 per cent less energy per produced unit than the least effective enterprises did. This was due both to choice of technology, and to how effectively the equipment is used. Average consumption of electricity fell from 20.2 to 17.7 kWh per kg produced aluminium from 1966 to 1986. In the most effective enterprise, electricity consumption dropped from 16.4 to 14.9 kWh per kg during the same period.

There are also large differences in labour costs per produced unit. From 1966 to 1976, there was a steady improvement in labour productivity in the aluminium industry. Apparently this improvement did not continue from 1976 to 1986. During the period 1966 to 1986, the total increase in labour productivity averaged as much as 56 per cent, with the greatest improvement in the least effective enterprises. Here too, there is a 30 per cent difference between the most effective enterprise and the least effective enterprise in terms of labour per ton.

Long-term contracts and licenses for electricity have been closely tied to the objectives for regional employment. This is one of the reasons why rationalization has been slower than would otherwise have been the case. So it can be said that low power prices have indirectly subsidized an overoptimal use of labour. There is reason to believe that, by improving labour productivity, the industry could maintain or even improve profitability even with a higher price for electricity. In the aluminium sector, electricity costs and labour costs accounted for about the same percentage of the total production costs, i.e. about 15-20 per cent.

Over time, the total variable costs per produced unit have been reduced substantially in the aluminium industry. At the most effective enterprises, costs have been reduced by about 80 per cent, and at the least effective enterprises by even more. The difference between the most effective and the average was much less in 1986 than it was in 1966. Probably there is still considerable potential for cost reduction, by more enterprises becoming equally effective as the most effective enterprise.

A long-term potential for reduced variable costs can be indicated by moving the average towards the most effective enterprise, both for labour costs and electricity costs. This would give a cost reduction of about 20 per cent for both electricity and labour, and would reduce total costs by about 8 per cent. The reduction in labour costs can probably be achieved without any marked increase in other costs, while reducing the cost of electricity will require investment in new capital equipment. However, with the present price that the branch has to pay for electricity, there are no strong signals that it will be profitable to invest in more energy-effective technology.

The ferro-alloy industry

The ferro-alloy industry is not as homogeneous as the aluminium industry. This has to be taken into account when assessing differences in the technology used by the different enterprises. Earlier on, the ferro-alloy industry in Norway was characterized by production of standard products for markets with steadily increasing competition. Today, about 50 per cent of the production is refined into special products for delivery to markets with much fewer competitors and better opportunities for profit.

Most Norwegian plants produce ferrosilicon as their main product. At some plants, the main product is ferromanganese, and at some ferrochromium. This means somewhat varying technologies, which partly explains the differences between enterprises as regards input of the different factors. There are large differences in energy consumption at the different enterprises (Bye and Førsund (1989b)). One reason are the choice of technology and the different products. On average, electricity consumption per produced unit was reduced by 15 per cent, or about 1 per cent per year, from 1972 to 1986.

There are also very big differences in labour costs per produced unit at the different plants. From 1972 to 1986, there was an approximately 35 per cent improvement in labour consumption per produced unit for the industry as a whole, or an average of about 2 per cent per year. Nevertheless, labour productivity in the most effective enterprise was about twice as high as in the least effective enterprise in 1986.

Like in the aluminium industry, the total average variable unit costs were also reduced from 1976 to 1986 in the ferro-alloy industry. The improvement has been marked at the least effective units in particular, but in 1986 there was still a big difference in variable unit costs between the most effective and the least effective enterprise. Thus there should be a large potential for greater effectiveness, so that the industry as a whole can stand a reorganization of the power market to give more equal prices.

The capital costs for existing plants are much lower than for new plants. It is assumed that modernization, reconstruction and extensions of existing plants can take place at capital costs about 20-30 per cent lower than for building completely new plants. This can also lead to a substantial rationalization in the use of other factors. Therefore, at given factor prices, there is a certain potential for increased production capacity at existing plants. On the other hand, there is no reason to expect investments in completely new plants in Norway up to the turn of the century, unless the price of power is very low indeed.

The pulp and paper industry

The pulp and paper sector in Norway has been characterized by very small units in an international perspective. This has affected competitiveness, and the possibility of standing higher prices of electricity. However, Norwegian pulp and paper production now tends to consist of different qualities of cellulose-based newsprint, mainly for newspapers and magazines. These are energy-intensive products with relatively low consumption of timber per ton final product. Today, newsprint accounts for about 75 per cent of Norwegian paper production. An important element in this development is that the production was to be based on timber from the coniferous belt in the Northern hemisphere. This means that Norway's competitors in the manufacture of this type of paper are Sweden, Finland, the Soviet Union, Canada and the United States. With the exception of the Soviet Union, all these are typical high cost countries. In this respect, the pulp and paper industry differs from metal production, where the competition comes mainly from newly industrialized low cost countries.

A main reason for the Norwegian pulp and paper industry's competition problems is high transport costs, particularly of raw materials (twice as high as in Sweden) and high wages (15 per cent higher than in Sweden). Other reasons are a limited supply of Norwegian raw materials, and small units compared with the competitors. Over a long period of time, there has been a shift to much fewer and larger units in the Norwegian pulp and paper industry.

Analyses carried out by the Centre for Applied Research and the Central Bureau of Statistics (Bye, Førsund and Johnsen (1989)) show that, like in the aluminium industry and the ferro-alloy industry, the costs per produced unit differ considerably between the different enterprises. For example, in 1986, many producers of wood pulp and cellulose consumed 50 per cent more energy per produced unit than the most effective enterprise.

For the pulp and paper sector as a whole, there was a marked improvement in labour consumption from 1972 to 1980. This improvement in effectiveness has continued after 1980 in the least effective enterprises.

As regards energy consumption, the greatest increase in effectiveness was in the least effective enterprises throughout the period 1972 to 1986. Due to the low cost of electricity, the Norwegian pulp and paper industry has a marked advantage over its competitors in Sweden, Finland and Canada.

The large differences in the use of input factors per produced unit, both as regards labour and energy, should imply a substantial potential for further improving effectiveness and reducing costs.

The analyses show that the average total variable unit costs for pulp and paper manufacturers were reduced substantially from 1972 to 1986. The reductions were greatest in the least effective units. However, there is still a marked difference between the least effective and the most effective units. This indicates a certain potential for further improvement of effectiveness if the majority of the units achieve the same degree of effectiveness as the most cost-effective units.

Previous macro-analyses of energy consumption in the pulp and paper sector only analyzed the substitution between the two energy carriers, electricity and oil. Firm power and surplus power were considered as one energy good, and the fact that this sector uses a large amount of solid fuel was not taken into account. In their analysis, Bye and Johnsen (1989) also include solid fuel as an energy good, and specify electricity as firm and surplus power. A main purpose of their analysis was to study whether it is the price or the supply that determines the sector's use of the different energy carriers. This was done by estimating prior determined cost functions, where the consumption of one or more energy goods is "fixed", that is to say, cannot be adjusted. The different specifications of cost functions are tested against each other. In the model which best explains the trends in the data, it is implicitly assumed that the consumption of firm power (e.g. based on long term contracts) is proportional to production. The rest of the energy consumption is decided by assessing oil against surplus power at given prices and a given level of consumption of solid fuel. For a given total use of energy in the sector, the demand for oil is reduced by about 0.8 per cent with a one per cent increase in the price of oil. The elasticity of the demand for surplus power is marginally higher, about -0.9. The substitution elasticity expresses by what percentage the ratio between the consumption of oil and surplus power is reduced when the relative price of the two energy goods is increased by one per cent. The calculations indicate that this elasticity is about 1.5 per cent. Previous studies that have examined the substitution between oil and total electricity, e.g. Bye (1984), report elasticities equal to about a third of these estimates. The above results indicate that the sector is much more flexible as regards shifting between oil and surplus power following changes in the prices of the two energy goods than previously calculated for use in the CBS's macro economic models.

2.8. Analysis: The petroleum wealth

Meaning of wealth

An important issue in macro-economic planning is to achieve a level of consumption that is adjusted to the limits imposed by production potentials, natural resources and the environment. Current income expresses these limits to some degree, but does not necessarily reflect the consumer potential over time adequately. Hence, an alternative is to start with the country's wealth. It is possible to estimate the wealth of real capital and foreign debts from the figures in the National Accounts, but other categories of wealth, such as the petroleum wealth, are not included in the National Accounts.

The National wealth shall express the value of the resources at a country's disposal. The petroleum wealth, together with, inter alia, environmental capital, real capital, human capital and reserves of foreign exchange, comprises part of the Norwegian national wealth. If it had been relevant to sell oil and gas in ground, the petroleum wealth could have been estimated as the market value of all the fields. However, sale of oil in ground has never been tried for Norwegian fields, which means that another method of estimating the petroleum wealth has to be found.

Wealth and expected return

A usual way of estimating the petroleum wealth is to calculate the present value of expected oil revenues. Such estimates are based on very doubtful assumptions. In the first place one has to choose the discount factor. In the second place, one has to make assumptions about future prices and the extraction profile. A third problem is connected to how to weigh together different categories of wealth. A significant difference between, for example, petroleum wealth and financial wealth is that the realization of petroleum wealth is linked to a time in the future, while financial wealth can be withdrawn for consumption as desired.

The discount factor expresses required rate of return on the petroleum wealth, and is decisive for how large the wealth is estimated to be. When choosing the discount factor, it is necessary to base the choice on the rate of return on investments in other activity. In the calculations, the discount factor is fixed at 7 per cent, which corresponds to about the average return on real investments in Norway.

The expected return on the petroleum wealth indicates how much can be used in the course of a year without reducing the wealth, provided there is no change in expectations. Thus, in such cases this does not necessarily mean that part of the national wealth is "consumed" even if some of the oil and gas is extracted, and some of the revenues go to consumption. In other words, it is necessary to distinguish between a barrel of oil and its value: If in the course of one year with unchanged expectations no oil is extracted and sold according to plans, then the volume will remain unchanged, but the wealth will increase because the planned time of oil extraction has moved one year nearer. If the expectations concerning estimated resources, future prices and costs remain unchanged from one year to the next, the petroleum wealth could increase if the value of the extracted oil and gas is less than the expected return.

Changes in the petroleum wealth

To be able to estimate the petroleum wealth it is necessary to make assumptions about future extraction. Ideally, the rate of extraction should be chosen to make the wealth as large as possible. A high rate of extraction may be favourable if oil and gas prices are not expected to increase in the future. In that case it will pay to extract the oil and gas as quickly as possible in order to invest in other activities. Similarly, expectations of high growth in prices prescribe a lower rate of extraction. Other factors should be taken into account when deciding consumption, for example that it is not advisable to "eat into" the national wealth, of which the petroleum wealth is a part. Therefore a high rate of extraction is not the same as using up the petroleum wealth. If the revenues from extraction are separated from how they are used, then large revenues from the petroleum activities simply means transferring the petroleum wealth to another category of wealth. The plan to establish an "oil fund" is an example of this kind of separation.

An estimate of the petroleum wealth based on expected income will be very uncertain. Especially expectations about prices have to be continually re-evaluated, but estimates of resources also change from year to year. Therefore the real size of the petroleum wealth is never known, nor the actual value of the return. This makes it unreasonable to use the same management rule for all types of wealth. For example, in applying the rule to use all the expected return from the petroleum wealth there will always be a risk of using too much ("eating up" the wealth). This will be the case when the expectations on which the calculation of the return was based are shown in retrospect to have been too optimistic. One way of taking this uncertainty into account is to calculate the national wealth using different discount factors for each category of wealth. In principle, such an adjustment implies that all assets can be freely converted into other assets. For example, the Norwegian State could sell securities with a guarantee in the future production of oil and gas.

Thus the annual change in the petroleum wealth has three causes: The expected return, which pulls in the direction of increased wealth; extraction, which pulls in the direction of reduced wealth; and reevaluations, which pull both ways.

Calculations

The uncertainty connected to the assumptions in estimating the petroleum wealth are illustrated in figures 2.16 and 2.17. Figure 2.16 shows the estimated exploitable

Table 2.7. Changes in estimated petroleum wealth. 1973 - 1989. Billion constant 1986-kroner

Year	Wealth	Value of extraction	Expected return	Value of changes in expectation
1973	47	- 4	3	428
1974	482	-12	34	-130
1975	398	-12	28	60
1976	499	- 7	35	13
1977	554	- 3	39	-6
1978	590	10	41	504
1979	1 125	24	79	777
1980	1 955	55	137	239
1981	2 273	59	159	-233
1982	2 136	51	150	-88
1983	2 143	59	150	-441
1984	1 789	62	125	-460
1985	1 388	56	97	-731
1986	694	16	49	-219
1987	506	21	35	-106
1988	413	20	29	162
1989	582	29	41	-

oil and gas reserves, updated annually during the period 1973-1989. Most of the reserves have been adjusted upwards during the period. This probably expresses a certain caution when the estimates were made. The reason for the large change from 1987 to 1988 is that, from 1988 onwards, the figures from the Petroleum Directorate include estimates of the resources north of latitude 62°. However, this change has little effect on calculations of the wealth, partly because the estimated value of these resources is relatively low, and partly because the income will not be realized for many years. The reserves in fields which it has been decided to develop, declined gradually from 1975 to 1983. The main reason is extraction, but the estimates of the reserves have also been adjusted down.

Figure 2.17 shows forecasts of the oil price in different reports to the Storting, perspective reports and the long-term programme for the period 1977 to 1988. These forecasts are interpreted here as expected oil prices referred to different times. The typical price path starts from the year to which the forecast applies, and grows at a constant rate. This can be taken to show that the oil price has never been regarded as particularly high or low in relation to the "normal" level. The choice of growth rate seems to be influenced by changes in prices during the previous year, except perhaps in 1986, when the price was expected to increase very soon. There is reason to note that, not at any time, is the price of oil expected to fall.

Figure 2.16. Expected petroleum resources in fields with a development plan and estimates for other recoverable reserves. 1973-1989. Million tons oil equivalents

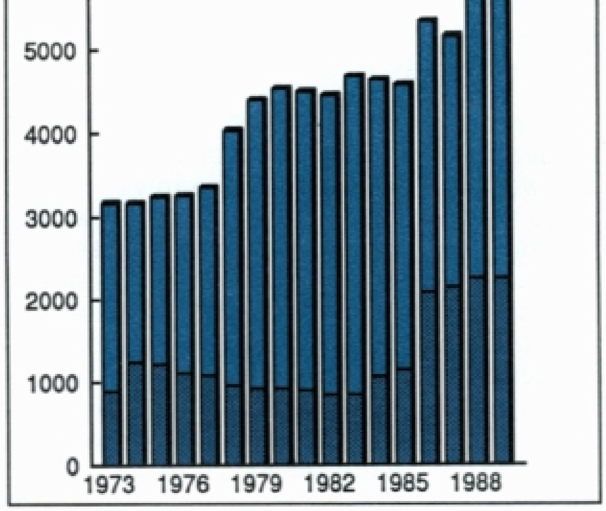
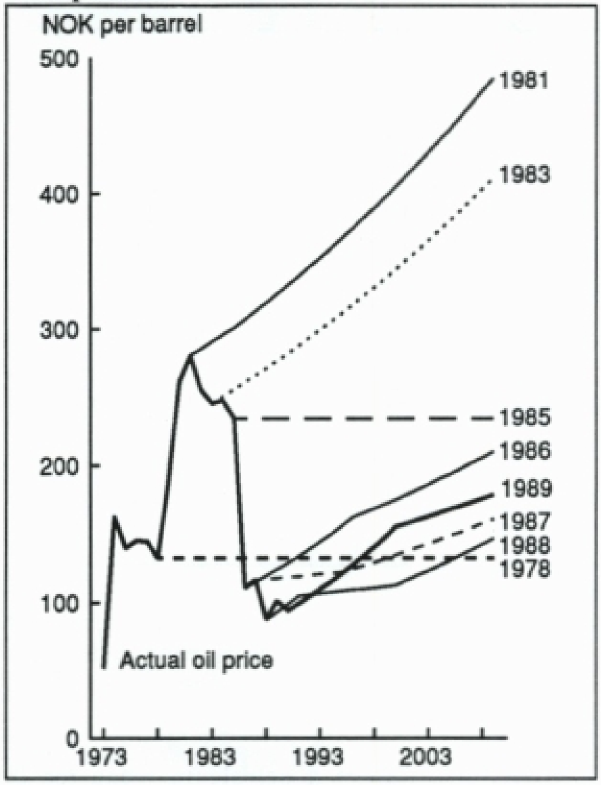


Figure 2.17. Crude oil price development. 1973-1989. Official forecasts of crude oil prices in selected years. Kroner per barrel. Constant 1986-prices



Calculations of the wealth are based on the assumptions about estimated resources and future oil prices in figures 2.16 and 2.17, and on assumptions about production profiles. These are taken from Wood & MacKenzie (1986). The estimates of wealth are shown in table 2.7. The changes are due, in the first place, to expected changes in prices. Around 1980, the estimated resources were adjusted up because of new discoveries, and at the same time a marked increase in the price of oil.

Changes in the petroleum wealth also causes changes in the expected return on the wealth. This is partly due to extraction, since we have defined the petroleum wealth as the value of remaining resources, but the main reason is changes in expectations. This is evident from table 2.7, which shows the total wealth, income and extraction, expected return on the wealth and the value of the re-evaluations. In all years after 1973, the expected return has been greater than the income from extraction. In other words, the petroleum wealth was expected to increase over time. Thus, the fact that the wealth has been reduced substantially during the 1980s is not because the intention has been to "tap" the petroleum wealth. If there had been no change in expected prices during this decade, the wealth would have increased. However, a gradual downward adjustment of the expected prices led to marked changes in the estimated wealth. These adjustments alone led to a reduction in the wealth of altogether NOK 2 300 billion from 1980 to 1987. This "loss" is equivalent to about NOK 0.5 million per capita.

Management of the wealth: How to gamble if you must?

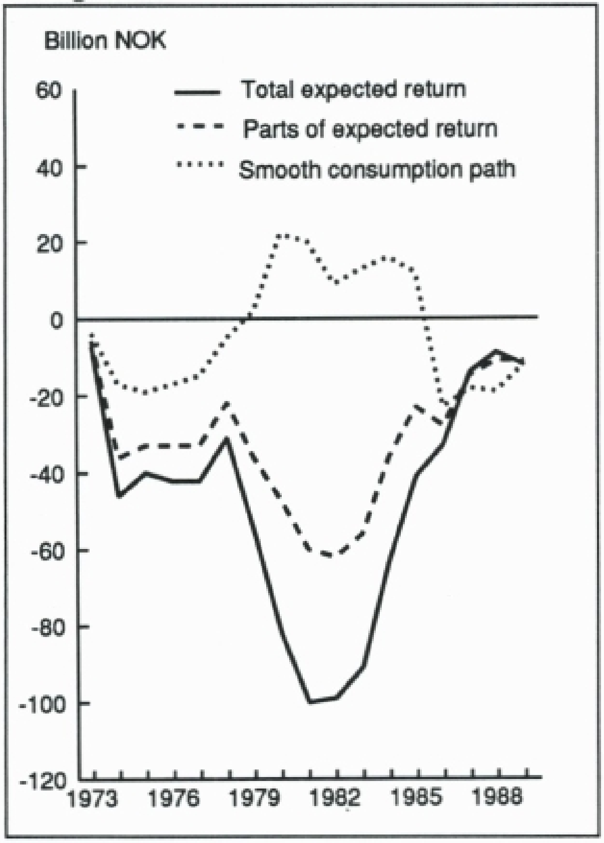
This section studies different rules for management of the petroleum wealth. Only the use of the oil revenues is studied, not how the reserves should be extracted. Moreover, it only examines the contribution made by the petroleum wealth to the current account balance and consumption under different rules, and does not consider any other macro-economic effects. The next section presents fairly comprehensive macro-economic calculations based on different sets of assumptions about the use of the oil revenues, without discussing what would be good management of the petroleum wealth. This section, on the other hand, does discuss in principle the problems connected to management of the wealth.

It is difficult to interpret *the quantification* of the petroleum wealth. The degree of uncertainty connected to the petroleum wealth is especially important. The uncertainty must influence how the wealth is managed, so a single figure for the petroleum wealth does not provide enough information to form a basis for proper management. To illustrate this, it might be a good idea to start with what would be proper management if the wealth had in fact consisted of securities with a risk free rate of return.

Use the expected return

Much of the discussion that has taken place on management of the petroleum wealth has been connected to whether future generations will receive a reasonable share of the wealth, i.e. whether the present generation has used too much. Therefore a natural objective might be to keep consumption constant at as high a level as possible. This means preferring consumption path A to consumption path B if the lowest consumption along A is higher than the lowest along B.

Figure 2.18. Contribution to current account balance for three different rules for wealth management

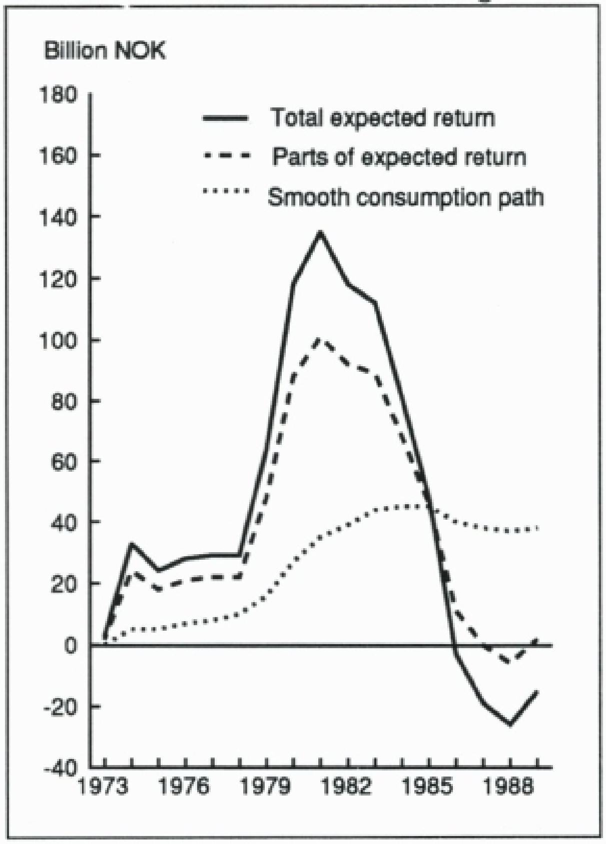


If the wealth gave a certain return which was constant over time, it would then be possible to use the return each year without reducing the wealth. The return would then give a certain annual income which does not change over time. This is the best alternative in the light of the objective.

Let W_{Pt} denote the petroleum wealth at time t. When the extraction path is fixed, the development of W_{Pt} will be totally determined by changes in the expected price. Let W_{Ft} be the value of foreign claims. The management rule now dictates that $W_{Pt} + W_{Ft}$ shall be constant. The contribution to consumption then becomes $r(W_{Pt} + W_{Ft})$, where r is the rate of return.

It is informative to show how a rule requiring use of the entire expected return would function as a rule of management for the petroleum wealth in the years after 1973. The contribution to the current account balance is shown in figure 2.18. This rule of management would mean borrowing large sums each year. In 1989, the foreign debt would have been NOK 794 billion and the contribution to consumption would have been NOK -15 billion. It may seem surprising that the contribution to consumption is negative. The reason is that W_{Ft} is negative, while W_{Pt} has decreased sharply and unexpectedly since 1981, thus the sum becomes negative.

Figure 2.19. Contribution to consumption for three different rules for wealth management



The assumption necessary for this rule to meet the objective of constant consumption is a risk free return. The above calculations show how fallacious this assumption is in the case of the petroleum wealth.

Uncertainty is a major problem if one uses the whole of the expected return. It is natural to compensate for the uncertainty by saving some of the return. Figure 2.18 also shows the contribution to the current account balance if one uses 5/7 of the expected return. This leads to only a small reduction of the loaned sum compared to the case when one uses the whole of the expected return. A main problem in both cases is that, as shown in figure 2.19, the contribution to consumption is very unstable. Even if one saves 2/7 of the expected return, consumption falls by over NOK 100 billion from 1981 to 1988. The next rule repairs this situation.

Smooth consumption path

The two previous management rules have linked consumption exclusive to the wealth, but the wealth is only meant to be an indicator of the future potentials. So there is nothing in such a rule to connect consumption in one year to consumption the year before, and the result is large fluctuations in consumption. This is disagreeable for the individual consumer and may lead to major social disadvantages in the form of unemployment, social problems, etc. The third rule for study is based on the assumption that a smooth path of consumption is to be preferred.

In the above example, where one uses 5/7 of the expected return, the consumption is expected to increase by 2 per cent per year, i.e.:

$$E^t [C_{t+1}] = 1.02\ C_t = 1.02*(5/7)*rW_t$$

where C_t is the consumption in year t and $E\ [C_{t+1}]$ is the expected consumption in the following year, W_t is the wealth and r is the interest rate. However, the growth will seldom be so smooth, but it is possible to ensure a smooth growth by choosing

$$C*_t = 1.02\ C_{t-1}$$

However, such a policy does not take into account changes in the wealth, which express what consumption is possible in the long term. Therefore, an intuitively attractive rule of management is to choose something between $C*_t$ and 5/7 of the expected return. If the consumption path is to be smooth, the consumption cannot deviate too much from C*, but it is also necessary to take into account what consumption is possible in the long term.

Brekke, Aslaksen and Thonstad (1989) define this rule more specifically, and show that, under certain assumptions (inter alia a sure future return), the optimal policy is, in fact, a weighted mean of the historically determined level of consumption (which is defined in more general terms than above), and a specific share of the expected return. How much weight should be given to the expected return and the historically determined consumption depends on how much weight one attaches to achieving a stable growth in consumption.

Figure 2.18 shows changes in the contribution to the current account balance for such a rule of management. In this calculation, the historically determined level of consumption is given a weight of around 80 per cent. The figure shows that this rule of management implies a substantial saving at the start of the 1980s, up to the fall in oil prices. Changes in the contribution to total consumption are shown in figure 2.19. This consumption path is very stable compared to the consumption paths obtained with the other two rules of management.

2.9. Analysis: A contra-factual analysis of Norway's development as an oil exporting country

Introduction

Looking back on Norway's development as an oil exporting country, it is clear that production of oil and gas from the Norwegian continental shelf started at a very favourable time. Norway was ready to produce oil in a decade when the high rise in oil prices shook the rest of the industrial world. Because of the income from oil, Norway was able to maintain the growth in production and demand. Oil income was included in the economy, and to some extent anticipated during the so-called "counter cyclical policy" of the 1970s. An important point in this connection is that oil activities gave a much higher return than other production. In 1985, *the oil rent*, defined as the "excess return" from the production of oil and gas (see section 2.2), reached a peak level of about NOK 60 billion, see table 2.2 and table 2.9 below. The effects on a country's economy of a large supply of income from excess return are well known: The use of the oil income will lead to increased domestic demand. The prices of protected products will be forced up, production that is exposed to competition will decrease, and sheltered production will bloom. At the same time, there will be an increase in imports. It is important to underline that there is nothing "wrong" with such a development; in fact it is only in this way that a country can achieve economic advantages from the large income from oil activities.

The problem of using the oil income is that this may take place too quickly. Costs are forced too high in relation to what is necessary to achieve adjustment and reorganization, and deindustrialization may go too far. The result may be long-lasting and high unemployment, and loss of important competence in industry and commerce. Such a condition in a country's economy is often called "Dutch disease", and reflects the situation in Holland at the end of the 1970s, when the country's income from the sale of natural gas decreased. It was impossible to build up the traditional export industry, and the result was a large increase in unemployment.

Such problems can suddenly come to light or can be intensified by sudden changes in the expected income from the oil activities. This was exactly what happened in Norway in the winter of 1985/86 when there was a big drop in the price of crude oil. As shown in section 2.8. this made it necessary to make a strong downward adjustment of the estimate of Norway's petroleum wealth. This increased the focus on the possible negative effects of using the oil income, and intensified the problems experienced by activities exposed to competition. In connection with the use of the future income from petroleum activities, the idea of establishing an "oil fund" has been raised once again.

Model calculations for the Norwegian economy 1971-1988 with and without oil

The following section presents a so-called contra-factual analysis of how the oil activities and the use of the income from oil has influenced the Norwegian economy during the period 1971-1988, based on Cappelen and Gjelsvik (1990). The term contra-factual means studying *alternative* paths for the economy in relation to what has actually taken place. The study focuses on the macro-economic effects of different ways of using the petroleum wealth. The analysis is carried out by means of calculations in a macro-economic model called AMEN (see Cappelen et al (1985)). Three alternative, contra-factual calculations are studied. In the first calculation, the oil sector (income and expenditures) is removed from the model, without changing the economic policy. In the second calculation, the oil rent, i.e. the income over and above wages and a normal return on real capital in the oil sector, is placed in financial assets abroad, that is to say in an oil fund. The return on this fund is included in the economy. In the third calculation, one first calculates the value of the petroleum wealth, i.e. the expected value of the remaining reserves. It is assumed that the annual return on this wealth, called the expected return, is used for domestic consumption.

Alternative 1. Norway without oil

This calculation is based on the hypothetical situation that Norway had no supply of oil and gas resources. Therefore, in the model calculations, the oil sector, both the large investments on the continental shelf and the income from them, is removed from the Norwegian economy. It is assumed, however, that the economic policy, including public purchases of goods and services, remains unchanged. Therefore the effect of demand in the Norwegian economy during this period will not change much, except that the direct effects of production activity in the oil sector on the supply industry will disappear, resulting in a more moderate pressure on prices and wages.

The most important effects of disregarding the oil sector are evident in the foreign accounts. Table 2.8 shows the changes in the current account and Norway's net debt during the period, both real and calculated ("without oil"). Without the income from oil, the demand management which was in fact gradually practised would have led to a large deficit in the foreign accounts. The

Table 2.8. The effect on current account and net debt by disregarding the oil sector

Year	Actual data		Norway without oil	
	Current account Billion kroner	Net debt Per cent of GDP	Current account Billion kroner	Net debt Per cent of GDP
1971	-3.7	14.1	-2.9	12.2
1972	-0.4	13.8	0.9	10.8
1973	-2.0	12.7	1.5	6.8
1974	-6.2	15.2	1.1	4.4
1975	12.7	23.7	-6.4	10.4
1976	-20.4	31.9	-11.1	15.6
1977	-26.8	44.1	-16.8	25.2
1978	-11.0	46.5	-12.1	31.2
1979	-5.3	43.4	-13.1	34.1
1980	-5.4	32.6	-23.7	37.4
1981	12.5	26.7	-29.1	45.5
1982	4.1	26.9	-43.1	59.6
1983	14.6	22.4	-40.9	70.1
1984	23.9	16.7	-50.6	81.7
1985	26.7	9.7	-56.0	89.3
1986	-32.9	16.0	-84.0	101.1
1987	-27.6	17.6	-85.7	107.6
1988	-23.8	21.2	-84.7	114.8

table shows, however, that it was not until 1980 that the net debt as a percentage of GDP became higher in a Norway without oil than actually observed.

The explanation lies in the direct and indirect effects on the net debt of the oil investments, which are also disregarded in the calculations. A large part of these investments in the North Sea were covered by imports. However, when Norway "lost" substantial revenues from the export of oil and gas after OPEC II, this caused a large deficit in the current account. In the calculation without oil, Norway's net debt increases to a level equivalent to the GDP in 1986. (Whether such a development would have been possible without income from oil is doubtful, however. A steadily increasing imbalance would have forced political change). A development with a more active political adjustment to a situation without oil is analyzed in Cappelen et al (1985). A more restrictive economic policy would have improved the current account, but would have led to a deterioration of the situation on the labour market. It can therefore be concluded that without a supply of oil and gas, the Norwegian economy would have developed more in line with that of other industrial nations, and would have had to face problems of unemployment and a low rate of growth 7-8 years earlier than was actually the case.

Alternative 2. An oil fund

In this alternative, the idea is that the government seizes the entire oil rent by taxing the oil companies. Table 2.9 shows the oil rent from 1973 to 1988 in current prices. The second column shows the development of the oil fund. The oil fund equals the accumulated value of placing the oil rent in international financial markets. It is further assumed that the real return (the rate of interest minus the rate of inflation) on this fund every year is used for consumption in Norway. (Note that the excess, nominal part of the annual income from the interest is thus added, and helps to increase the fund over time). This continual real return on the oil fund is shown in the third column in table 2.9.

As long as the oil rent is positive, the oil fund will increase, and it can be seen that at the end of the period it has reached the amount of over NOK 390 billion. Each year, per definition, the real return is used domestically. It is seen that the real rent was relatively moderate up to the beginning of the 1980s. Furthermore, it is seen that a consumption level based on a real return obtained by placing the oil rent abroad would not have led to reductions in the consumption level corresponding to the decrease in oil prices. Therefore, an important point is that a use of income based on the real return on an oil fund will fluctuate far less than the current oil revenues.

An interesting question is how much of this potential fund of NOK 394 billion has been used up in the period 1973 to 1988. In Cappelen and Gjelsvik (1990) this is estimated as follows: First the observed current account balance is adjusted for all transactions which are directly connected to oil activities, both income and expenditures. This gives a current account balance for "non-oil Norway". To this is then added the real return on an oil fund. The adjusted current account balance is then compared with a current account balance which assumes an unchanged relationship between the net foreign debt and the GDP for non-oil Norway from 1973 onwards (unchanged rate of debt). The difference between these two "current account balances", cumulated for the period 1973 to 1988, can be said to give an estimate of how much of the potential fund of NOK 394 billion that has been used domestically. This estimated difference is NOK 210 billion, that is to say, rather more than 50 per cent of the potential fund in 1988 was "eaten" up during the period from 1973 to 1988.

Another main question is: What kind of economic policy, combined with the establishment of an oil fund, could have produced a balanced development, that is to say, a constant rate of debt for non-oil Norway?

Such a development can be simulated by assuming a more restrictive economic policy as from 1975. Public consumption and investments are reduced and taxes increased, so that the accumulated effects on the current account balance during the period 1975 to 1988 correspond to a development with a constant rate of debt.

The restrictive policy in this model simulation implies that Norway experiences a much lower economic growth and a rate of unemployment of 5-6 per cent already towards the end of the 1970s. On the other hand, Norway experiences a better economic development in the 1980s, with a higher rate of investment and a lower level of unemployment than has actually been experienced. For a more detailed description of the results of this alternative calculation, see Cappelen and Gjelsvik (1990).

Table 2.9. Oil rent, oil fund and real return on the oil fund. 1973-1988. Billion kroner

Year	Oil rent	Oil fund	Real return on the oil fund
1973	-0.6	-1.7	-0.0
1974	-0.9	-2.8	-0.0
1975	1.5	-1.6	-0.0
1976	3.3	1.6	0.0
1977	2.8	4.5	0.0
1978	7.0	11.8	0.1
1979	13.7	26.1	0.5
1980	31.8	59.5	1.3
1981	36.4	99.9	4.5
1982	37.8	142.9	7.0
1983	48.0	195.5	11.1
1984	59.5	260.4	16.4
1985	62.3	331.0	18.2
1986	18.3	358.4	14.0
1987	13.2	380.4	16.7
1988	0.9	394.2	15.8

Alternative 3. Use of the expected return on the wealth

The expected return is defined as the income that can be consumed without expecting a reduction in the oil wealth. In Brekke et al (1989), the oil wealth is calculated as the discounted value of the future net income from oil and gas activities. The prices that are used are the expected future prices at different times, see section 2.8.

Table 2.10 shows the calculated changes in the petroleum wealth (in 1986 prices) and the expected return from petroleum activities during the period 1973 to 1988. The variations in these series of figures are mainly due to changes in prices, but also to changes over time in the volume of production and the estimates of remaining reserves of oil and gas.

Table 2.10 shows that during the period 1979-1985, the estimated petroleum wealth and the consequently estimated revenues from oil and gas production were considerable. If one again starts with the estimated current account balance for non-oil Norway, and adds to this the expected return in table 2.10, one obtains a new adjusted "current account balance" for non-oil Norway. The expected return gives the potential for the domestic use of the revenues from the petroleum wealth. By comparing this with a current account balance which assumes a constant rate of debt (debt/GDP), it can be concluded that the actual use of the revenues from oil in Norway up to the mid-1980s was much lower than a "rule" about using the expected return. Therefore, compared with a continual use of the expected return, the actual use of the revenues from oil in Norway can be characterized as modest.

Table 2.10. Petroleum wealth and expected return on the petroleum wealth

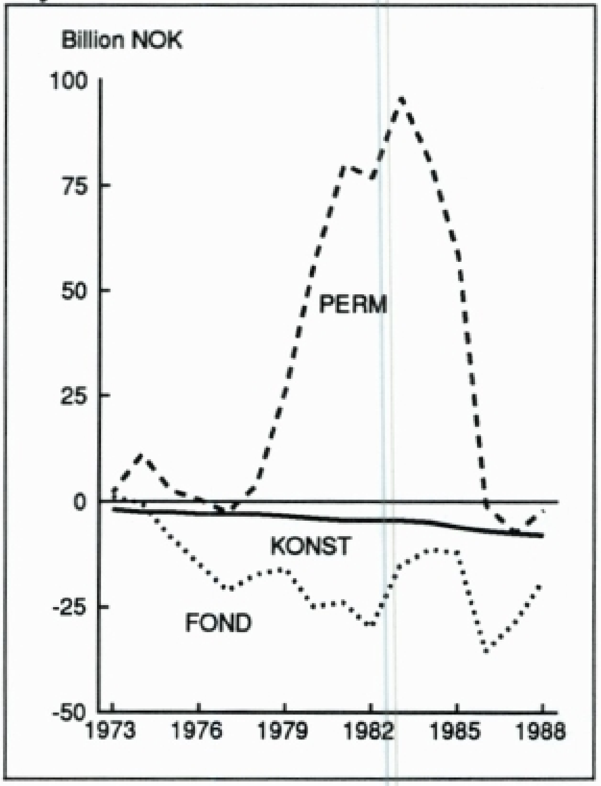
Year	Petroleum wealth in 1986-prices Billion kroner	Expected return, current prices. Billion kroner
1973	47	1.1
1974	482	11.8
1975	398	11.2
1976	499	15.3
1977	554	18.6
1978	590	21.5
1979	1 125	43.5
1980	1 955	83.4
1981	2 273	108.4
1982	2 136	113.7
1983	2 143	122.2
1984	1 789	108.4
1985	1 388	88.9
1986	694	48.6
1987	506	37.9
1988	413	32.5

Table 2.10 also illustrates, however, the dramatic change in expected prices, and the reduction in the estimated petroleum wealth, and thereby future revenues from this wealth, which occurred after the fall in oil prices in 1986. In the light of this, it can well be added that it was beneficial that the economic policy had not been based on expectations of large revenues from oil which prevailed in the early 1980s. If this had been the case, Norway would have accumulated a substantial net foreign debt and would suddenly have been left without the large, future income with which it was planned to pay off this debt.

Summary

Figure 2.20 shows changes in the current account for non-oil Norway in three hypothetical cases.

Figure 2.20. Current account for non-oil Norway[1)]



1) The three alternatives are explained in the main text.

KONST is the calculated current account in a situation where Norway maintains a constant rate of foreign debt,

FOND is the current account for non-oil Norway, adjusted for the return on an oil fund based on the above calculations, and

PERM is the current account adjusted for the expected return from alternative 3 above.

The difference between **PERM** and **KONST** shows how much more of the oil revenues

Norway could hypothetically have used if it had been permitted to consume the return on the estimated petroleum wealth at any time. According to this scheme, one should start to consume part of the expected oil income as soon as the oil and gas reserves are discovered. The difference between **KONST** and **FOND** illustrates, on the other hand, the "excess consumption" which has actually taken place if one alternatively adopts the standpoint that it is sensible to build up an oil fund, and that the income from this fund is incorporated into the economy. This policy implies totally ignoring the value of non-extracted oil and gas when assessing the income, and thus expresses a quite extreme form of risk aversion. The actual use of petroleum revenues in Norway during this period can be said to lie somewhere between these two extremes for utilization of income, but closest to the oil fund alternative.

2.10. Units and conversion factors

Table 2.11 shows average theoretical energy content and thermal efficiency coefficients for a number of selected energy goods in different applications. The theoretical energy content will vary within one and the same type of energy good. For example, crude oil from the North Sea has a different chemical composition and thermal efficiency coefficient than crude oil from the Middle East. Therefore, the factors presented in table 2.11 should be regarded as average values. The estimates of the thermal efficiency coefficient are very uncertain. Some studies include results which deviate strongly from the thermal efficiency coefficients presented in the table.

There are a large number of measuring units for energy in use. Several contributory factors decide the relation between them. The conversion factors presented in table 2.12 must be regarded as approximate. This applies to the measuring units for oil (toe and barrels), and to an even greater degree to the measuring units for gas (m^3 and Scuft), and to the conversion factors between these units. Table 2.12 is based on the densities and thermal efficiency coefficients in table 2.11. Some commonly used prefixes are given in table 2.13.

Table 2.11. Average energy content, thermal efficiency coefficients and density, by energy source

Energy source	Theoretical energy content	Unit	Thermal efficiency coefficient: Manufacturing, mining	Transportation	Other consumption	Density
Coal	28.1	TJ/ktons	0.80	0.10	0.60	..
Fuelwood[1]	8.4	TJ/kfm³	0.65	-	0.65	0.5 tons/fm³
Paper waste (solid)	12.6-15.5	TJ/ktons	..	..	..	..
Wood waste (solid)	15.0-18.5	TJ/ktons	..	..	..	..
Crude oil	42.3	TJ/ktons	..	..	..	0.85 tons/m³
Natural gas	40.4	TJ/MSm³	..	..	..	0.77-1.07 kg/Sm³
Liquefied petroleum gas (LPG)	46.0	TJ/ktons	0.95	-	0.95	0.53 tons/m³
Gasoline	44.0	TJ/ktons	0.20	0.20	0.20	0.74 tons/m³
Kerosene	42.7	TJ/ktons	0.80	0.30	0.75	0.79 tons/m³
Diesel oil. gas oil. fuel oil nos. 1 and 2	42.3	TJ/ktons	0.80	0.30	0.70	0.83 tons/m³
Heavy fuel oil	41.9	TJ/ktons	0.90	0.30	0.75	0.95 tons/m³
Electricity	3.6	TJ/GWh	1.00	0.95	1.00	..

1) fm³ = m³ solid wood.

Table 2.12. Energy units[1]

Unit	PJ	TWh	quad (oil)	Mtoe (oil)	M-barrel (gas)	GSm³ (bcm) (gas)	GScuft
1 PJ	1	0.278	9.50×10^{-4}	0.024	0.175	0.025	0.83
1 TWh	3.60	1	3.42×10^{-3}	0.085	0.629	0.089	3.00
1 quad	1053	292.5	1	24.9	184.1	26.1	877.5
1 Mtoe	42.3	11.8	0.04	1	7.4	1.05	35.3 (oil)
1 Mbarrel (oil)	5.72	1.59	5.4×10^{-3}	0.135	1	0.142	4.8
1 GSm³ (bcm) (gas)	40.4	11.2	3.8×10^{-2}	0.96	7.1	1	33.7
1 GScuft (gas)	1.20	0.33	1.1×10^{-3}	0.028	0.21	0.03	1

1) 1 quad = 10^{15} Btu (British thermal units).
Mtoe = 1 million tons of (crude) oil equivalents.
Mbarrel = 1 million barrels crude oil (1 barrel = 0.159 m^3).
GSm^3 = 1 billion standard cubic meters natural gas.
GScuft = 1 billion standard cubic feet natural gas. (1 Scuft = 0.0283 Sm^3).

Table 2.13. Prefixes

Name	Symbol	Factor
Kilo	k	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}

2.11. Appendix of tables

Table 2.14. Reserve accounts for crude oil. Developed fields and fields to be developed. 1979-1989. Million tons of oil equivalents

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989*
Reserves per 1/1	570	520	496	509	495	495	650	733	838	871	1028
New fields	-	24	80	-	38	147	65	29	60	155	-
Reevaluation	-31	-24	-43	11	-7	43	56	118	22	59	..
Extraction	-19	-24	-24	-25	-31	-35	-38	-42	-49	-57	-76
Reserves per 31/12	520	496	509	495	495	650	733	838	871	1028	952

Source: Petroleum Directorate, Central Bureau of Statistics.

Table 2.15. Reserve accounts for natural gas. Developed fields and fields to be developed. 1979-1989. Million tons of oil equivalents

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989*
Reserves per 1/1	445	406	385	381	348	332	399	387	1259	1247	1267
New fields	-	32	40	-	15	84	9	893	8	20	-
Reevaluation	-17	-27	-18	-8	-6	10	66	6	10	28	..
Extraction	-22	-26	-26	-26	-26	-27	-27	-27	-29	-29	-30
Reserves per 31/12	406	385	381	348	332	399	387	1259	1248	1267	1237

Source: Petroleum Directorate, Central Bureau of Statistics.

Table 2.16. Extraction, conversion and use[1] of energy goods. 1988*. PJ

	Total	Coal	Coke	Fuelwood, paper waste, other solid waste	Crude oil	Natural gas	Petroleum products[2]	Electricity	District heating
Extraction of energy goods	4013	7	-	-	2352	1212	48[2]	394	-
Energy use in extraction sectors	-73	-	-	-	-	-63	-2	-8	-
Imports and Norwegian purchases abroad	394	22	27	0	51	0	288	6	-
Exports and foreign purchases in Norway	-3416	-7	-6	0	-2044	-1127	-206	-26	-
Stocks (+Decrease, -Increase)	-1	5	1	.	-5	.	-2	.	-
Primary supply	917	27	22	0	354	22	126	366	-
Petroleum refineries	-15	-	5	-	-350	-	331	-1	-
Other energy sectors, other supply	41	-6	5	35	-	-	2	1	4
Registered losses, statistical errors	-49	-2	-1	-	-4	-22	13	-32	-1
Registered use outside energy sectors	894	19	31	35	-	-	472	334	3
Ocean transport	143	-	-	-	-	-	143	-	-
Domestic use	751	19	31	35	-	-	329	334	3
Agriculture and fishery	32	0	-	-	-	-	28	4	0
Energy intensive manufacturing	206	12	27	0	-	-	59	108	0
Other manufacturing and mining	108	7	4	16	-	-	28	52	1
Other industries	197	-	-	-	-	-	134	62	1
Private households	208	0	0	19	-	-	80	108	1

1) Including energy goods used as raw materials.
2) Including liquefied gas. Coke includes petrol coke.

Table 2.17. Electricity balance[1]. 1975 - 1989. TWh

	1975	1980	1983	1984	1985	1986	1987	1988*	1989*
Production	77.5	84.1	106.4	106.7	103.3	97.3	104.3	110.0	119.2
+Imports	0.1	1.8	0.4	0.9	4.1	4.2	3.0	1.7	0.3
-Exports	5.7	2.3	13.8	9.1	4.6	2.2	3.3	7.4	15.2
=Gross dom. consumpt.	71.9	83.6	93.0	98.4	102.7	99.3	103.9	104.4	104.3
-Consumption in pumping plants	0.1	0.5	0.5	0.6	0.8	0.9	0.7	1.0	0.5
-Surplus power	3.2	1.2	4.1	4.8	4.8	2.7	4.1	4.5	5.0
-Losses in exports and surplus power	0.8	0.3	1.6	1.3	1.0	0.3	0.5	0.8	1.4
=Gross firm power consumption	67.7	81.6	86.8	91.7	96.2	95.4	98.6	98.1	97.4
Energy intensive industries	27.0	28.7	29.5	32.1	30.9	29.2	29.8	30.4	31.2
Regular consumption[2]	40.7	52.9	57.3	59.6	65.3	66.2	68.8	67.7	66.2
-Losses in the transmission lines, consumption in the power stations, statistical differences[3]	6.3	7.7	7.7	8.0	8.7	9.1	9.2	9.1	8.9
=Net firm power cons.[3]	61.4	73.9	79.1	83.7	87.5	86.4	89.3	89.0	88.6
Energy intensive ind.	26.2	27.9	28.7	31.2	30.0	28.4	28.9	29.6	30.3
Regular consumption[2]	35.2	46.0	50.4	52.5	57.5	58.0	60.4	59.4	58.3
Regular consumption[2], temperature adjusted	36.3	45.1	51.7	53.0	55.0	57.1	58.6	60.2	61.5
Average annual change. Per cent		4.4	4.7	2.5	3.8	3.8	2.6	2.7	2.2

1) The definitions in the table follow the definitions of the Electricity Statistics. The figures are preliminary.
2) Firm power consumption outside energy intensive industries.
3) In the Electricity Statistics the sum of losses and statistical differences is registered. From 1983 losses are estimated as the difference between gross and net electricity consumption in energy intensive industries plus an estimated loss in regular consumption of 14 per cent (from 1989 13.5 per cent). Net consumption appears as the difference between gross consumption and estimated losses. This estimation procedure implies a slight deviation between the figures for regular consumption and those of the Electricity Statistics.

Table 2.18. Use of energy goods outside the energy sectors and ocean transport, by energy source. 1976 - 1989. PJ

Energy source	1976	1981	1982	1983	1984	1985	1986	1987	1988*	1989*
Total	617	677	664	677	722	743	747	772	751	743
Electricity	241	280	280	298	319	329	324	335	334	337
Firm power	232	271	271	283	302	312	315	321	320	319
Surplus power	9	9	9	15	17	17	10	15	14	18
Oil total	311	321	309	293	312	323	336	348	329	319
Oil other than transportation	161	120	100	84	80	84	95	84	73	65
Gasoline	13	6	4	4	5	4	4	0	0	0
Kerosene	17	12	9	8	7	9	10	11	10	8
Medium distillates	65	55	48	41	40	43	43	45	40	36
Heavy fuel oil	66	47	39	31	28	28	37	29	23	21
Oil for transportation	147	162	166	171	181	187	202	208	204	201
Gasoline, gasoline type jet fuel, kerosene type jet fuel	69	78	80	81	84	89	96	102	103	104
Medium distillates	75	79	80	84	89	91	98	99	95	92
Heavy fuel oil	3	5	6	6	8	7	8	7	6	6
Liquefied gas	1	39	41	40	50	52	40	56	53	53
District heating	.	.	.	.	.	.	.	3	3	3
Solid fuels	65	76	75	86	91	91	88	86	85	84
Coal, coke	47	48	47	56	60	57	53	51	50	48
Fuelwood, paper waste, other solid waste	18	28	28	30	31	34	34	35	35	36

Table 2.19. Average prices[1] of electricity[2] and selected petroleum products. Delivered energy. 1980-1989

Energy source	1980	1981	1982	1983	1984	1985	1986	1987	1988*	1989*
Heating products: Price øre/kWh										
Electricity[3]	17.5	20.1	23.2	26.9	30.5	32.5	35.6	37.9	41.7	43.0
	(15.7)	(17.5)	(20.2)	(23.4)	(26.5)	(28.5)	(31.6)	(34.3)	(37.2)	(38.6)
Heating kerosene . .	20.7	26.9	30.5	31.8	32.5	32.8	24.8	25.0	25.7	28.3
Fuel oil no. 1	18.0	22.8	25.1	26.2	26.9	27.2	19.4	19.6	19.7	21.6
Fuel oil no. 2	17.0	21.7	23.8	25.0	25.7	25.7	18.1	18.3	18.8	20.7
Heavy fuel oil	10.3	13.8	13.7	14.8	17.7	17.8	10.4	12.4	11.7	14.7
Transportation prod.: Price øre/liter										
Super gasoline . . .	371.5	435.0	460.5	492.5	520.9	512.8	476.0	510.0	536.0	578.5
Regular gasoline . .	263.5	427.0	461.7	480.2	505.3	501.8	.	.	.	.
Unleaded gasoline .	.	.	.	.	.	521.2	457.0	489.0	503.0	540.5
Auto diesel	191.9	240.0	262.7	272.3	280.3	282.0	207.6	210.0	214.0	233.0

1) All taxes included.
2) Households and agriculture.
3) The figures in parentheses comprise the variable part of the price (the energy part of the H4-tariff).

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3. FISH

The stock of North-East Arctic cod is now estimated to be very low (about 680 thousand tons), and the catch quota for 1990 is only 160 000 tons. Norwegian fishermen have been allocated 73 000 tons of this quota, and in addition 40 000 tons of Norwegian coastal cod. The spawning stock of Norwegian spring spawning herring was estimated to be about 1.5 million tons at the beginning of 1989. The year class from 1983 accounts for about 90 per cent of this stock. The stock of Barents Sea capelin is building up gradually, but is still low. The total catch of fish in Norwegian fisheries in 1989 was about 1.7 million tons. This is an increase of about 20 thousand tons compared with 1988. Including crustaceans, molluscs and seaweed, the total catch in 1989 was about 2.0 million tons, with a first-hand value of NOK 4.8 billion. The first-hand value has fallen by about 6 per cent since 1988. However, the export value of fish products (including reared salmon) increased by 3 per cent in 1989 to slightly more than NOK 11 billion, of which exports of reared salmon amounted to about NOK 3.5 billion. The exported quantity of reared salmon has increased by about 45 per cent since 1988, while the value has increased by only about 13 per cent.

3.1. Stock development

This section reviews the development of some important fish stocks, based mainly on reports from the International Council for the Exploration of the Sea (ICES).

North-East Arctic cod

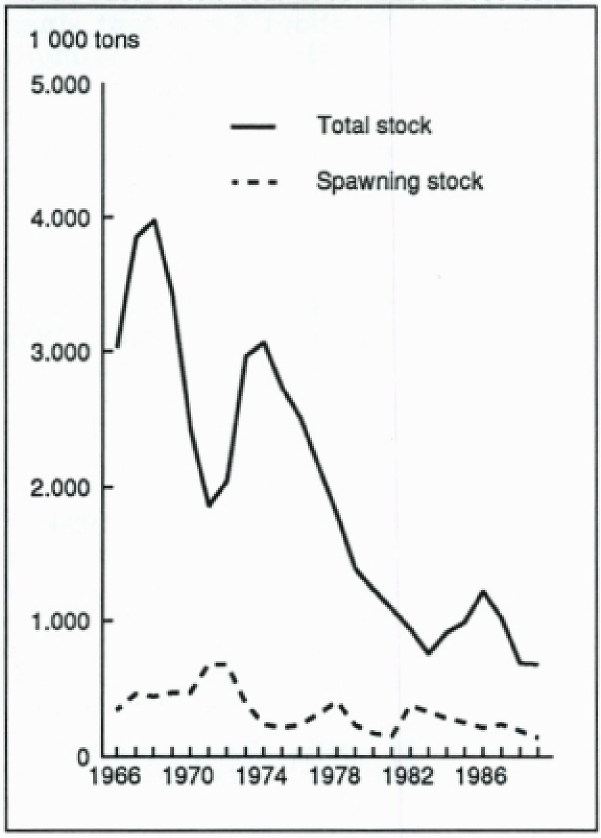
The size of the stock of North-East Arctic cod was estimated to about 680 thousand tons at the start of 1989, see figure 3.1. The development of the stock has been much weaker than expected. The estimated spawning stock is very low, about 140 thousand tons. The accounted stock of North-East Arctic cod include fish more than 2 years old at the turn of the year. Figure 3.2 presents a recruitment index where the strength of the year class at the time of inclusion in the accounted stock is used as a measure of the size of the year class when spawning took place. The recruitment index shows that all year classes from the 1980s, except for the strong 1983 year class and the more "normal" year classes from 1981 and 1982, have been weak. Cod usually mature when 7 or 8 years old.

The promising forecasts in the mid-1980s of growth in the stock of North-East Arctic cod have not been fulfilled. The reason for the poor stock development is not entirely clear, but several contributory causes have been suggested: too intensive fishing, discarding small fish, lack of food due to collapse of the capelin stock, increase in natural mortality and increased predation pressure from seal.

Herring and capelin are "key species" in the ecosystems of the Norwegian and Barents Seas. Natural variations, such as changes in water temperature, will affect the interaction between these and other species. Fishing may then influence or intensify such changes. Over-fishing of the herring stock in the years prior to 1970, and the breakdown of the migration pattern of this species, are probably important contributory factors to the development observed in the 1980s in the stocks of such species as cod and capelin.

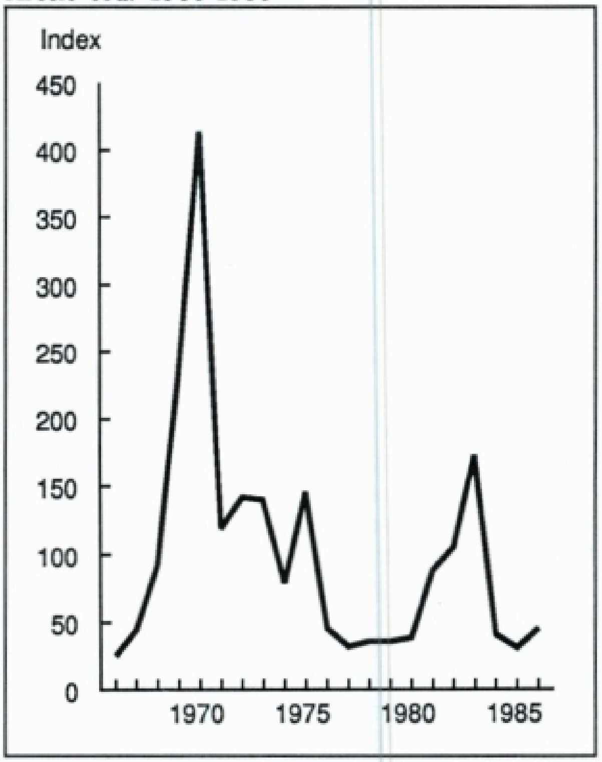
Based on the most recent estimates of the stock, recursive calculations are carried out on the stock development, using data on the catch and on natural mortality. In this way, the estimated stocks in previous years are re-evaluated. Table 3.1 shows the size of the stock of North-East Arctic cod, as evaluated the first time for each year, and as evaluated in 1989. The estimate of 1 500 thousand tons for 1987 as stated in the same year was scaled down by 480 thousand tons in 1989.

Figure 3.1. Total stock[1)] and spawning stock. North-East Arctic cod. 1966-1989. 1 000 tons



1) Fish over 2 years of age.

Figure 3.2. Recruitment index[1)]. North-East Arctic cod. 1966-1986



1) Average 1966-1986=100.

Table 3.1. Stock development[1]. North-East Arctic cod. 1975-1989. 1 000 tons

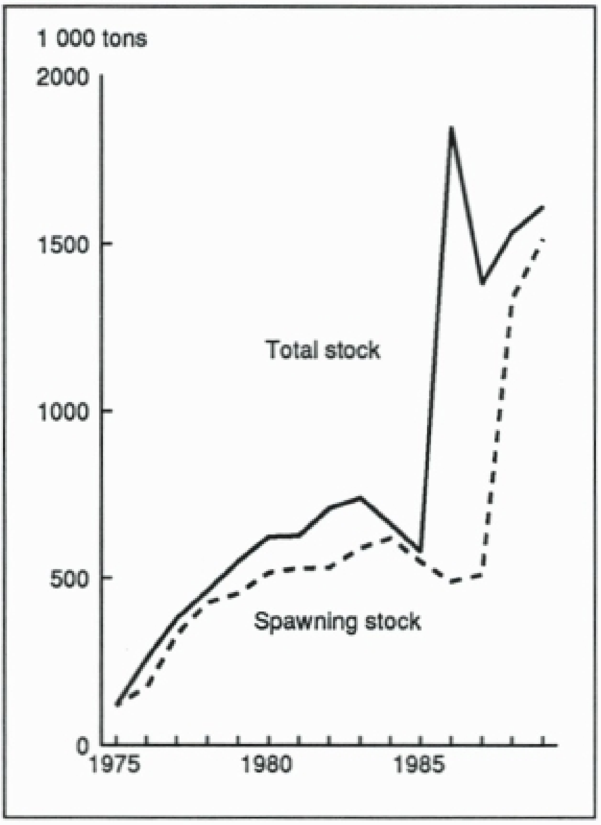
Year	First estimate (1)	1989-estimate (2)	Re-evaluation (3)=(2)-(1)
1975 . . .	3 600	2 730	-870
1976 . . .	4 110	2 510	-1 600
1977 . . .	2 500	2 150	-350
1978 . . .	1 920	1 790	-130
1979 . . .	1 690	1 390	-300
1980 . . .	1 500	1 240	-260
1981 . . .	1 560	1 090	-460
1982 . . .	1 410	940	-470
1983 . . .	960	750	-210
1984 . . .	730	910	180
1985 . . .	1 020	990	-30
1986 . . .	1 880	1 220	-660
1987 . . .	1 500	1 020	-480
1988 . . .	900	690	-210
1989 . . .	680	680	.

1) Stock size estimated for the first time the same year and in 1989.

Norwegian spring spawning herring

The stock of Norwegian spring spawning herring was estimated to be about 1.5 million tons in 1988, see figure 3.3. A prognosis from ICES estimated the total stock of Norwegian spring spawning herring to be about 1.6 million tons as per 1 January 1989.

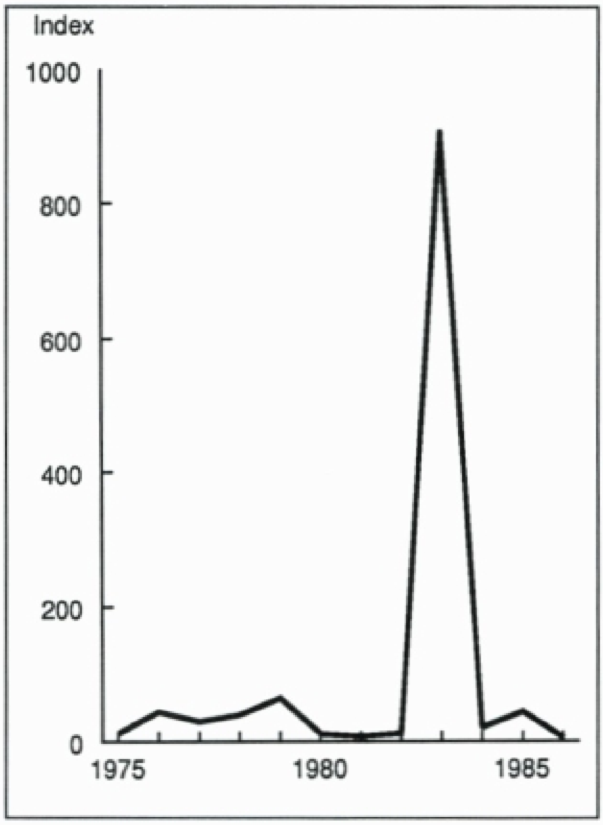
Figure 3.3. Total stock[1] and spawning stock. Norwegian spring spawning herring. 1975-1989. 1000 tons



1) Fish over 2 years of age.

From a level of between 7 and 10 million tons in the 1950s, the stock was fished down to an extremely low level at the end of the 1960s. No spawning stock was registered during the early 1970s, but a reasonably good year class in 1969 produced about 80 thousand tons of mature herring, most of which spawned in 1973. Recruitment was fairly good from the 1973 and some of the later year classes, and a particularly rich year class was registered in 1983, see figure 3.4. This year class has now been recruited to the spawning stock. The estimated spawning stock of 1.5 million tons in 1989 is about three times as large as the spawning stock in 1987. The year classes after 1983 are not expected to contribute substantially to the spawning stock. The further development of the stock is very uncertain, and depends very much on what happens to the 1983 year class in the next few years. This year class accounts for about 90 per cent of both the number and the biomass of herring that are three years old or more.

Figure 3.4. Recruitment index[1]. Norwegian spring spawning herring. 1975-1986



1) Average 1975-1986=100.

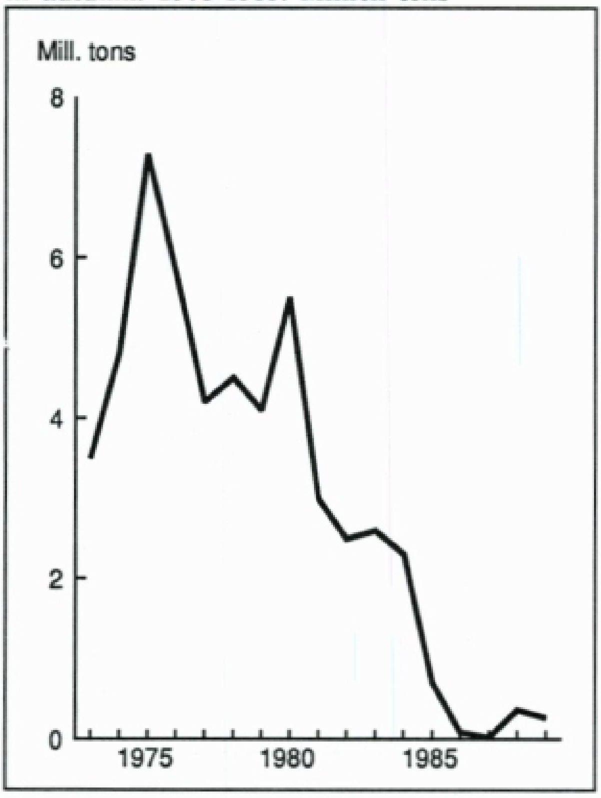
In 1989 the catch quota for herring was 100 000 tons. The recommended largest quota for 1990 is 80 000 tons. By comparison, during the period 1964-1967, total annual catches of Norwegian spring spawning herring varied from 1 282 thousand tons to 1 955 thousand tons.

Barents Sea capelin

The stock of Barents Sea capelin remains seriously low, and there may still be risk of recruitment failure in the years to come. However, the basis for recruitment improved slightly from 1988 to 1989.

Figure 3.5 gives the estimated size of the capelin stock (fish that are two years old or more) in the Barents Sea based on acoustic measurements in autumn. The estimated stock was 0.36 million tons for 1988 and 0.26 million tons for 1989, implying a decrease from 1988 to 1989 in this part of the stock. If one-year-old fish are included in the estimates, the biomass was about 0.9 million tons in autumn 1989. The corresponding figure for autumn 1988 was about 0.4 million tons.

Figure 3.5. Stock size[1] of Barents Sea capelin in autumn. 1973-1989. Million tons



1) Fish 2 years of age and older.

Capelin usually become mature when four years old, and most of the fish die after spawning. Since the capelin stock consists of such a small number of year classes, it is strongly affected by natural fluctuations in recruitment. In recent years, recruitment has been poor, but 0-group surveys in the Barents Sea in 1989 indicate that the size of the 1989 year class is about the same as for the year classes from 1983 and 1984.

Over-fishing is not considered to be the only cause of the failure of the capelin stock, although it has been found in retrospect that the quota of 120 thousand tons fixed for winter fishing in 1986 was a very unfortunate exploitation of an already reduced stock. The decrease in stock is to a large degree due to natural causes. The capelin may have had to compete for food with the increasing stock of Norwegian spring spawning herring. Growing stocks of cod (in particular the 1983 year class) and haddock have also periodically placed greater predation pressure on capelin.

Other important fish stocks

Table 3.2 shows the development of several stocks that are important for Norwegian fisheries.

The stock of North-East Arctic haddock has undergone a period of serious reduction. In 1984, the stock reached a bottom level of 50 thousand tons, about 5 per cent of the size in 1973. However, from 1984 to 1985 it increased to 170 thousand tons and in 1986 to 340 thousand tons. The estimated stock size of haddock in 1989 is 160 thousand tons, and it seems to be declining again.

It has been found that the estimates stated for North-East Arctic saithe in 1988 were too high. Therefore, in 1989 the figures for the saithe stock were scaled down substantially, and the estimated size of the stock in 1989 is about 370 000 tons.

Table 3.2. Stock development[1]. 1975-1989. 1 000 tons

Year	North-East Arctic cod	North-East Arctic haddock	North-East Arctic saithe	Barents Sea capelin	Norwegian spring spawning herring	North Sea cod	North Sea saithe
1975	2 730	650	580	4 100	110	270	640
1976	2 510	470	570	6 210	250	240	630
1977	2 150	310	520	4 440	380	240	430
1978	1 790	280	420	3 130	460	200	360
1979	1 390	280	440	3 220	550	290	350
1980	1 240	240	450	3 260	620	270	320
1981	1 090	190	540	4 570	630	280	420
1982	940	120	480	2 465	710	310	430
1983	750	70	500	3 840	740	200	390
1984	910	50	420	1 840	660	200	400
1985	990	170	370	1 680	580	170	410
1986	1 220	340	380	..	1 850	180	450
1987	1 020	280	410	..	1 380	120	380
1988	690	190	420	..	1 540	180	350
1989	680	160	370	..	1 570	150	400

1) Fish over 2 years of age.

3.2. Quotas and catch

North-East Arctic cod

Table 3.3 shows quotas, recommendations and catches of North-East Arctic cod during the period 1980-1989. The figures are based on information in ICES working groups reports and "Resource Survey" from the Norwegian Institute of Marine Research.

The fundamental objective of the marine biologists' recommendations has been to reduce the fishing mortality to a level which will exploit the growth potential of the fish in the most sensible way, biologically speaking, in the long term (F_{max} level). However, in the recommendations for each year it is assumed that the level of exploitation will be reduced over time, so that, except in 1984 and 1985, the recommended limits in the 1980s were higher than the F_{max} level. In table 3.3, these recommendations are placed in the column "Upper recommended limit". This can be illustrated by quoting from the "Resource Survey, 1986", from the Institute of Marine Research:

"In the opinion of the International Council for the Exploration of the Sea, the fishing mortality of this stock should be reduced to the level which will exploit the growth potential of the fish in the best way biologically in the long term (the so-called F_{max} level). This level of exploitation is half the fishing mortality of 1985. This level of exploitation implies a total quota of 244 000 tons for 1986. The same level of exploitation as in 1985 implies a total quota of 446 000 tons for 1986. In spite of the fact that the strength of the year classes 1984 and 1985 is still uncertain, there is no doubt that the stock will increase substantially in coming years as a result of recruitment from the year classes 1982-1985. In the light of this fact, the International Council for the Exploration of the Sea indicates that the fishing mortality can be reduced over time towards F_{max}. Such a management strategy makes it possible to increase the total quota and build up the stock again. ..... This implies that the fishing mortality must be reduced to F_{max} by 1988, and that the total quota for 1986 be fixed at 388 000 tons".

In connection with the above it should be noted that it is correct that the stock increased in 1986, but has since then decreased, and in 1989 the spawning stock (between 130 and 140 thousand tons) has fallen to a level which ICES describes in its report as historically low.

Figure 3.6 shows stock development as expected by marine biologists in 1986, given a gradual reduction of the fishing mortality to F_{max} in 1988, and the expected catches with this fishing strategy. The figure also shows stock development for the period 1985-1988 as estimated by researchers in 1989, as well as the registered catches in these years. The figure shows that the stock development has been very different than expected in 1986. There are no big differences between the catches for the period, as estimated in 1986, and the registered catches. However, the exploitation has taken place in a population which has undergone a totally different development than assumed in 1986.

Table 3.3. Quotas, recommendations and catch. North-East Arctic cod. 1980-1989. 1 000 tons

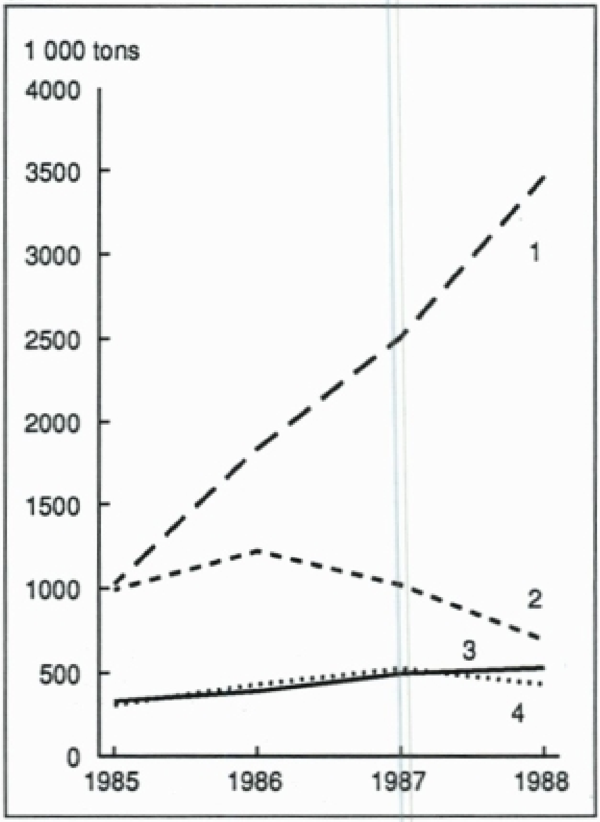
	Fixed quotas[1]	Recommendations: F_{max}	Recommendations: "Upper recommended limit"	Catch[1]
Total .	3 441	2 395	3 256	3 735
1980 .	390	213	390	381
1981 .	300	220	300	399
1982 .	300	240	300	364
1983 .	300	200	300	290
1984 .	220	150	150	278
1985 .	220	170	170	308
1986 .	400	244	388	430
1987 .	560	402	595	523
1988 .	451[2]	383[3]	363[4]	432
1989 .	300	173	300	330

1) Murman cod included, but not Norwegian coastal cod. 2) Original quota: 590 thousand tons. Reduced in summer 1988. 3) Original F_{max} that was calculated before the new recommendations. No new F_{max} was calculated for 1988. This figure is consequently too high compared with the indicated recommendation. 4) Original "upper recommended limit" was 530 thousand tons.

If the 1980s are considered as a whole, the fixed quotas were 185 000 tons higher than the "upper recommended limit". It should be noted in this connection that when the new recommendations for 1988 were issued, a large share of the original quota had already been caught. Therefore, for the period as a whole, the quotas did not deviate very much from the recommendations, except in 1984 and 1985, when the quotas were fixed respectively 70 and 50 thousand tons higher than recommended.

For the 1980s as a whole, the registered catch exceeded the quotas by 294 000 tons, mainly due to substantial over-fishing in 1981, 1982, 1984 and 1985. Furthermore, the catch was 479 000 tons above the "upper recommended limit" and as much as 1 340 000 tons above the sum of the calculated F_{max} values for the period.

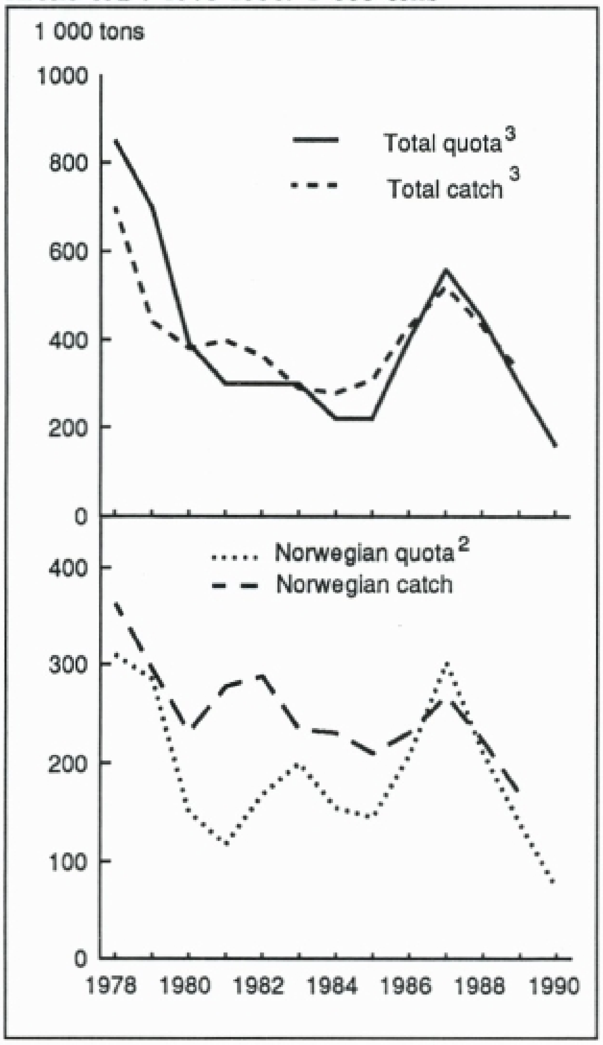
Figure 3.6. Stock development as expected in 1986 with a reduction in fishing mortality to F_{max} by 1988 and estimated stock development in 1989. Catch development as expected in 1986 with the same reduction in fishing mortality and registered catch in 1989. 1985-1988. 1 000 tons



1) Expected stock development in 1986.
2) Estimated stock development in 1989.
3) Expected catch development in 1986 with a reduction in fishing mortality to F_{max} by 1988.
4) Registered catch.
Sources: Institute of Marine Research, 1986 and ICES, 1989.

Since 1989, marine biologists have used new methods of calculating different exploitation alternatives (F_{high}, F_{med}, F_{low}). These new methods of calculation are based, inter alia, on an analysis of recruitment and spawning stock, and are expected to provide a better basis for recommendations than provided by F_{max}.

Figure 3.7. Quotas and catch. North-East Arctic cod[1]. 1978-1990. 1 000 tons



1) Norwegian coastal cod not included.
2) Included transfers from the USSR quota.
3) Murman cod included.

For 1990 the total quota of North-East Arctic cod is fixed at 160 thousand tons (including Murman cod). To this is added 40 thousand tons of Norwegian coastal cod. After a transfer to Norway from the Soviet Union quota, Norwegian fishermen are allowed to catch 73 thousand tons of North-East Arctic cod in 1990 and in addition 40 thousand tons of Norwegian coastal cod. Figure 3.7 illustrates the relationship between quota and catch of North-East Arctic cod since 1978.

Other stocks

Table 3.4 shows quotas and catches of North-East Arctic haddock, North-East Arctic saithe and Barents Sea capelin.

The stock of North-East Arctic haddock was strongly reduced for a period. Since 1984, the stock increased, and in 1987 and 1988 the quotas were fixed at respectively 250 and 240 thousand tons. However, in both these years, catches were far below the quotas; 151 thousand tons in 1987 and 92 thousand tons in 1988. Nor does the quota of 83 thousand tons for 1989 appear to have been fished. In spite of this the haddock stock is again declining, and the quota for 1990 has been reduced to 25 thousand tons.

No capelin have been fished in the Barents Sea since 1986.

Catches in 1989

Table 3.5 shows Norwegian catches during the period 1982-1989. In 1989 the total catch was about 1.7 million tons. This is an increase of about 20 thousand tons compared with 1988. Catches of cod and haddock decreased about 30 per cent in relation to 1988, while the catch of saithe was about the same as in 1988. Catches of mackerel have gone down by about 13 per cent from 1988, while catches of capelin (Norwegian Sea capelin) have increased by about 47 per cent. There has been a marked increase in the total quantity of the catch within industrial fishing. This is due to increased catches of blue whiting, horse mackerel and Norway pout. The catch of sandeel was about the same as in 1988.

The first-hand value of the fish species covered in table 3.5 dropped from NOK 4.2 billion in 1988 to NOK 3.9 billion in 1989. The total first-hand value of the fisheries in 1989 (including crustaceans, molluscs and seaweed) was NOK 4.8 billion. This is a decrease of about NOK 300 million compared with 1988. The total catch was about 2.0 million tons; an increase of about 30 thousand tons compared with 1988.

Table 3.4. Quotas and catch by stock. 1978-1990. 1 000 tons

Year	North-East Arctic haddock		North-East Arctic saithe		Barents Sea capelin	
	Quota	Catch	Quota	Catch	Quota	Catch
1978	150	95	160	154	.	1 894
1979	206	104	153	164	1 800	1 783
1980	75	88	122	145	1 600	1 649
1981	110	77	123	175	1 900	1 987
1982	110	47	130	168	1 700	1 759
1983	77	22	130	157	2 300	2 375
1984	40	17	103	159	1 500	1 481
1985	50	41	85	107	1 100	868
1986	100	97	75	70	120	123
1987	250	151	90	92	0	0
1988	240	92	100	114	0	0
1989*	83	57	120	120	0	0
1990*	25	.	103	.	0	0

Table 3.5. Norwegian catch by groups of fish species. 1982-1989. 1000 tons

	1982	1983	1984	1985	1986	1987	1988*	1989*
Total	2 408	2 707	2 346	1 974	1 790	1 800	1 685	1 708
Cod	343	284	276	248	270	305	252	187
Saithe	231	231	241	206	131	152	148	144
Haddock	47	27	23	25	58	75	63	39
Other cod fish	61	61	62	65	63	57	48	62
Flatfish	5	7	7	7	10	9	10	11
Other fish for consumption	23	25	40	41	44	45	51	50
Capelin	1 153	1 493	946	641	273	142	73	107
Mackerel	74	80	143	115	157	159	162	141
Herring and sprat								
Herring	40	68	158	239	331	347	339	268
Sprat	31	23	16	17	5	10	12	5
Other industrial fish species	392	408	435	370	450	500	527	695

3.3. Transfer of fishing rights

In 1977, Norway established a 200-mile economic zone after many years of over-exploitation of fish resources. There is a general prohibition on foreign fishing within the 200-mile zone, but the Government may permit regulated and limited foreign fishing in accordance with bilateral agreements.

The most important agreements entered into by Norway are with the EEC on fishing in the North Sea and with the Soviet Union (USSR) on fishing in the Barents Sea. The purpose has been to ensure a reasonable balance in mutual fishing and establish rules of cooperation for an effective management of common stocks.

Exclusive stocks, that is to say, stocks only occurring in the zone of one particular country, are owned and managed by this country alone.

In the Barents Sea, cod, haddock and capelin are regarded as common stocks. Cod and haddock are divided equally between Norway and the Soviet Union, while 60 per cent of the capelin belongs to Norway and 40 per cent to the Soviet Union, see table 3.6.

In the North Sea, the parties have reached agreement on a zone division of cod, haddock, saithe, whiting, plaice and North Sea herring, see table 3.7, but have not yet been able to reach agreement on the division of North Sea mackerel.

No special measures of regulation have been agreed for the other common stocks in the North Sea. Neither a distribution ratio nor a TAC (Total Allowable Catch) has been fixed for these stocks, since the present level of fishing is presumed not to threaten the stocks.

The annual fishery negotiations with the EEC, the Soviet Union, the Faero Islands and other countries have two objectives. The first is to fix a TAC, based on the recommendations from the International Council for the Exploration of the Sea (ICES), and the second is to divide and transfer fishing rights, so that, as far as possible, each of the parties will be able to fish to an extent which conforms with its own particular needs. The TAC is divided in accordance with the agreed zone distribution, and these zone quotas form the basis for the exchange of fishing rights referred to below as transfers.

Table 3.6. Division of stocks in the Barents Sea. Per cent

Stock	Norway	USSR
North-East Arctic cod . . .	50	50
North-East Arctic haddock	50	50
Barents Sea capelin	60	40

Table 3.7. Division of stocks in the North Sea. Per cent

Stock	Norway	EEC
Cod	17	83
Haddock	23	77
Saithe	52	48
Whiting	10	90
Plaice	7	93
North Sea herring[1] . .	25-32	75-68

1) Depending on the size of the spawning stock.

Table 3.8 shows the extent and balance of the exchange agreements between Norway and other countries in 1989. By fixing weight-values, the transfers are translated from tons of each fish species to equivalent quantities of cod, or cod equivalents.

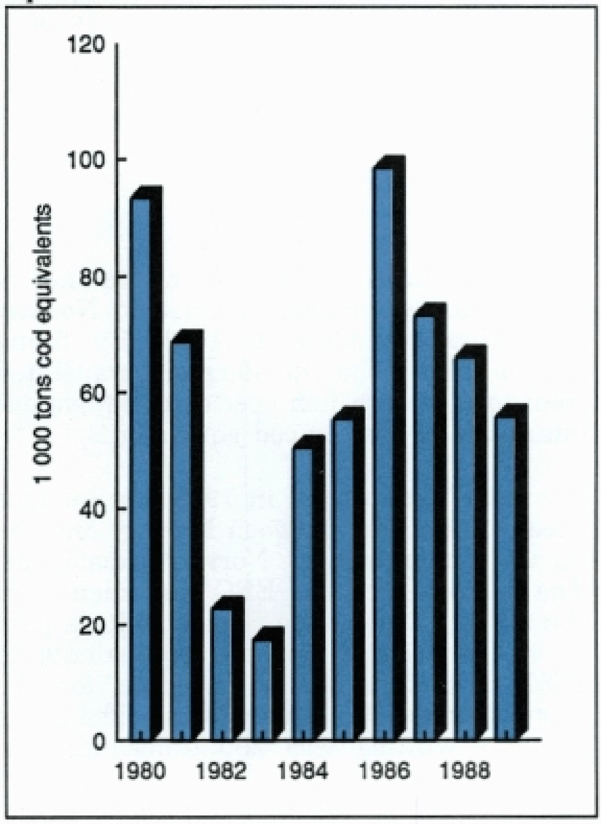
The table shows that, in 1989, the balance sheet of transfers between Norway and the Soviet Union was in Norway's disfavour. The balance with the EEC was slightly in the EEC's favour. The Soviet Union's gain of 49.7 thousand tons cod equivalents in 1989 is mainly due to a quota for the Norwegian stock of blue whiting. The quota for blue whiting was 290 thousand tons, corresponding to 36 thousand tons cod equivalents. The agreement with the Soviet Union also covers seals, with a Norwegian quota in the White Sea and a Soviet quota in the Jan Mayen area. This part of the agreement is not included in the transfer balance sheet.

Table 3.8. Transfer of fishing rights between Norway and other countries. 1989. 1 000 tons cod equivalents

	Transfer to Norway (1)	Transfer from Norway (2)	Balance in favour of Norway (3)=(1)-(2)
Total	134.3	190.1	-55.8
EEC	89.2	92.6	-3.4
USSR	29.3	79.0	-49.7
Faroe Islands	12.0	8.8[1]	3.2
Others	3.7	9.7	-6.0

1) Quotas in the Svalbard zone not included.

Figure 3.8. Net transfer from Norway to foreign countries. 1980-1989. 1 000 tons cod equivalents



In the agreement with the Faroe Islands, it has been decided that also the quota assigned to the Faroe Islands by the Soviet authorities can be fished in the Norwegian zone. In addition, it has been agreed that the Faroese can also fish in the fishery protection zone around Svalbard. These agreements are not regarded formally as transfers from Norway, and are therefore not included in table 3.8.

Quotas to other countries refer to Swedish fishing in the Norwegian part of the North Sea and Skagerrak, and Polish and East German quotas, mainly on Norwegian stocks of red-fish and blue whiting in the Barents Sea and around Jan Mayen. "Other" transfers in table 3.8 also include transfers to Norway from Canada.

Figure 3.8 shows the development of Norway's balance of transfers with other countries in the period 1980-1989.

3.4. Aquaculture

Production of reared fish has increased substantially since this activity started at the beginning of the 1970s. Figure 3.9 shows the development of the production of reared fish since 1979. 79 thousand tons of fish were slaughtered in 1988, compared with 46 thousand tons the year before. In 1988, trout production was about 10 thousand tons. According to preliminary figures, salmon production was about 110 thousand tons in 1989, while production of trout decreased to between 3 and 4 thousand tons. Prognoses from the Fish Farmers' Sales Organization indicate an increase in production of salmon in 1990 to about 150 thousand tons.

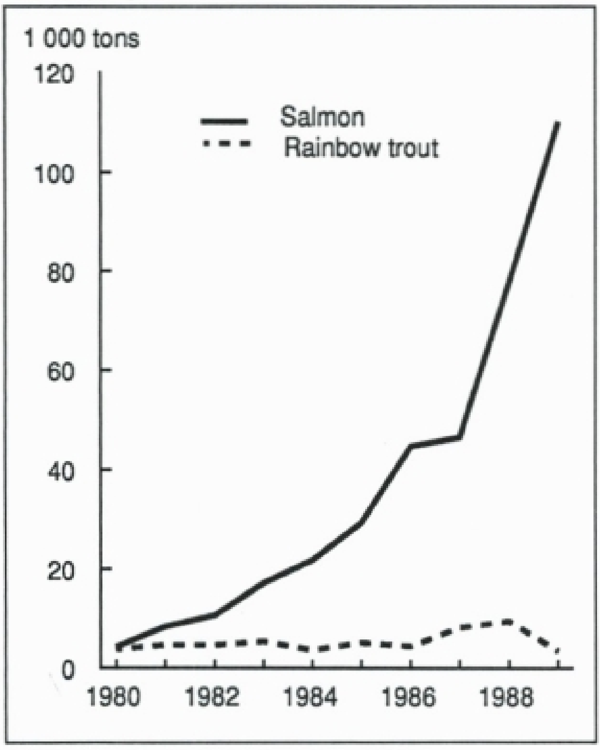
A total of 691 stations slaughtered salmon or trout in 1988, see table 3.9. Hordaland is the county with the most production stations, and the largest quantity of slaughtered fish.

Investments in fish farming amounted to NOK 758 million in 1988. Of this amount, NOK 311 million was invested in hatcheries/working units for rearing of fingerlings, and NOK 447 million in units for rearing fish (salmon and trout) for food. A total of 4 797 persons were employed in this aquaculture industry in 1988, distributed between 1 432 persons in hatcheries/fingerling rearing units, and 3 371 persons in stations for rearing fish for food.

Table 3.9. Rearing of fish for food. County. 1988

County	Number of stations	Slaughtered quantity Tons
Total	691	88 435
Rogaland	50	7 221
Hordaland	124	23 327
Sogn og Fjordane	73	12 442
Møre og Romsdal	96	16 221
Sør-Trøndelag	71	7 620
Nord-Trøndelag	53	4 719
Nordland	121	12 500
Troms	50	2 638
Finnmark	28	1 019
Others	25	730

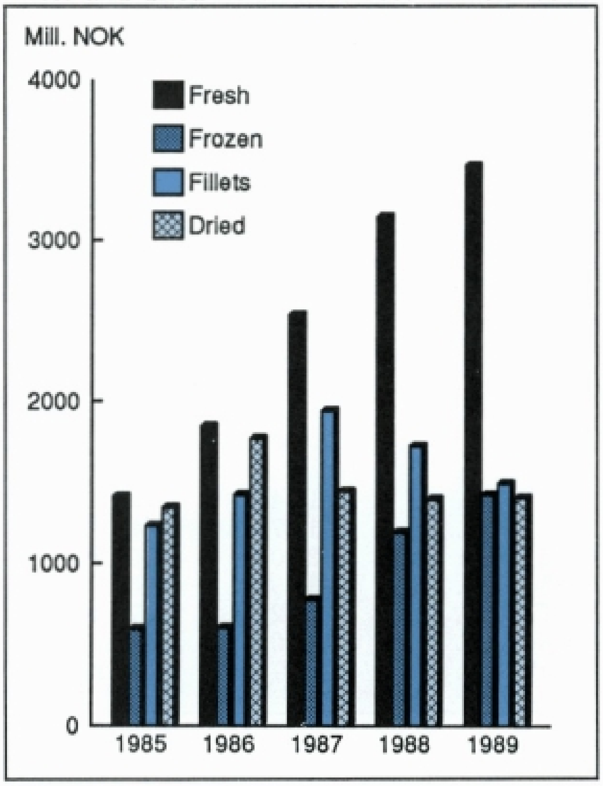
Figure 3.9. Rearing of fish. Slaughtered quantity of salmon and rainbow trout. 1980-1989. 1 000 tons



3.5. Exports of fish products

Table 3.10 shows the exported quantities of the most important fish products during the period 1979-1989, including exports of reared fish. Exports of frozen fish increased by 26 per cent from 1988 to 1989, and exports of salted or smoked fish by 28 per cent. Exports of fish meal decreased by 34 per cent from 1988 to 1989, and exports of fish oil by 14 per cent. Only small changes have been registered in the exported quantities of the other products included in table 3.10. Figure 3.10 shows the export value of fresh fish, frozen fish, fillets and dried fish during the period 1985-1989. The total export value of these groups increased by about 3 per cent from 1988 to 1989. Only exports of fillets decreased in value, by about 15 per cent.

Figure 3.10. Export of fresh fish, frozen fish, fillets and dried fish. 1985-1989. Million NOK



The value of reared fish has increased substantially in recent years. Most of the trout is consumed in Norway, while most of the salmon is exported. Table 3.11 shows that 96 thousand tons (just less than 90 per cent of the slaughtered quantity) of reared salmon was exported in 1989, to a value of NOK 3 488 million. This amounts to about 32 per cent of the total export value of fish and fish products in 1989, and an increase of 45 per cent in the exported quantity, and 13 per cent in the export value. Thus, the price trend for salmon on the export market was poor in 1989.

The total export value of fish products increased to just over NOK 11 billion in 1989, see table 3.12. This corresponds to 10.1 per cent of the total traditional export of commodities (export of commodities, not including crude oil, natural gas, ships and oil platforms, etc.)

Table 3.10. Exports of fish products. 1979-1989. 1 000 tons

Year	Fresh	Frozen	Fillets	Salted or smoked	Dried	Canned	Meal	Oil
1979	24.3	56.7	80.5	22.3	82.1	14.8	326.8	79.0
1980	19.0	54.6	66.6	14.5	73.3	13.9	275.2	79.4
1981	24.6	58.7	74.0	13.6	86.2	15.0	266.5	107.3
1982	46.2	100.2	76.3	14.9	68.8	11.2	228.6	101.1
1983	91.5	62.6	91.6	24.9	59.4	22.4	283.9	128.0
1984	72.9	78.7	98.5	24.6	69.5	22.7	248.9	76.9
1985	74.5	79.5	95.9	20.3	64.6	23.4	173.9	114.3
1986	139.4	98.8	95.2	22.7	62.9	24.4	92.6	38.8
1987	189.6	114.2	105.0	38.0	40.6	24.3	88.3	71.3
1988	212.5	126.7	105.1	36.9	47.0	22.9	68.9	45.6
1989*	215.0	160.2	94.1	47.1	47.6	23.2	45.4	39.1

Table 3.11. Exports of reared salmon. 1981-1989

Year	Total		Fresh		Frozen	
	Quantity 1000 tons	Value Mill. NOK	Quantity 1000 tons	Value Mill. NOK	Quantity 1000 tons	Value Mill. NOK
1981	7.4	292.9	5.5	211.4	1.9	81.5
1982	9.2	395.3	7.9	330.8	1.3	64.5
1983	15.4	709.1	13.0	582.6	2.4	126.5
1984	19.7	944.9	17.3	819.1	2.4	125.8
1985	24.0	1 308.3	21.4	1 160.6	2.6	147.8
1986	38.9	1 663.7	34.4	1 458.6	4.5	205.1
1987	43.2	2 174.4	39.2	1 967.3	4.0	207.1
1988	66.0	3 079.7	56.0	2 594.9	10.0	484.8
1989*	95.7	3 488.2	81.3	2 957.1	14.5	531.0

Table 3.12. Export value of fish products[1] in million NOK and as percentage of value of other traditional exports. 1979-1989

Year	Fish and fish products	Fish and fish products as percentage of total Norwegian exports of commodities	Fish and fish products as percentage of Norwegian exports of commodities, except crude oil, natural gas, ships and oil platforms
	Mill. NOK	Per cent	Per cent
1979	4 772	7.0	11.6
1980	5 054	5.5	10.9
1981	5 955	5.7	11.6
1982	5 931	5.2	11.4
1983	7 368	5.6	12.4
1984	7 675	5.0	11.1
1985	8 172	4.8	11.0
1986	8 749	6.5	12.6
1987	9 992	6.9	12.4
1988	10 693	7.3	11.6
1989*	11 088	5.8	10.1

1) The table includes a few more products than table 3.10.

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4. FORESTS

The Forest Damage Survey Programme has recorded only minor changes in the forest health status from 1988 to 1989. Recordings from the counties of Aust-Agder and Nord-Trøndelag indicated a deterioration of forest health from 1984/85 to 1987/88. In 1989 the average defoliation of conifers was 15 per cent, and about 45 per cent of all trees was more than 10 per cent defoliated. It is premature to conclude to which degree the observed pattern is natural variation due to age and habitat of the forests, and to which degree it is due to air pollution and other human interference.

4.1. Forest health status

The state of health of the Norwegian forests is monitored by a survey programme. This section describes the programme and its most recent results. It also includes results from the forest damage survey of the Federal Republic of Germany, which has been in operation for several years.

Monitoring of forest damage in Norway

The Forest Damage Survey Programme was started in 1985 following increasing awareness of forest damage, and was motivated by a desire to identify negative trends as early as possible. The Norwegian Institute of Forest Research (NISK) coordinates the programme, which is part of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests in the FAO/ECE region.

The survey programme has four main parts:

- **A nationwide yearly survey** based on systematic sampling forms the basis of regular national forest health reports. The survey is conducted by the National Institute of Land Inventory (NIJOS). About 700 permanent plots in a 9x9 km grid are used. Half of the plots were established in 1988, the remaining ones in 1989. The intention is to use the same method of evaluation as in Central European forest damage surveys.

- **Permanent plots in each county** in order to supplement the nationwide survey with information on local long-term trends in the forest health status. This part comprises about 760 plots. Data are recorded by the County Forestry Boards and are analysed at NISK.

- A small number of permanent plots are subject to **detailed monitoring** of forest ecological parameters. A major objective is to develop methods of identifying slight changes in forest health over small time spans. This part of the programme is managed by NISK, which also handles the plant and soil analyses. Air quality is monitored by the Norwegian Institute for Air Research (NILU).

- Reported forest damage is **inspected** by personnel from NISK when such reports are received.

Defoliation and discolouration of trees form the basis of evaluation in the yearly forest health reports. A sparse or discoloured crown is no specific symptom of damage caused by air pollution, but is rather a general stress symptom. However, it is hard to obtain more direct measures of pollution effects. The aim of the programme is thus twofold: first, a detailed monitoring of trends in the forest health status, and second, the development of methods for analysing the role of pollution in these trends.

Forest health status in Norway

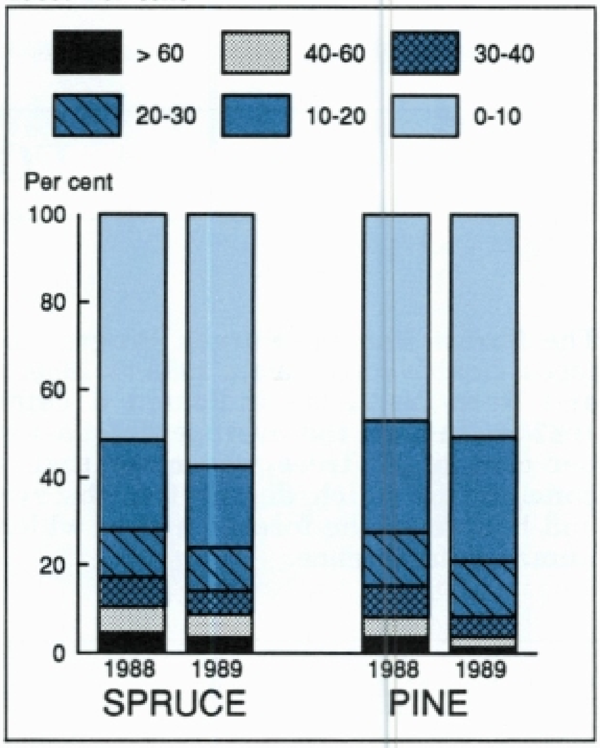
Nationwide and countywise surveys both recorded only small changes in the forest health status from 1988 to 1989. The nationwide survey found that average defoliation declined from 16.4 to 14.9 per cent for spruce and from 16.4 to 14.3 per cent for pine. The results are detailed in figure 4.1. The proportion of "healthy" trees (with less than 10 per cent defoliation) increased for both species. For spruce the proportion was reduced in all classes of "non-healthy" trees. For pine there was an increased proportion also in the classes with slight defoliation (NIJOS, 1989).

The countywise surveys also showed a slight reduction in defoliation of pine, but a minor increase was found for spruce. There were considerable differences between counties. As an example, spruce trees had reduced defoliation in the counties most affected by acid rain (Vest-Agder and Aust-Agder).

The first recordings of forest vitality according to Central European methods were made in connection with the national forest inventory in 1984/85. For the counties Aust-Agder and Nord-Trøndelag recordings also are available from 1987/88, giving data for a longer time span than the surveys described above. The results showed a marked increase in average defoliation; 3-8 percentage points depending on species and county, cf. table 4.1.

The table also gives changes in the proportion of "non-healthy" trees (with more than 10 per cent defoliation). Over the three years there was a sharp increase in the number of such trees, particularly for pine in Aust-Agder, where the proportion increased from 21 to 66 per cent. It was mainly trees with slight defoliation

Figure 4.1. Forest health status in Norway as indicated by average defoliation of trees. 1988-1989. Per cent



Source: Norwegian Institute of Land Inventory, 1989.

Table 4.1. Forest health status in Aust-Agder and Nord-Trøndelag. Average defoliation and proportion of sample trees more than 10 per cent defoliated. 1984/85 and 1987/88. Per cent

Species	Aust-Agder 1985	Aust-Agder 1988	Nord-Trøndelag 1984/85	Nord-Trøndelag 1987
Average defoliation:				
Spruce . . .	10	16	15	20
Pine	8	16	15	17
Proportions of trees with more than 10 per cent defoliation:				
Spruce . . .	31	54	46	64
Pine	21	66	47	61

Source: Norwegian Institute of Land Inventory, 1988.

that gained in number, but there was also an increase in the small classes of moderately to severely defoliated trees (NIJOS, 1988).

The scientists point out that different sets of trees were surveyed in 1984/85 and in 1987/88. This calls for some caution when interpreting the results. It is furthermore emphasized that the magnitude of the changes in defoliation depends to a certain degree on how defoliation classes are defined. The changes from 1984/85 to 1987/88 appear smaller if classes with defoliation less than 20 per cent are combined. With these reservations, the scientists conclude that there has been a significant increase in defoliation of conifers over the three year period in the two counties.

All recent surveys have shown increasing defoliation with increasing age of the forest. Defoliation also appears to increase with altitude.

According to the scientists, it is likely that the pattern of natural variation of forest health might be similar to the pattern observed. One would expect the health status to decline with increasing age of trees, and that trees growing under extreme soil and climate conditions are subject to stresses which affect their health.

On the other hand, one can reasonably expect declining forest health due to long-range air pollution to appear first in trees already under stress from natural causes. Thus it is hard to conclude whether or not the observed defoliation is due to air pollution. However, scientists do not reject the hypothesis that long-range transboundary air pollution influences the forest health status i Norway.

A number of hypotheses on the effects of air pollution on forests have been proposed in recent years, cf. CBS (1988). The prevailing hypotheses postulate that emissions of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) are the main agents of forest damage. It is assumed that the damage is due to effects on leaves, either by acid depositions or by high concentrations of SO_2, NO_X, and ozone in the air. It is furthermore assumed that SO_2 and NO_X may be an indirect cause of forest damage by affecting the soil through acidification, increasing aluminium concentration, etc.

It is therefore important for the future forest health status in Norway and other European countries that emissons of SO_2 and NO_X be reduced. An international treaty on reduction of SO_2 emissions was signed in 1985, and a treaty on NO_X reduction was signed in 1988.

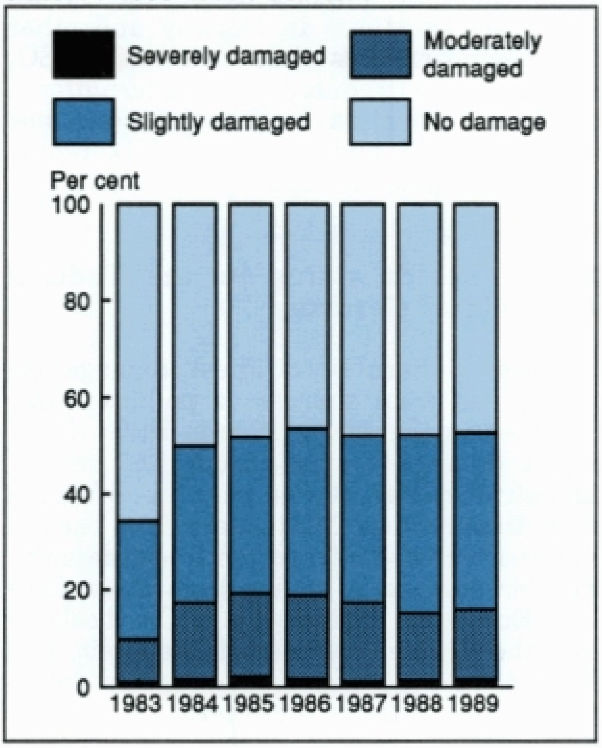
Forest health status in the Federal Republic of Germany

A novel pattern with forest damage occuring far from sources of pollution was observed in the early 1970s in FRG. (Local forest damage in the vicinity of heavily industrialized areas has been known for a long time.) Since 1981 there has been a marked increase in reported forest damage. Similar damage is known from other Central European countries, e.g. Czechoslovakia, the German Democratic Republic, and Poland. In 1989 areas with slightly damaged to dead forests comprised 53 per cent of the total forested area. This was 0.5 percentage points above the level of 1988. After three consecutive years of improving forest health, the extent of both moderately and severly damaged forest increased from 1988 to 1989. The proportion of slightly damaged forest decreased slightly. However, the extent of moderately and severly damaged forest is still below the level of 1984-1987.

Recordings from FRG up to 1983 indicated that the conifers spruce, fir, and pine were especially vulnerable to damage. However, from 1983 to 1984 a sharp increase was recorded in damage to the important hardwood species beech and oak. Since then the hardwoods have deteriorated more or less steadily, whereas the status of the conifers has improved slightly. Damage to oak has increased continously since 1983, and presently more than 70 per cent of the oak forest is damaged. For beech a new increase in the extent of damage was recorded in 1989, after a minor improvement from 1987 to 1988. Extent and proportion of damage to the major tree species are shown in table 4.2.

A decrease in the extent of moderately and severely damaged forest was recorded for all conifers. For pine and fir, however,

Figure 4.2. Area of damaged forests in the Federal Republic of Germany after damage classes[1]. 1983-1989[2]. Per cent



1) Damage classes are defined by degree of defoliation:

No damage	Defoliation	0-10 per cent
Slightly damaged	"	10-25 per cent
Moderately damaged	"	25-60 per cent
Severely damaged	"	> 60 per cent

Moderately to severely discoloured trees are placed in a higher damage class than indicated by defoliation alone.
2) Data from 1983 are not directly comparable to data from later years.

Source: Bundesministerium für Ernährung, Landwirtschaft und Forsten, 1989.

there was an increase in slightly damaged forest, leading to an increase in total proportion of damaged forest for these two species.

Details of the recordings show greater extent of damage in forests more than 60 years old for all species. In most of the Bundesländer there were only minor changes in the extent of forest damage. The evident decrease of moderately to severely damaged forest in the southern Länder in recent years ceased and in some places reversed in 1988-89.

The forest health status, as measured by defoliation and discolouration of tree crowns, is similar in Norway and FRG, compare figures 4.1 and 4.2. However, this does not mean that the forests are damaged by air pollution to the same extent in both countries. As mentioned above, defoliation and discolouration are general symptoms of trees under stress. Thus the data from Norway and FRG may indicate different levels of damage according to the age, habitat etc. of forests. To ascertain the exact level of damage, more research is needed, as carried out in other parts of the Norwegian survey programme. The yearly recordings of defoliation and discolouration are intended primarily to identify the trends in forest health status, and figures 4.1 and 4.2 should be evaluated in this context. A complete comparison of absolute damage levels in the two countries is not available.

Table 4.2. Area of damaged forests in the Federal Republic of Germany, after tree species. 1986-1989. Mill. ha. and per cent of area for each species

Species	1986		1987		1988		1989	
	Area	Proportion	Area	Proportion	Area	Proportion	Area	Proportion
	Mill.ha.	Per cent	Mill.ha.	Per cent	Mill.ha.	Per cent	Mill.ha.	Per cent
Total	3.967	54	3.863	52	3.873	52	3.909	53
Spruce	1.561	54	1.410	49	1.404	49	1.347	47
Pine	0.794	54	0.729	50	0.784	53	0.790	54
Fir	0.145	83	0.136	79	0.127	73	0.128	74
Beech	0.754	60	0.825	66	0.799	63	0.822	66
Oak	0.378	61	0.403	65	0.433	70	0.439	70
Other species .	0.335	34	0.360	37	0.326	33	0.383	39

Source: Bundesministerium für Ernährung, Landwirtschaft und Forsten, 1989.

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5. Agriculture - land use and pollution

Pollution from agriculture has increased in the last decades. Soil erosion causes mudding of watercourses, and runoff of nutrients (nitrogen and phosphorus) lead to eutrophication of freshwater and salt water. The North Sea Declaration of 1987, when Norway undertook to reduce runoff of nutrients to vulnerable parts of the North Sea by 50 per cent during the period 1985 to 1995, has led to increased focus on pollution from agriculture. However, estimates of the amounts of emissions and their impacts are subject to uncertainty. Analyses carried out by the Department of Economics and Social Sciences, at the Agricultural University of Norway, and by the Central Bureau of Statistics, indicate that the pollution can be considerably reduced by less intensive fertilization, less soil preparation and less specialized production.

5.1. Land use and land resources

Agricultural land in Norway covers about 9500 km^2 and accounts for about 3.1 per cent of the total land area. Figure 5.1 shows how much of the agricultural area is used for grain production, fully cultivated meadow, surface cultivated meadow (extensive cultivation) and other crop farming.

The greater part of the agricultural area consists of grain production and meadow. In the last 50 years, the grain area has increased, while the meadow area has been reduced. Nearly all the increase in the area used for grain has taken place in Eastern Norway. In the counties of Østfold, Vestfold and Akershus, the grain area has increased from about 26 per cent of the total agricultural area in 1949 to about 85 per cent in 1987. The climate in Eastern Norway is favourable for grain production, and the terrain and local reallocation of estates have facilitated mechanization. The transition from mixed production with animal husbandry (which requires meadow) to monocultures of grain has reduced the need for labour.

Compared with many other countries, the agricultural area in Norway is small in relation to the population and the total area of land. The cold climate strongly limits the cultivation of many kinds of crops. Only about 10 per cent of the agricultural area is suitable for grain production (Norwegian Institute of Land Inventory, NIJOS, 1989). Figure 5.2 shows the distribution of land resources by land capability classes.

There are very few unused areas in land capability class 1, and this means that the best areas have been taken into use already.

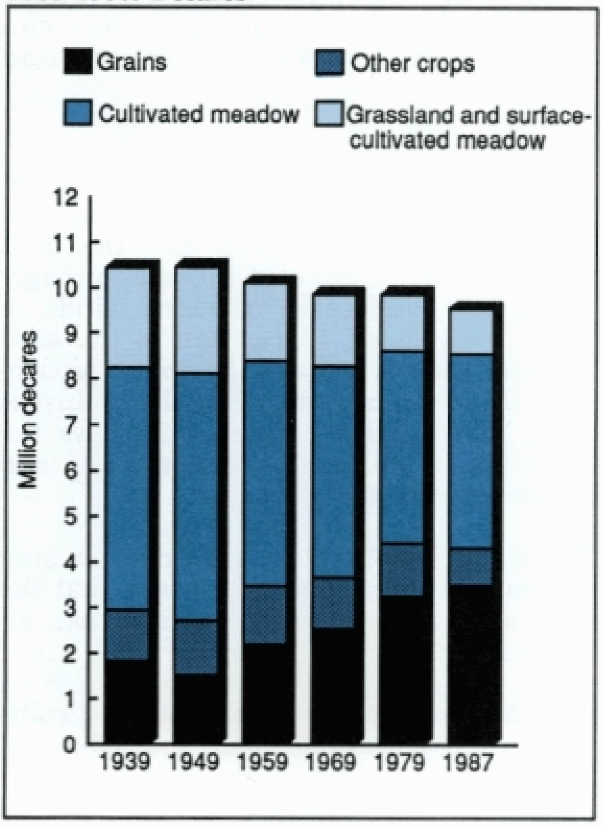
The pressure to use cultivated and cultivable land (cultivable land is arable land that is not cultivated) for purposes other than agriculture has increased with increasing urbanization and the growth of other industries. At the same time, through larger inputs of purchased production factors, agriculture has managed to increase the yield per unit of land, which means that food production has increased in spite of loss of cultivated land. Figure 5.3 shows cultivated and cultivable land transferred to other purposes (roads, buildings, etc.) since 1967. Cultivable land was not included in these statistics before 1976.

About 400 000 decares (1 decare=0.1 hectare) cultivated and cultivable land has been transferred to other uses since 1967. This is about 4.5 per cent of today's agricultural land. Most of this land has been lost for later agricultural production.

The greater part of the transferred land is located in areas with other pressing needs of land - around towns and urban settlements. Often, these places have the best climate and the best agricultural land.

The total area that is cultivated also depends on two other factors; new cultivation of cultivable land and cultivated land that is abandoned.

Figure 5.1. Agricultural area by type of crop 1939-1987. Decares

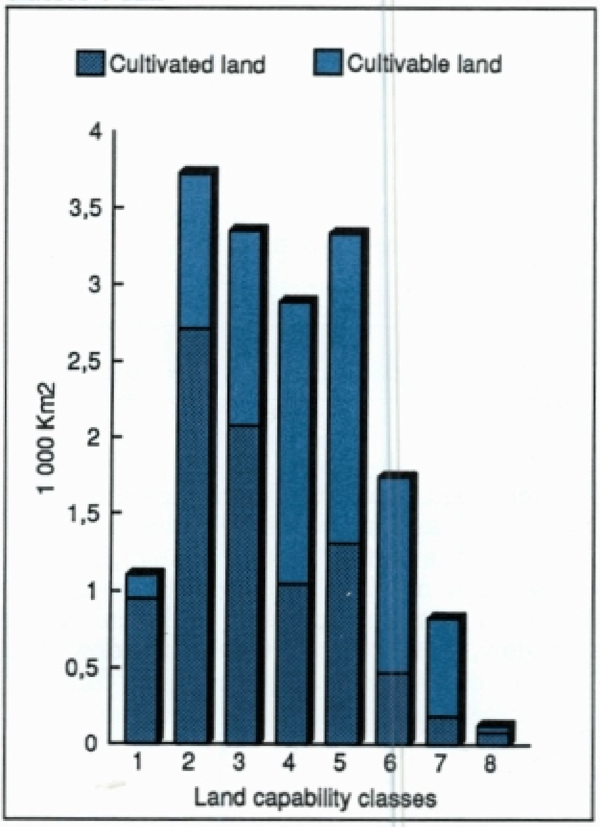


Source: CBS.

Since the population has increased, the cultivated area per capita has gradually declined (see figure 5.4).

If all land resources are taken into use, it would be possible to increase the area of cultivated land from about 9 million decares at present to 17-18 million decares (see figure 5.2). This would give a cultivated area per capita about the same as in 1939. The average quality of the land will be not be so good, however, because the remaining cultivable land is of poorer quality, and because much of the best land has been built on. If the import and distribution of input factors such as fertilizers, fuel, etc. is restricted, and the yield per unit area thus reduced, the agricultural area could become a limiting factor for sufficient agricultural production.

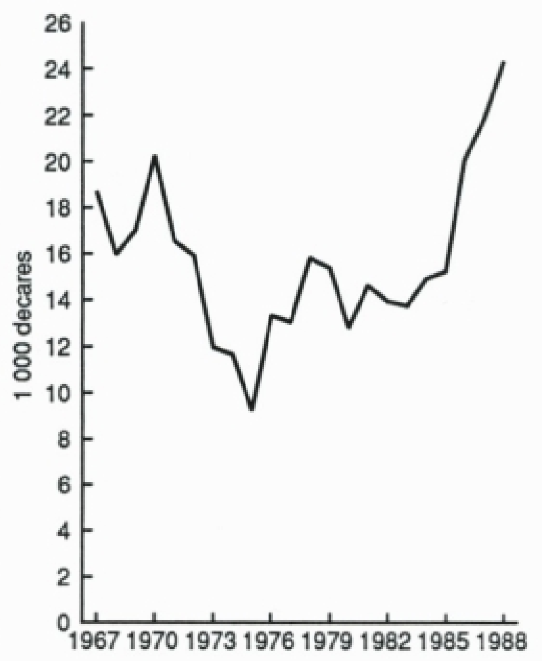
Figure 5.2. Land resources by land capability classes[1)]. Km^2



1) Land capability classes:
- 1: Areas without important limitations.
- 2: Areas with few limitations
- 3: Areas with moderate limitations.
- 4: Areas with considerable limitations.
- 5: Areas with serious limitations. Of little interest for annual crops. Moderate grass yields.
- 6: Areas with very serious limitations. Marginal for cultivation. Of interest as pastures.
- 7: Not arable land. May be of interest as pastures.
- 8: Not arable land. Of little interest as pastures.

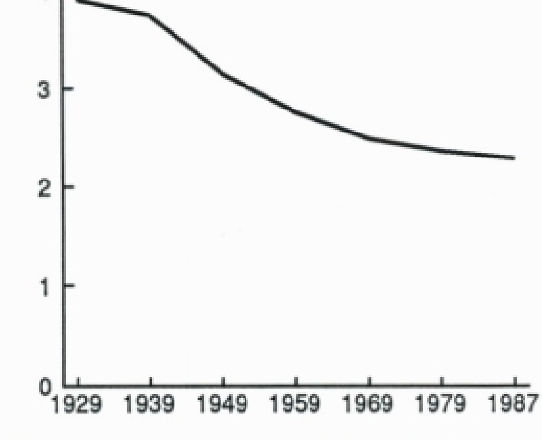
Sources: Norwegian Institute of Land Inventory (NIJOS), 1989, Grønlund, 1984.

Figure 5.3. Cultivated and cultivable land transferred to non-agricultural uses. 1967-1988. Cultivable land not included in the statistics before 1976. Decares



Source: Ministry of Agriculture.

Figure 5.4. Cultivated area. 1929-1987. Decares per capita



Source: CBS.

5.2. Pollution from agriculture

Methods of production in Norwegian agriculture have changed markedly since World War II. One way of expressing this change is to examine changes in the use of input factors. The input factors in the agricultural system of production can be divided into three groups: labour, natural resources (land), and capital and commodity inputs. Figure 5.5 shows relative change in the use of these three groups of input factors since 1959.

In the figure, cultivated land is used to express the input of natural resources. The labour input is measured in terms of number of manyears with a fixed number of hours. Capital and commodity inputs comprise a composite group of production factors. In the figure, capital and commodity inputs are measured as the calculated depreciation of capital, plus consumable production factors which the farmer purchases externally, such as fertilizers, feed, seed, fuel etc. The production volume is based on the volume index for livestock and plant production (Agricultural Budget Commission, 1989).

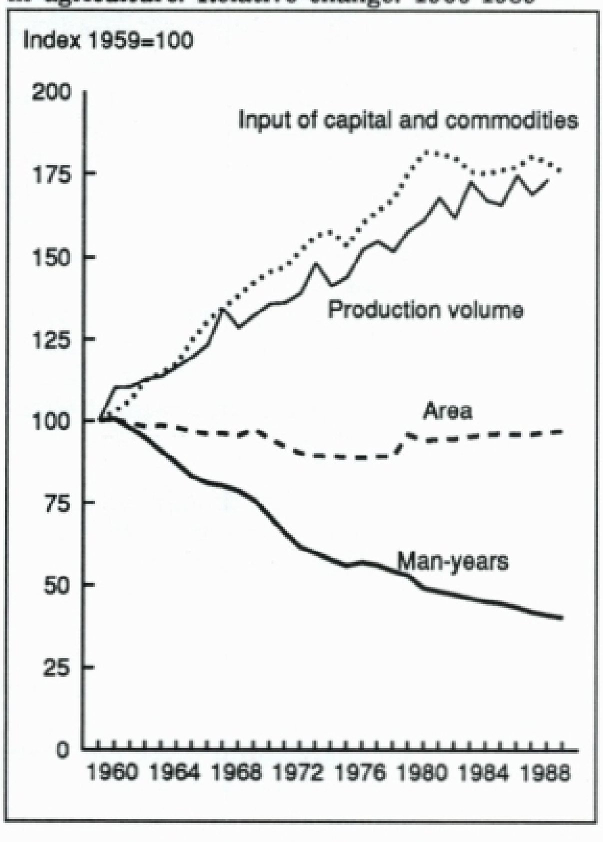
The figure shows that, although total production has increased, the manyear input has decreased. This means that each farmer produces much more food. The number of employees working in branches of industry that supply agriculture with production factors, and distribute and further process agricultural products, has not declined to the same degree, and these employees are not included in the calculations. Therefore, the total input of labour used in connection with the country's *food supply* has not been reduced to the same degree as the number of manyears in agriculture.

The figure also shows that production per unit of land has not increased to the same degree as production per manyear, and there has been little change during the period in the production per unit of capital and commodity input.

Changes in the use of the different factors is a result both of the agricultural policy and of economic and technological developments in general. Up to now, the reduction of employment and the decrease in cultivated area have created only minor problems, because food production has increased, and because other sectors have been able to absorb the labour leaving agriculture.

The higher input of machinery, fertilizers, chemical plant protectants, etc. has had strong impacts on the physical environment. In many ways the changes have been negative, for example, more pollution of watercourses, loss of soil and a more monotonous cultural landscape.

Figure 5.5. Production volume and use of input in agriculture. Relative change. 1960-1989



Source: Agricultural Budget Commission, 1989.

Rational use of agricultural machinery requires large and unbroken areas of land. There are fewer boundaries or field edges, which are important animal and plant biotopes, and streams have been filled in. The proportion of crop land has increased, leading to higher risk of erosion. Large and heavy machines compact the soil. This reduces the water flow through the soil, and the water runs more easily off the surface, carrying with it plant nutrients and particles of soil.

Each farm has become more specialized. Some livestock farms, particularly farms with production based on concentrated feeds (pigs and poultry) buy large amounts of feed from outside sources. This means that so much animal manure is produced in relation to the area of land that it is difficult to spread it without polluting the environment. The regional specialization in grain production and livestock production has intensified the pollution problems. An increasing share of the farms have no animals at all, which means increased consumption of fertilizers. Fertilizers are cheap and easy to handle, so the farmers normally fertilize with the amount that roughly gives maximum yield, and this leads to considerable runoff of nutrients. The specialization increases the share of monocultures, which leads to more serious problems from weeds and a greater threat of insect or fungal attack. This increases the need for chemical plant protectants.

Pollutants

The following groups of substances leak out of the agricultural production system and pollute the environment: nutrients containing nitrogen (N) and phosphorus (P), organic material, soil particles and micropollutants.

Up to now, greatest attention has been focused on runoff of nutrients containing nitrogen and phosphorus. This is due to two conditions. In the first place, from the biological point of view, these substances have on many occasions led to particularly disturbing algal blooming, both in freshwater and in the sea. In the second place, in connection with the Declaration of Ministers in 1987 on Protection of the North Sea, Norway has undertaken to reduce emissions of nutrients to vulnerable parts of the North Sea by 50 per cent from 1985 to 1995. Of the anthropogenic, Norwegian emissions to the North Sea, agriculture accounts for about 50 per cent of the nitrogen emissions and about 27 per cent of the phosphorus emissions (State Pollution Control Authority, 1990).

However, in the case of nitrogen and phosphorus runoff and organic material, it is often possible to reduce the polluting effect by reducing the emissions. From this point of view the situation is more serious in the case of micropollutants such as heavy metals (cadmium) in fertilizers and highly stable chemical compounds (e.g. DDT (no longer used in Norway) and various chlorinated hydrocarbons) in pesticides. Unlike nitrogen and phosphorus, these substances are not included in a natural cycle, and accumulation of the substances in the soil and in organisms may produce unpredictable and permanent toxic effects.

It is worth noting that nutrients, organic material and soil particles which leak out of the production system are, in fact, input factors in the production. The large increase in these leakages is due to several conditions. Farmers, and to some extent also the agricultural advisory services, have known little about runoff. Moreover, fertilizers have been cheap, so that farmers, without too great expense, have been able to fertilize enough to maintain the level of the yield, instead of taking other measures or managing their farm in a way which in itself helps to reduce the leakages.

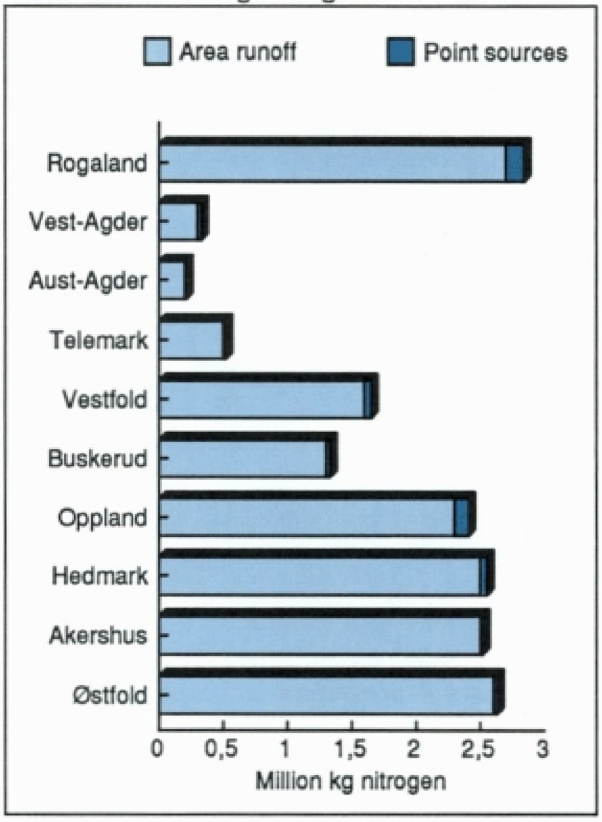
In the following sections the discussion of agricultural pollution is confined to emissions of nutrients, N and P, to water.

Sources of emissions

There are two kinds of sources of nutrient emissions; point emissions and diffuse emissions (area runoff). Point emissions are mainly effluents from manure and silage stores. Area runoff includes nutrients lost from crop land and meadows. Point emissions can be stopped by sealing the stores. Area runoff is more complicated to control, because these leakages are closely connected to the management practices, variations in climate, and soiltypes.

Calculations show that the loss of nutrients from area runoff is far greater than from point sources (Centre for Soil and Environmental Research, 1989). Point emissions are connected to livestock production, as shown in figures 5.6 and 5.7. In Rogaland, with a relatively large amount of livestock production, point emissions are responsible for a larger share of the pollution than, for example, in Østfold and Vestfold, where the animal density is low. Point sources are responsible for a larger proportion of phosphorus emissions than of nitrogen emissions. This may be because the relative share of phosphorus in manure is higher than in the plants' nutrient intake, and because phosphorus is more easily adsorbed to the soil particles.

Figure 5.6. Emissions of nitrogen from agriculture. Point sources and area runoff. Selected counties. Million kg nitrogen

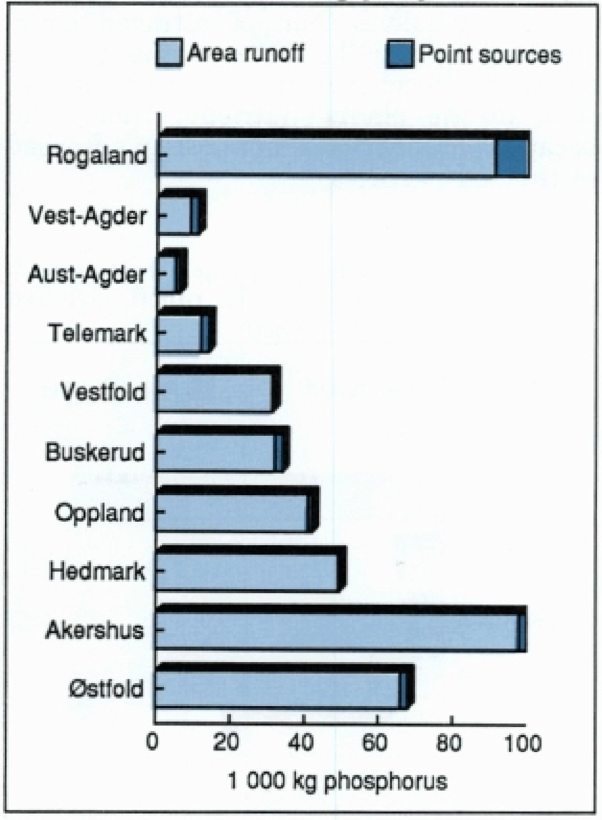


Source: Centre for Soil and Environmental Research, 1989.

The farmers' economy are determined to a large degree by transfers fixed in the Agreement on Agriculture. In practice, the costs of anti-pollution measures are either incorporated into the Agreement, or paid by subsidies. Table 5.1 shows the distribution of subsidies from the Ministry of Agriculture to reduce pollution from point sources and area runoff.

Investments in manure stores can either be used to seal the stores (reduced point emissions) or to extend them, so that all

Figure 5.7. Emissions of phosphorus from agriculture. Point sources and area runoff. Selected counties. 1 000 kg phosphorus



Source: Centre for Soil and Environmental Research, 1989.

Table 5.1. Distribution of subsidies to reduce runoff from point sources and areas. 1989. Mill. NOK

Measures	Type of effect[1]		Amount granted
Total			89
Manure stores	A	P	59
Waste water from cow sheds		P	1
Silos and silage effluent plants		P	16
Barn dryers		P	3
Hydrotechnical systems	A		2
Vegetation zones	A		0
Households (waste water)		P	8

1) A = area runoff. P = point sources.
Source: Ministry of Agriculture, 1990.

the manure can be stored and then spread in the growth season (reduced area runoff). Information from some county agricultural offices indicates that about 2/3 of the subsidies are spent on extensions, and about 1/3 to seal the stores. This means that roughly 45 per cent of all the subsidies are used to reduce area runoff, although area runoff accounts for more than 90 per cent of the total runoff.

Trends in pollution from agriculture

Records of pollution from agriculture are fairly new, and few previous calculations of agricultural pollution are available. For example, up to now, the agricultural statistics have not recorded any information aiming at describing the impacts of agriculture on the environment, e.g. information on fertilization and soil preparation practices. Therefore, the attempts to estimate changes in nutrient runoff from agriculture are subject to considerable uncertainty.

By studying the relationship between how much nitrogen and phosphorus is supplied to the agricultural land by fertilization, and how much is removed in the harvest, it is possible to get some idea of the surplus or deficit of nutrients in the production system.

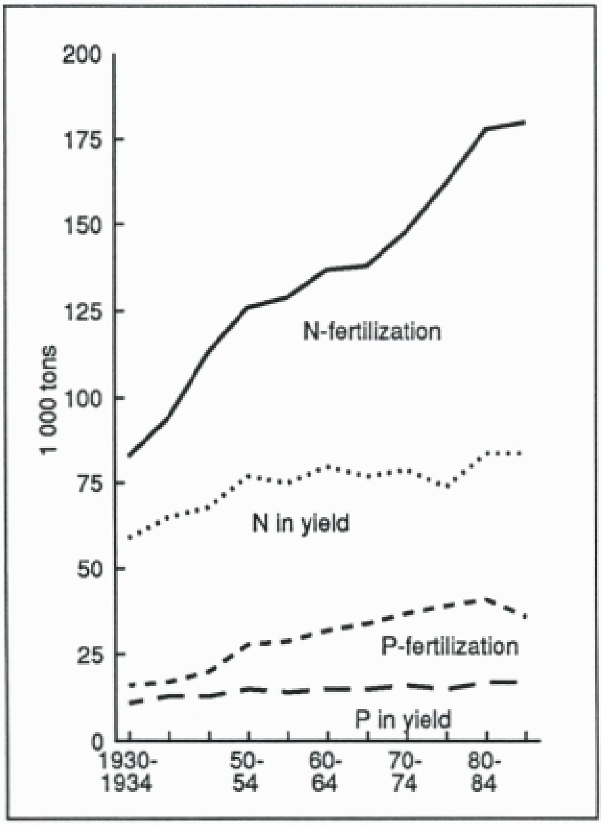
However, it is difficult to set up complete accounts. The agricultural land receives nitrogen not only from fertilizers and manure but also from precipitation and, with the help of nitrogen-fixing organisms in the soil, from nitrogen gas in the air. The relative quantities from these three sources vary with the intensity of the fertilization, the "acidity" of the rain, and the amount of plants with nitrogen-fixing bacteria (leguminous plants). It can be assumed that, totally speaking, the largest share comes from fertilization. Phosphorus comes almost entirely from fertilization.

Figure 5.8 shows a large surplus of nitrogen and phosphorus, and that this surplus has increased from 1934 to 1987. The nitrogen surplus has increased most. The calculations of the nitrogen and phosphorus content in manure are somewhat uncertain, and similarly the calculations of the quantities removed in the harvest.

Part of the nitrogen and phosphorus surplus will end up as runoff to the watercourses, but it is uncertain how much. As for nitrogen, a large amount leaks into the air in the form of denitrification and evaporation of ammonia. Some nitrogen can be stored in the soil if the organic content of the soil is increased, for example, by increasing the area of meadow. However, in actual fact the area of meadow has decreased. Phosphorus can be stored in the soil through chemical adsorption to the soil particles.

Figure 5.8 gives strong indication that increased fertilization has contributed to increased runoff. Figure 5.8 indicates, furthermore, that for every new unit of fertilizer introduced to the production system, a steadily smaller share is removed from the soil in the harvest.

Figure 5.8. Contents of nitrogen and phosphorus in fertilizers and manure and removal in crops. 1930-1987. The whole country. 1 000 tons

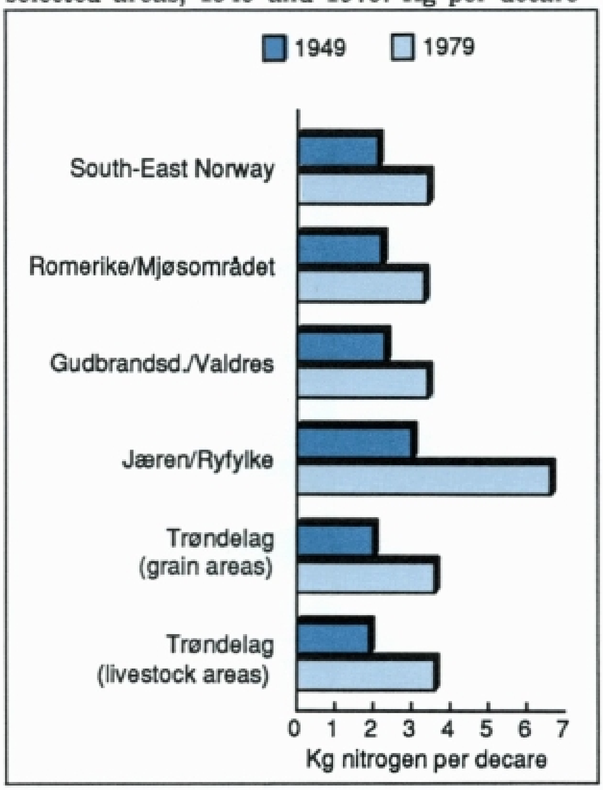


Source: GEFO, 1986, CBS and Åstebøl and Tveitnes, 1988.

It is difficult to measure runoff of nitrogen and phosphorus from large areas, and the quantification has to be based on theoretical estimates. Such estimates will always be uncertain. The calculations of nitrogen runoff are based on the assumption that the level of runoff is determined mainly by the level of fertilization. However, phosphorus runoff is not so dependent on the level of fertilization, since phosphorus is easily adsorbed to the soil particles. For this reason, phosphorus runoff is more dependent on soil erosion and the P-concentration in the soil.

Figure 5.9 shows estimated runoff of nitrogen in selected areas in 1949 and 1979.

Figure 5.9. Estimated runoff of nitrogen in selected areas, 1949 and 1979. Kg per decare



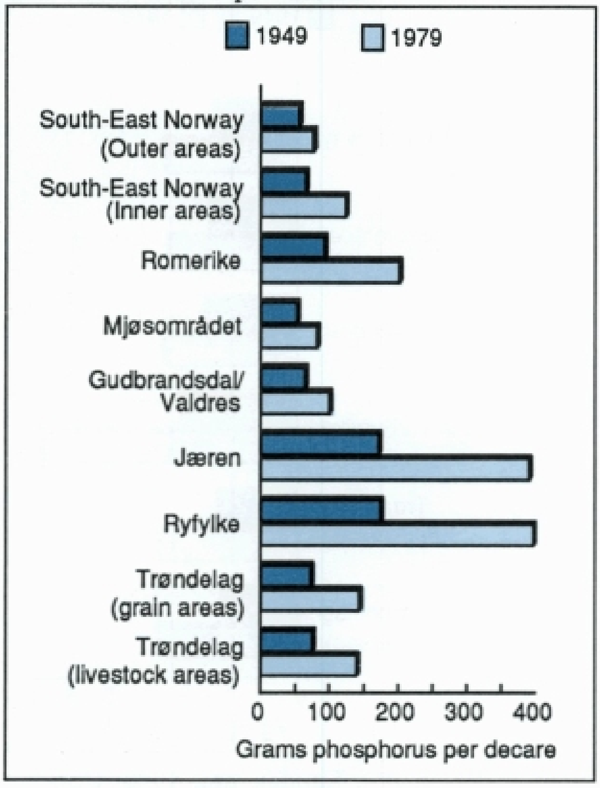
Source: Uhlen and Lundekvam, 1988, CBS.

The calculations show that nitrogen runoff per unit area has increased by between 20 and 120 per cent from 1949 to 1979 (Uhlen and Lundekvam, 1988, Calculations by the Central Bureau of Statistics for 1979, based on the assumptions in Uhlen and Lundekvam, 1988). The figures for 1949 are calculated on the basis of the total N-consumption, and are therefore uncertain. The figures for 1979 are based on the use of fertilizer-N, and estimated quantities of animal manure-N on each holding.

The Census of Agriculture, 1979, provides the most recent detailed information on use of fertilizers in large areas. Therefore, the calculations for subsequent years will be more uncertain than the calculations for 1979. The Census of Agriculture for 1989 will soon be published, and the calculations can then be updated.

The estimates of phosphorus runoff for selected areas show a similar increase (see figure 5.10). These figures are also uncertain, particularly for 1949.

Figure 5.10. Estimated runoff of biologically accessible phosphorus in selected areas. 1949 and 1979. Grams per decare



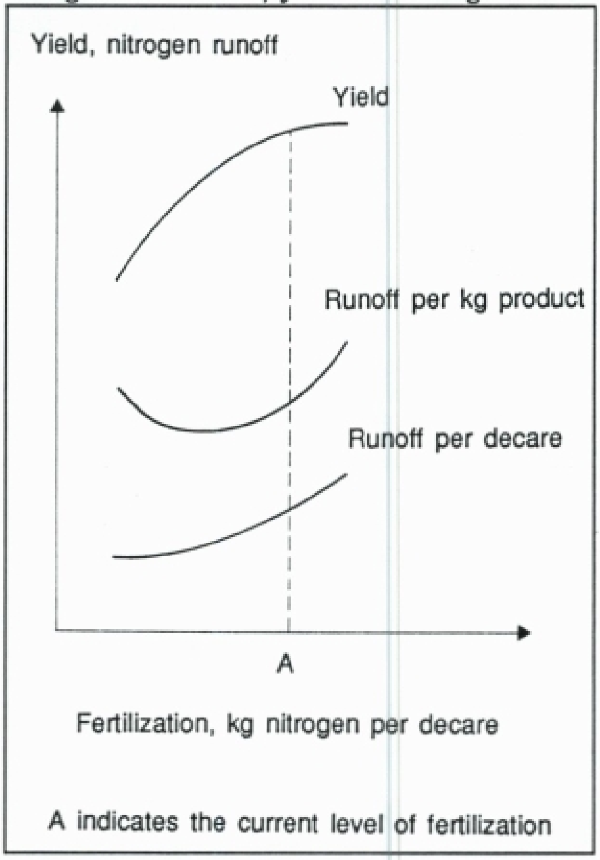
Source: Uhlen and Lundekvam, 1988.

The increase of phosphorus runoff in Eastern Norway can be put down to increased erosion as a result of larger areas for cultivation of grain. In addition, Romerike, for example, has a lot of easily erodible land. The increase in Rogaland is mainly due to increased livestock density.

5.3. Analysis: Effect of reduction of intensity and reorganization of production

Figure 5.8 indicates that the amounts of nitrogen and phosphorus leaking out from the agricultural production system have increased, both totally and per unit of land.

Figure 5.11. Schematic relationship between nitrogen fertilization, yield and nitrogen runoff



Many livestock farms produce such large quantities of manure in relation to the area on which it is spread that this leads to excessive fertilization in relation to the plants' intake of nutrients. The manure store capacity is often so small that manure has to be spread at other times than in the growth season. This leads to inefficient use of the manure, and thereby increased nutrient losses. Other areas are concerned only with production of grain, and this leads to large, unbroken areas which are plowed every year. This causes serious erosion in soil types with a high erosion hazard.

Figure 5.11 shows schematic relationship between nitrogen fertilization, nitrogen runoff, and yield.

Today the intensity of fertilization is much higher than the level which gives minimum runoff per unit of product.

Given today's situation, it can be assumed that:

- less fertilization with nitrogen and phosphorus will reduce runoff. Starting with today's level of nitrogen fertilization, the nitrogen runoff will be reduced relatively more than the level of the yield.

- cultivation of meadow in areas with high erosion hazard will reduce loss of soil and thereby loss of particle adsorbed phosphorus.

Nitrogen fertilization is regulated first and foremost through the use of fertilizers. Phosphorus fertilization is reduced by having sufficient land on which to spread manure (minimum spreading area) and through use of fertilizers.

Cultivation of meadow in areas with a high erosion hazard can be implemented by introducing animals that feed on coarse fodder (cattle and sheep).

In cooperation with the Institute of Economics and Social Sciences at the Agricultural University of Norway, the Central Bureau of Statistics has developed a model which can be used to simulate three measures, namely introduction of a requirement for minimum spreading area, reduced soil preparation and changed intensity of fertilization. The introduction of a requirement for a minimum spreading area implies that farms with too many animals in relation to the requirement will have to reduce the number. In the model, these animals can be "transferred" to farms with surplus spreading area. In this way, the model can direct livestock production based on coarse fodder to areas with a serious erosion hazard, and in this way introduce meadows into these areas.

After simulating the minimum spreading area requirement, reduced soil preparation and/or changed intensity of fertilization, the model can be used to calculate the effect on area runoff, the need for labour, the farmer's compensation for work, and production. The results can be aggregated to all geographical levels higher than a municipality. The model, called SIMJAR (Norwegian abbreviation for Simulation Model for Soil Erosion and Area Runoff from Agriculture) is found in two versions:

SIMJAR 1 can be used for calculations in two limited areas (in Jæren and in Romerike). The input data are based on production statistics ("The Subsidies Register") and soil type data from the Norwegian Institute of Land Inventory (NIJOS). The erosion hazard is determined from the soil type data. Changes in both nitrogen and phosphorus runoff are calculated after simulating the different measures. This version of SIMJAR is presented in detail in Natural Resources and the Environment, 1988 (Central Bureau of Statistics, 1989). Since then the model has been improved in various ways, and the most up-dated version of SIMJAR 1 and results of simulations will be published in Aanestad and Sødal, 1990.

SIMJAR 2 applies to the whole of Southern Norway. Soil type data are not available, so phosporus losses have not been calculated as yet, only nitrogen leakage. SIMJAR 2 takes into account different growing conditions by dividing Southern Norway into 4 yield zones. This is important for the correlation between fertilization, nitrogen runoff and yield.

Results of simulated measures

1. Reduced area intensity

Using SIMJAR 2, reductions of fertilization intensity have been simulated down to a level corresponding to a 10 per cent reduction in yield, and to a level giving minimal runoff per unit of product (see table 5.2).

Some farms have too much manure to be able to achieve the reduction in intensity of fertilization assumed by the model. For these farms, the fertilization intensity is estimated from the quantity of manure.

From the correlations between N-fertilization, N-runoff and yield on which the model is based, it can be seen from table 5.2 that both runoff and fertilization are reduced much more than the yield. No other measures are taken into account. The figures will become more uncertain if the lower intensity is maintained, and today's production methods are retained in other respects. Table 5.2 shows that a reduction of the fertilization intensity seems to have the greatest effect on meadow. Fertilization intensity is generally higher for meadow than for grain area, which according to figure 5.11 leads to greater reduction of runoff with less fertilization. The fertilization intensity for grain is limited because of risk of lodging.

Table 5.2. Relative levels of fertilization, yield and nitrogen runoff at 90 per cent yield level and minimum runoff per unit of product. Average for Southern Norway. Current level=100

	Approximately 90 per cent yield	
	Grains	Meadows
Fertilization	67	69
Yield	90	91
Runoff	73	54
	Approximately minimum runoff per unit of product	
Fertilization	60	39
Yield	86	77
Runoff	70	32

2. Introduction of minimum spreading area

As from 1 March 1989, it will be required to have at least 4 decares fully cultivated area per animal manure unit available for spreading of manure. The purpose is obviously to limit excessive fertilization with manure and reduce pollution. This requirement is expected to have major consequences for many farms with livestock.

By simulating the spreading area requirement, the SIMJAR model converts the number of animals on each farm into a number of animal manure units, and estimates the number of animal manure units per decare spreading area. In this way it is possible to find out how many excess animals there are if the minimum spreading area requirement is complied with. Table 5.3 shows the excess animals in selected regions and counties in Southern Norway if a requirement of 4 decares per animal manure unit is introduced. The conversions to animal manure units are based on the phosphorus content in the manure. This means that the estimates of excess animals can be somewhat higher than the regulations demand.

The calculations are based on areas and number of animals in applications for production subsidies for 1987 ("the Subsidies Register"), and on the assumption that no spreading area is available outside the farm's own existing agricultural area. If the farm has several kinds of animals, the first to be removed are those which give the least income per produced amount of manure (Sødal, 1988). This means that animals feeding on concentrates, such as poultry and pigs for slaughter, are reduced first.

The table shows that farms rearing animals that feed on concentrates (pigs and poultry) are the ones with greatest difficulty in meeting the minimum spreading area requirement. As much as 36 per cent of the pigs and 54 per cent of all poultry in Southern Norway will have to be slaughtered or moved if the requirement for 4 decares area per animal manure unit is introduced. This corresponds to about 22 per cent of the meat production in the agriculture. The size of these stocks is not limited by the farm's feed production capacity (almost all feed concentrates are purchased externally), and large stocks allow rationalization and therefore a higher return to labour. The size of the stocks of cattle and sheep is determined mainly by the farm's capacity to produce coarse fodder, and for this reason there will normally be no lack of spreading area for the manure.

Rogaland is clearly different from other counties in respect of animal density. In addition, a large share of Norway's livestock is found in Rogaland, so that domestic husbandry is an important industry in this county. Calculations using the SIMJAR

Table 5.3. Proportion of domestic animals that are in excess (must be moved or slaughtered) by introduction of a minimum spreading area of 4 decares per animal manure unit. Counties and regions in Southern Norway. Per cent

Type of animal	Total Southern Norway	Roga-land	Vest-landet	Akershus/ Østfold/ Vestfold	Hedmark/ Oppland	Trøndelag
Cow	0.5	1.5	0.5	0	0	0
Sheep	3.0	10.0	2.0	1.5	0.5	0.5
Pigs for slaughtering	36	76	60	14	19	19
Poultry	54	77	71	50	33	48

Source: CBS.

model show that unless the reduction in domestic animals indicated in table 5.3 is compensated by moving production to farms with available spreading area, the number of manyears in Rogaland's agriculture will be reduced by just under 1 000, or about 8 per cent of the labour force employed in agriculture. Corresponding figures for Southern Norway as a whole are about 3 000 manyears, and 2.5 per cent.

3. Meadow on soil with high erosion hazard, and less tillage (soil preparation)

When a minimum spreading area requirement is introduced, it is possible to envisage moving the animals to farms with available spreading area. If animals who eat grass are moved to farms with easily erodible soil, then it is possible to cultivate meadow on this soil and so reduce erosion. Less tillage of crop land will also reduce erosion. A large share of the phosphorus runoff is carried by the eroded soil particles.

A requirement for transfer of animals cannot be imposed without information on type of soil in each production unit. Information on soil type is based on soil mapping. Only small parts of Norway's agricultural areas have been mapped for this factor. SIMJAR 1 has done simulations within an area where such soil type information is available.

Figure 5.12 shows the effects on phosphorus runoff in the event of an intended increase in the number of animals in an area of Ullensaker, combined with different degrees of reduced soil preparation on crop land (Aanestad and Sødal, 1990). If cows are introduced, grassland must be increased.

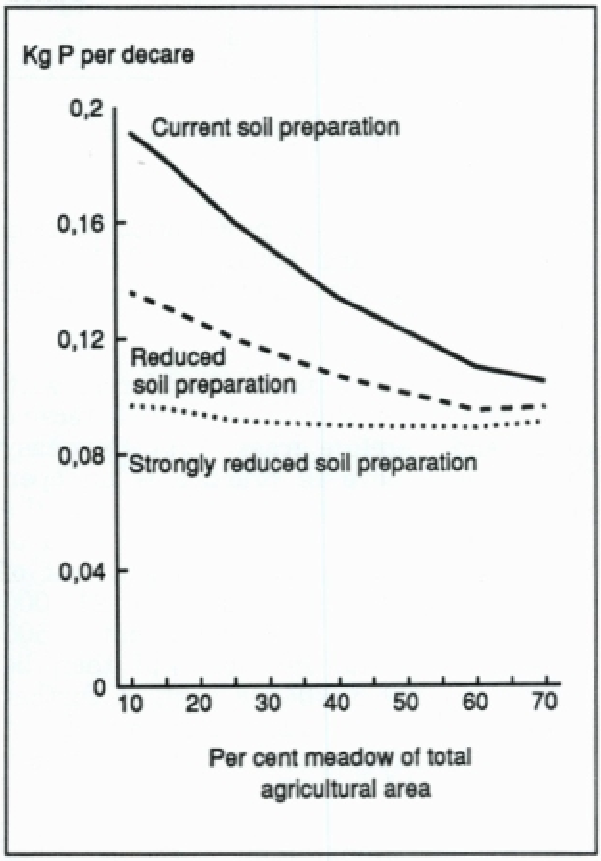
The calculations assume that farms with the greatest erosion hazard will receive cows - and therefore grass - first. How easy this is to achieve in practice is an open point. Today the number of cows in the area is about 250. Increasing the area of meadow from about 10 to 70 per cent of the agricultural area (totalling 21 000 decares) imposes a need for about 3 500 cows in the area. P-runoff will then be reduced by about 40 per cent. A further increase of the meadow area would not lead to much further reduction of P-runoff.

It is worth noting that a maximum reduction of soil preparation, with no other changes in the pattern of production, gives a greater benefit as regards P-runoff than does a radical changeover to meadow and livestock production, with no changes in soil preparation on the remaining crop land.

Seen in a Norwegian perspective, Ullensaker is an extreme area as regards the combination of crop land and highly erodible soils. This means having to expect that in other places, changing over from crop land to meadow would not give an equally large reduction in P-runoff.

If cows are moved from areas with high animal density, this would be expected to lead to a reduction in P-runoff in these places. The analyses indicate, however, that reducing the number of animals in areas with a high animal density does little to reduce phosphorus runoff in the short term.

Figure 5.12. Reductions in runoff of phosphorus after transition from crop land to meadows on areas with high erosion hazard, combined with different degrees of reduced soil preparation. A selected area of the municipality Ullensaker. Average for the whole area. Kg per decare



Source: Aanestad and Sødal, 1990.

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6. AIR

Each year CBS produces inventories of Norwegian emissions of several polluting compounds. The emissions are caused by production and consumption of commodities and services. Accounts of indirect emissions associated with final deliveries of commodities and services have also been prepared. The indirect emissions are caused by production of input factors in manufacturing and the service sectors. These emissions frequently dominate the direct emissions emerging from the production of final goods and services.

The inventories are a necessary part of the monitoring of the state of the environment, and are also used as a basis for analyses of future trends in emissions to air and potential control policies. Such policies represent a cost to society, but also provide benefits in the form of reduced damage to human health, nature and capital equipment. This chapter presents analyses of the use of environmentally motivated taxes on the use of fossil fuels. In one case, tax rates are based on estimates of local marginal damage from emissions to air. In another case, the tax rate is determined implicitly by the requirement that emissions of carbon dioxide (CO_2) should be kept below a certain level. Estimates of social costs and some of the benefits emerging from these tax regimes are presented.

International aspects of air pollution are important. The chapter includes forecasts of emissions to air of sulphur dioxide, nitrogen oxides and carbon dioxide in the ECE region under various assumptions. The effects of relocating resources for cleaning emissions to air from the Nordic countries to Poland and GDR are assessed. The calculations indicate that it is cheaper to reduce sulphur depositions in the Nordic countries by cleaning East European emissions than it is to clean the relatively smaller Nordic emissions. The consequences for emissions to air of a transition from the use of oil and coal to the use of natural gas are also considered. Finally, some aspects of the greenhouse effect are discussed, with special emphasis on describing the various greenhouse gases and their contribution to the increased greenhouse effect.

6.1. Air pollution - some sources and consequences

The main cause of emissions to air is combustion of coal, coke and oil products. Additional sources include certain industrial processes and evaporation. Process emissions account for emissions from the use of input factors other than energy. Evaporation is due to use of solvents and handling of light oil products. It is customary to separate emissions into classes by type of source, e.g. stationary sources and mobile sources.

Air pollution in Norway is partly due to domestic emissions from manufacturing, transportation and heating, and partly due to transboundary pollution brought to Norway from abroad. Norwegian emissions are the main sources of local pollution which damages health and materials, while transboundary pollution from the continent and Great Britain is the main source of acidification of the natural environment.

The emissions are governed largely by the level and structure of production and consumption of goods and services. The emissions can be reduced by cleaning. Other efforts to reduce emissions can be directed at the use of polluting production factors and products, either in the form of requirements regarding their composition or quality, e.g. the sulphur content of fuel oil, or by taxing the use of polluting substances.

Meteorological conditions, the regional pattern of emissions, etc. are factors which also affect the concentration of pollution.

The damaging effects of pollution depend on the concentration level as well as length of exposure. For some of the polluting components, damage appears only when the concentration is above a certain threshold or critical level. For other components such critical values do not exist, i.e. even extremely low concentration levels may induce damage to human beings or nature. This is particularly the case for pollutants causing cancer (carcinogenic substances). Quite often already weak groups of the population, such as children, asthmatics and old people, are hardest hit by pollution.

The effects of air pollution are sometimes due to secondary pollution components. These are components created, for instance, by oxidation of the primary components in the original emission. Examples of secondary pollution components are sulphate (SO_4^{2-}) produced by oxidation of sulphur dioxide (SO_2), and ozone (O_3) created in photochemical reactions between nitrogen oxides (NO_X) and hydrocarbons or carbon monoxide (CO) under the influence of solar radiation. Health damage from exposure to ozone seems to be more serious and common, and appears at lower ozone concentrations than previously thought (i.e. concentrations down to 0.08 ppm O_3, corresponding to 170 µg/m^3 averaged over an 8 hour period).

Table 6.1 shows some sources, effects and threshold levels associated with some of the more serious air pollution problems. Limits for health damage (threshold level) means an exposure level which, according to present knowledge, a population can be exposed to without risk of damage to health.

Box 6.1

Some chemical substances

Sulphur dioxide	SO_2
Sulphate	SO_4^{2-}
Nitrogen oxides	NO_X
Nitrate	NO_3^-
Carbon monoxide	CO
Carbon dioxide	CO_2
Ozone	O_3
Volatile organic compounds	VOC
Lead	Pb
Methane	CH_4
Benzene	C_6H_6
Nitrous oxide	N_2O
Chlorofluorocarbons	CFC
Hydroxyl	OH

Table 6.1. Sources, damage and threshold levels associated with some polluting compounds

Compound	Source	Damage	Threshold level
Sulphur dioxide	Combustion of oil Transportation Process emissions: - Refining - Manuf. of basic metals - Silicon carbide - Paper and paper products	Health: SO_2 together with dust increases the risk of respiratory diseases. Nature: Damage to vegetation. Acidification of water and soil. Corrosion.	Health: 100-150 $\mu g/m^3$ (day) 40-60 $\mu g/m^3$ (half year) Vegetation: 30 $\mu g/m^3$ (half year)
Nitrogen oxides	Transportation Combustion of oil Process emissions: Manuf. of fertilizers Manuf. of basic metals	Health: Increase the risk of respiratory diseases. NO_2 more harmful than NO. Nature: Contribute to acidification of water and soil. Produce ozone through reaction with VOC or CO under influence of solar radiation. Corrosion (only to a limited degree). Influence the oxidation capacity of the atmosphere.	Health (NO_2): 200 $\mu g/m^3$ (hour) 100-150 $\mu g/m^3$ (day) 75 $\mu g/m^3$ (half year)
Carbon monoxide	Transportation Burning of wood Combustion of oil Process emissions: - Silicon carbide	Health: CO adheres to red blood cells and reduces the uptake of oxygen. Effects: - Increased risk of cardiac spasm - Reduced activity for healthy people - Lower birth-weight of children Nature: Influences the oxidation capacity of the atmosphere. Produces ozone through reactions with NO_x under influence of solar radiation	Health: 25 mg/m^3 (hour) 10 mg/m^3 (8-hours)
Volatile organic compounds	Transportation Burning of wood Combustion of oil Solvents Filling stations	Health: Might contain carcinogenic substances like PAH and benzene Nature: Produces ozone through reaction with NO_x under influence of solar radiation. Influences the oxidizing capacity of the atmosphere	
Polycyclic aromatic hydrocarbons	Burning of wood Aluminium plants	Health: PAH in air might cause cancer in the respiratory system	
Soot	Burning of coal Burning of wood Transportation	Health: Soot together with SO_2 can cause respiratory diseases. Soot is often a carrier of carcinogenic substances (Lead, PAH)	Health: 100-150 $\mu g/m^3$ (day) 40-60 $\mu g/m^3$ (half year)
Dust	Burning of coal Dust from roads (studded tyres)	Well-being: Dust cover on vegetation and constructions in the vincinity of the emission sources	
Lead	Gasoline-driven cars	Health: Increased risk of coronary diseases and spontaneous abortion. Altered behavioural pattern and reduce intelligence and fertility. Anemia	Health: 1,5 $\mu g/m^3$ (half-year)
Photochemical oxidants (Ozone, PAN)	Formed in the atmosphere by reactions with NO_x, CO, hydrocarbons under the influence of solar radiation	Health: Can cause respiratory diseases. Nature: Damage to forests and other vegetation Materials: Damage to for example rubber and plastics	Vegetation: 200 $\mu g/m^3$ (hour) Health: 100-200 $\mu g/m^3$ (hour) measured as O_3 concentration

Table 6.1. Sources, damage and threshold levels associated with some polluting compounds

Compound	Source	Damage	Threshold level
Carbon dioxide	Fossil fuels Deforestation/land-use changes, burning of biomass Manufac. of cement	Contributes to increased greenhouse effect	
Methane	Extraction, transportation and combustion of fossil fuels, burning of biomass, wetlands, rice fields, ruminants, etc.	Contributes directly to increased greenhouse effect, entails tropospheric ozone production and alteration of the characteristics and composition of the atmosphere. (Methane also affects stratospheric ozone.)	
Nitrous oxide	Fossil fuels, land-use changes, burning of biomass, fertilizers, microbiological processes	Contributes to increased greenhouse effect. Reduces the stratospheric ozone layer.	
Chlorofluorocarbons	Refrigeration installations, chemical cleaning, aerosols	Reduces the stratospheric ozone layer. Contributes to the greenhouse effect.	
Halons	Fire extinguishers	Reduces the stratospheric ozone layer	

Source: CBS.

6.2. Emissions to air in Norway

Domestic emissions to air 1987

Inventories of emissions to air of sulphur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOC), particulates and lead (Pb) have been compiled for the years 1973-1987. Preliminary inventories for the years 1988 and 1989 have been compiled by the State Pollution Control Authority (Statens forurensningstilsyn - SFT). There also exist cruder estimates of emission levels for certain components for the period 1962-1972. In general, the inventories for earlier years are less detailed and more uncertain than corresponding inventories for later years. Emission inventories for the later years are based on detailed resource accounts for energy and manufacturing statistics from the Central Bureau of Statistics, emission coefficients, and registered emissions from manufacturing firms with emission permits from SFT.

Tables 6.2 and 6.3 give some of the emission coefficients used in the calculation of emission levels. The emission coefficients change from year to year, partly due to changes in the chemical composition of fuels, partly because of changes in combustion technology, and partly due to accumulated and increased knowledge on other factors determining emission coefficients.

Emissions of SO_2 and of Pb from combustion are determined respectively by the content of sulphur and lead in the fuels. CO_2 emissions from the use of different fuels are determined by the carbon content of the fuels, and by the emission levels of other compounds containing carbon. The emissions of the latter compounds are mainly determined by the conditions under which the combustion takes place. Since the carbon content of these emissions are usually very much smaller than the carbon content of the corresponding CO_2 emissions, carbon emissions are counted as CO_2 in the inventories.

The emission inventories do not provide direct information on the pollution concentration of the various damaging components. For some of the components however, a good correlation is found between measured concentration levels and levels of emissions, see section 6.3. For this and other reasons, the emission inventories provide the necessary information on whether and where control measures should be used, and show the effects of already implemented control measures. The emission inventories are also a necessary data base for making forecasts of emissions to air, and thereby provide indicators on whether Norway is able to fulfil national aims and international agreements on reductions of emissions to air.

Emissions to air by economic sector and type of source

Emissions of SO_2, NO_x, VOC, CO, CO_2, particulates and Pb from various economic sectors in 1987 are shown in table 6.4, while table 6.5 gives emissions by type of source. In contrast to earlier inventories, these tables do not include emissions from ocean transport in Norwegian territorial waters. In 1987 these emissions amounted to approximately 9 thousand tons of SO_2,

Table 6.2. Emission coefficients for NO_x, VOC, CO and particulates. 1987

		NO_x	VOC	CO	Particulates
		kg/ton			
STATIONARY COMBUSTION					
Natural gas	Industry	7.0	1.5	2.0	0.0
Heating oil	Households	2.5	0.6	6.5	0.3
	Industry	3.0	0.4	2.0	0.3
Heavy oil	Households	4.2	0.3	0.4	1.3
	Industry	5.0	0.3	0.2	1.3
Coal	Households	1.4	10.0	100.0	8.5
	Industry	4.5	0.8	3.0	1.4
Wood	Households	0.7	20.0	100.0	10.0
	Industry	0.9	1.3	15.0	2.4
EVAPORATION					
Gasoline	Sales	.	2.8	.	.
	Storage	.	1.7	.	.
MOBILE SOURCES					
Marine fuels	Ocean transport	70.0	5.0	7.0	4.0
		g/km			
GASOLINE					
Light vehicles	Town driving	1.7	4.0	39	0.07
	Highway and country driving	2.3	1.2	9	0.07
Heavy vehicles	Town driving	5.2	9.0	85	0.14
	Highway and country driving	7.8	3.0	30	0.14
DIESEL					
Light vehicles	Town driving	1.0	1.0	2	0.45
	Highway and country driving	1.5	1.0	2	0.45
Heavy vehicles	Town driving	9.0	1.5	4	0.90
	Highway and country driving	13.5	1.5	4	0.90

Sources: CBS, SFT (State Pollution Control Authority).

Table 6.3. Emission coefficients for SO_2 and CO_2. 1987

Energy good	Kg SO_2 /ton energy good	Tons CO_2 /ton of energy good[1)]
Natural gas	-	2.75
LPG (propane)	-	3.00
Kerosene	0.4	3.15
Gasoline	0.7	3.15
Heating oils	4.4	3.15
Diesel	4.4	3.15
Marine fuel	4.4	3.15
Special distillate	9.0	3.15
Heavy oil LS	19.0	3.15
Heavy oil NS	44.0	3.15
Coal, industry	16.0	2.42
Coal, households	20.0	2.42
Wood	0.4	-

1) The emission coefficients for CO_2 are based on total carbon content of the fuels; i.e. the carbon in other emitted substances containing carbon are included in the coefficients for CO_2.

Sources: NP, SFT.

21 thousand tons of NO_X, 2 thousand tons of CO, nearly 1 million tons of CO_2, 1 thousand tons of both particulates and VOC and only small amounts of lead. Generally,-emissions from air transport cover landing and take-off cycles only. For CO_2, however, all emissions from Norwegian flights are included.

Sectors with relatively high emission levels include private households, domestic transport and production of metals, see table 6.4. From table 6.5 it is clear that road traffic and coastal water transport are among the larger sources of emissions of most of the compounds. Below follows a short survey of sectors and sources that made relatively large contributions to total emission levels in 1987.

Emissions of SO_2

The most important source of SO_2 emissions is non-energy related industrial processes, which in 1987 contributed approximately 42 per cent of the total SO_2 emissions. Stationary combustion was responsible for 33 per cent, while mobile sources contributed 25 per cent.

The manufacturing sectors combined were responsible for 66 per cent of the total SO_2 emissions. Production of metals is still the most SO_2-polluting sector, despite the large reductions achieved over the years. In 1987 this sector alone contributed 26 per cent of the total emission level. Other sectors with relatively high emission levels include domestic transport (16 per cent), pulp and paper (9 per cent), production of industrial chemicals (9 per cent) and production of non-industrial chemicals and mineral products (8 per cent).

Emissions of NO_X

Mobile sources were responsible for 85 per cent of the total NO_X emissions in 1987. Stationary combustion contributed another 12 per cent, while other industrial processes accounted for only 3 per cent. Diesel-powered vehicles and vessels are among the dirtiest sources as regards pollution by NO_X. Measured in terms of unit of fuel consumed, they have far higher emission rates than other types of engines, e.g. gasoline engines.

Commercial domestic transport accounted for approximately one third of the total amount of NO_X emitted in 1987. Contributions from private households were 16 per cent, while the fishing fleet was responsible for 14 per cent of the total emissions.

Table 6.4. Emissions to air by sector. 1987. In 1000 tons when nothing else is indicated

MSG-sector	SO_2	NO_x	VOC[1]	CO	CO_2	Particu-lates	Pb
					Mill. tons		Tons
Total	74.7	231.8	115.0	652.6	34.2	25.4	277.0
11 Agriculture	1.0	5.4	3.6	11.3	0.7	0.8	1.9
12 Forestry	0.1	0.7	1.1	3.1	0.1	0.1	0.8
13 Fishing etc.	2.2	32.8	3.6	6.3	1.5	1.9	1.0
14 Manufacture of food, beverages and tobacco	4.2	2.5	0.4	1.8	0.8	0.3	0.8
18 Man. of textiles, wearing apparel etc.	0.2	0.2	0.0	0.2	0.1	0.0	0.1
26 Man. of wood and wood prod.	0.5	0.8	0.2	1.0	0.1	0.1	0.3
28 Printing and publishing	0.0	0.2	0.1	0.7	0.0	0.0	0.4
29 Man. of non-ind. chemical and mineral products	6.1	6.3	0.5	2.0	2.9	0.4	0.7
34 Man. of pulp and paper prod.	6.6	1.6	0.1	0.6	0.5	0.3	0.2
37 Man. of ind. chemicals	7.0	6.0	0.8	32.4	1.4	0.1	0.0
40 Petroleum refining	4.1	1.9	3.6	0.0	1.1	0.1	0.0
43 Man. of metals	19.5	5.2	1.3	4.2	3.8	0.2	5.1
44 Man. of metal prod., machinery, building of ships, etc	0.9	1.2	0.3	1.7	0.3	0.1	1.0
55 Construction	0.9	8.2	1.2	4.8	0.6	0.6	1.5
63 Financing and insurance	0.1	0.5	0.5	4.0	0.1	0.0	2.6
64 Oil and gas extraction	0.2	11.3	2.4	3.3	4.3	0.0	0.0
68 Oil well drilling	1.2	13.7	1.0	1.4	0.6	0.8	0.0
71 Prod. of electricity[2]	0.6	1.1	0.3	0.4	0.2	0.1	3.5
74 Domestic transp. and comm.	12.2	76.4	12.3	49.8	5.9	5.1	16.9
81 Wholesale and retail trade	1.2	11.7	7.0	57.2	1.3	0.6	35.8
83 Housing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
85 Other private services	0.6	3.4	2.8	24.2	0.7	0.1	15.4
92 Defence	0.4	3.7	0.4	2.3	0.6	0.2	0.6
93 Education and research	0.3	0.1	0.0	0.1	0.2	0.0	0.0
94 Health and social welfare services	0.7	0.2	0.0	0.1	0.3	0.0	0.0
95 Other public services	0.1	0.7	0.1	0.8	0.1	0.0	0.5
P Private households	3.9	36.1	71.4	439.1	6.0	13.1	188.0

1) Evaporation not included. (Evaporation: see table 6.5.)
2) Includes emissions from waste incineration plants.
Sources: CBS, SFT.

Emissions of CO

As for NO_X, mobile sources are the dominant sources of CO. In 1987 they contributed approximately three quarters of the total CO emissions. Stationary combustion contributed 20 per cent, mainly as a consequence of burning of wood. Private households generated 95 per cent of all stationary CO emissions in 1987.

Emissions of CO_2

CO_2 emissions from mobile and stationary combustion were almost equal in 1987, contributing 45 and 41 per cent of the total respectively. Industrial processes contributed the remaining 14 per cent. The most polluting sectors were private households (18 per cent), commercial domestic transport (17 per cent), oil and gas activities in Norwegian territorial waters (15 per cent), production of metals (11 per cent) and production of non-industrial chemicals and mineral products (8 per cent). All in all, several types of sources and sectors made a sizeable contribution to total CO_2 emissions in 1987.

Table 6.5. Emissions to air by type of source. 1987. In 1000 tons when nothing else is indicated

Sources	SO_2	NO_x	CO	CO_2	VOC	Particulates	Pb
				Million tons			Tons
TOTAL	74.7	231.8	652.6	34.2	188.2	25.4	277.0
STATIONARY COMBUSTION	24.4	27.5	123.9	14.0	26.2	13.0	4.1
- Industrial combustion	17.9	22.6	4.8	10.0	2.9	1.2	0.4
- Non-industrial combustion	6.0	3.8	118.8	3.9	23.1	11.7	0.2
- Incineration of waste	0.6	1.1	0.4	0.1	0.3	0.1	3.5
INDUSTRIAL PROCESSES	31.2	7.9	36.1	5.0	5.4	0.0	5.0
- Paper and paper prod.	3.3	-	-	-	-	-	-
- Industrial chemicals	5.8	4.3	32.3	0.5	0.7	-	-
- Mineral products	1.9	-	-	1.1	-	-	-
- Petroleum refining	3.4	-	-	-	3.6	-	-
- Metals	16.8	3.6	3.8	3.3	1.1	0.0	5.0
- Agriculture (liming)	-	-	-	0.2	-	-	-
EVAPORATION	-	-	-	-	73.2	-	-
- Storage of gasoline	-	-	-	-	3.0	-	-
- Filling stations	-	-	-	-	5.0	-	-
- Solvents	-	-	-	-	50.0	-	-
- Oil- and gas extraction	-	-	-	-	15.2	-	-
MOBILE SOURCES	19.0	196.5	492.6	15.3	83.4	12.5	267.9
- Automobiles	4.6	79.6	406.4	7.8	49.7	4.5	252.4
-Light vehicles	1.7	44.7	370.3	5.3	43.2	2.2	234.6
-Gasoline	1.1	42.5	367.1	4.9	41.6	1.4	234.5
-Diesel	0.6	2.2	3.2	0.4	1.6	0.7	0.0
-Heavy vehicles	3.0	34.9	36.1	2.5	6.5	2.4	17.8
-Gasoline	0.1	3.9	25.9	0.4	2.7	0.1	17.8
-Diesel	2.9	31.0	10.2	2.1	3.8	2.3	0.1
- Motorcycles, mopeds, tractors etc.	1.4	13.7	65.6	1.1	24.3	2.0	15.2
- Railways	0.1	0.5	0.2	0.1	0.1	0.1	0.0
- Air traffic	0.2	4.1	10.6	1.8	2.2	0.2	0.0
- Coastal water transport	9.6	52.1	5.2	2.4	3.7	3.0	0.2
- Fishing fleet	2.2	32.8	3.3	1.5	2.3	1.9	0.1
- Oil well drilling	0.9	13.7	1.4	0.6	1.0	0.8	0.0

Sources: CBS, SFT.

Emissions of VOC

Almost all of the VOC emissions in 1987 were either due to evaporation (40 per cent) or to incomplete combustion in mobile sources (45 per cent). Use of solvents was the largest source of evaporation, but also offshore oil and gas activity and stocking and handling of gasoline made significant contributions. Stationary combustion contributed 14 per cent to total VOC emissions in 1987. Estimates of VOC emissions are generally more uncertain than emission estimates of other components.

Emissions of particulates

Emissions of particulates were evenly distributed among stationary (51 per cent) and mobile (49 per cent) sources in 1987. Other sources are not accounted for at present in the inventories. Again diesel engines are a dominant source of pollutants, in addition to burning of wood. Private households were responsible for approximately half of all emissions in 1987, while commercial domestic transport accounted for 20 per cent.

Emissions of lead

As much as 97 per cent of the lead emissions in 1987 came from mobile sources as a result of lead additives to gasoline. The remaining 3 per cent were due to process emissions from the production of metals and from incineration of waste and combustion of oil products. Important emitting sectors were private households (68 per cent) wholesale and retail trade (13 per cent) commercial domestic transport (6 per cent) and other private services (6 per cent).

Norwegian emissions 1973-1989

The economic development and the associated consumption of energy, together with special measures to control the emissions, explains the growth or decline in emission levels. The historical record on use of energy is described in chapter 2. This section briefly describes the evolution in emissions of SO_2, NO_X, CO, CO_2, VOC, Pb and particulates over the period 1973-1989. The emissions do not include emissions from ocean transport. The figures for the years 1988 and 1989 are preliminary estimates by SFT.

Emissions of SO_2 were reduced dramatically over the period 1973-1989, see figure 6.1. Emissions from stationary sources decreased from 73 000 tons in 1973 to below 20 000 tons in 1989, a reduction of over 70 per cent. Similarly, process emissions of SO_2 decreased from 67 000 tons to approximately 30 000 tons over the same period, a reduction of over 50 per cent. Several factors explain these remarkable results:

- The sulphur content of many oil products has been reduced. Regulations on the sulphur content of heavy fuel oil used in the southern part of the country were introduced in 1977 and extended in 1986.

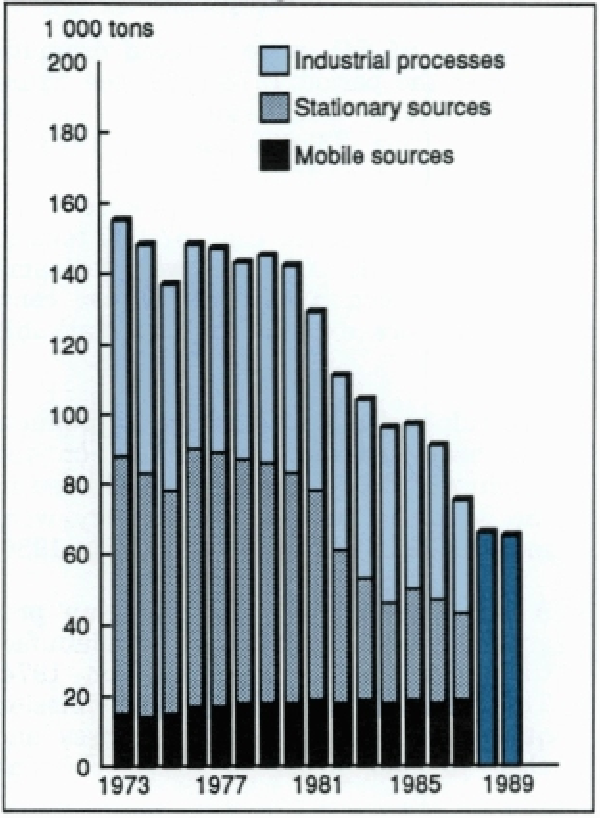
- A comprehensive 10-year clean-up programme for elderly polluting manufacturing industry was initiated in 1974. The programme included issuing emission quotas to a number of enterprises and also directed firms to instal cleaning equipment.

- The supply of cheap surplus hydropower was abundant both in the early and the late 1980s. This led to reduced consumption of fuel oils.

- The last part of the period was characterized by a number of very mild winters, which reduced the need for heating.

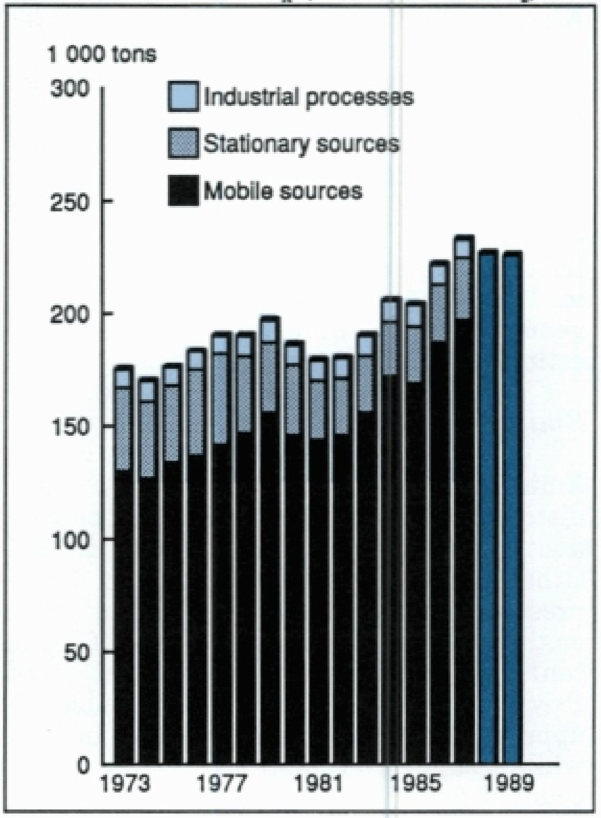
The largest reductions in emissions were observed in the pulp and paper industry. E.g., while the emissions were 33 000 tons SO_2 in 1976, they were reduced to 6 600 tons in 1987. This sector is characterized by extensive use of surplus hydropower. Emissions from the energy-intensive industries remained more or less constant over the period. Emissions from refineries were much reduced and emissions from other production sectors, not counting the transport sectors, were more than halved due to reduced demand for oil and diminishing sulphur content. In 1984-1985 the emissions increased somewhat due to a higher level of activity. Thereafter the emissions decreased due to new regulations of the sulphur content of oil and the close down of a copper melter in Sulitjelma.

Figure 6.1. Emissions of SO_2 by source. 1973-1989*. 1 000 tons SO_2



Sources: CBS, SFT.

Figure 6.2. Emissions of NO_X by source. 1973-1989*. 1 000 tons NO_X (measured as NO_2)



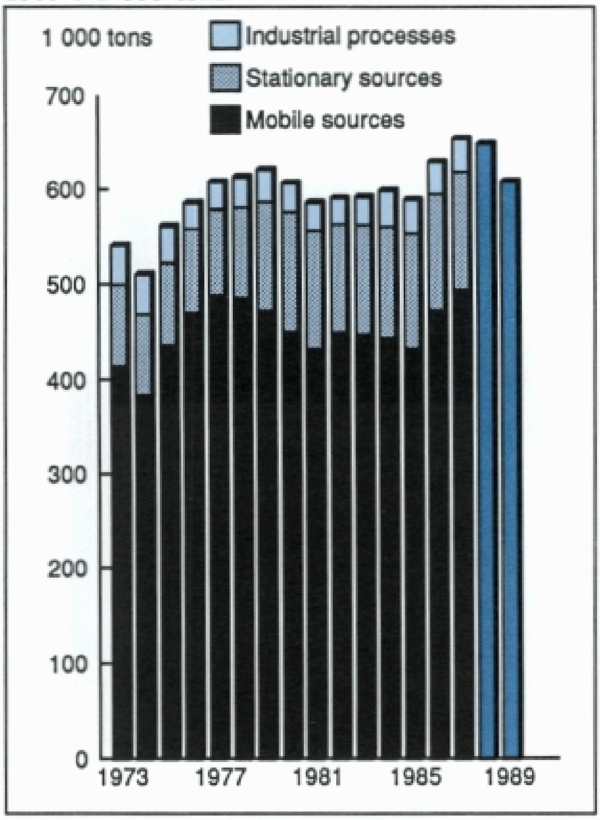
Sources: CBS, SFT.

NO_X emissions increased substantially from the beginning of the 1980s to 1987, whereafter they decreased slightly in 1988 and 1989, see figure 6.2. The reduction in later years seems to be due to reduced emissions from mobile sources, in particular diesel engines and vessels in coastal waters. Diesel fuel and marine fuels are among the biggest contributors to overall NO_X emissions. The largest contribution to the earlier growth came from private households. A fairly large part of the growth in consumption expenditure in the 1980s referred to buying and driving new cars. Simultaneously, technological development, with increased energy efficiency, implied an increase in NO_X emissions per unit fuel consumed. Emissions from stationary combustion sources decreased, while emissions from other industrial processes remained almost constant.

Emissions of CO remained fairly stable up to the mid-1980s. After a slight increase towards 1987, they now seem to be declining, see figure 6.3. Almost 70 per cent of total CO emissions are due to combustion of gasoline, and the increase from 1985 to 1987 was due to a rapid growth in the use of private cars, outpacing the effects of improved technology which tends to reduce CO emissions per kilometer driven. The last few years have shown a decrease in the demand for transport fuels.

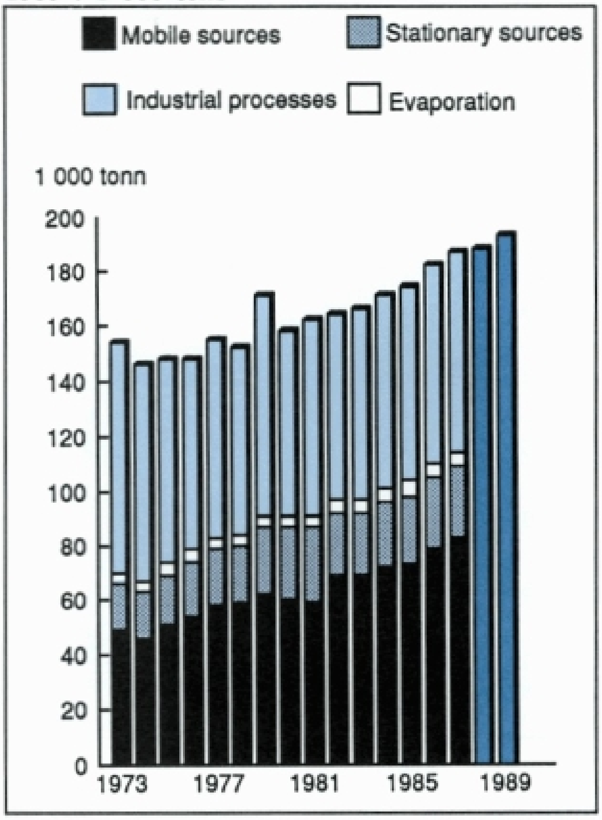
Process emissions of CO have remained stable throughout the period, while emissions from stationary combustion increased somewhat due to increased use of fuel wood. Almost 90 per cent of CO emissions from stationary combustion are due to use of fuel wood.

Figure 6.3. Emissions of CO by source. 1973-1989*. 1 000 tons



Sources: CBS, SFT.

Figure 6.4. Emissions of VOC by source. 1973-1989*. 1 000 tons



Sources: CBS, SFT.

Emissions of VOC showed a stable trend up to about 1985, followed by a slight increase in the last few years, see figure 6.4. Emissions from mobile sources increased most.

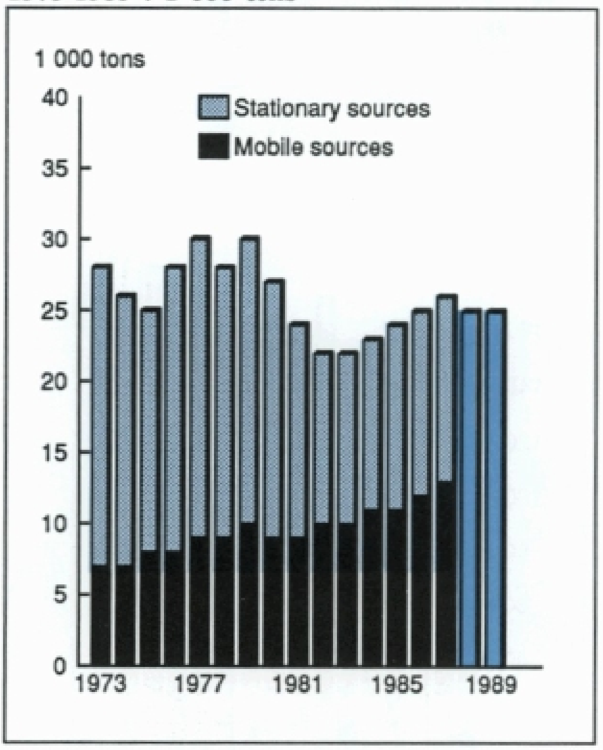
Emissions of particulates decreased from 1973 to 1983, see figure 6.5. This was mainly due to reduced use of heavy oil, but also to increased cleaning of emissions from heavy industry. From 1983 to 1987 the total emissions increased, due to more use of fuel wood and increased road traffic. The emission level has remained almost constant the last few years.

Emissions of lead decreased drastically from 1973 to 1986, see figure 6.6. This reflects a reduction of the permitted lead content of gasoline (new regulations were introduced in 1980 and 1983) and the introduction of unleaded gasoline in 1986.

Process emissions of lead were more or less stable in the period 1973-1986. Since 1986, several important industrial sources of lead emissions have been closed, and process emissions are now very small.

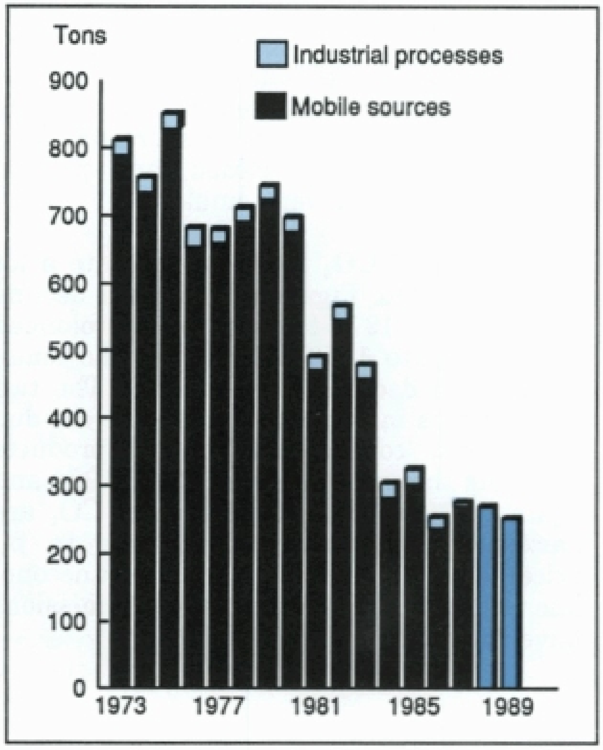
Emissions of CO_2 have varied quite a lot over the period. Figure 6.7 shows a decline from 1973 to 1974 followed by a prolonged increase up to 1979. After 1979 the emissions again decreased up to 1982. The two marked dips in the emission level were due to reduced consumption of oil products following the price shocks in 1973-1974 and again in 1979-1980. Emissions of CO_2 are particularly sensitive to changes in oil prices since, at least so far, it is uneconomic to clean these emissions. The emissions have increased since 1982.

Figure 6.5. Emissions of particulates by source. 1973-1989*. 1 000 tons



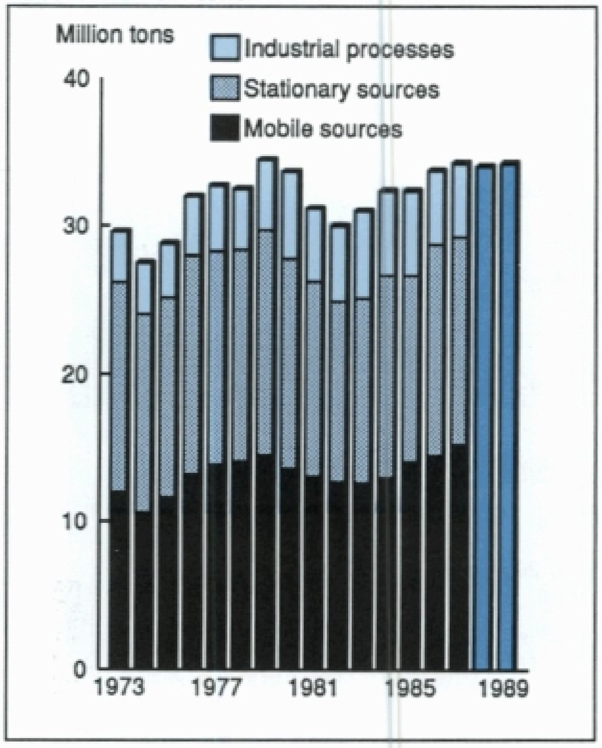
Sources: CBS, SFT.

Figure 6.6. Emissions of Pb by source. 1973-1989*. Tons



Sources: CBS, SFT.

Figure 6.7. Emissions of CO_2 by source. 1973-1989*. Million tons



Sources: CBS, SFT.

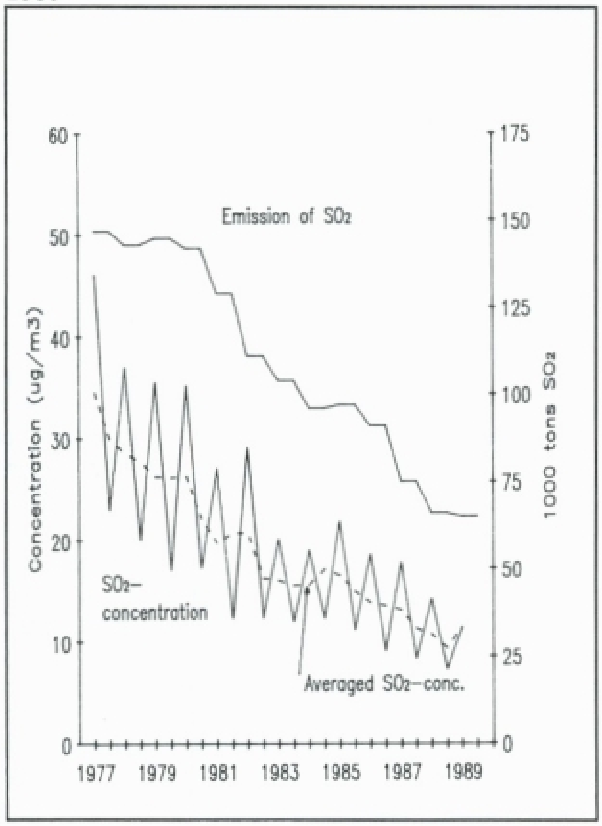
6.3. Local concentration of some pollutants

During the period from April 1988 to March 1989 air pollution concentrations were measured at 29 stations in 25 urban areas as part of the national pollution monitoring programme. The measurements give 24 hour averages for sulphur dioxide, lead, soot and nitrogen oxides. The measurements were taken at different times of the year and the time series varies a great deal in length. For instance, measurements of NO_x concentrations only started in 1986.

The measurements show that the concentration of all components varies significantly over the year, with higher levels in winter and lower levels in summer. Figures 6.8-6.10 show the seasonal variation and average concentration of sulphur dioxide, soot and lead as measured by stations in some larger Norwegian cities (Fredrikstad, Oslo, Drammen, Kristiansand, Stavanger, Bergen, Trondheim and Tromsø). Superimposed on the figures are the national emission levels for the various compounds.

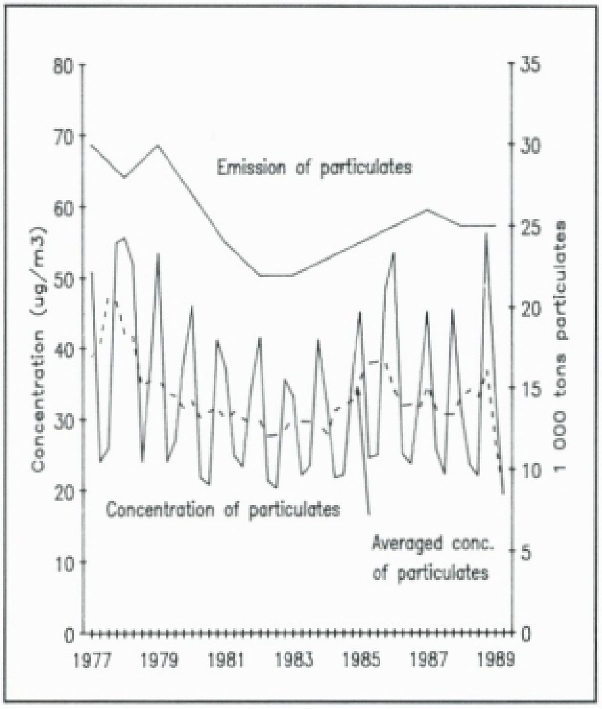
Figure 6.8 illustrates that the average concentration of sulphur dioxide has declined considerably over the last 10 years. Also the concentration of soot decreased in the earlier part of the period, but has levelled out the last few years, see figure 6.9. The concentration of lead in city air was reduced considerably as a consequence of reduced lead additives in gasoline and the introduction of unleaded gasoline. The concentration has remained more or less constant, however, in the last few years, see figure 6.10.

Figure 6.8. Average concentration of SO_2 in air in some larger Norwegian cities. µg SO_2 /m³. National emissions of SO_2. 1 000 tons. 1977-1989*



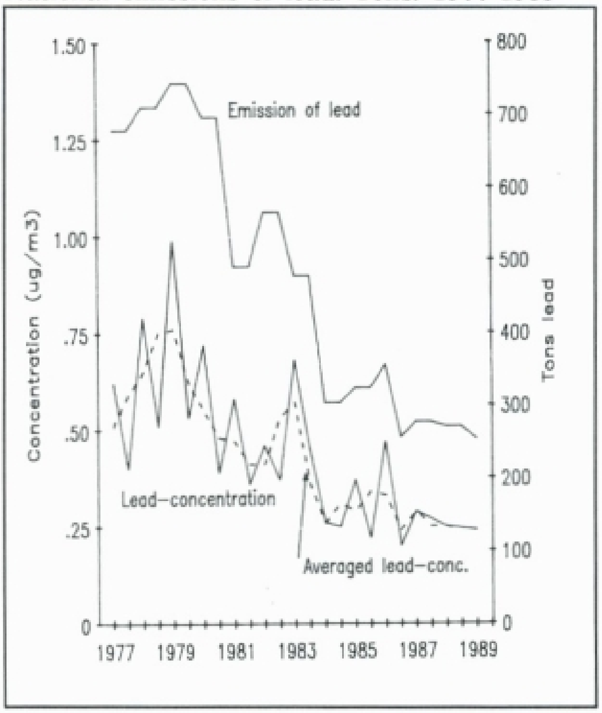
Sources: NILU, CBS.

Figure 6.9. Average concentration of soot in air in some larger Norwegian cities. µg soot/m³. National emissions of particulates. 1 000 tons. 1977-1989*



Sources: NILU, CBS.

Figure 6.10. Average concentration of lead in air in some larger Norwegian cities. µg Pb/m³. National emissions of lead. Tons. 1977-1989*



Sources: NILU, CBS.

Table 6.6. Measuring stations which exceeded quality levels of SO_2 during the winter 1988-1989. µg SO_2 /m³

City/ Settlement	Station	Mean value	Max. daily average	Number of observations Total	>100 µg/m³	>150 µg/m³
Halden	Stubberudveien	22	101	182	1	-
Sarpsborg	St. Olavs Vold	71	361	182	41	15
Øvre Årdal	Farnes	27	147	181	5	-
Kirkenes	Rådhuset	18	187	182	1	1

Source: NILU.

Changes in air pollution, averaged over several cities, tend to follow variations in national emissions of the polluting compounds. However, average values may conceal air pollution problems, since for some components like SO_2 and NO_x, brief episodes with high concentration levels are the most damaging.

Measurements show that episodes with high SO_2 concentration were fewer and of lower concentration during the winter of 1988-1989 than at any time since 1977. This is a direct consequence of the reductions in SO_2 emissions, see section 6.2. SO_2 episodes occur most often at locations with high levels of emissions from industrial processes other than combustion. The highest levels of SO_2 concentrations are now measured in the county of Østfold (Sarpsborg and Halden) and in Øvre Årdal, see table 6.6. Kirkenes in Finnmark experiences high SO_2 concentration due to extremely high emission levels in the Soviet Union near to the Norwegian border.

Measurements of NO_X concentration did not start until 1986. In the winter of 1988-1989, 9 out of 12 measurement stations registered concentrations above the lower critical level for 24 hour mean values (100 µg/m³). Highest values were observed in Oslo, Stavanger and Drammen. At one station, in Stavanger, the critical level for half year average concentration (75 µg/m³) was also exceeded, see table 6.7. Car traffic is the main cause of NO_X pollution at these stations. The values measured last winter were rather higher than during the year before despite the fact that last winter was considerably milder than the previous one. This reinforces the impression that NO_X pollution may become a serious problem in the years ahead.

Measurements exceeding the critical level for 24 hour average values (150 µg/m³) were also obtained for soot. These occurred in the cities of Fredrikstad, Oslo, Drammen, Skien, Stavanger and Bergen. It is safe to assume that most urban areas will experience soot concentration levels above the critical level from time to time along roads with heavy traffic.

No measurements of lead concentration above critical levels were made during the winter 1988-1989.

Air pollution at Norwegian background stations

Transboundary pollution is measured at 7 background stations. These are stations that are influenced by local emission sources to only a very low extent. Table 6.8 gives the yearly averaged concentration of sulphur dioxide and particulate sulphate at some of the background stations.

The measurements reveal a slight reduction in overall concentrations over the period 1980-1988. There are large regional differences, however, in the pollution loads. The highest values are observed in the southern (Birkenes), south-western (Skreådalen) and north-eastern (Jergul) parts of the country.

The air quality at background stations can vary considerably from day to day. A large

Table 6.7. Measuring stations which exceeded quality levels of NO_2 during the winter 1988-1989. µg NO_2 /m³

City	Station	Mean value	Max. daily average	Number of observations Total	>100 µg/m³	>150 µg/m³
Fredrikstad	Brocks gate	50	129	179	2	-
Halden	Rådhuset	40	106	178	1	-
Drammen	Engene	74	233	175	18	3
Lillehammer	Kirkegata	62	121	172	4	-
Skien	Kongens gate	57	102	162	1	-
Stavanger	Handelens hus	80	149	171	37	-
Bergen	Chr.Michelsens institutt.	44	115	180	4	-
Trondheim	Brattøra	46	111	169	1	-
Oslo	St. Olavsplass	62	130	179	12	-

Source: NILU.

Table 6.8. Concentration of SO_2 and particulate sulphate at some background stations. Yearly averages[1]. 1980-1988. µg/m³

	1980	1981	1982	1983	1984	1985	1986	1987	1988
SO_2									
Hedmark (Hummelfjell/Osen)[2]	..	0.8	0.4	0.7	0.8	0.7	0.7	0.3	0.7
Aust-Agder (Birkenes)	1.5	2.4	1.0	1.3	1.6	1.2	1.6	1.4	1.0
Vest-Agder (Skreådalen)	1.3	2.1	1.0	1.4	1.5	1.4	1.4	1.5	1.2
Møre- og Romsdal (Kårvatn)	0.7	1.1	0.4	0.7	1.1	0.7	1.3	0.7	0.4
Nordland (Tustervatn)	0.9	1.4	0.5	1.2	1.5	0.9	1.4	1.5	0.4
Finnmark (Jergul)	2.6	2.4	1.3	2.3	2.6	2.3	3.4	2.6	1.0
Particulate sulphate									
Hedmark (Hummelfjell/Osen)[2]	1.3	1.5	1.0	1.2	1.4	1.4	1.1	0.7	1.7
Aust-Agder (Birkenes)	3.2	3.6	2.7	3.2	3.7	2.5	2.6	2.2	2.2
Vest-Agder (Skreådalen)	2.8	3.0	2.4	2.8	3.0	2.4	2.4	2.2	1.7
Møre- og Romsdal (Kårvatn)	1.4	1.5	1.1	1.3	1.7	1.4	1.3	1.2	1.0
Nordland (Tustervatn)	1.8	1.7	1.4	1.8	2.1	1.5	1.6	2.0	0.8
Finnmark (Jergul)	1.9	1.9	1.5	2.4	2.3	2.3	2.3	2.5	1.3

1) Average of mean half-year values.
2) Hummelfjell until 1987. Osen from 1988.

Source: NILU.

part of the yearly supply of pollutans often comes within relatively few days, most often during winter. The highest values are measured when air that has been lying relatively stable over strongly industrialized areas in Europe is transported to Norway.

6.4. Indirect emissions to air

Section 6.2 presented an overview of emissions to air from various production sectors, giving an impression of what *types of firms* contribute to a lesser or greater degree to air pollution. Normally, many different types of materials are used in the production processes. In order to assess by what amount consumption of a particular service or commodity contributes to air pollution problems, it is also necessary to take into account the emissions associated with the manufacturing of the input factors used in the final production process; the so-called indirect emissions. Input-output adjusted emissions cover both the direct emissions from the production of the final product as well as the indirect emissions coming from the manufacturing of the input factors. For instance, the printing and publishing of this report will in itself not contribute very much to the total pollution level. But if the emissions associated with the manufacturing of the necessary paper and ink, the distribution of the report, etc. are taken into account, the picture of the environmental impact of this report changes dramatically, since the input-output adjusted emissions associated with printing and publishing are several order of magnitudes larger than the rather small direct emissions, see tables 6.9-6.11.

This section presents input-output adjusted emission levels for the compounds carbon dioxide (CO_2), nitrogen oxides (NO_X) and sulphur dioxide (SO_2). The analysis has been carried out at the request of the State Pollution Control Authority (SFT).

Commodities are either employed as input factors in the manufacturing of further products or directed to *final use*; that is consumed, invested in real capital, exported or stocked. The input-output adjusted emissions presented below are emissions associated with an increase in the final use of one million NOK, measured in fixed 1987 prices.

The calculations have been carried out by the use of MODIS V, a macroeconomic model which contains a relatively detailed description of the structure of Norwegian economy. However, ocean transport and offshore oil and gas activities are not included in the analysis.

Export and import of commodities

The input-output adjusted emission levels will vary according to how the export and import of goods are treated in the analysis. Here, all emissions from the production of goods for export are included. A great deal of the materials used for production purposes in Norway are imported. Two sets of input-output adjusted emission levels are presented below. In the first set, emissions associated with the production of imported goods are included, assuming a production process similar to the one employed in Norway. In the second set, these emissions are excluded from the adjusted emission levels. A problem arises with regard to how to handle emissions from the production of goods not produced in Norway, so-called non-competitive commodities. In 1987 this type of commodities accounted for approximately 5 per cent of the total imported volume. Emissions from the production of these goods are not included in this study.

Table 6.9 gives changes in emission levels when the final use of commodities and services is increased by one million 1987-NOK. Emissions from the production of imported goods are included. Table 6.10 gives the changes in emission levels when emissions from the production of imported goods are excluded. For comparison, table 6.11 shows the direct emissions measured per unit gross production.

In MODIS V the production in the agriculture, forestry and fishery sectors is determined outside the model. Thus, an increase in the demand for commodities produced in any of these sectors is met by import alone. This implies that effects on emission levels from an increase in the final use of these commodities are included only in the results presented in table 6.9. The emission levels in table 6.10 associated with commodities using any of these goods as input factors are therefore somewhat low. This is the case in particular for emission levels associated with final use of food, beverages etc.

Some comments on the figures

A given commodity can be produced by many different firms, and a firm can produce many different types of commodities. This makes it difficult to establish a one-to-one correspondence between commodities and types of firms (sectors). The adjusted emission levels reported in tables 6.9 and 6.10 refer to sets of commodities, while the direct emission levels presented in table 6.11 refer to production sectors. Furthermore, the direct emission levels are given per unit of gross production, while the adjusted emission levels are given per unit increase in final use of commodities. Thus, the two sets of figures are not strictly comparable.

Nevertheless, a comparison gives an indication of the importance of the indirect emissions associated with different commodities or sectors. In particular it is of interest to ask the two following questions:

- Will the ranking of the most polluting commodities change when the input-output adjusted emission levels are considered instead of the direct emissions?

- Are there commodities that exhibit very large indirect emission levels compared to the direct emission levels?

Results

By and large, the ranking of commodities/sectors is unaffected by the input-output corrections. However, there are exceptions, and these will be mentioned below when the different pollution compounds are discussed.

The indirect emissions turn out to be considerable for all commodity groups included in this analysis. Also, there are large variations in the relative importance of the indirect emissions compared to the direct emissions. Thus, the persistence of the ranking of the most polluting sectors/commodities may at first sight seem strange. There are two main explanatory factors: First, very large discrepancies are observed between the direct emission levels from the various sectors, cf. table 6.11. Although the indirect emissions associated with some sectors are considerably larger than the direct emissions, this is usually not sufficient to alter the ranking of the most polluting activities. Second, those sectors/commodities that have large direct emissions also tend to have large indirect emissions.

Generally, the input-output adjusted emission levels are much higher when emissions associated with imported goods are included, see tables 6.9 and 6.10. This is a reflection of the fact that Norway is a country with considerable foreign trade. It also implies that Norway to a large degree swaps emissions with other nations through trading.

The public sectors are not included in the tables 6.9-6.11. This is because it is difficult to calculate emission levels for these sectors that are comparable with the rest of the figures in the tables. Simple estimates indicate, however, that these sectors/services are among the least polluting, even when the indirect emissions are included.

Emissions of carbon dioxide

Coastal transport generates the largest CO_2 emissions measured per produced unit. Then follow *metals* and *non-industrial chemical and mineral products*. This ranking is valid whether direct emissions or direct plus indirect emissions are considered, and whether emissions associated with imported goods are included or excluded.

Production of metals and non-industrial chemical and mineral products generate large direct as well as indirect emissions. Coastal transport produces relatively small indirect emissions, but the direct emissions from this activity are so much higher than any other activities, that even adjusted for indirect emissions, coastal transport retains its position as the most CO_2 polluting activity.

Table 6.9. Input-output adjusted emissions to air, inclusive emissions from the production of imported commodities and services. Emissions from the production of non-competitive commodities are excluded. Changes in emissions from an increase in final use of each type of commodity by 1 million 1987-NOK

Commodity group	CO_2 tons	NO_x kg	SO_2 kg
Agricultural products	118	774	331
Food etc.	90	950	325
Textiles etc.	70	404	274
Pulp and paper products	133	509	1131
Printing and publishing products	52	384	257
Non-ind. chemical and mineral products	234	694	590
Basic metals	323	732	2239
Fabricated metals, ships, oil plattforms	71	365	392
Construction	77	429	275
Wholesale and retail trade	43	272	87
Private services	33	305	87
Domestic transp. excl. coastal transp.	101	807	148
Coastal transport	645	13553	2999
Private health- and veterinary services	35	298	92

Source: CBS.

Table 6.10. Input-output adjusted emissions to air, exclusive emissions from the production of imported commodities and services. Emissions from the production of non-competitive commodities are also excluded. Changes in emissions from an increase in final use of each type of commodity by 1 million 1987-NOK

Commodity group	CO_2 tons	NO_x kg	SO_2 kg
Agricultural products	51[1]	341[1]	161[1]
Food etc.	27	152	153
Textiles etc.	25	166	107
Pulp and paper products	97	338	942
Printing and publishing products	29	292	126
Non-ind. chemical and mineral products	171	427	350
Basic metals	235	423	1779
Fabricated metals, ships, oil platforms	17	180	78
Construction	40	286	114
Wholesale and retail trade	34	227	47
Private services	20	210	42
Domestic transp. excl. coastal transp.	88	741	94
Coastal transport	617	13413	2887
Private health- and veterinary services	21	200	48

1) The figures for agricultural products are calculated with a somewhat different model specification than the figures for the other commodity groups. This implies that the figures for agricultural products are somewhat higher compared to the other figures in this table.

Source: CBS.

Table 6.11. Direct emissions measured per million 1987-NOK gross production

Production sector	CO_2 tons	NO_x kg	SO_2 kg
Agriculture	23	222	44
Food etc.	12	36	78
Textiles etc.	13	33	62
Pulp and paper products	60	149	645
Printing and publishing	1	9	2
Non-ind. chemical and mineral products	119	190	215
Basic metals	172	227	1352
Fabricated metals, ships, oil platforms	4	13	10
Construction	8	97	10
Wholesale and retail trade	14	5	1
Private services	5	105	12
Domestic transp. exlc. coastal transp.	70	522	51
Coastal transport	570	12561	2705
Private health- and veterinary services	5	35	3

Source: CBS.

Publishing and printing matters are products with huge indirect emissions compared with their direct emissions. This is because the production of these products requires polluting input factors like paper and transport. Since the direct emissions are small, however, publishing and printing are not among the most polluting activities undertaken. Also activities like construction, and commodities like metal products, machinery and equipment and ships and oil platforms, are responsible for large indirect emissions.

Emissions of nitrogen oxides

Also for these compounds, the direct emissions from *coastal transport* are so dominating that they totally engulf the indirect emissions from other products. *Other industrial products* are a clear number two as regards direct emissions, and also when the input-output adjusted emissions exclusive of emissions associated with imported goods are taken into account. If these emissions are included, however, *food, beverages and tobacco* is ranked as number two in NO_x pollution. This is probably due to the fact that these commodities use input factors from agriculture, fishing and transport, three sectors with relatively large direct emissions of NO_x. Due to characteristics of the MODIS model, these effects are not included when emissions from imported goods are excluded.

Wholesale and retail trade and *publishing and printed matter* do not have particularly high indirect emissions of NO_x, measured in absolute terms. However, when compared with the very small direct emission levels, the indirect emission levels are very high. This is because wholesale and retail trade are dependent on transport as an input factor, while printing and publishing use pulp and paper products. Another sector with a low direct emission level, but relatively high indirect emission level is *production of metal products, machinery and equipment, ships and oil platforms*, which uses large amounts of metals as input factors.

Emissions of sulphur dioxide

Even for this component, *coastal transport* shows the highest direct emission level measured per unit produced. Then follows production of *metals* and *pulp and paper*. This pattern is preserved when indirect emissions are taken into account, whether emissions from imported goods are included or not. Metals, however, show very much higher indirect emissions than coastal transport, especially when emissions from imported goods are included.

Publishing and printed matter are responsible for very low direct emissions of SO_2. When indirect emissions are included however, these commodities climb several steps up the list of the most polluting goods. Printing and publishing depends on the production of pulp and paper, an activity with a relatively high SO_2 emission level.

Metal products, machinery and equipment, and ship and oil platforms are product groups with large indirect SO_2 emissions, particularly when emissions from imported goods are included.

It should also be noted that *wholesale and retail trade* generates large indirect emissions in relation to the direct emission level. This is primarily due to the transport intensity of this type of activity.

6.5. Environmental taxes on fossil fuels

Norway has approved the polluter pays principle, saying that the polluter shall pay for the adverse effects of emissions. As to pollution from fossil fuel combustion, the introduction of fuel taxes seems to be a practical approach to the polluter pays principle. The taxes shall equal the costs of the environmental damage caused by one unit increase in fuel consumption (marginal environmental cost).

Increasing concern about environmental quality has been accompanied by considerable research on the adverse effects of pollution. It is hardly possible to achieve a satisfactory overview of environmental costs. However, the knowledge of some impacts has become substantive. By aggregating results from several studies of different adverse effects, the study presented in this section aimed at estimating marginal environmental costs associated with fossil fuel consumption. The information on damage and costs stems mainly from the State Pollution Control Authority (SFT), the Norwegian Institute for Air Research (NILU) and the Institute of Transport Economics (TØI). The data include estimates of health damage due to emissions of NO_X, SO_2, CO and particulates, acidification of watercourses and soil related to emissions of NO_X and SO_2, and corrosion costs caused by Norwegian SO_2 emissions. The estimate of optimal fuel tax also includes costs associated with the negative external effects of road traffic, e.g. accidents, congestion, road damage and noise. It must be emphasized that the estimates are very uncertain.

Economic impact

The impact on economic growth by taxing fossil fuels according to their environmental damage is studied by means of a macroeconomic model called MSGTAX, see box 6.2. The marginal damage from fuel use varies between production sectors depending on differences in the composition of their fuel input. Therefore fuel tax rates were made sector-specific when implemented in the model. Measures that are already decided will cause minor reductions in emissions per unit fuel during the next 10 years. One exception is the introduction of three-way catalytic cleaning of exhaust gases from new passenger cars. The tax on gasoline was thus adjusted in proportion to the emission reduction following an increasing share of converter cars over the years 1989-1999. The tax rates have not been adjusted for a rise in willingness to pay for environmental quality, which may be expected from a future increase in the level of income.

Table 6.12. Impact of environmental taxes. Deviation from the reference scenario. Year 2000. Per cent

Gross domestic production.	-1.8
Imports	-1.8
Exports	-4.1
Private consumption	-0.8
Public consumption	0.2
Investments	-1.3

Source: CBS.

Table 6.12 shows the impact of environmental taxes on economic indicators, expressed as deviation from the reference scenario.

Gross domestic product (GDP) in the year 2000 is NOK 14 billion or 1.8 per cent lower in the tax scenario than in the reference scenario. The level of private consumption falls by only 0.8 per cent. Fuel-intensive goods are substituted to a large degree by other commodities, however, thus considerably changing the consumer basket. The export volume is down by 4.1 per cent. This is due to the rise in domestic price level following the fuel tax, making Norwegian export goods less competitive on the world market. Import is reduced about as much as GDP, and less than export. As the current account is assumed to be fixed in this study, reduced exports must be offset by reduced imports. However, the rise in terms of trade keeps imports from being reduced as much as exports, and thus protects the loss in resources for domestic consumption.

Fuel taxes provide an increase in tax revenue of NOK 13 billion (1986-prices) in the year 2000. This additional revenue is not explicitly redistributed to any particular industry or to households. It is indirectly redistributed, however, since the model assumes that the resources of the economy are fully utilized after as well as before the fuel tax is introduced. Only relative prices determine the allocation of resources. The results may be interpreted as an illustration of the impact of changing relative prices, independent of how the tax system is changed to achieve this.

Energy consumption

Table 6.13 shows impact of the tax on the price of oil products and on oil consumption. A tax reflecting marginal environmental costs leads to a 75 per cent increase in the user price of oil products in the year 2000. Households experience a price rise of heating oil of almost 30 per cent. The gasoline price is 35 per cent higher because of the fuel tax. In production sectors the consumption of gasoline and fuels (measured in tons) is reduced by about 35 per cent. Household consumption of gasoline is reduced by 10 per cent, and consumption of heating oils by 12 per cent.

Households respond to the rising oil prices by increasing the demand for electricity by 8 per cent. However, the production sectors reduce their electricity demand by 10 per cent due to a fall in output in electricity-intensive export industries. Exports decrease due to the increase in domestic level of prices and hence the export prices.

Table 6.13. Price of oil products and consumption of gasoline and heating fuel. Deviation from the reference scenario. Year 2000. Per cent

	Price of oil products	Use of gasoline[1]	Use of heating oils[1]
Production sectors	75	-37	-36
Households			
Heating . . .	27	.	-12
Private transport . .	35	-10	.

1) Measured in tons.
Source: CBS.

Emissions to air

Yearly emissions are reduced considerably for all four components that are included in the sub-model for environmental benefits.

Table 6.14. Emissions. Deviation from the reference scenario. Year 2000. Per cent

Sulphur dioxide (SO_2)	-25
Nitrogen oxides (NO_x)	-24
Carbon monoxide (CO)	-18
Particulates	-20
Carbon dioxide (CO_2)	-23

Source: CBS.

CO_2 emissions are also significantly decreased. Emissions of SO_2, NO_X and CO_2 are all reduced by around 25 per cent in the year 2000 compared with the reference scenario. Emissions of CO and particulates stem to a larger extent from combustion of wood in households, a predominantly non-commercial fuel not covered by the tax. Emissions of CO and particulates are reduced by roughly 20 per cent. Emission reductions as a result of fuel taxes are presented in table 6.14.

Environmental benefits

Table 6.15 shows estimated environmental benefits from introducing fuel taxes according to marginal environmental damage. Benefits include reduced damage to health, less acidification, less corrosion damage and reduced noise from traffic.

Table 6.15. Benefits from fuel taxes according to marginal damage. Year 2000. Billion 1986-NOK

Type of damage		Cost reduction
Acidification of forests and watercourses		0.0
Health damage		5.3
NO_x	4.7	
SO_2	0.4	
CO	0.0	
Particulates	0.2	
Corrosion damage		0.1
Traffic accidents		1.6
Congestion		1.8
Wear and tear of roads		2.2
Traffic noise		1.3
Total cost reduction		12.4

Source: CBS.

Fuel taxes equalling marginal environmental costs may create yearly benefits of NOK 12 billion (1986-prices) around year 2000. This is of the same magnitude as the estimated loss in GDP (NOK 14 billion 1986-prices). Forests and lakes are hardly influenced by the reductions in emissions. The reason is that transboundary pollution is the dominating source of acidification in Norway. Reductions in NO_X emissions lead to a marked health benefit of approximately NOK 5 billion (1986-prices). Concentration levels of other pollutants are relatively low at the outset. Thus only minor health impacts stem from reduction of pollutants other than NO_X. Benefits from less traffic seem to be considerable; NOK 7 billion (1986-prices), including NOK 1.3 billion worth of noise reductions. Hence, the impacts of less traffic contribute more to total benefits than improved air quality.

Box 6.2 MSGTAX

MSGTAX is a version of the macroeconomic planning model MSG-4 (Longva et al. 1985), used for long term planning purposes by, among others, the Ministry of Finance in Norway. Like the model MSG-4, MSGTAX is a general equilibrium model covering 31 production sectors. There are substitution possibilities between the input factors real capital, labour, energy and materials in the production sectors. Energy is an aggregate comprised of electricity and oil products. Relative prices determine the composition of the energy aggregate.

Economic development is mainly determined by expected exogenous growth in the labour force, growth in stock of real capital and sectoral (Hicks neutral) technological changes. Private consumption is determined by requiring full utilization of labour and real capital. Price and expenditure elasticities determine the composition of private consumption. 18 consumption activities are specified. Fossil fuels are part of the consumption activities heating and transportation. In contrast to the MSG-4 model, sectoral export and import shares are determined by differences between home market and world market prices. Accumulation of real capital and external debt are exogenously determined in the model. For further details, see Holmøy and Vennemo (1989).

The reference scenario in the present analysis describes a possible development path of the Norwegian economy without an environmentally motivated tax on fossil fuels. The scenario is characterized by a relatively modest growth in the production level, but a rather high growth in private consumption, in particular the consumption of gasoline and fuel oils.

It must be remembered that estimates of marginal costs are very uncertain. Some effort has been made, however, to study how the uncertainty of input data influences the estimate of total benefits. The probability distribution of total benefits has been simulated on the basis of distributions of single cost elements. The variances of these single cost elements are sometimes large, but estimated benefits are always in the range of NOK 10-15 billion (1986-prices).

6.6. Stabilizing the emissions of CO_2

Restricting the emissions of carbon dioxide (CO_2) to the atmosphere will be an important part of the efforts to reduce global warming. Use of fossil fuels is the main source of CO_2 emissions. On a global scale use of fossil fuels (coal, oil and gas) covers approximately 80 per cent of the total demand for energy. CO_2 emissions from fossil fuels were responsible for almost half of the man-made greenhouse effect in the 1980s.

The World Commission on Environment and Development (the Brundtland Commission) recommended a 50 per cent reduction in the use of energy in the industrialized countries over the next 50 years. Norwegian authorities has proclaimed as a national aim a stabilization of the CO_2 emissions in the 1990s and a gradual levelling out at the 1989 level before year 2000. No international agreements on emission restrictions have been signed, but a stabilization of the emission levels by year 2000 and a further 20 per cent reduction before the year 2005 have been proposed for discussion in international fora.

Since emissions of CO_2 are not at present amendable to cleaning in any economic way, emission reductions imply a reduction in the use of fossil fuels. The costs of reducing CO_2 emissions are therefore not due to a need for investment, but rather to a reduction in economic growth as a consequence of restrictions on the use of fuels. Difficulties in reaching international agreements may indicate that many countries regard this cost as significant.

The Central Bureau of Statistics has analyzed how restrictions in CO_2 emissions may affect the growth potential of the Norwegian economy. By introducing an appropriate tax on CO_2 emissions, the emission level is stabilized after year 2000, and this emission ceiling is supposed to apply throughout the time horizon of the study; to the year 2010.

Very little coal or gas is consumed in Norway. Thus, only the use of oil products (fuel oil and oil for transportation purposes) are restricted in this analysis. All categories of oil have approximately the same carbon content. Thus, the CO_2 tax is assumed equal for both fuel oils, gasoline and diesel oils. The tax rate is determined by use of the MSGTAX model, see box 6.2.

Table 6.16. Economic development in the baseline scenario. Billion 1986-NOK

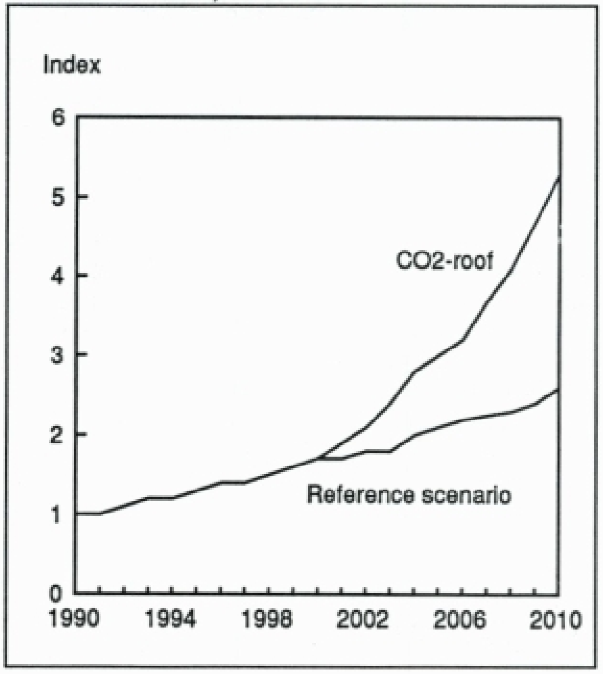
	Level 1990	Yearly increase 1990-2010 Per cent
GDP	586	2.6
Imports	197	3.5
Exports	295	3.6
Private consumption	163	3.8
Public consumption	112	1.6
Investments	211	2.7

Source: CBS.

The baseline scenario of the analysis is very similar to an economic scenario described in NOU 1988:21; Norsk økonomi i forandring (Norwegian Official Report 1988:21; The Norwegian economy in transition). The scenario describes a development with higher average growth in the consumption of oil products than in GDP. Although perhaps not the most likely development path, the scenario is a useful basis for a sensitivity analysis of changing oil prices. Table 6.16 gives the main indicators of economic growth as observed in the baseline scenario.

Oil consumption in the baseline scenario is about 30 per cent above the present level in the year 2000. Figure 6.11 illustrates how the oil price must rise in the years beyond 2000 in order to stabilize the consumption level. The gap between the oil price path with restrictions on CO_2 emissions and in the baseline scenario represents the additional tax needed. Although technological changes reduce the need for input factors over time, also the use of oil, per unit produced, the economic growth generates a demand for oil that more than compensates the increase in energy efficiency. Thus, an increasing tax rate is necessary in order to stabilize the demand for oil. To achieve this, the oil price must be doubled relative to the price in the baseline scenario in year 2010.

Figure 6.11. Price of oil products in the baseline scenario and under restrictions on CO_2 emissions. Index, 1990 = 1



Source: CBS.

Introduction of a ceiling on CO_2 emissions reduces the economic growth, but not drastically. According to the model calculations, GDP is reduced by 2.7 per cent relative to the baseline scenario in the year 2010, but is nevertheless 80 per cent above the 1988 level. The modesty of the reduction is due to the fact that fossil fuels represent only a small part of the total cost of production (approximately 5 per cent) and that the use of oil can be partly substituted by electricity or other input factors like capital, labour or materials. In this long term study, the increase in taxation of oil products is assumed to be compensated by a decrease in other taxes in such a manner as to assure full utilization of available real capital and labour. In a shorter term perspective however, the introduction of a CO_2-based oil tax may reduce the economic activity level and thus increase the unemployment rate. In an earlier study on industrial development, energy use and environmental development, referred to by the acronym SIMEN, it was shown that even in a short term perspective economic activity is not much influenced by an increase in oil taxes as long as it is compensated by a reduction in income tax (SIMEN, 1989).

Table 6.17 gives the estimated changes in price of oil products and the use of oil due to the tax on oil.

Table 6.17. Price of oil products and use of gasoline and fuel oil. Deviation from the baseline scenario. Per cent. Year 2010

	Price of oil products	Consumption	
		Gasoline[1]	Heating oil[1]
Production sectors	107	-35	-30
Households			
Heating	130	.	-54
Private transp.	116	-36	.

1) Measured in tons.
Source: CBS.

Although the effect of a ceiling on CO_2 emissions on total production is small, the sectoral structure of production changes significantly. Thus, as a consequence of price increases and reduced market shares, some of the exporting sectors must reduce their level of activity. This is particularly true for the production of pulp and paper and production of industrial chemicals.

The composition of private consumption is also strongly affected by the oil tax. Use of fuel oil for heating purposes is reduced by 54 per cent in year 2010, while use of private transportation (gasoline and maintenance) is reduced by a third relative to the baseline scenario. The CO_2 tax on gasoline also reduces the demand for new cars by approximately one fourth. Total private consumption in the year 2010 is reduced, however, by only 1 per cent under the CO_2 ceiling. The notable reduction in oil related private consumption allows an increase in the consumption of other commodities. The largest increases are found in the consumption of electricity (hydropower) and housing.

The reduction in the use of oil products implies additional environmental gains over and above those associated with the greenhouse effect. Control policies aimed at reducing other pollution components which damage human health, materials and nature, should be considered in conjunction with abatement strategies directed at CO_2 emissions. Table 6.18 gives the impact of the CO_2 tax on some other important pollution compounds.

Table 6.18. Emissions to air under a CO_2 ceiling. Deviation from the baseline scenario. Per cent. Year 2010

Sulphur dioxide (SO_2)	-25
Nitrogen oxides (NO_x)	-23
Carbon monoxide (CO)	-28
Particulates	-20
Carbon dioxide (CO_2)	-26

Source: CBS.

Estimates have been made of the benefits from reductions in emissions to air following a CO_2 tax. The estimates are primarily based on information from SFT's studies of the impacts of control policies in the Oslo and Fredrikstad/Sarpsborg regions. In addition to environmental benefits, benefits from an expected reduction in traffic accidents, reduced road damage and efficiency gains due to less traffic congestions, have also been included, cf. section 6.5. Table 6.19 gives an indication of the magnitude of the benefits accruing from an introduction of a ceiling on CO_2 emissions to air.

Table 6.19. Yearly benefits from a CO_2 stabilization. Year 2010. Billion 1986-NOK

Type of damage	Cost reduction	
Total		19.1
Acidification of forests and lakes		0.1
Health damage		7.6
NO_x	6.7	
SO_2	0.5	
CO	0.0	
Particulates	0.4	
Corrosion		0.2
Traffic accidents		2.7
Traffic congestion		2.9
Wear and tear of roads		3.6
Traffic noise		2.1

Source: CBS.

6.7. Forecasts of emissions to air in ECE-countries

Air pollution is an international problem, both from the point of view of the global consequences of emissions of greenhouse gases like CO_2, and of the regional damage inflicted by acid depositions caused by emissions of SO_2 and NO_X. For these and other reasons it is of interest to try to analyze the possible future trends in emissions to air in regions larger than single countries. This section presents forecasts of emissions of SO_2, NO_X and CO_2 in four ECE-regions in the year 2000.

Economic and technological development, the demand for energy and the extent of abatement policies are important factors in determining future emissions. However, in addition to handling these elements within a consistent framework, as in the case of national forecasts of emissions to air, international forecasts must also take into account and describe international trade in a consistent and integrated manner. In national studies the requirement for consistency in the treatment of the various sectors and factors is usually met by employing general economic models which include important national accounting identities as the core of the analysis. At the international level, some models also exist which allow consistent treatment of economic development, energy use and emissions to air. Thus, the forecasts presented below are based on model calculations performed by the UN Economic Commission for Europe (ECE) and the Central Bureau of Statistics of Norway. A detailed description of the methodology and assumptions used in producing the economic forecast employed in all energy and emission scenarios is found in *Overall Economic Perspectives to the Year 2000 (OEP)* (ECE, 1988).

The emission forecasts cover emissions of sulphur dioxide, nitrogen oxides and carbon dioxide in ECE member countries, which, in addition to Western and Eastern Europe, also includes USA and Canada. Four regions are recognized in the forecasts; North America, Western Europe, Eastern Europe and the European part of USSR. Occasionally, the centrally planned economies (Eastern Europe plus the European part of USSR) are considered as one region.

The scenarios presented are not to be interpreted as best guesses on the most likely development in the years ahead. They rather give an illustration of a useful methodology for closer integration of economic, energy and environment issues, with special emphasis on employing internally consistent assumptions on development in key variables like world market prices and international trade. The scenarios thus provide only rather crude pictures of possible development paths, rather than opinions about what, in fact, is likely to happen in the next decade. The large uncertainty present in exercises like these also points to a need for caution in interpreting the results.

Economic development

Table 6.20 gives some indicators of economic growth rates and the composition of this growth in the various ECE-regions as observed historically and projected to year 2000. All energy and emission scenarios presented later are based on the economic scenario outlined in the table. Basically, the path represents a continuation of the historically observed trend over the period 1973-1985. However, it is not a replication. For instance, the trade imbalance experienced by the USA was considered to be unsustainable. For this reason domestic demand was adjusted downward in relation to the historical trend. The rate of inflation was also assumed to be close to the rate observed in the middle of the 1980s, i.e. well below the average rate for the period 1973-1985. Growth in productivity is assumed to be relatively low in North America and somewhat higher in Western Europe. However, the unemployment problems experienced in Western Europe are not expected to be solved within the time horizon of the study.

In the centrally planned economies, productivity growth rates in line with the historically observed values are assumed also for the next decade. These represent quite ambitious targets, not at least in view of the huge transition problems most of the countries face today. On the other hand, successful transitions to more efficient economies within a reasonably short time are probably prerequisites for reaching these targets.

Energy paths

The baseline scenario presented in the OEP describes total energy use by region and fuel type. Table 6.21 reports the actual use in 1985 and the calculated growth rate in total demand over the period 1985-2000 for solid, liquid and gaseous fossil fuels.

While the market economies (North America and Western Europe) in the baseline scenario are expected to have a relatively high growth in demand for solid fuels, the centrally planned economies are presumed to depend more on gaseous fuels to supply their energy needs. The centrally planned economies show relatively low growth in use of fossil fuels, both compared with other regions and compared with the envisaged economic growth within the region. This is due to the relatively high growth in energy efficiency assumed for this region.

Table 6.20. Economic indicators for the ECE-regions. Average yearly growth rates. Per cent

	1965-1973	1974-1980	1981-1985	1986-1990	1991-2000
Western Europe					
GDP (real prices)	4.3	2.6	1.3	2.4	2.5
Private consumption	4.9	2.5	0.8	3.1	2.6
Public consumption	3.8	3.0	0.4	2.1	2.3
Investments	5.0	0.4	1.5	2.8	2.8
North America					
GDP (real prices)	3.8	2.3	2.4	2.5	2.6
Private consumption	4.2	2.8	3.2	1.8	2.6
Public consumption	2.9	2.3	1.8	0.8	1.8
Investments	3.8	0.7	6.0	2.3	2.7
Centrally planned economies					
NMP[1] produced	7.1	4.6	3.1	3.9	4.0
NMP consumed	6.3	6.0	3.1	4.1	4.1
NMP accumulated	9.3	0.6	3.0	3.3	3.5

1) NMP = Net Material Product.

Sources: OEP/EEC.

Table 6.21. Fossil fuel use in the baseline scenario

	Consumption 1985			Yearly growth rate 1985-2000		
	Solid	Liquid	Gas	Solid	Liquid	Gas
	Mtoe			Per cent		
Western Europe	308	562	200	2.8	1.2	1.3
Eastern Europe	252	92	73	0.1	0.1	2.3
Soviet Union	366	437	472	0.5	1.8	3.4
North America	526	785	472	3.0	0.1	2.1

Sources: ECE Energy Balances for Europe and North America 1970-2000. UN 1989. ECE's Overall Economic Perspectives to the Year 2000. UN/ECE, 1988.

Alternative energy paths

Other energy paths than the one termed baseline scenario in the OEP can be envisaged as consistent with the conjectured economic growth path. In order to illustrate the impact of the intrinsic uncertainty in the energy forecasts on emission scenarios, two alternative energy paths were explored. These alternative paths are based on very rough assumptions.

Thus, in the alternative labelled *1a*, it is assumed that 1 per cent growth in production in a sector implies a growth equal to 0.5 per cent in the sector's demand for fossil fuels in all regions except North America, where the associated percentage growth in use of fossil fuels was assumed to be 0.7 per cent. In the alternative labelled *1b* the corresponding ratios (energy elasticities) were assumed to be 1.0 and 1.1 respectively. In a certain sense, these alternatives can be said to represent a low and a high energy path. Table 6.22 shows how the various assumptions affect the growth rates of the total demand for fossil fuels.

Table 6.22. Demand for fossil fuels. Yearly growth rate 1985-2000. Per cent

	Baseline scenario	Alternative 1a	Alternative 1b
Western Europe .	1.7	1.4	2.7
Eastern Europe . .	0.6	2.1	4.2
Soviet Union . . .	2.1	2.1	4.1
North America . .	2.4	1.9	3.0

Source: CBS.

Growth in the demand for fossil fuels in Eastern Europe in alternative 1a are far above the growth rates implicitly assumed for this region in the baseline scenario. This is again an illustration of the extremely high growth in energy efficiency assumed for this region in the baseline scenario. The alternatives 1a and 1b can be said to represent more conventional assumptions on gains in energy efficiency.

Emissions to air

Given the various energy paths, emissions to air can be calculated by employing a suitable set of emission coefficients. The emission coefficients reflect partly the chemical composition of the fuels, partly the conditions under which the combustion takes place, and finally, partly the cleaning measures introduced.

Information used for estimating emission coefficients is taken from various sources. For sulphur dioxide, extensive use has been made of the RAINS model developed by the International Institute for Applied System Analysis (IIASA) in Laxenburg in Austria. The data base for this model includes information on European emissions of sulphur dioxide to air in 1985 and expected control measures to reduce these emissions towards year 2000. Emission coefficients for North America are assumed to be close to those used for Western Europe. Emission coefficients for NO_X are based on detailed studies of NO_X emissions in Western and Eastern Europe carried out by the Norwegian Institute for Air Research (NILU). CO_2-coefficients are based on simple assumptions on carbon content of the various fuel types and carbon retention in combustion processes in the various regions. All in all, there is a large degree of uncertainty connected to all emission coefficients.

Emissions associated with the baseline scenario and the two alternative energy paths *1a* and *1b* are based on the coefficients estimated for the year 1985. Thus, it is assumed that no cleaning measures over and above those implemented in 1985 are carried out within the time horizon of the study.

In addition to the emission scenarios based on the baseline scenario and the alternative energy paths, two alternative emission scenarios are developed; *alternative 2 and alternative 3*. Both these alternatives are based on the same economic development and the same energy path as described in the baseline scenario. Thus, only the emission coefficients are different. Since CO_2 emissions are not amendable to cleaning economically, the emission coefficients of this component were kept unchanged in the alternative emission scenarios.

In *alternative 2*, it is assumed that planned measures against emissions of SO_2, as reported by RAINS, are carried out. Regulation of NO_X emissions in Western Europe and North America are assumed to conform with today's most stringent standards; i.e. California standards for emissions from mobile sources and West German standards for emissions from stationary sources. Emission coefficients applying to the centrally planned economies are not changed from their base year value in this alternative.

In *alternative 3*, maximum feasible cleaning of SO_2, as defined in RAINS, is assumed in all regions. Furthermore, the stringent standards assumed to apply for NO_X emissions within the western market economies in alternative 2 are extended to all regions in alternative 3.

Table 6.23 gives the yearly average growth rate of emissions in the different regions as calculated on the basis of the assumptions underlying the different alternatives. The results are also illustrated in figure 6.12. Tables 6.24 and 6.25 show how the growth in emissions is distributed among fossil fuels and economic sectors.

Table 6.23. Average yearly growth in emissions. 1985-2000. Per cent

	Baseline	Alternatives			
		1a	1b	2	3
Emissions of SO_2					
ECE	1.5	1.7	3.3	-0.3	-9.2
Western Europe	1.9	1.3	2.6	0.6	-9.5
Eastern Europe	0.1	2.1	4.2	-0.8	-9.3
Soviet Union	1.3	2.1	4.2	-1.1	-8.9
North America	2.3	1.5	2.4	-0.1	-9.1
Emissions of NO_x					
ECE	2.0	1.9	3.6	-1.7	-3.9
Western Europe	1.7	1.5	3.0	-3.2	-3.2
Eastern Europe	0.3	2.1	4.3	0.3	-6.1
Soviet Union	1.8	2.2	4.3	1.8	-3.4
North America	2.6	2.1	3.3	-4.4	-4.4
Emissions of CO_2					
ECE	1.9	1.8	3.4	1.9	1.9
Western Europe	1.8	1.4	2.7	1.8	1.8
Eastern Europe	0.4	2.1	4.2	0.4	0.4
Soviet Union	1.8	2.1	4.1	1.8	1.8
North America	2.4	1.9	3.0	2.4	2.4

Source: CBS.

Although forecasts of this kind are highly uncertain and, moreover, several decisive factors are only treated in a rudimentary fashion, the results represent information which may be useful in the further discussion of the state of the environment within the ECE region:

i) *SO_2:* Without further measures to control and abate emissions, and with an economic development not too removed from the one sketched in the baseline scenario, the expected average yearly growth in SO_2 emissions are between 0.1 per cent (Eastern Europe) and 2.3 per cent (North America) over the period 1985-2000. Power production is the dominant source of emissions in all regions, the greater part from the combustion of solid fuels. In Western Europe, power production is also the source with the highest growth rate. In North America other industries dominate the growth in emissions, while transport-related emissions of SO_2 show the highest growth rate in the centrally planned economies.

NO_X and CO_2: Average yearly growth in emissions of NO_X and CO_2 varies between 0.3 per cent (Eastern Europe) and 2.6 per cent (North America). Transportation and power production is responsible for the largest shares of emissions. Use of solid fuels are responsible for the highest growth rates of emissions in Western Europe and North America, while the strong growth in the use of gaseous fuels in Eastern Europe and USSR implies that the emissions from this type of fuel are responsible for the highest growth rates in these regions.

ii) *Moderate cleaning (alternative 2):* By carrying out planned abatement measures against SO_2 and introducing vigorous regulations of NO_X emissions in North America and Western Europe, these emissions can be stabilized at the 1985 level and reduced by

Table 6.24. Emissions by region and type of fuel in the baseline scenario

	Emissions 1985			Growth rate 1985-2000		
	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2
	Million tons			Per cent		
Western Europe						
Total	20.7	14.0	3 872	1.8	1.7	1.8
Solid fuel	9.2	3.1	1 387	2.7	2.7	2.8
Liquid fuel	9.1	10.0	2 025	1.0	1.3	1.2
Process/gas[1]	2.4	0.8	461	1.0	1.3	1.3
Eastern Europe						
Total	17.5	4.0	1 633	0.1	0.3	0.4
Solid fuel	13.8	2.7	1 135	0.1	0.1	0.1
Liquid fuel	3.7	1.0	331	0.1	0.2	0.1
Process/gas[1]	..	0.3	167	..	2.3	2.3
Soviet Union						
Total	18.0	12.0	4 305	1.3	1.8	1.8
Solid fuel	7.6	4.1	1 648	0.5	0.5	0.5
Liquid fuel	10.4	5.8	1 572	1.8	1.9	1.8
Process/gas[1]	..	2.1	1 085	..	3.4	3.4
North America						
Total	26.7	19.5	6 280	2.3	2.6	2.4
Solid fuel	15.0	8.2	2 369	2.8	2.9	3.0
Liquid fuel	6.3	9.8	2 825	1.3	2.4	2.1
Process/gas[1]	5.5	1.5	1 086	1.8	2.3	2.1

1) Process emissions of SO_2. Emissions of NO_x and CO_2 from the combustion of gaseous fuels.

Source: CBS.

approximately 10 per cent by the year 2000 for the ECE region as a whole. CO_2 emissions are not influenced by the control measures in this alternative.

iii) *Strong regulations (alternative 3):* By introducing maximum feasible cleaning of SO_2 emissions, these emissions can be reduced by approximately 80 per cent before the turn of the century. Strict abatement of NO_x emissions can almost halve these emissions in relation to the emission level in the base year (1985).

iv) *Alternative energy paths (alternative 1a and 1b):* With a growth in energy efficiency in line with the assumptions in the baseline scenario, emission levels in the ECE region may grow fast. Alternatives 1a and 1b illustrate clearly that any ambition of reducing emissions in the future requires at least a continued growth in energy efficiency along the trend observed from 1973 to 1985, or even an acceleration in development.

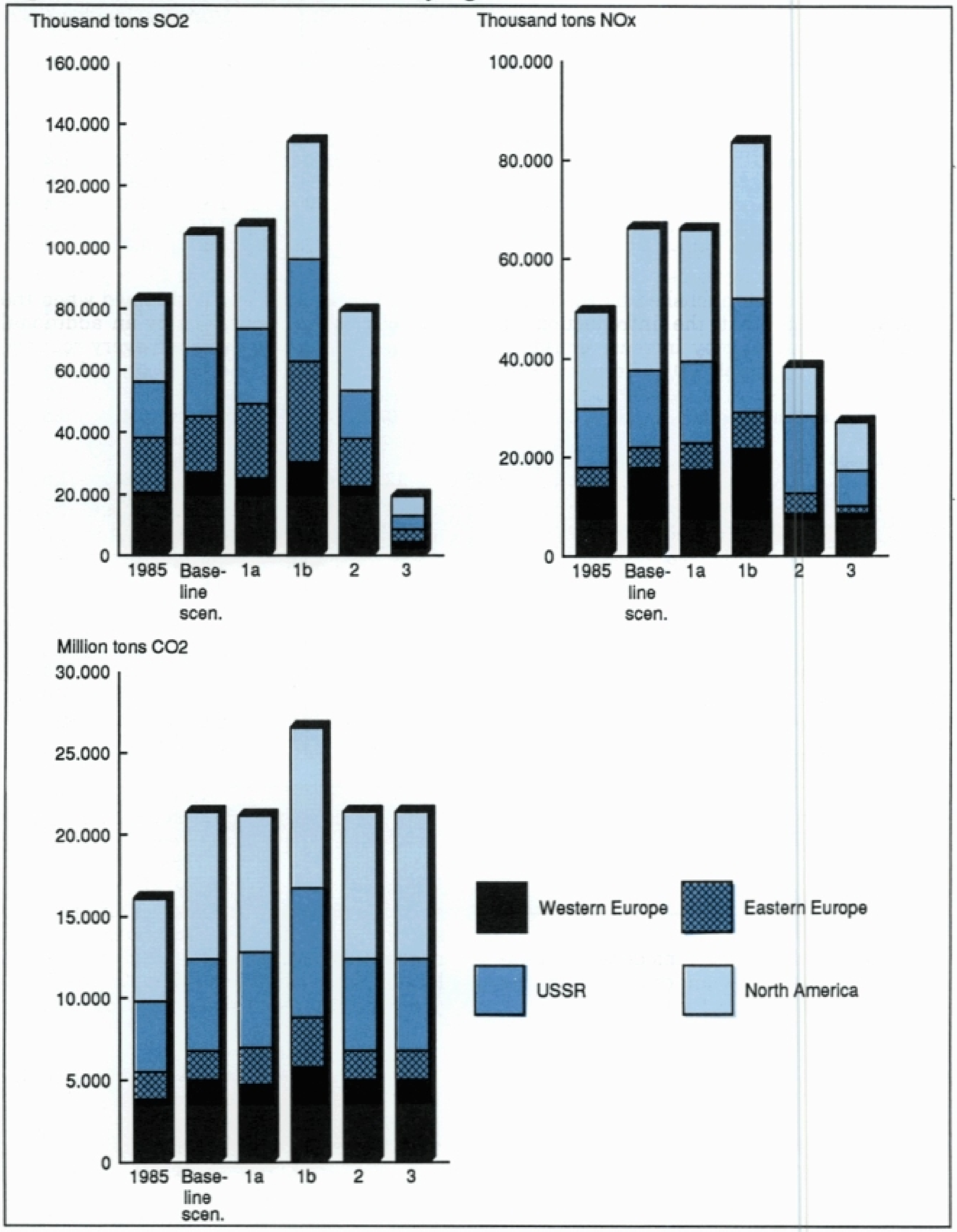
As a whole the calculations indicate that, given a growth in energy efficiency along the historically observed lines, and a relatively moderate effort to combat emissions, SO_2 emissions can be significantly reduced, while more moderate reductions can be achieved in NO_x emissions. CO_2 emissions are projected to continue growing. More ambitious aims for reduction of NO_x emissions by, say, 50 per cent, appear to be difficult to achieve.

Table 6.25. Emissions by region and economic sector in the baseline scenario

	Emissions 1985			Growth rate 1985-2000		
	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2
	Million tons			Per cent		
Western Europe						
Total	20.7	14.0	3872	1.8	1.7	1.8
Power production	9.2	2.6	1004	2.3	2.4	2.4
Industry	4.6	1.9	728	1.5	2.0	1.9
Transport	0.6	8.4	790	1.4	1.4	1.4
Others	2.4	..	472	1.0	..	1.4
Households, agriculture etc.	2.1	1.0	878	1.6	1.3	1.4
Eastern Europe						
Total	17.5	4.0	1633	0.1	0.3	0.4
Power production	11.3	2.2	810	0.1	0.3	0.3
Industry	2.1	0.7	249	0.1	0.6	0.7
Transport	0.1	0.7	69	0.3	0.3	0.3
Others	1.3	..	156	0.1	..	0.7
Households, agriculture etc.	2.7	0.4	349	0.0	0.4	0.3
Soviet Union						
Total	18.0	12.0	4305	1.3	1.8	1.8
Power production	10.5	5.5	2068	1.3	1.6	1.8
Industry	3.0	1.6	785	0.8	1.6	1.7
Transport	1.5	4.1	396	2.0	2.0	2.0
Others	1.6	..	400	1.8	..	2.0
Households, agriculture etc.	1.4	0.8	656	0.6	1.6	1.2
North America						
Total	26.7	19.5	6280	2.3	2.6	2.4
Power production	15.4	7.2	1954	2.4	2.6	2.5
Industry	2.7	2.5	1067	3.1	3.2	2.3
Transport	0.9	8.8	1737	2.5	2.5	3.1
Others	6.4	..	642	1.7	..	1.5
Households, agriculture etc.	1.3	1.0	881	1.4	2.0	1.9

Source: CBS.

Figure 6.12. Emissions in 1985 and 2000 by region



Finally, two important issues should be mentioned which may strongly influence the realism of the above calculations, but which have not been discussed so far. One of these issues concerns the planned introduction of an internal market within the European community in 1992. A higher rate of economic growth, together with more centrally located production and associated increase in demand for transportation, may lead to enhanced levels of emission. On the other hand, the internal market also opens up for rationalization of an initially very inefficient use of transportation capital. Studies published by the Commission indicate that the introduction of the internal market may increase emission levels by approximately 10 per cent in year 2010 compared with a hypothetical situation without the extended internal market.

The second issue has to do with the remarkable changes which have been observed and are being observed today within the (formerly) centrally planned economies. It is far too early to predict what impact these changes will have on economic growth, energy use and emissions to air. But, already now it seems clear that the widespread neglect of the environment that has taken place in these regions for decades will no longer be tolerated. Although the means of correcting past negligence are not very many in the next few years, the willpower is certainly present.

6.8. Acid rain: Nordic cleaning efforts in Eastern Europe?

Acid rain yearly inflicts considerable damage on the Scandinavian countries in the form of fish death, forest damage and general acidification of the environment. Emissions to air of sulphur dioxide (SO_2) and nitrogen oxides (NO_X) on the Continent and in Great Britain are transported over long distances. Deposition is largely governed by meteorological conditions. Prevailing wind direction and climatic conditions cause southern Scandinavia to receive large amounts of acid rain and dry deposited sulphur. The damage is amplified by the fact that the natural environment in general is quite vulnerable to acidification in these regions.

In 1985 an international protocol on reducing SO_2 emissions by 30 per cent over the period 1980-1993 was signed by 21 European countries, among them Norway. In addition, the Nordic countries have all declared more stringent (percentage) aims for reduction of sulphur emissions. Since the cost of cleaning differs greatly from country to country, the same total reduction in emissions could be achieved more cheaply if countries with lower cleaning costs reduced their emissions more than countries where the cleaning is expensive. The minimal total expenditure for a given total reduction in emissions is obtained when the cost of reducing emissions by an additional unit is the same in each and every country.

But not only the emitted amounts of SO_2 and NO_X are of interest in this connection. It also matters where the emissions take place, since this determines where the depositions will take place, and the vulnerability of the natural environment varies from region to region. Emission reductions should be judged in the light of the damage the emissions and depositions inflict on the different countries. Ideally the various countries' willingness to pay for reduction of the damage caused by the emission of SO_2 and NO_X should also be taken into account. This depends, among other things, on the level of income and perception of damage to the environment.

So far, international negotiations have not taken these factors into account, but have instead settled for an equal percentage reduction in emissions. The reasons can be sought in the complexity of international negotiations, and a lack of tradition in seeking cost-effective outcomes of such negotiations. In addition, there is also the lack of knowledge regarding to the interplay between emissions, cost of cleaning and damage.

However, during the last year, the Nordic countries have undertaken to provide economic support for abatement activities in some Eastern European countries. This reflects that damage inflicted in the Nordic countries by acid rain is to a large degree due to East European emissions, their lack of resources for cleaning of these emissions and the fact that reductions in damage measured per invested krone is larger in these countries than in the Nordic countries themselves.

The efforts to understand the connections between emission, deposition and damage have made good progress since the SO_2 treaty was signed. The International Institute for Applied System Analysis (IIASA) in Austria has developed a model for analyzing cost-effective emission reductions in the European countries (Alcamo et al. 1987). The model RAINS (Regional Acidification Information and Simulation Model) calculates emission scenarios on the basis of future energy paths and assumptions on the use of cleaning technologies. The cost of cleaning is specified for each country. The sub-model for calculating the transportation and deposition of pollution among European countries is based on meteorological data and has been developed by the Norwegian Meteorological Institute in Oslo for EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe) (Iversen et al. 1989). The RAINS model also contains modules describing the effects of depositing acid components on soil, watercourses and forests. An example of the use of RAINS for analyzing the effects of transferring resources for SO_2 cleaning from the Nordic countries to Eastern Europe is presented below.

Nordic cleaning is cheaper in Eastern Europe

The Nordic countries have already reduced their SO_2 emissions considerably. Table 6.26 gives the percentage reductions relative to the level in 1980. The costs of further reducing these emissions are now far higher than reducing the emissions in the surrounding countries that cause acid rain in the Nordic countries. SFT has estimated the cost of reducing SO_2 emissions in Norwegian industry to be approximately NOK 20 000 per ton. In Poland the cleaning potential is 700 000 tons SO_2 to the cost of NOK 2 000 per ton. In GDR the marginal cleaning cost is approximately NOK 2 700 when the emission level has been reduced by 30 per cent relative to the 1980 level.

Finland and Norway have already attained their national aims of a 50 per cent reduction in emissions in relation to the 1980 level. Denmark has the same national aim, but has still some cleaning to do before the goal is reached. Sweden has the most ambitious aim; a 65 per cent reduction in relation to the 1980 level, but has so far only reached 38 per cent. For all countries it is a constant challenge to keep the emission levels down in face of economic growth.

Table 6.26. Reductions in the emissions of SO_2[1]. Per cent

	Reduction 1980-1989	National aim 1993/ 1995
Norway	50	50
Denmark	40	50
Sweden	40	65
Finland	50	50

1) Preliminary estimates.

Sources: CBS, SFT.

Partly as a response to the above, a common Nordic plan of action against air pollution is being prepared. As part of this preparation further reductions in SO_2 emissions are contemplated. The reason is the recognition that in order to keep below the critical level for damage to nature from acid deposition, emissions should be reduced by 70-80 per cent in relation to the 1980 level. However, the cost of achieving this in the Nordic countries is considerable. Reducing emissions in Eastern Europe is far cheaper and will reduce the damages from acid depositions in the Nordic as well as in the Eastern European countries. The State Pollution Control Authority and the Central Bureau of Statistics of Norway have carried out a study, based on the RAINS model, of the potential gains from transferring abatement resources from the Nordic countries to Poland and GDR. Two alternatives were compared:

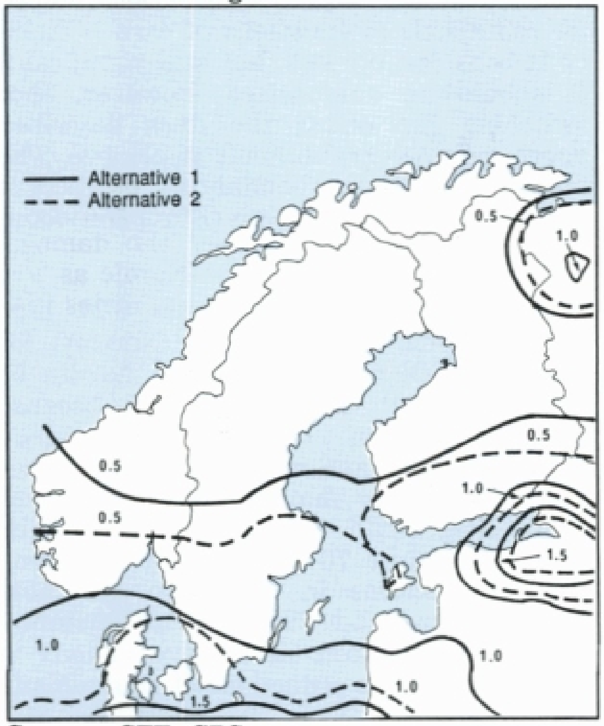
Alternative 1: All the Nordic countries reduce their SO_2 emissions to 70 per cent below their 1980 level.

Alternative 2: No further cleaning in the Nordic countries, but an amount of money equal to the cost of carrying out alternative 1 is transferred to Poland and GDR.

In both alternatives it is assumed that the planned measures to combat emissions have been carried out. This implies that GDR is expected to reduce its SO_2 emissions by 30 per cent in relation to the 1980 level by 1993, using its own resources. Poland, which has not signed the SO_2 protocol, is not expected to reduce emissions without transfers of funds from the Nordic countries.

It is estimated that reducing Nordic emissions by 70 per cent in relation to the 1980 level will require approximately NOK 7 billion. Alternative 2 implies that this amount of money is spent instead on reducing emissions in Poland and GDR, divided between these countries in such a manner as to ensure maximal reduction in depositions in the Nordic countries. Taking into account the differences in cleaning costs in the different regions involved, and that emissions in Poland and GDR contribute to different degrees to deposition in the Nordic countries, estimates of deposition patterns under the two alternatives were computed by the RAINS model.

Figure 6.13. Deposition of sulphur in the Nordic countries. g/m²



Sources: SFT, CBS.

Figure 6.13 is a map of the Nordic regions with isolines illustrating the amount of depositions. Unbroken lines show the estimated deposition pattern under alternative 1, i.e. when the Nordic countries finance and implement the control policy within their own borders. The broken lines illustrate the situation if alternative 2 is applied. The calculations indicate that deposition levels in Southern Scandinavia and Finland are reduced from a level between 0.5 and 1.0 g/m² to below a maximum of 0.5 g/m², which is reckoned to be approximately the critical level for the ecosystems in these areas.

Analyses like these are of course fraught with uncertainties, but may still indicate what a cost-effective ranking of control measures looks like when a region is considered as a whole instead of as separate parts. Thus, damage from acid rain may be reduced considerably if, instead of considering a Nordic plan for reductions of SO_2, one were to consider a North European plan for reduction of emissions, with the same amount of financial resources behind it.

As a consequence of Nordic investments in cleaning equipment, emissions in GDR and Poland are reduced by 40 and 20 per cent respectively below todays level. Significant reductions in local damage from SO_2 pollution can thus be expected in these countries, both of which at present suffer considerable damage to health and capital equipment from pollution. On the other hand, the emission levels in the Nordic countries will not be reduced in alternative 2. This implies that local damage to health and materials, which stems mainly from local emission sources, will not be reduced in this alternative. This damage is quite small, however, at least in Norway. Thus this negative aspect of cleaning emissions of SO_2 in Poland and GDR instead of cleaning local sources does not carry much weight.

6.9. Environmental effects of a transition from the use of coal and oil to natural gas in Europe

Natural gas can be considered as a "clean" fuel compared with other fossil fuels like oil and coal:

- The sulphur content of natural gas is very small, while the amount of sulphur in coal and oil varies, depending on quality. Light oil products generally contain less sulphur than heavier products. Coal usually contains large amounts of sulphur. Thus, a transition from the use of coal and oil to the use of natural gas will significantly reduce emissions of sulphur.

- The amount of carbon dioxide (CO_2) emitted per unit energy obtained from combustion depends on the carbon content of the fuel, the energy content of the fuel and the efficiency of the combustion process. Generally, the carbon content is somewhat lower, and the heating value and the efficiency of combustion somewhat higher, for natural gas than for oil and coal. Therefore, a transition from consumption of oil and coal to consumption of natural gas will also lower CO_2 emissions somewhat.

Emissions of sulphur and carbon dioxide are among the most important international air pollution problems today. Sulphur emissions lead to acid rain, while carbon dioxide dominates among the so-called greenhouse gases.

The level and composition of energy consumption depends on a number of factors, such as the demand for energy, technological possibilities of efficient transformation and, not least, the relative prices of the different energy goods. The Central Bureau of Statistics of Norway has already published estimates of potential reductions of emissions connected to a switch from the use of oil and coal to the use of natural gas in Europe (Alfsen et al. 1989). The estimates are based on, inter alia, the assumption that the transition is carried out in such a manner that the utilized energy delivered to each separate economic sector is kept constant. Two different alternatives were considered. In *alternative 1* only power production was assumed to switch fuel. In *alternative 2* such a switch was assumed to take place in all sectors except the transportation sector. Table 6.27 presents some of the most important results.

Table 6.27. Percentage reduction in emissions of SO_2 and CO_2 and deposition of sulphur in Europe given a transition from the use of oil and coal to the use of natural gas

	Alternative 1	Alternative 2
Emissions of SO_2 in Europe	55	92
Deposition of sulphur in Europe	48	80
Emissions of CO_2 from combustion of fossil fuels in OECD Europe	15	28

Source: CBS.

The results illustrate that there is a large potential for reduction of emission and deposition of sulphur if natural gas is substituted for oil and coal. The potential for reductions of emissions of carbon dioxide is considerably less, but still significant. It should be emphasized, however, that switching fuel along the lines described above may be very difficult to achieve. The main reason is the dominating position of the coal industry in many European countries.

The figures reported in table 6.27 hide large regional differences. In Norway, for instance, SO_2 emissions would hardly be reduced at all in alternative 1, because power production in Norway is based on hydropower. Poland and GDR, on the other hand, with their mainly coal-based power production, could reduce their SO_2 emissions by almost 70 per cent by switching fuels. Reductions in deposition are more evenly distributed. Norway, for instance, will experience considerable reductions in deposition due to reductions of emissions in other countries.

More use of natural gas as fuel in Europe is of interest to Norway for several reasons:

- Norway has large reserves of natural gas.

- A European transition from the use of oil and coal to the use of natural gas will almost eliminate the serious damage Norway experiences from acid rain, due to deposition of transboundary sulphur emissions.

- Emissions of carbon dioxide from a large part of the industrialized world can be reduced.

However, it is important to recognize that even use of natural gas has negative environmental consequences. CO_2 emissions from combustion of natural gas are large, even though they are less than from the combustion of oil and coal. Production, distribution and use of natural gas causes emissions of methane (CH_4), a greenhouse gas. Finally, a transition to the use of natural gas will not by itself reduce emissions of nitrogen oxides (NO_X), an important pollutant, unless the emissions are cleaned.

The transportation sector has been excluded from the calculations. There are good reasons for this. For most other end users of fossil fuels, alternative and viable solutions already exists for using natural gas. For transportation purposes, however, there are at present no economic alternatives to the use of liquid or solid fuels. If one wants to economize on the use of fossil fuels, for instance for environmental reasons, it might be reasonable to reserve these fuels for transportation purposes.

6.10. The changing atmosphere

The Earth's atmosphere has always been changing. But never before in the history of man have the chemical characteristics of the change been as rapid as over the last century or so. This is naturally of concern, and the concern is particularly directed at gases that are present only in very low concentrations, but still are crucial for the chemical processes in the atmosphere.

This section discusses briefly how changes in the chemical composition of the atmosphere may influence the global climate. it deals in particular with relations between the atmospheric chemistry of certain gases and the greenhouse effect. The consequences of increased greenhouse effect, like a rise in temperature, rise of sea level, etc., are not discussed.

The atmosphere acts as an oxidizing medium in the global cycling of important substances like carbon, nitrogen and sulphur. When released into the atmosphere, these substances are usually in a reduced state (CH_4, non-methane hydrocarbons, H_2S, NO). In the atmosphere they are oxidized either to nonreactive long-lived species, or to acidic species that are removed by wet and dry deposition. Thus, the oxidizing capacity of the atmosphere is an important characteristic that determines the self-cleansing capacity of the atmosphere.

Along with the growing world population, human (anthropogenic) emissions of reduced or not fully oxidized compounds have increased, and are for certain gases larger than the naturally occurring emissions. This has increased the strain on the oxidizing capacity of the atmosphere. If the self-cleansing capacity of the atmosphere is decreased, compounds can accumulate, and this can in turn affect the chemical, physical and climatic characteristics of the atmosphere.

Table 6.28 shows the increase in concentration levels of some important greenhouse gases. Some of the gases are naturally present in the atmosphere, but anthropogenic emissions have increased the growth rates of their concentration levels. Other compounds, like chlorofluorocarbons (CFCs) are artificial, and were not present in the atmosphere before anthropogenic emissions commenced.

Increasing concentrations of ozone (O_3), methane (CH_4) and carbon monoxide (CO) give some indication of important changes in the chemical activity of the troposphere (roughly the lower 15 km of the atmosphere).

The hydroxyl radical (OH) is the most important oxidizing species in the tropos-

Table 6.28. Greenhouse gases in the atmosphere[1]

Gas	Preindustrial concentration	Today's concentration	Increase of concentration (per cent per year)
CO_2	275 ppm	350 ppm	0.4
CH_4	0.7 ppm	1.7 ppm	0.8-1.0
N_2O	280 ppb	308 ppb	0.2-0.3
CFC-11	-	240 ppt	4.0
CFC-12	-	415 ppt	4.3
CFC-113	-	45 ppt	11.3
CFC-22	-	100 ppt	7.1
O_3 (tropospheric)	10-20 ppb	20-40 ppb	1

1) ppm: Parts per million(1 molecule per 10^6 molecules of air).
ppb: Parts per billion(1 molecule per 10^9 molecules of air).
ppt: Parts per trillion(1 molecule per 10^{12} molecules of air).

Sources: Institute of Geophysics at the University of Oslo and NILU.

phere. (A radical or free radical is an atom or group of atoms with one or more unpaired electrons, making it highly reactive.) Other important oxidants are O_3, NO_3, HO_2, organic peroxy radicals (RO_2) and H_2O_2. The concentration of OH radicals controls the concentration of several gaseous compounds of anthropogenic origin (CO, CH_4 and other hydrocarbons, and nitrogen and sulphur species).

It is uncertain whether the oxidizing capacity of the atmosphere has changed significantly, but strong indications are present (Isaksen, 1988). Changing concentrations of O_3 and chemical precursors of O_3 indicate changes in the concentration of OH. Emissions of NO_X, CO, and CH_4 and other hydrocarbons are of significance for the oxidizing capacity of the atmosphere. Model calculations taking increasing emissions of CO and CH_4 into account show a decrease up to the present of 20-40 per cent in the concentration of OH. Other studies also including the increased emissions of NO_X have concluded that the concentration of OH radicals has only changed slightly (Isaksen, 1988).

Increasing ultraviolet (UV) radiation due to a reduction of the stratospheric ozone layer may increase the concentration of OH radicals. Thus, the concentration of compounds destroyed by UV radiation or reacting with OH in the troposphere or lower stratosphere will be reduced as a consequence of stratospheric ozone depletion.

Climatic change may influence the chemistry of the stratosphere through temperature dependent reactions. In the troposphere a rise in temperature may increase OH concentrations and stimulate photochemical activity, thus affecting the concentration levels of gases like CH_4, CO and O_3.

Increasing greenhouse effect

The greenhouse effect is a naturally occurring phenomenon decisive to the global climate. Roughly half of the solar radiation passes through the atmosphere and heats the surface of the Earth. The Earth returns heat radiation (infrared radiation) to the atmosphere. Gases which are naturally present in the atmosphere absorb a significant part of this radiation. Thereafter it is re-emitted, partly to space and partly back to the surface of the Earth. This trapping and re-emission of energy in the atmosphere is what is called the greenhouse effect. Without this effect, the average surface temperature on Earth would be about 33 centigrades below the present level.

Already in 1827, the French mathematician Fourier described this feature of the atmosphere. He also pointed out that human activity may have an impact on the global climate through modifications of the radiation balance. The Swedish chemist Swante Arrhenius continued this line of research by studying the possible climatic effects of increases in the concentration level of CO_2. In 1896 he presented a model of the radiation energy balance for the surface-atmosphere system. Among the factors considered in the model were the radiative properties of CO_2, water vapour, the surface of the Earth and clouds. The model calculations indicated that a doubling of the CO_2 concentration level may lead to an increase in the surface temperature of about 5 centigrades, not too far from today's best estimates (1.5-4.5 centigrades).

As shown in table 6.28, the present concentration of CO_2 in the atmosphere is slightly more than 25 per cent above the pre-industrial level. This increase is due to combustion of coal, oil and gas, deforestation and burning of wood, and cultivation of new land.

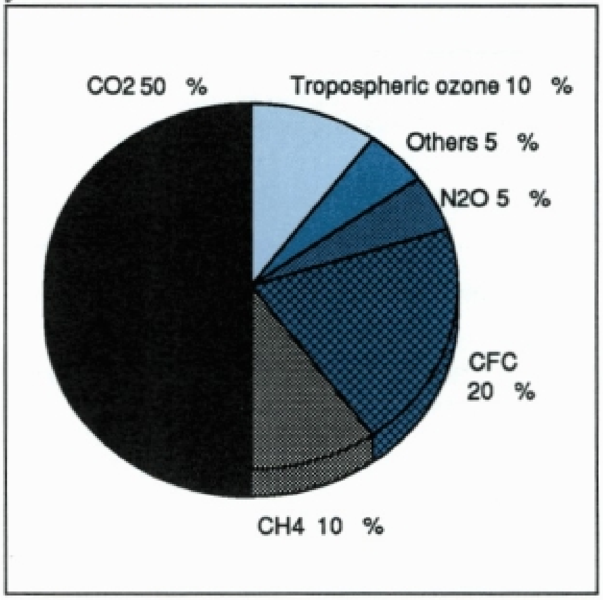
More recently, scientists have become aware of other gases, in addition to CO_2 and water vapour, which can cause greenhouse warming. The most important of these are methane (CH_4), nitrous oxide (N_2O), and several of the chlorofluorocarbons (CFC). The CFC-gases are important factors behind the depletion of the stratospheric ozone layer, but many of them also contribute to the greenhouse effect. The most powerful in this respect are CFC-12 (CF_2Cl_2), CFC-11 ($CFCl_3$), CFC-113 ($C_2F_3Cl_3$), and CFC-22 (CHF_2Cl).

Ozone (O_3) is also an important greenhouse gas. This compound is not directly emitted to the atmosphere, but is formed by photochemical reactions, that is reactions where solar radiation provides the necessary energy for the reactions to take place.

Water vapour is the dominating compound responsible for most of the natural greenhouse effect. However, water vapour is usually not reckoned as a greenhouse gas. Human activity does not directly influence the concentration level through emissions. The amount of water vapour is determined by climate. Climatic changes due to changing concentrations of other greenhouse gases will therefore influence the vapour concentration, and this represents an important feedback mechanism in the climatic system.

Among the greenhouse gases, CO_2 makes the largest contribution to the greenhouse effect. Figure 6.14 shows the estimated contributions to expected temperature rise by the year 2030 from the most important greenhouse gases.

Figure 6.14. Contributions of important greenhouse gases to expected temperature rise by the year 2030



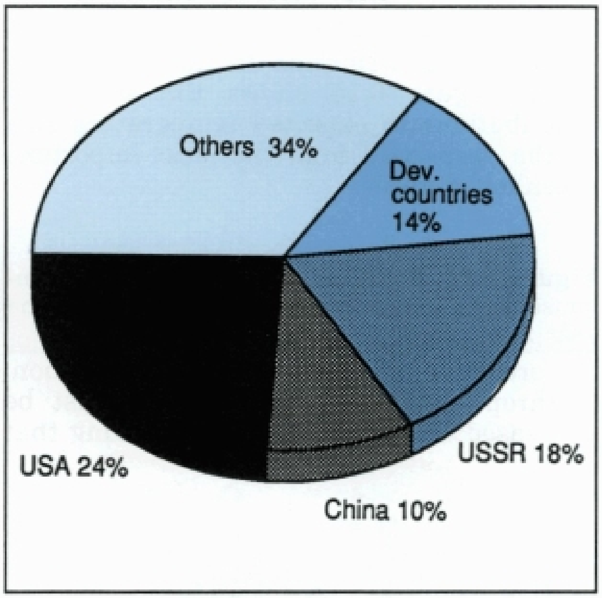
Source: The Norwegian Institute of Air Research (NILU).

Emissions of greenhouse gases

The most important emission sources of CO_2 are combustion of coal, oil and gas (5.5 billion tons C per year), deforestation and changes in land use (0.4-2.6 billion tons C per year) and production of cement (0.13 billion tons C per year). Carbon releases due to human activity are small compared to the natural fluxes. However, anthropogenic emissions of CO_2 represent a net contribution of CO_2 to the atmosphere, and the natural balance may be perturbed.

Countries making the largest contributions to global emissions from the combustion of fossil fuels are USA, USSR and China. Figure 6.15 shows the distribution of anthropogenic emissions from fossil fuels on countries and groups of countries.

Figure 6.15. Contributions by countries and groups of countries to global CO_2 emissions from combustion of fossil fuels

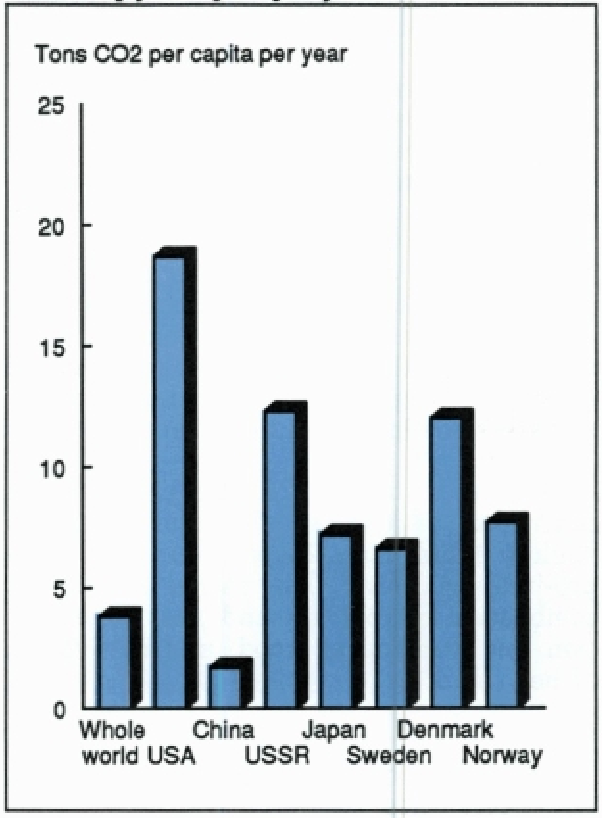


Source: Centre for Applied Research (SAF).

Roughly 25 per cent of the world population emits 75 per cent of the total anthropogenic CO_2 emissions. The industrialized countries generate most of the CO_2 emissions, and also have the highest potential for emission reductions. However, the potential for increase in emissions is highest in the developing countries.

Energy consumption per capita differs considerably between countries. USA and Canada are at top of the list, while large countries like India and China are among the countries with the lowest energy consumption per capita. Norway is on a high Western European level. Hence, CO_2 emissions per capita also differ considerably, but are modified somewhat due to differences in the composition of the energy commodities and in energy efficiency. Figure 6.16 shows per capita emissions of CO_2 from fossil fuels in various countries. The world average is somewhat below 4 tons CO_2 per capita per year. For USA, the level is almost 20 tons per capita per year. In China, the emissions were less than 2 tons per capita per year. Despite a large share of hydropower in the energy consumption, per capita emissions in Norway are approximately 8 tons CO_2 per year (emissions from non-domestic ocean transport not included).

Figure 6.16. Emissions of CO_2 from fossil fuels. Tons CO_2 per capita per year



Sources: Centre for Applied Research (SAF), CBS.

As mentioned above, the release of carbon from deforestation/changes in land use is estimated to be about 0.4-2.6 billion tons C per year. In the 1980s, 6 countries (Brazil, Indonesia, Colombia, the Ivory Coast, Thailand and Laos) were responsible for approximately 55 per cent of net carbon emissions from tropical deforestation.

During the last couple of hundred years, the atmospheric concentration of methane (CH_4) has increased at roughly the same rate as the world population. Human activities generate more than 50 per cent of global CH_4 emissions. Population growth has thus increased the concentration of methane in the atmosphere. However, this increase may also be partly due to a lower concentration of OH radicals, causing reduced destruction of CH_4 in the atmosphere. Methane is formed via anaerobic decomposition in biological systems. It is a major component of natural gas and coal-gas, and is also formed by incomplete combustion during biomass burning. Table 6.29 shows estimates of global emissions by sources.

Table 6.29. Annual Methane release rates for identified sources

	Annual Release 10^{12} g CH_4	Range, 10^{12} g CH_4
Total	540	400-640
Enteric fermentation (animals) . .	80	65-100
Natural wetlands (forested and non-forested bogs, forested and non-forested swamps, tundra and alluvial formations) . .	115	100-200
Rice paddies	110	60-170
Biomass burning . .	55	50-100
Termites	40	10-100
Landfills	40	30- 70
Oceans	10	5- 20
Freshwaters	5	1- 25
Methane hydrate destabilization . . .	5(?)	0-100 (future)
Coal mining	35	25- 45
Gas drilling, venting, transmission	45	25- 50

Source: Cicerone and Oremland, 1988.

Table 6.30. Emissions of nitrous oxide (N_2O) by source. Million tons of N per year

NATURAL SOURCES	
Oceans and river outlets . . .	2.0 ± 1.0
Non-cultivated land	6.5 ± 3.5
ANTHROPOGENIC SOURCES	
Fossil fuels	6.5 ± 1.0
Burning of biomass	0.7 ± 2.0
Fertilized fields	0.8 ± 0.2
Cultivated, non-fertilized fields	1.5 ± 0.5

Source: Wuebbles and Edmonds, 1988.

Global emissions of N_2O are not very well known. The main sources are biological processes in soil and water, and combustion of fossil fuels. Table 6.30 presents rough estimates of sources and global emission levels per year.

Calculations illustrate that in order to stabilize the atmospheric concentration of CO_2, anthropogenic emissions must be reduced by more than 50 per cent. For methane, which has a much shorter lifetime in the atmosphere, it is sufficient to reduce the emission level by 10-20 per cent in order to stabilize the concentration. Anthropogenic emissions of N_2O must be decreased by 80-85 per cent, assuming that the observed increase in concentration level is caused by anthropogenic emissions alone. To stabilize the concentration of CFC-11 and CFC-12, emissions must be reduced by 75 and 85 per cent, respectively. However, in order to stabilize the concentration of chlorine in the stratosphere where the depletion of the ozone layer takes place, it is necessary to halt all emissions of completely halogenated compounds. In addition the use of methylchloroform should be stabilized (EPA, 1989).

For gases like CO and NO_x, which are not counted among the greenhouse gases but nevertheless influence the chemistry in the atmosphere, it is sufficient to stabilize emissions at present levels in order to stabilize the composition of the atmosphere, given that the concentration of long-lived gases are stabilized (EPA, 1989).

The strenght of greenhouse gases

The greenhouse gases described above are gases which have a direct impact on the global radiation balance, that is, they absorb heat radiation emitted from the surface of the Earth. Conditions which determine the efficiency of this (direct) greenhouse effect are:

- At which wavelength the gases absorb radiation from the Earth,
- how efficient they absorb the radiation, and
- at what concentration levels they are present in the atmosphere.

CFC-12 has roughly 22 000 times greater direct greenhouse effect measured per molecule than CO_2. The reason is that CFC-12 mainly absorbs radiation within a part of the radiation spectrum where the heat radiation from the Earth to space is strong. However, due to the much greater abundance of CO_2 in the atmosphere, the total greenhouse effect of CO_2 is greater than for CFC-12.

Some gases have an indirect effect on the radiation balance through their impact on the concentration levels of other greenhouse gases. It is mainly O_3 and CH_4 that are affected in this manner.

The concentration of O_3 is controlled by the presence of other compounds in the atmosphere. Ozone is generated and lost through the following chemical reactions:

First, atomic oxygen is produced by photodissociation of NO_2:

$$NO_2 + \text{solar radiation} \dashrightarrow NO + O$$

The oxygen atom then reacts with molecular oxygen (O_2) in the presence of a molecule M of air (usually O_2 or N_2):

$$M + O + O_2 \dashrightarrow O_3 + M$$

Ozone reacts further with NO:

$$NO + O_3 \dashrightarrow NO_2 + O_2$$

In this way, ozone is produced and lost without any net production. This balance is disturbed, however, when other compounds oxidize NO to NO_2, thus inhibiting this way of destroying ozone. Among compounds that oxidize NO to NO_2 are hydroperoxyl radicals (HO_2) and organic peroxy radicals (RO_2). These are generated when CO and hydrocarbons are oxidized in the atmosphere through reactions with hydroxyl radicals (OH). For instance:

$$CH_4 + OH \overset{O_2}{\dashrightarrow} CH_3O_2 + H_2O$$

where CH_3 = R, and

$$CO + OH \overset{O_2}{\dashrightarrow} CO_2 + HO_2$$

Oxidization of NO to NO_2 may now take place through the following reactions:

$$NO + HO_2 \dashrightarrow NO_2 + OH$$

$$NO + CH_3O_2 \dashrightarrow NO_2 + CH_3O$$

Through this mechanism, emissions of NO_x, CO, CH_4 and other hydrocarbons determine the distribution of ozone in the troposphere.

Since these reactions also affect the amount of OH radicals, they also have an impact of the concentration of CH_4. As much as 90-95 per cent of the destruction of methane takes place through reactions with OH (the residual is decomposed in the stratosphere). Increasing emissions of CH_4 lead to a decrease in the concentration of OH radicals. This, in turn, slows down the decomposition rate of CH_4, thus creating a positive feedback mechanism in the chemistry of the troposphere.

Table 6.31. Greenhouse strength of some gases. * indicates that indirect effects have been taken into account

Gas	Greenhouse strength (CO_2-equivalents per kg emission)
CO_2	1
CH_4	8 / 14 *
N_2O	300
CFC-11	3 400
CFC-12	9 200
CFC-113	4 200
CFC-22	1 150
Methyl chloroform	70
CCl_4	1 650
NMHC[1)]	1.7 *
NO_x	16 *
CO	4 *

1) NMHC: Non-methane-hydrocarbons.
Source: Isaksen (1990)

In brief, the indirect greenhouse effect associated with methane is related to by the generation of O_3 and the feedback mechanism whereby increases in CH_4 concentration hamper the rate of decomposition of CH_4. CO_2 and H_2O, two other greenhouse gases, are the end products when CH_4 is broken down.

Based on knowledge of the direct impact which various gases have on the radiative balance (direct greenhouse effect) and their role in atmospheric chemistry, it is possible to calculate the total greenhouse strength of the gases (Isaksen, 1989). The total greenhouse strength is usually related to the strength of CO_2, see table 6.31. The calculation is based on an increase in CO_2 concentration from 315 to 445 ppm. This reference is of importance, since the greenhouse effect of CO_2 does not increase linearly but logarithmically with concentration levels. For O_3 and CFC, the greenhouse effect increases linearly, while for CH_4 and NO_2 it increases with the square root of the concentration level.

Atmospheric concentrations of the different compounds are determined by the magnitude of the emissions, their production and their destruction rates. This information was taken into account when estimating the total greenhouse strenght.

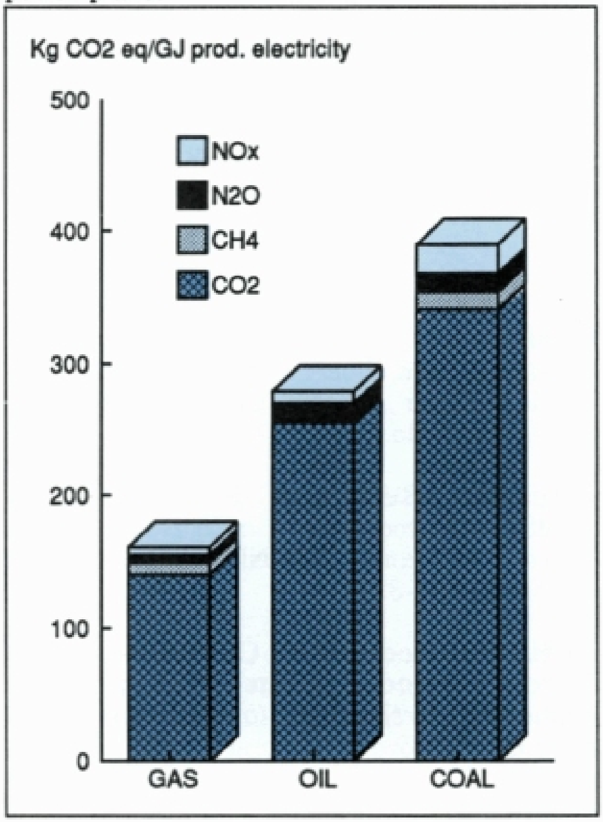
CO_2-equivalent emissions from the combustion of coal, oil and gas

The total greenhouse strength associated with different gases can be used to evaluate the impact of different fuels on the increased greenhouse effect. Power generation is an important source of emissions, and this section discusses the total greenhouse forcing associated with different fuels in power generation.

Figure 6.17 shows the result of such a comparison between electricity generation based on coal, oil and natural gas. Emissions from mining, transport and refining of fuels, leakages and combustion are included. The greenhouse forcing is given in CO_2 equivalents per unit electricity generated. The figure shows that the CO_2 emissions dominate for all three fuels, but also other compounds contribute significantly. The total greenhouse forcing from oil fired power plants is approximately 70 per cent of the greenhouse forcing caused by emissions from coal fired plants measured per unit electricity produced. Gas fired plants only produce 40 per cent of the greenhouse forcing of a similar coal fired plant.

These evaluations depend to a large degree on assumptions about technology (cleaning equipment, NO_x emissions, etc.) and in particular on the assumed efficiency of the different power plants. In addition, there are uncertainties associated with the estimates of the greenhouse strength of each polluting compound. The impacts of the various fuels on the greenhouse effect may be somewhat different in other applications of the fuels. The results in figure 6.17 can, however, still be used to illustrate the differences between the different fuels and compounds with respect to the greenhouse effect.

Figure 6.17. Emissions of CO_2-equivalents from electricity generation in coal, oil and gas fired power plants



The calculations include effects of leakages of methane from production and distribution of natural gas. The amount leaked is of particular importance to the evaluation of natural gas as a comparatively "clean" fuel. Studies indicate that leakages must be kept below 10 and 14 per cent to give natural gas a greenhouse advantage over oil and coal respectively (Isaksen and Roland, 1990). Estimated rates of leakage are well below these limits.

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