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Benefits of climate policies: Some tentative calculations

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Abstract

Consequences for the Norwegian economy of an active policy against anthropogenic climate change can be analyzed by use of an economic model evaluating the differences between a reference scenario without control policies and alternative paths using economic incentives to reduce emissions of greenhouse gases. In traditional economic models the effect of the new taxes usually appears as reduced growth in macroeconomic indicators such as GDP, gross production and private consumption. When measures against climate change nevertheless are contemplated, it is due to a belief that the benefits of a policy more than outweighs the costs. Many benefits are hard to quantify. This is true for instance for the effects associated with the general welfare of people under different climatic conditions. However, it is possible to associate some tentative figures with some of the benefits likely to emerge from an introduction of a vigorous climate policy.

In this paper we try to evaluate some usually neglected benefits associated with an introduction of a carbon tax. The benefits emerge from reduction in local pollution levels and the ensuing reduction in environmental damages to forests and lakes, health damages and damages to certain types of materials. In addition, benefits accruing from reduced traffic congestion, road damage, traffic accidents and noise levels are quantified.

We find that the benefits thus accounted for go a long way toward compensating the economic loss measured as a reduction in GDP by the macroeconomic model MODAG. The uncertainty in the estimates of the benefits is assessed, and distributional consequences of the carbon tax are analyzed.

1 Introduction

1.1 Background

A deteriorated environment affects our welfare in different ways. Partly, our welfare is reduced by just being surrounded by a polluted environment, a sort of negative aesthetical welfare effect. Partly, we are exposed to economic losses through a reduction in the efficiency of an economy in a highly polluted environment. To combat these effects, environmental control policies are introduced. The control policies usually have positive aesthetical effects, while the total economic effect are sometimes positive and sometimes negative. In the positive direction counts efficiency gains due to fewer days of sick leave, less resources needed in the health care etc., while in the negative direction counts the cost of implementing the policy, for instance by increasing the price of important input factors like fossil fuels.

When the economic effects of environmental control policies are analyzed by employing available macroeconomic models, one usually finds that indicators such as GDP and private consumption fall because of the control policy. There are several reasons for this.

First, current economic models usually do not contain relations capturing the economic efficiency gains following an improvement of the state of the environment. These gains are related to a reduction in environmental health damages and an improvement of biological productivity. Also, the effective lifetime of certain materials may be prolonged due to a reduction in corrosion rates in a cleaner environment. The economic models describe how much raw materials, capital and labour that is necessary to produce a unit output under current environmental conditions. However, they are not capable of saying how much lower the use of input factors could have been under better environmental conditions. The efficiency gains following from improved environmental standards are thus not captured in the calculations based on current economic models.

Secondly, the efficiency gains will change the relative prices of the various input factors, and by that both the structure and level of economic growth. This simultaneity between economic development and development in the state of the environment can only be described by a model fully integrating both economic and environmental variables of importance.

Economic indicators like GDP and private consumption are very incomplete indicators of the level of welfare in a society. (Brekke, 1991) Environmental policy can have substantial positive welfare effects without increasing the traditional economic indicators irrespective of the sophistication of the economic models employed. The well-being of living in a clean environment are but one element affecting welfare, but impossible to include in general market based economic indicators. The total benefit of environmental control policies is impossible to assess on the basis of economic indicators alone.

However, it is still useful to try to capture some of the economic efficiency gains expected from environmental control policies, such as a budget neutral increase in environmental taxes. If nothing else, this will provide a more complete picture of the pure economic costs and benefits associated with the policy.

In this paper we will try to quantify the first order benefits of reducing air pollution and road traffic due to a new tax on fossil fuels. We denote it first order benefits since the effects of changes in relative prices due to efficiency gains from environmental improvements are neglected.

1.2 Types of environmental cost reductions included

Table 1 lists the types of benefits due to lower use of fossil fuels and associated emissions to air studied in this paper. Whether pure welfare effects are evaluated in addition to the economic efficiency gains is also indicated in the table.

Table 1. Types of cost reductions covered in this paper

	Welfare effects	Economic effects
Nature		
Damage to forests	x	x
Acidification of fresh water lakes	x	x
Materials		
Corrosion		x
Health		
SO_2	x	x
NO_x	x	x
CO	x	x
Particulates	x	x
External costs of road traffic		
Accidents	x	x
Congestions		x
Damage to roads		x
Noise	x	x

Whether pure welfare effects are included or not, is determined by the primary data material. Thus, studies of willingness to pay for freshwater fisheries are assumed to cover both pure welfare effects like aesthetical value, option and existence value as well as economic gains. Concerning damage to materials due to an acid atmosphere, only maintenance costs are covered. Regarding health, the pure welfare effect constitutes 5 per cent of the total cost.

When making model based analysis of control policies affecting future emissions to air, many of the economic effects listed in table 1 can, at least in principle, be included in the analysis. This can be done either by explicitly modelling the feedback from the environment to the economic activity, or implicitly by properly adjusting parameters and exogenous variables of the model. The ex post calculations of benefits of a new environmental tax presented in this paper would in this case represent a double counting of the benefits.

1.3 Overview of the rest of the paper

The motivation for introducing the environmental tax analyzed in this paper is the threat of global warming. In the next section we therefore briefly describe some of the expected effects of emission of the so called greenhouse gases carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC). The benefits of reducing the emissions of these gases will *not* be quantified, but some preliminary results from the international literature will be presented.

In section 3 we present the data behind the assessment of the benefits associated with the reduction in emissions of pollutants causing local damages and reduction in road traffic. These benefits are treated here as roughly additional to benefits coming from a reduced rate of climatic change, although impacts on biological growth, damage to materials and human health do depend on climate conditions. However, the climate impact of lower greenhouse gas emissions in Norway are small and thus ignored in this study. Local pollutants covered are sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulates.

Then, in section 4, we present the benefits of reducing the level of local pollutants and road traffic coming from the introduction of a tax on fossil fuel in Norway. The uncertainty of the estimates are discussed, together with the distributional consequences on some socio-economic groups from the new tax.

Finally, in section 5 we compare the estimated benefits with calculated reductions in GDP and private consumption due to the control policy. Similar calculations, based on other control policies and economic growth paths, have been published earlier in the annual report "Natural resources and the environment" from the Central Bureau of Statistics of Norway (CBS, 1990, 1991).

2 Some effects of climate change and the costs of reducing emissions of greenhouse gases

Emissions of greenhouse gases like CO_2, CH_4, N_2O and CFC affects the global climate by changing the radiation balance of the earth. How continued emission will affect the climate and what consequences this will have for the living conditions on earth is subject to substantial uncertainties. Usually one assumes that a doubling of the equivalent CO_2 content of the atmosphere[1] from pre-industrial times, will increase the global equilibrium temperature by from 2 to 5

[1] It is usual to denote the total effect of greenhouse gases in the atmosphere by *equivalent CO_2 units*, i.e. how much CO_2 would be needed to obtain a similar greenhouse effect.

degree Centigrade. (referanse IPCC) Together with changes in the pattern of precipitation, this will change the growing conditions for whole ecosystems. The rate of change in the chemical composition of the atmosphere will also by itself strongly influence the biosphere. Increased temperature can increase the level of the oceans, flooding the low coastal plains of the earth and increasing erosion damages in these areas. The economic impacts of such events are very difficult to estimate, but some assessments have been carried out.

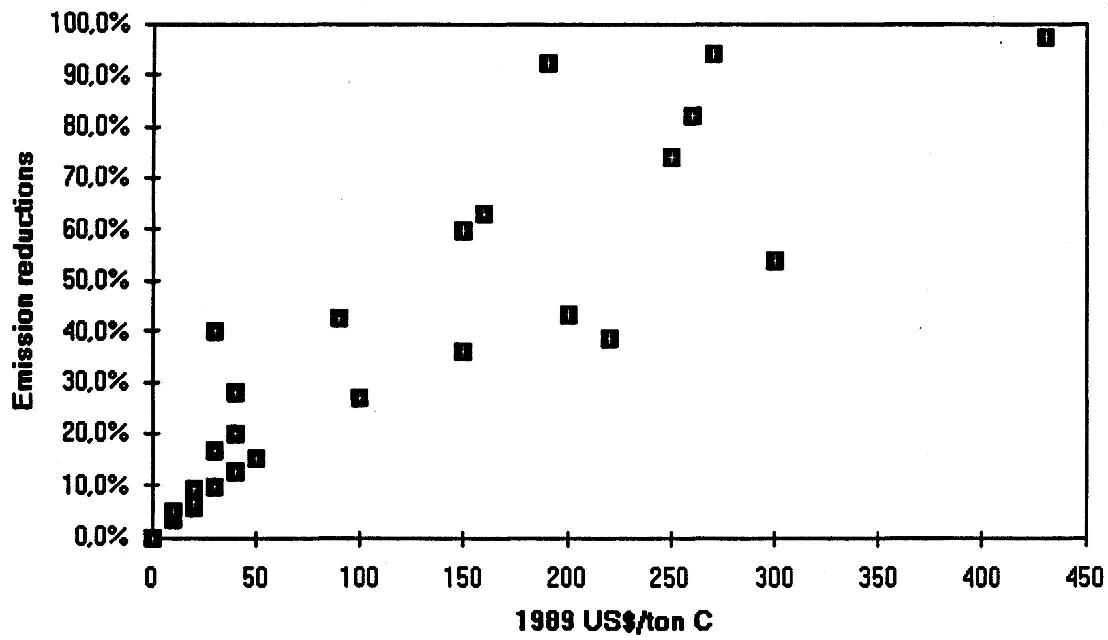
For instance, Nordhaus (1991) refers an estimate of damages from greenhouse gas emissions leading to an increase in global mean temperature of 3 degree Celsius. The estimate, which only includes damages possible to assess and which for instance neglects damages from loss of genetic materials and aesthetical valuables, gives a damage of US$ 1,80 per ton carbon in CO_2 equivalent emissions. This is a very low estimate of the damages of greenhouse gas emissions. Nordhaus also present two *ad hoc* estimates of the damage rate. A mean estimate is US$ 7,30 per ton carbon, while a high estimate is US$ 65 per ton carbon.

In the same article Nordhaus also presents estimates of the cost of reducing greenhouse gas emissions. In a theoretical optimum, where the marginal damage of greenhouse gas emissions equal the marginal cost of reducing these emission, he finds that with the low estimate on damages, only CFC emissions need to be curbed to reach optimum. With the medium damage estimate, he finds that greenhouse gas emissions must be reduced by approximately 11 per cent from present levels, while using the high damage alternative lead to a reduction of approximately one third in optimum relative to present emission levels.

Another set of data showing the economic costs of combatting CO_2 emissions is presented in figure 1 based on Hoeller et al. (1991). The figure presents estimates reduction in GDP due to increases in the price of fossil fuels versus reductions in CO_2 emissions. Note that the individual results in this figure are not strictly comparable, since they may be based on different and inconsistent sets of assumptions.

In none of the calculations are the positive effects of reductions in local pollutants taken into account. A higher price on fossil fuels will necessarily reduce emission of local pollutants in addition to e.g. CO_2, and also reduce some of the external costs associated with road traffic. It is to these effects we turn next.

Figure 1. Emission reductions vs. tax on fossil fuels.



3 Assumptions underlying the calculations of benefits from reduced road traffic and emissions causing local damages

Two types of benefits (or costs) are calculated on the basis of a set of economic model scenarios with associated projections of emissions to air. One type is related to changes in emission levels of sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulates. These are compounds inflicting damages on, among other things, human health, forests, fresh water lakes and certain types of capital equipment. In addition, the presence of these compounds reduce the welfare of mankind by aesthetical damages and by inducing fear in people.

The other type of benefits calculated are related to road traffic, and cover aspects such as congestion, accidents, damage to roads and noise from road traffic. In this section we will briefly describe the data and assumptions underlying the calculation of marginal benefits from reduced emissions and traffic. A more detailed documentation is offered in Brendemoen et al. (1991) (in Norwegian).

3.1 Forest damages

The Commission of Forest Damages (Skogskadeutvalget) appointed in 1988 a project group with the task of evaluating how air pollution will affect Norwegian forests in the long run (25-30 years). The project report (Ministry of Environment, 1988) describes some of the many hypothesis that exists on the connection between air pollution and forest damages. High ozone levels, abundant nitrogen supply and damages from acidification of the soil are viewed as the most important causes for damages to forests. Norwegian forests are mainly afflicted by transboundary air pollution. Thus, domestic sources are only responsible for 5-10 per cent of total sulphur and nitrogen deposition.

The commission estimates that biomass losses in Norwegian forests in 1988 due to excessive air pollution amounts to 1-2 million m^3. This is valued at 300-600 million 1988-NOK. In the longer run, the buffer capacity of the forests against acidification will decline, increasing the annual loss in growth from approximately 10 per cent in 1988 to 20 per cent in 25-30 years time.

In addition to loss of growth, forest damages also imply a loss in the recreational value of the forests. This loss has not been separately valued, but referring to willingness-to-pay studies of acidification of water sheds, the commission estimates the present recreational loss of forests to between 400 and 500 million 1987-NOK, i.e. of the same order of magnitude as the loss of recreational value of watersheds due to excessive acidification.

At the outset, the ratio of forest acidification damages due to one ton of NO_x and one ton of SO_2, is estimated as 1:2 (Syvertsen, 1988). However, recognizing that NO_x also contribute to forest damages through the formation of O_3, NO_x should be given greater weight than this. In this report we therefore assume that the marginal forest damages from NO_x, and SO_2 are equal.

The critical load of sulphur and nitrogen is assumed to be 80 per cent below the 1980 deposition level of these substances. Below this level, no damages are assumed to be inflicted on forests from air pollution. In calculating the damages from Norwegian emissions of sulphur and nitrogen, we assume proportionality between emission levels and deposition levels (of domestic SO_2 and NO_x) in Norwegian forests, and linearity between deposition above the critical load level and damage amount. By itself, Norway is incapable of reducing deposition below critical load.

3.2 Acidification of fresh water lakes

Total willingness to pay for conservation of sport fishing possibilities in rivers and lakes in Norway has been estimated to be approximately 4.000 million 1987-NOK on an annual basis (Strand, 1980, Syvertsen, 1988). About 10 per cent of the area of Norway show signs of heavy damages from acidification (Syvertsen, 1988). If we assume that the same proportion of possibilities for sport fishing are destroyed, this damage can be valued at 400 million 1987-NOK annually. In addition comes the loss of catch valued at 10 million 1987-NOK annually, and loss of recreational values estimated to be between 50 and 120 million NOK per year. As for the forest damages, 10 per cent of the damages to rivers and lakes are ascribed to Norwegian emissions of acid compounds. With a reasonable assessment of the uncertainty intervals, we then find that total damages to fresh water lakes and rivers from Norwegian emission of SO_2 and NO_x amounts to between 29 and 70 million 1987-NOK annually.

3.3 Damages from corrosion of capital equipment

Several types of emissions to air cause damages to materials. Here, we only consider damages caused by SO_2 emissions to galvanized and painted steel and painted wood. The estimates are based on Glomsrød and Rosland (1988). Here, direct corrosion costs due to domestic emission of SO_2 was estimated to be 220 million 1985-NOK in 1985, based on regionalized data on pollution levels and stock of materials. In addition to the direct costs, corrosion damages causes the price of capital to be higher than in a situation without SO_2 pollution. This incurs additional costs on the economy, estimated by means of a general equilibrium model run to be of the order of 100 million NOK on annually basis.

Including the substantial uncertainty associated with the above estimates, we employ in this report an interval of 0-640 million NOK as estimate of annual corrosion costs in 1985. We assume these damages to be linearly related to national emissions of SO_2.

3.4 Health damages caused by local air pollution

Estimates of marginal costs associated with pollution of SO_2, NO_x, CO and particulates are based on studies of local conditions in Sarpsborg/Fredrikstad and Oslo carried out by the State Pollution Control Authority (SFT) (SFT, 1987, 1988). SFT provides figures for the cost associated with bringing one person from below certain concentration levels (thresholds) to above. These thresholds are based on recommendations made by the World Health Organization (WHO). The cost figures are given as best estimates with uncertainty intervals.

SFT mainly base their cost estimates on several studies carried out by Lave and Seskin on the link on the margin between sulphur concentration in air and health costs due to increased mortality and morbidity. These estimates are then reduced by more than 50 per cent to adjust for the lower concentration levels experienced in Norway compared to USA.

Concerning damages associated with the other polluting compounds, NO_x, CO and particulates, it is assumed as a starting point that the exposure standards for these compounds are determined by requiring the marginal damage at this level to coincide with the marginal damage of SO_2. The estimate thus obtained are however somewhat adjusted to take care of special considerations such as that the number of people exposed to levels above recommended health standards are much higher for NO_x and CO than for SO_2, and that the different compounds affect different population groups, such as asthmatic people, elderly people, children, etc.) differently. The final estimates compares favorably with willingness-to-pay surveys carried out in Norway in connection with proposed introduction of catalytic converters in private cars.

As a second step dispersion models are used to calculate the number of people exposed to pollution above the threshold levels for different emission levels. Combined with individual cost the result is an estimate of the marginal health cost of SO_2, NO_x, CO and particulate emissions. In this study, marginal health cost estimates are taken from the study of Oslo.

Two cases are then considered. In one case it is assumed that damage to health due to SO_2 emissions only occur in Oslo. In the other case such damages are assumed to occur in the five most populated areas of Norway: Oslo, Bergen, Trondheim, Stavanger and Bærum. This gives an interval for the total marginal costs of SO_2 emissions due to health damages.

Table 2 provides the estimation results emerging from the above procedure.

Table 2. Data used for estimation of marginal health damages

	SO_2	NO_x	CO	Prt[a]
Change in emission levels. 1000 tons	2,5	0,8	44,6	0,2
Change in number of persons exposed to levels above standards. 1000	154	88	1	20
Annual cost of bringing one person above recommended standards. 1000 1986-NOK[b]	2,0 (0,8-0,3)	4,0 (1,4-7,7)	6,0 (2,2-11)	4,4 (1,5-8,3)
Marginal health costs. 1000 1986-NOK per ton emission[b]	123 (47-205)	440 (154-847)	0,1 (0,05-0,25)	440 (154-833)

a) Particulates
b) Best estimates with lower and upper limit given in parenthesis
Source: SFT (1987)

3.5 Some additional external costs of road traffic

The externalities of road traffic are many and substantial. In addition to be an important source of air pollution, road traffic imposes costs on society by road accidents, wear and tear of the roads, congestion and noise generation. The costs of air pollution is covered in earlier subsections. Here, we will focus on the other cost elements.

The State Pollution Control Authority (SFT) has in a study of possible control measures to combat air pollution in Oslo (SFT, 1987) recommended several measures directed at road traffic. These measures were calculated to give a reduction in road traffic of between 20 and 30 per cent. This reduction should in turn reduce the number of accidents, damage to roads, congestion and noise coming from road traffic. SFT also estimated the benefits accruing from these reductions, thus providing a basis for calculating the marginal costs of additional use of fuels for road transport purposes in Oslo.

The cost figures of SFT include all effects, not only loss due to lower economic efficiency and direct economic outlays. The Institute of Transport Economics (TØI) in Norway has in a separate study estimated only the direct marginal economic losses due to road traffic. Their value for total marginal cost were 58 per cent lower than the corresponding figure from SFT. In the following we will base our estimates on the SFT figures.

3.6 Excluded cost components

In the above description most cost elements associated with the use of fossil fuels are tried captured. A number of negative effects are however neglected, mainly due to lack of data.

Global damages due to increased climate change are not covered. The World Commission of Economy and Development (WCED, 1987) recommended drastic reductions in use of fossil fuels for this reason, something which indicates that the costs of these damages are expected to be potentially large.

High ozone levels near the ground is probably an important source for health damages, but these damages are not included in the above assessment. Recent research indicates that damages will appear at relatively low ozone levels. Also, ozone is causing lower biological growth, a cost that is also excluded in this report.

Corrosion damages to materials in this paper do not cover damages to cultural important buildings and monuments. Damage to concrete constructions from deposition of sulphur and ozone damages to rubber and plastic materials are also excluded. Furthermore, costs of dirt, smell and lower visibility in a polluted atmosphere are also neglected. (These costs are estimated to be lower than the health damages of SO_2, see Syvertsen, 1988).

3.7 A summary of the assessment of marginal damages

Below, in table 3, we present a summary in the form of a model for calculating the marginal damages associated with changes in emissions to air and use of transport fuels. The estimated parameter values entering the model are presented in table 4. Note that the estimates of marginal damage are based on an assumption of linearity of the damages within a limited range of emission variations. Also, constant real prices of environmental benefits are assumed, although the they probably rises with income and scarcity of environmental goods and services.

Table 3. Model for calculating costs of emissions to air and use of transport fuels.

Type of costs	Marginal cost		Parameters
Acidification of water	$b_1\ \Delta(SO_2 + NO_x)$	b_1	Thousand 1990-NOK per ton
Acidification of forests	$b_2\ \Delta(SO_2 + NO_x)$	b_2	Thousand 1990-NOK per ton
Health damage from compound j=SO_2, NO_x, CO, particulates	$b_3^j(\Delta M_j{*}\ a_m j + \Delta S_j{*}a_s j)$	b_3^j	Cost of increase in number of people above ambient standard. Thousand 1990-NOK per ton
		$a_m j$	Share of emission from mobile sources causing health damage. %
		$a_s j$	Share of emission from stationary sources causing health damage. %
		ΔM_j	Change in emission from mobile sources. Tons
		ΔS_j	Change in emission from stationary sources. Tons
Corrosion	$b_4\ \Delta SO_2$	b_4	Thousand 1990-NOK per ton
Road traffic	$b_i\ \Delta$(petrol + diesel); $i=5,...,8$	b_5	Cost of accidents per ton fuel. Thousand 1990-NOK
		b_6	Cost of congestion per ton fuel. Thousand 1990-NOK
		b_7	Cost of damage to roads per ton fuel. Thousand 1990-NOK
		b_8	Cost of noise. Thousand 1990-NOK

Table 4. Model parameters

Type of costs	Parameter	Low	Medium	High
Acidification of water	b_1	0,2	0,1	0,3
Acidification of forests	b_2	0,41	0,49	0,51
Health	b_3^{SO2}	47	150	251
damages	a_m^{SO2}	9	18	27
SO_2	a_s^{SO2}	3	7	11
Health	b_3^{NOx}	188	538	1.036
damages	a_m^{NOx}	8	18	28
NO_x	a_s^{NOx}	3	6	10
Health	b_3^{CO}	0,06	0,1	0,31
damages	a_m^{CO}	9	20	31
CO	a_s^{CO}	5	14	23
Health	b_3^{Par}	188	538	1.019
damages	a_m^{Par}	6	7	8
particulates	a_s^{Par}	8	17	26
Corrosion	b_4	0	4	8
Traffic accidents	b_5	770	1.790	5.099
Congestion	b_6	0	1.970	3.940
Damage to roads	b_7	0	2.500	5.000
Noise	b_8	1.220	2.160	3.100

4 Estimation of benefits of environmental taxation

4.1 The scenarios

The consequences for the Norwegian economy of actively pursuing environmental taxation can be calculated as the difference between the development in a reference path without special control measures and alternative paths with implementations of environmental taxes. The detailed assumptions underlying the reference path and the two alternative scenarios employed in this report is documented in detail elsewhere (Miljøavgiftsutvalget, 1991). Here, we only comment on some main features of the scenarios of particular importance for the benefit estimates.

4.2 The reference path

The reference path illustrates an economic development in Norway with moderate growth towards the year 2000, partly due to more efficient use of resources. No other than already determined environmental regulations are taken into account in calculating the emissions to air.

Energy efficiency is assumed to increase by 1 to 1,5 per cent annually over the period 1990-2000 in dwellings and other buildings. In the process industry, energy efficiency is assumed to increase by between 0,5 and 1 per cent on an annual basis over the same period. The power intensive sectors are assumed to keep their contracts on cheap electricity, while the price of electricity to other sectors is determined by the long run marginal cost. Electricity is assumed to be generated by hydro power alone in year 2000.

Demand for gasoline and fuel oils grow at an average annual rate of 1,4 per cent towards year 2000 in the reference scenario. Demands for oil products in general are much lower in the households than in the rest of the economy, see table 5.

Table 5. Demand for energy in the reference scenario.

	1988	2000	Growth rate 1988-2000 (Per cent)
Electric power, TWh			
Net domestic demand	92,8	105,0	1,0
Power intensive firms	30,4	31,0	0,2
Other demand	62,3	74,0	1,4
Petroleum products, 1000 tons			
Oil products (except gasoline)	4.963	5.869	1,4
Production sectors	4.390	5.257	1,5
Households	573	612	0,6
Gasoline	1.899	2.254	1,4
Production sectors	654	867	2,3
Households	1.245	1.386	0,9

Table 6 shows estimated projection of emissions to air in the reference scenario and some national targets for these emission levels. Only compounds entering the later benefit estimates are included in the table.

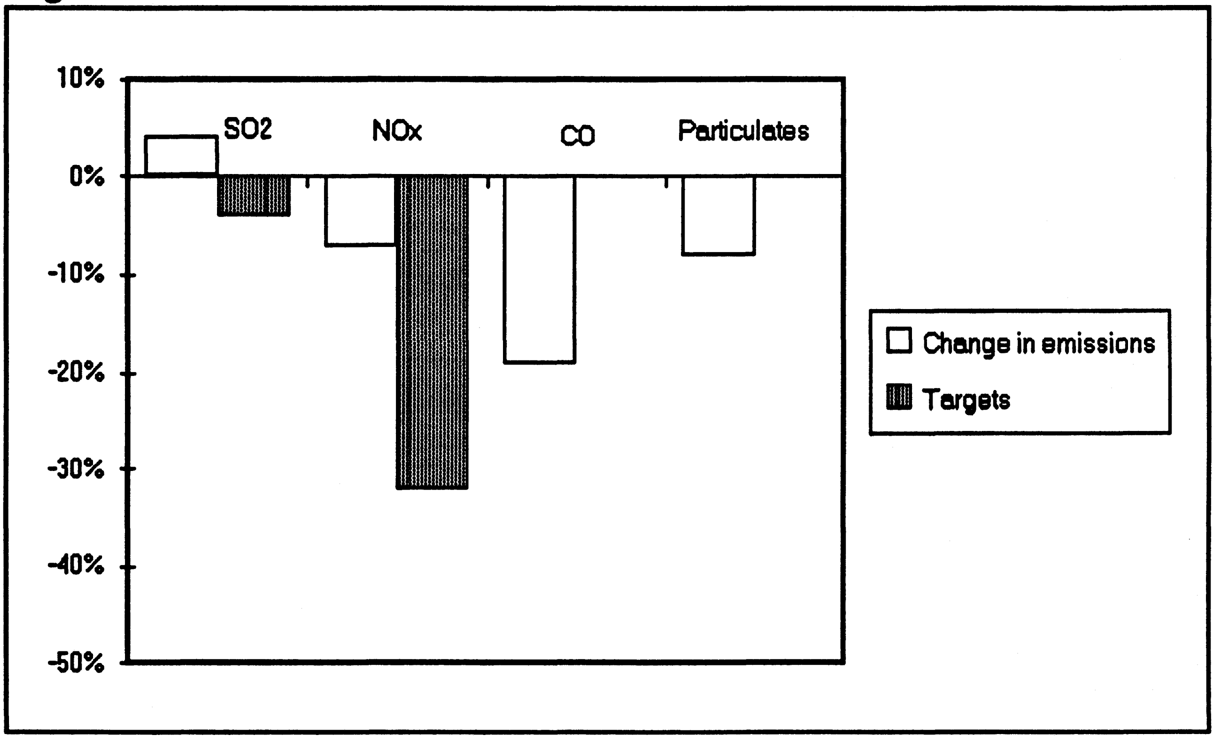
Table 6. Emissions to air. Reference scenario.

	1988 (1000 tons)	2000 (1000 tons)	Growth rate 1988-2000 (Per cent)	Target levels[1] (1000 tons)
SO_2	74	77	0,3	71 (1993)
NO_x	228	212	-0,6	155 (1998)
CO	635	514	-1,7	
Particulates	25	23	-0,7	

1) Year for target fulfillment in parenthesis

Figure 2 depicts relative changes in emission levels from 1988 to year 2000. Note that the targets indicated in the figure refer to earlier years than 2000, cf. table 6.

Figure 2. Growth in emissions 1988 - 2000. Reference scenario. Per cent



Control measures already implemented or decided on makes the growth in emissions much lower than the growth in demand for petroleum products. For NO_x, CO and particulates the emission levels are even lower in year 2000 than in the base year. However, there is still a considerable gap between projected emission levels and the national targets. This is particular true for the NO_x emissions, which must be reduced by approximately 30 per cent to year 2000 if the national emission target is to be within reach.

4.3 The stabilization alternative

In this alternative the point of departure is the national target of stabilizing CO_2 emissions at the 1989 level before year 2000. The control policy employed is a tax on emissions of CO_2, also those not due to combustion of fossil fuels. The necessary tax rate is calculated to be approximately 900 1990-NOK per tons CO_2. A cost effective approach is followed, implying that each polluter is faced with an identical tax on their emissions.

The price on gasoline is expected to be 1,75 1990-NOK higher in year 2000 with this carbon tax compared to the reference alternative. Similarly, the price on diesel and fuel oil will increase with 2,30 1990-NOK per liter. The stabilization alternative assumes that other countries abstain from similar measures against CO_2-emissions. Assumptions on international oil prices and international economy are therefore the same as in the reference alternative. Table 7 shows the calculated growth rates of energy use in the stabilizing alternative and the changes from the reference alternative.

Table 7. Demand for energy. The stabilization alternative. Year 2000.

	Year 2000	Growth rate 1988-2000 (Per cent)	Deviation from the reference alternative (Per cent)
Electric power, TWh			
Net domestic demand	92,7	0,0	-11,7
Power intensive industries	17,2	-4,6	-44,5
Other demand	75,5	1,6	2,0
Petroleum products, 1000 tons			
Oil products (except gasoline)	4.986	0,0	-15,0
Production sectors	4.518	0,2	-14,1
Households	468	-1,7	-23,5
Gasoline	2.014	0,5	-10,6
Production sectors	844	2,1	-2,7
Households	1.170	-0,5	-15,6

Since we in the stabilization alternative assumes that Norway is alone in introducing measures against CO_2-emissions, the situation for the export sectors, and the power intensive industries in particular, will be very difficult. For instance, the gross product of the metal sector is estimated to be reduced by a staggering 40 per cent in this scenario in year 2000 compared to the reference alternative.

The carbon tax will reduce the use of oil products others than gasoline by 15 per cent relative to the reference alternative in year 2000. The households will reduce their use of oil for heating purposes by almost 25 per cent. With respect to use of gasoline, the households are clearly more affected that the production sectors. In fact, the use of gasoline in the households will in the stabilization alternative in year 2000 be below the 1988 level. The consequences for emissions to air are shown in table 8.

Table 8. Emission to air. Stabilization alternative. Year 2000.

	Year 2000 (1000 tons)	Growth rate 1988-2000 (Per cent)	Deviation from the reference alternative (Per cent)
SO_2	61	-1,6	-20,8
NO_x	189	-1,6	-10,8
CO	390	-4,0	-24,1
Particulates	22	-1,1	-4,3

The SO_2-emission level in year 2000 is markedly below the 1993 target level. The NO_x-emission level is also clearly below the level in the reference alternative, but still 25 per cent higher than the target 1998-level.

4.4 The treaty scenario

The treaty scenario is based on the assumption that an international protocol on stabilization of global CO_2-emissions are negotiated, signed and implemented by year 1995. Estimates indicate that an international carbon tax of NOK 650 per ton CO_2 is sufficient to at least stabilize the CO_2-emissions from the industrialized countries (see e.g. Moum, 1992), and this tax is assumed implemented in the treaty alternative. Since Norway already has introduced taxation of some CO_2-emissions, the price increase in Norway is somewhat less than in most other countries. Relative to the price paths in the reference alternative, the price on gasoline is expected to increase by NOK 0,75 per liter in year 2000 (1990-NOK), while the price on other oil products are NOK 1,40 higher in the treaty alternative than in the reference alternative in year 2000.

As a consequence of the protocol, the world price on crude oil is assumed to be reduced by 15 per cent relative to the reference path, thus reducing the gross disposable income for Norway by approximately 2 per cent in year 2000 relative to the reference scenario.

An international tax on CO_2 will benefit the hydro-power based power intensive industry of Norway, since the foreign competition will have to pay more for the fossil fuel based electric power. Still, this sector will be affected through its use of coal as a reduction medium.

The use of electricity in other types of manufacturing industries is reduced in the treaty scenario relative to the reference path. The reason is that the effect of a reduced income level and less demand for industrial commodities outweighs the effect of a lower price on electricity relative to oil. In the service sector the situation is reversed, leading to an increase in the overall use of electricity in the production sectors of some 3 TWh relative to the reference alternative in year 2000, see table 9.

Table 9. Demand for energy. The treaty alternative. Year 2000.

	Year 2000	Growth rate 1988-2000 (Per cent)	Deviation from the reference alternative (Per cent)
Electric power, TWh			
Net domestic demand	105,2	1,1	0,2
Power intensive firms	29,8	-0,2	-3,8
Other demand	75,4	1,6	1,9
Petroleum products, 1000 tons			
Oil products (except gasoline)	5.411	0,7	-7,8
Production sectors	4.854	0,8	-7,7
Households	557	-0,2	-9,0
Gasoline	2.180	1,2	-3,3
Production sectors	865	2,4	-0,2
Households	1.135	0,5	-4,1

Use of heating oils and transport fuels others than gasoline is reduced by approximately 8 per cent in year 2000 when compared to the reference scenario. This is roughly half of the reduction expected in the stabilization alternative. The reduction is evenly distributed among the households, which predominantly use heating oils, and the production sectors which mainly use transport oils. Domestic use of gasoline is reduced by 3 per cent in the treaty alternative relative to the reference scenario. The reduction in the households is almost 5 per cent with only minor reductions in the production sectors. The consequences for emissions to air in year 2000 are shown in table 10.

Table 10. Emission to air. Treaty alternative. Year 2000.

	Year 2000 (1000 tons)	Growth rate 1988-2000 (Per cent)	Deviation from the reference alternative (Per cent)
SO_2	74	0,0	-3,9
NO_x	203	-1,0	-3,8
CO	409	-3,6	-20,4
Particulates	23	-0,7	0,0

The calculations indicates that Norway will fulfil its obligation on reduced SO_2-emissions in 1993 without further control measures, while the emissions in year 2000 will be slightly above the target level of 71 thousand tons SO_2. The NO_x-target will not be reached in this alternative - the gap is larger than 30 per cent. It is therefore clearly a need for further control measures to reduce future NO_x-emissions, also if an international CO_2-treaty is established.

4.5 Reduction in pollution and traffic related costs in year 2000 relative to the reference scenario

Table 11 shows the estimated cost reductions in the stabilization and treaty alternative, respectively, relative to the reference path in year 2000. The estimates are also illustrated in figures 3 and 4.

Table 11. Pollution and traffic related costs. Reductions from the reference path . Year 2000. Millions 1990-NOK.

Type of damage	The stabilization alternative	The treaty alternative
Nature	**26**	**8**
Water courses	7	2
Forests	18	6
Health damages	**2.390**	**859**
NO_x	2.000	761
SO_2	285	62
CO	1	0
Particulates	104	36
Corrosion	**14**	**63**
Road traffic	**3.725**	**1.519**
Accidents	782	319
Congestion	834	340
Road damages	1.048	427
Traffic noise	1.061	433
Total	**6.155**	**2.449**

Figure 3. Cost reductions from the reference scenario. The stabilizing alternative. Year 2000.

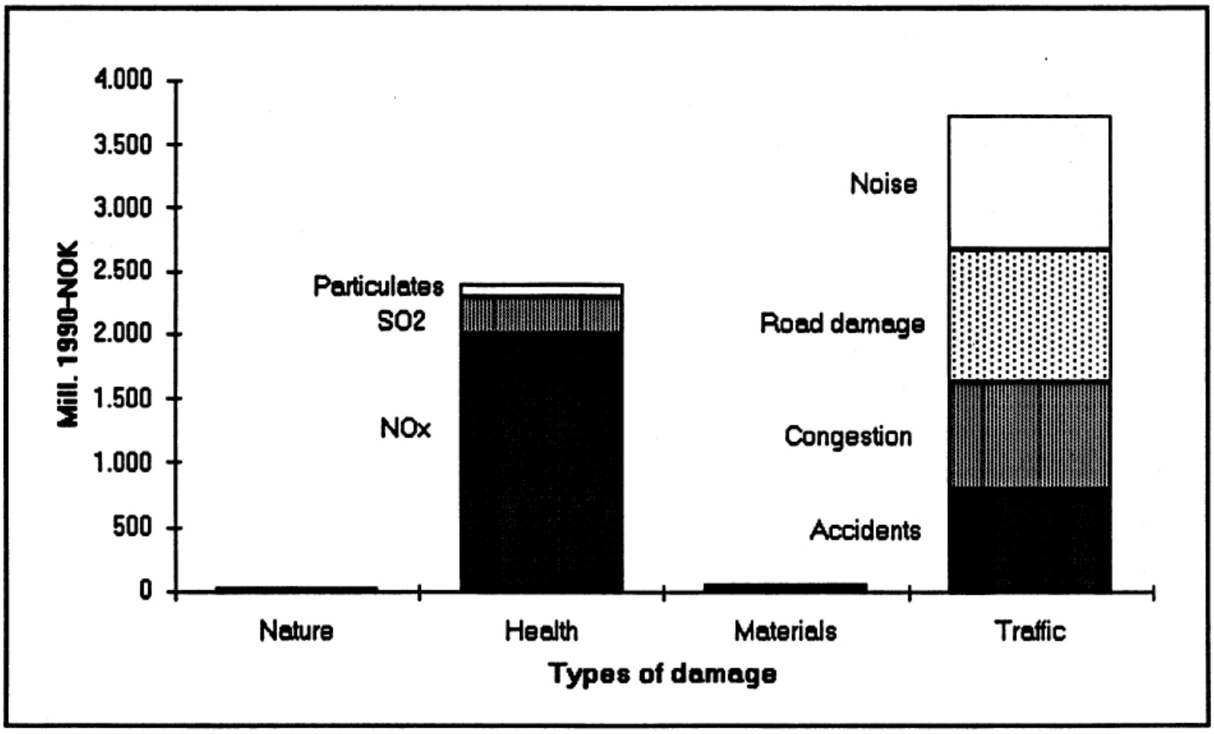
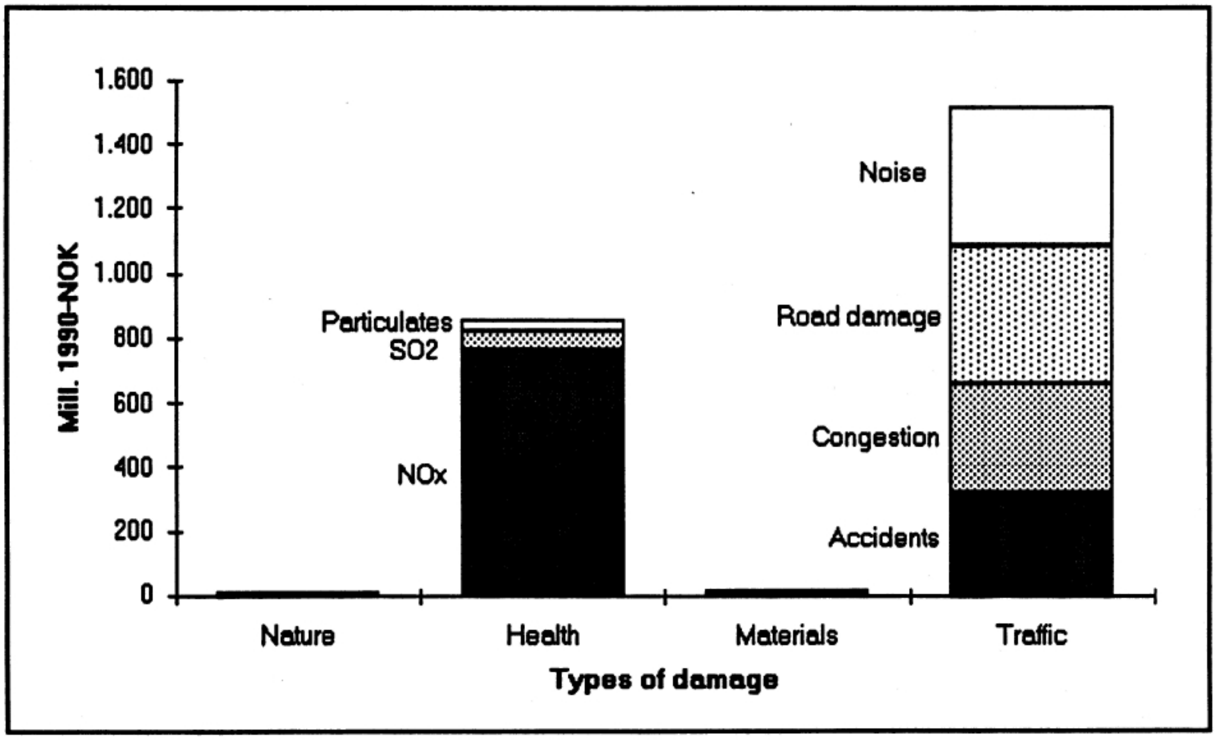


Figure 4. Cost reductions from the reference scenario. The treaty alternative. Year 2000.



The estimates of the cost reductions, which are based on the model described in section 3 with associated point estimates for the parameters, indicates that a unilateral introduction of a tax on CO_2-emissions in Norway will lead to a total environmental and traffic related cost reduction of almost 6 billion 1990-NOK in year 2000. This benefit exceeds the loss in private consumption due to the tax relative to the reference path, which is estimated to be 1,6 billion 1990-NOK in the same year. Total loss in GDP is estimated to be somewhat lower than 13 billion 1990-NOK in the stabilization alternative.

In the treaty alternative the loss in private consumption is reckoned to be 2,6 billion 1990-NOK in year 2000 relative to private consumption in the reference path. The loss in GDP is 3,1 billion 1990-NOK. Both of these losses are almost compensated by the cost reductions, which in this alternative is calculated to be 2,4 billion 1990-NOK in year 2000.

Water courses and forests are relatively little affected by the reduction in Norwegian emissions. Here, the main problem is related to transboundary air pollution, from Great Britain in particular. Reduction in NO_x-emissions gives a substantial benefit in the form of reduced health damages. NO_x-emissions are mainly related to transport activities and are thus located in areas where many people are affected. The health effect of a reduction in emissions of other compounds are relatively minor in comparison.

The calculated benefit of reduced traffic work on the roads must be said to be substantial; over 1,5 billion 1990-NOK in year 2000 in the treaty alternative and more than 3,7 billion 1990-NOK in the stabilization alternative.

4.6 Uncertainties in the benefit estimates

All the benefit estimates quoted above are of course suffering from rather large uncertainties. For instance, the estimates are based on an assumption that a constant fraction of the emissions are causing damage, either to human health, materials or nature. In real life the damages will depend on the localization of the emissions with respect to population centra, forests, etc. Reduction of NO_x-emissions from the fishing fleet will for instance have minimal effects on human health, while a similar reduction caused by reduced traffic in a large city as Oslo will have a relatively major impact, both on human health and on the traffic related costs. Again a similar reduction in road traffic in the rural areas will not imply the same overall benefit. The geographical distribution of road traffic and population is, however, assumed constant in the calculations reported in the last section. If the current trend of urbanization continues in Norway, this implies again that the benefit estimates are likely to underestimate the true benefit. Also, only a subset of all conceivable benefits of reduced use of fossil fuels have been included in the present calculation, see section 3.6 above.

In addition to the above factors, we also have considerable uncertainty in the model parameters, as expressed by the relatively wide uncertainty intervals reported in table 4. It is illustrating to outline the significance of this type of uncertainty by carrying out Monte Carlo simulations. By repeatedly drawing of parameter values from the respective probability distributions, and by calculating the overall benefits in the two alternative scenarios relative to the reference path, it is possible to get an idea of the probability distribution of the total benefit associated with each scenario. However, the detailed probability distributions of the parameters are unknown, only a rough indication of the width of the uncertainty interval is given. For this reason, several Monte Carlo simulations has been carried out based on the schematic assumption that all parameter distributions are either normally distributed, log-normally distributed[2] or uniformly distributed. Each simulation is based on a sample of 1000 independent drawings of parameter values. Table 12 gives some of the results of the simulations, while figure 5 and 6 show the estimated distributions of the total benefit of reducing emissions from the level in the reference alternative in year 2000.

Table 12. Characteristics of the distributions of total cost reductions in the stabilization and treaty alternative relative to the reference alternative in year 2000. Million 1990-NOK.

	The stabilization alternative			The treaty alternative		
	Normal	Log-normal	Uni-form	Normal	Log-normal	Uni-form
Standard deviation	1.410	340.763	1.898	604	138.964	817
Expectation	6.313	32.086	6.491	2.642	13.132	2.728
Minimum	2.151	1.533	1.348	937	638	556
10% fractile	4.531	2.458	3.999	1.882	1.026	1.674
Median	6.305	3.603	6.372	2.633	1.505	2.667
90% fractile	8.107	6.392	9.034	3.426	2.732	3.829
Maximum	13.267	7.029.000	12.423	5.611	2.867.000	5.261

[2] If the stochastic variable Y is normally distributed, X = exp(Y) will be log-normal distributed.

Figure 5. Distributions of total benefits in the stabilization alternative relative to the reference alternative in year 2000.

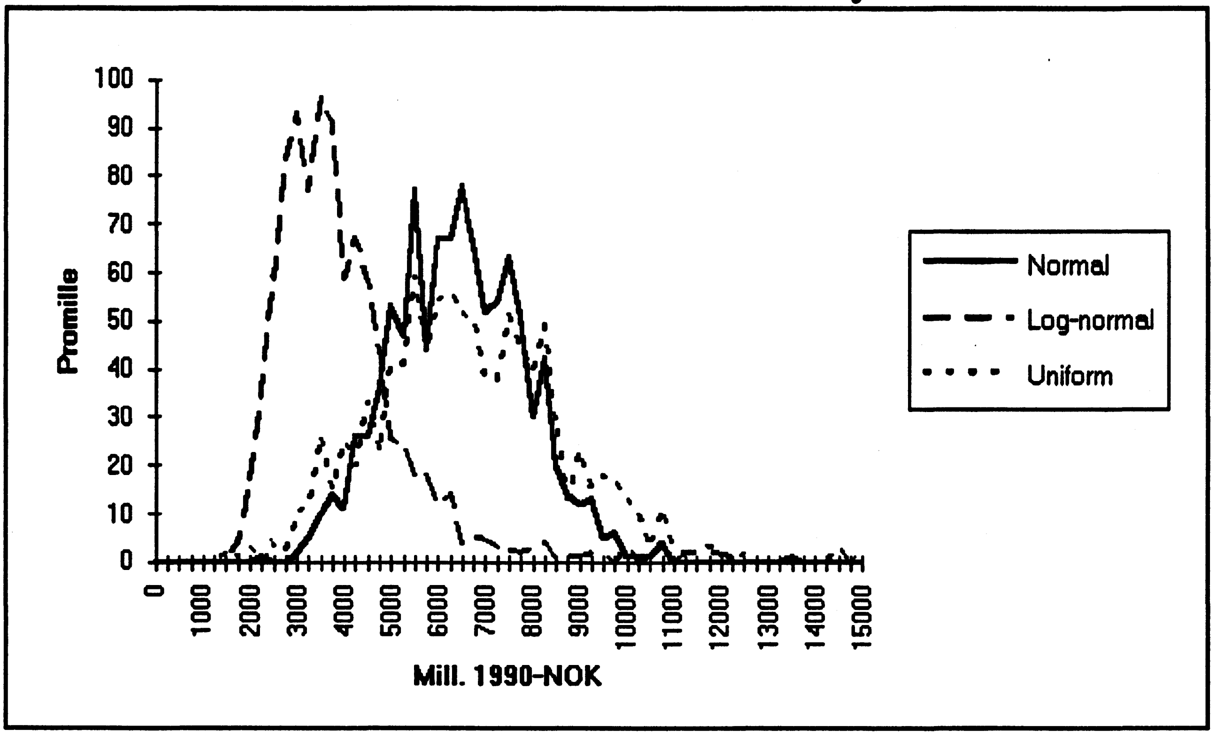
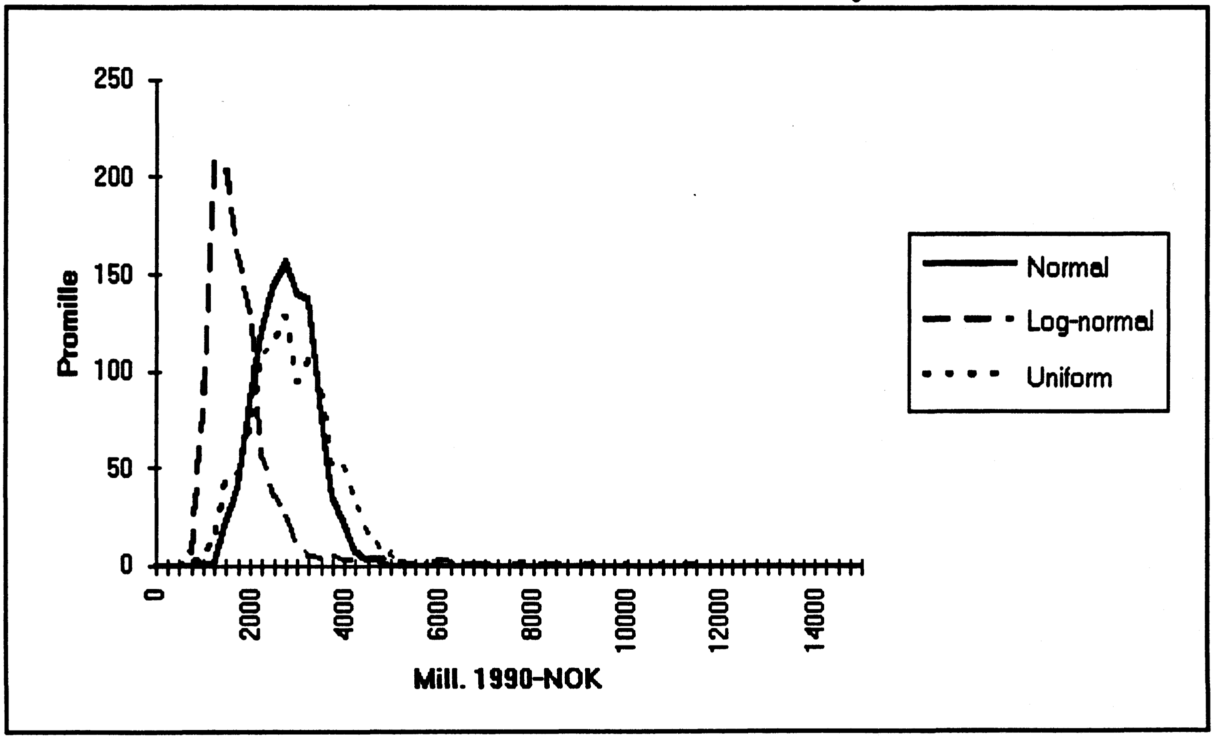


Figure 6. Distributions of total benefits in the stabilization alternative relative to the reference alternative in year 2000.



The simulated probability distributions based on normally or uniformally distributed parameters are seen to be rather similar both in mean values and in term of variances. Expected cost reductions are in the intervals from 2,6-2,7 billion 1990-NOK in the treaty alternative and 6,3-6,5 billion 1990-NOK in the stabilization alternative. These are close to the point estimates of 2,4 and 6,2 billion 1990-NOK, respectively.

The log-normal distribution is characterized by having a long tail towards high values. This explains the high expected values obtained with this type of parameter distribution. The median value is, however, lower than the corresponding values calculated on the basis of normal or uniform parameter distributions.

A conservative estimate for an uncertainty interval for the total benefit is the interval from the 10 per cent fractile to the 90 per cent fractile. This gives that the overall cost reduction in the stabilization alternative in year 2000 is between 2,5 and 9,0 billion 1990-NOK relative to the reference alternative, while similar values for the treaty alternative are from 1,0 to 3,8 billion 1990-NOK.

In addition to the uncertainties treated above, there is of course also uncertainties associated with the economic forecasts and the emission projections themselves. We have not tried to analyze these uncertainties in this report.

4.7 Distributional consequences of a CO_2-tax

An often repeated objection to the introduction of environmental taxes like the CO_2 tax, is that it will have unfortunate distributional consequences. The worry is particularly directed at families with children, households in remote areas of the country and poor families. The distributional impact of an environmental tax will depend on several factors:

1) How the new prices will influence the consumption pattern of the individual household. The various types of households will be affected differently depending on how important those commodities are that experience the highest jump in price as a consequence of the tax.
2) How the welfare gains from an improved environment is distributed among the households.
3) How the generation of income is changed as a consequence of a new structure of the economy with an environmental tax.
4) How the income from the tax is redistributed in the society.

In the following we shall only be concerned with point 1. The distributional impact is measured by relative compensated variation, and is based on consumer surveys of 1.500 households in the period from 1986 to 1988.

4.8 How the consumer prices are affected by an CO_2-tax

A tax on fossil fuels will affect the price of most consumer goods since oil is an important input factor for the production of most goods and services. Table 13 shows the price levels in the stabilization and treaty alternatives relative to the reference alternative in year 2000. Note that world market prices are unaffected by the tax in the stabilization alternative, but increases relative to the reference scenario in the treaty alternative.

Table 13. Changes in consumer prices relative to the reference alternative. Year 2000. Per cent.

	The stabilization alternative	The treaty alternative
Food	0,6	5,9
Beverage and tobacco	0,8	6,5
Electricity	1,3	5,5
Fuel	68,5	40,4
Gasoline, etc	29,7	18,2
Clothing, shoes	0,5	5,9
Furniture, etc	0,6	6,7
Health care	0,2	6,7
Housing	-1,1	4,5
Purchase of cars, etc.	0,6	6,4
Public transport, etc	1,4	7,8
Other commodities	0,8	7,1
Other services	0,2	6,4
Norwegians consumption abroad	0,0	5,5
Total	1,6	6,7

In assessing the impact of the price changes on the welfare, assumptions on the relevant utility function have to be made. In this study we assume that each household maximizes a Cobb-Douglas utility function:

$$U(x_1,x_2,...,x_n) = \prod_i x_i^{a_i}; \quad \sum_i a_i = 1 \qquad (1)$$

under the budget restriction:

$$\sum_i p_i \cdot x_i \leq y \qquad (2)$$

where x_i is the consumption of commodity i, p_i is the price of commodity i, y is total expenditure, and the a_i's are constants.The demand function for commodity i is then given by:

$$x_i(p_1,p_2,...,p_n) = \frac{a_i y}{p_i} \tag{3}$$

Thus, a_i is the budget share of commodity i. Insertion into (1) gives the indirect utility function:

$$V(p_1,p_2,...,p_n) = \frac{Ky}{\prod_i p_i^{a_i}} \tag{4}$$

where K is a constant. Inversion of (4) gives now the expenditure function as a function of prices and utility level V:

$$e(p_1,p_2,...,p_n;V) = \frac{V}{K}\prod_i p_i^{a_i} \tag{5}$$

The welfare effect of going from the reference alternative *(0)* to an alternative path *(1)* can now be measured by the compensating variation:

$$CV = e(p_1^0,p_2^0,...,p_n^0;V^0) - e(p_1^1,p_2^1,...,p_n^1;V^0) \tag{6}$$

which tells us how much total expenditure has to increase or decrease in order to keep welfare constant under the change of prices.

In the case of the stabilization alternative, a typical household must be given a compensation of 3 per cent in order to be indifferent between this alternative and the reference path in year 2000, see table 14. In the treaty alternative the price increase is larger, and the households require a compensation of 7,2 per cent.

In the upper part of the table we see that the compensation necessary is weakly increasing with income. This is mainly due to the fact that the budget share of gasoline is increasing with increased income. A partial price increase in gasoline therefore serves to equalize income differences. The increase in the price of electricity and fuel oil counteract this effect, since these commodities have decreasing budget shares with income. Since the relative increase in the price of gasoline is largest in the stabilization alternative, the equalizing effect of the CO_2 tax is most prominent in this alternative. The gap in the compensations between those that are hardest hit by the tax and those that are less affected is 0,8 per cent in this alternative, while in the treaty alternative the gap is only 0,3 per cent.

Table 14. Distributional effects of environmental taxes. Per cent change in compensated variation. Year 2000.

		The stabilization alternative	The treaty alternative
All households		3,0	7,2
Households by income	< 50.000	2,3	7,0
	50.000-109.999	2,4	7,0
	110.000-159.999	3,0	7,2
	160.000-219.999	3,1	7,3
	220.000-299.999	3,1	7,3
	>300.000	3,1	7,3
Households by type	Single	2,4	7,0
	Couple without children	3,1	7,3
	Couple with children under 6 years	2,6	7,0
	Couple with children from 7 to 19 years	3,1	7,3
	Single with children	2,4	7,0
	Others	3,2	7,4
Households by region	Oslo and Akershus	2,6	7,1
	Eastern part except Oslo and Akershus	3,2	7,3
	Agder of Rogaland	2,9	7,2
	The West coast	2,6	7,1
	Trøndelag	3,2	7,3
	North-Norway	3,2	7,3
	Rural areas	3,4	7,4
	Urban areas except Oslo, Bergen and Trondheim	3,0	7,2

A similar pattern is observed when the households are grouped according to type. Also in this case the relative advantage goes to groups that one normally wants to treat favorably; i.e. single parents and households with small children. The reason is that these households are using private cars relatively sparingly, but also the relative decline in the price on housing in the two alternatives benefit these groups.

When the households are grouped according to localization, the distributional consequences of the environmental tax become even smaller. This is due to the constancy of the consumption pattern among the different regions of Norway.

Summarizing, we find that the calculated welfare losses associated with the introduction of a CO_2-tax are relatively homogeneously distributed. However, this conclusion is contingent on the use of a specific utility function (Cobb-Douglas), and another function might have changed the conclusion. Also, the distribution of the welfare effects associated with a better environment is also expected to play a part when the total effect of the tax is to be estimated.

5 Summary and conclusions

The consequences for the Norwegian economy of using environmental taxes, can be estimated as the difference between the development in a reference path without such taxation and alternative paths with environmental taxes. In traditional economic models the added taxation will normally lead to reduced economic growth. When one nevertheless contemplate introducing environmental taxes, the reason is of course a belief that the total benefit of such taxes outweighs the total cost. Many of the benefit components are, however, difficult to quantify, such as effects on general well-being, etc. But, some of the benefits are possible to estimate, at least in a rough manner.

In this paper we have looked at effects associated with a change in emissions to air of some pollution compounds and changes in the amount of road traffic due to two alternative implementations of taxation aimed at reducing the emissions of the greenhouse gas CO_2. In one alternative Norway unilaterally reduced its national emissions, while in the other alternative it was assumed that an international treaty was implemented to reduce or at least stabilize global CO_2 emissions. The results, calculated on the basis of the methodology exposed in this paper, is of course highly uncertain. Monte Carlo simulations were employed in order to analyze some of the consequences of the parameter uncertainty underlying the benefit calculations. The main results are summarized in table 15.

Table 15. Changes relative to the reference path in year 2000. Billion 1990-NOK

	The stabilization alternative	The treaty alternative
Loss in GDP	13,0	3,1
Loss of private consumption	1,6	2,6
10 % fractile of benefits	2,5	1,0
Point estimate of benefits	6,2	2,4
90 % fractile of benefits	9,0	3,8

The estimated benefits of reducing local pollution of SO_2, NO_x, CO and particulate matter seems to at least go some way toward mitigating the economic costs often associated with environmental control policies.

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