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Valuation of environmental benefits in Norway: A modelling framework

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Abstract[1]

When environmental regulations of emissions to air are contemplated, it is of course because one believes that the benefit outweighs the cost of the control policy. Unfortunately, information on the value of cleaner air is often partial, covering only one or a few types of damage from air pollution. Furthermore, the data are usually presented in a manner making it difficult to compare results across cost-benefit studies. In this paper we present a model for assessing the value of changes in emission to air of local air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter in Norway. The assessment covers damage to forest and freshwater fish due to acid precipitation, damage to common building materials due to an acid atmosphere and health damage. In addition, some commonly neglected external costs of road traffic such as the cost of accidents, congestion, damage to roads and noise generation, are also covered in the analysis. The model is applied to changes in emissions to air and the volume of road traffic in Norway over the period 1973-1991. The model is constructed to be used in conjunction with macroeconomic models used by the Norwegian government.

[1]**Key words**: Environmental regulations, cost-benefit analysis

Table of content

1. Introduction

It has become common in many countries to precede specific proposals for environmental regulations with an assessment of the benefits to be had from the regulations. Thus, after many years of environmental regulation there exists quite a lot of information on the economic benefits associated with an improved state of the environment. Early North-American surveys are Kneese (1984) and Tolley et al. (1982). Unfortunately, information on benefits of a cleaner environment in Norway is scattered among many sources and presented in a variety of formats making it difficult to compare and aggregate the data. Most of the available data stem from government institutions or government funded research. The data are used as a basis for decision making, but are usually of a partial nature and do not invite to broader studies of links between the environment and the economy.

This paper surveys some of the information on the value of improved air quality in Norway, and brings it into a common framework making it possible to compare benefits both across types of benefits and across emission compounds. It should be recognised, however, that the data quality is often poor. Nevertheless, the information compiled is the best we have got at the moment. Also, by organising the data in a systematic manner facilitates consistent analysis by the decision makers. This is of value in itself. Furthermore, the macro approach to cost-benefit analysis of environment-economic policy options adopted in this paper might stimulate the measuring and modelling of the value flows so far missed by the national accountants.

The data are employed in a calculation of changes in historical air pollution costs for the years between 1973 and 1991. A companion paper (Alfsen and Glomsrød, 1992) explores the data set in an analysis of future costs and benefits from a tax on carbon emissions to air.

The air pollutants we are concerned with are sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulates. These are all compounds emitted during combustion of fossil fuels to a greater or lesser extent. For some of them, SO_2 in particular, other non-energy related sources are also of importance. The types of environmental damage covered in this paper are damage to forests and lakes due to acid deposition of sulphur and nitrogen, corrosion of certain types of materials (capital equipment), and damage to health.

Use of fossil fuels have other external effects besides those connected with emission of pollutants to air. Chief among these are probably the external effects associated with road traffic, such as congestion, accidents, damage to roads and generation of noise. A reduction in use of fossil fuels for road transport will reduce these external costs. These non-emission related benefits come in addition to the benefits reaped from a reduction in the combustion related emissions.

In section 2, we briefly present the data on which the benefit assessments are based. A more detailed documentation of the data base is given (in Norwegian) in Brendemoen et al. (1992). The data are summarised in a model presented in section 3. The model is then used for estimating the variation in external costs in Norway over the last 2 decades in section 4.

2. Assumptions underlying the calculations of benefits from reduced emission of local air pollutants and reduced road traffic

2.1. Forest damage

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

The commission estimates that biomass losses in Norwegian forests in 1988 due to excessive air pollution amount 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 damage also implies a loss in the recreational value of the forests. This loss has not been separately valued, but referring to travel cost studies of the recreational value of fresh water fishing, the commission estimates the present recreational loss of forests to be 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, see next sub-section.

At the outset, the ratio of forest acidification damage from one ton of NO_x and one ton of SO_2, is approximately 1:2 (Syversen, 1988). However, recognising that NO_x also contributes to forest damage through the formation of ozone (O_3), NO_x should be given greater weight than this. In this report we therefore assume that the marginal forest damage from NO_x, and SO_2 are equal.

The critical load of sulphur and nitrogen is assessed by experts to be 80 and 60 per cent below the 1980 deposition levels, respectively. Below these levels, no damage is assumed to occur from air pollution. In calculating the damage 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. Due to high transboundary fluxes of acid compounds, Norway is by herself incapable of reducing the deposition levels below the critical loads.

2.2. Acidification of lakes

The value of fish catches and sport fishing possibilities in rivers and lakes in Norway has been estimated to be approximately 4 thousand million 1987-NOK on an annual basis (Strand, 1980, Syversen, 1988). About 10 per cent of the area of Norway show signs of heavy damage from acidification (Syversen, 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 catches valued at 10 million 1987-NOK annually, and loss of recreational value estimated to be between 50 and 120 million NOK per year. As in the case of forest damage, 10 per cent of the damage to fish in rivers and lakes is ascribed to Norwegian emissions of acid compounds. Including a reasonable assessment of the uncertainty intervals, we then find that total damage inflicted by present Norwegian emission of SO_2 and NO_x to lakes and rivers, amounts to between 29 and 70 million 1987-NOK annually.

2.3. Damage from corrosion of capital equipment

Several types of emissions to air cause damage to materials. In this report, we only consider damage caused by SO_2 emissions to galvanised and painted steel and painted wood. The estimates are based on Glomsrød (1990). Here, direct corrosion costs due to domestic emission of SO_2 were 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 damage 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 to be of the order of 100 million NOK annually.

Including the substantial uncertainty associated with the above estimates, we assess the annual corrosion costs in 1985 to be in the interval from 0 to 640 million NOK. We assume the damage to be linearly related to national emissions of SO_2.

2.4. Health damage caused by local air pollution

Estimates of marginal health costs associated with pollution of SO_2, NO_x, CO and particulates are based on studies of local conditions in some city areas (Oslo and Sarpsborg/Fredrikstad) 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 recommended maximum levels (thresholds) to above these levels. These thresholds are based on recommendations made by the World Health Organization (WHO).

At that time, SFT based their cost estimates on several studies carried out by Lave and Seskin on the link between sulphur concentration in air and health costs due to increased mortality and morbidity in USA (see Lave and Seskin, 1970, 1977, Seskin, 1979). These cost estimates were then reduced by 50 per cent to adjust for the lower concentration levels prevailing in Norway compared to USA.

Concerning health damage associated with the other polluting compounds, NO_x, CO and particulates, SFT takes as a starting point that the recommended maximum levels for these compounds are determined by requiring that the marginal damage at the threshold levels coincide with the marginal damage of SO_2. The estimates obtained in this manner are then adjusted to take care of some special considerations. For instance, people exposed to levels above recommended health standards for NO_x and CO are frequently experiencing concentrations far above these thresholds. The final estimates compare favourably with willingness-to-pay surveys carried out in Norway in connection with proposed introduction of catalytic converters in private cars (Strand, 1985).

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 the individual cost estimates referred to above, it is possible to establish an estimate of the marginal health cost of SO_2, NO_x, CO and particulate emissions.

The estimates of marginal health costs are based on studies of past and futures air pollution in Oslo, the capital and largest city of Norway. Table I provides some of the data and results from the studies. In applying the marginal health cost estimates on a national scale, two cases are considered. In one case it is assumed that damage to health due to air pollution occurs only in Oslo. In the other case such damage is assumed to occur in the five most densely populated areas of Norway: Oslo, Bergen, Trondheim, Stavanger and Bærum. This gives an interval for the total marginal costs of health damage.

Table I. Data used for estimation of marginal health damage

	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 (0,8-3,3)	4,0 (1,4-7,7)	6,0 (2,2-11,0)	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)

2.5. Some non-emission related external costs due to road traffic

The externalities of road traffic are many and substantial. In addition to be an important source of air pollution, road traffic impose costs on society by road accidents, wear and tear of the roads, congestion and noise. The costs of air pollution are 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 policies to combat air pollution in Oslo (SFT, 1987), recommended several actions directed at reducing the volume of road traffic. Together, these actions were estimated to give a reduction in road traffic of between 20 and 30 per cent from a forecasted level in year 2000. This reduction should in turn reduce the number of accidents, damage to roads, congestion and noise coming from road traffic. SFT also gives figures for 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 are meant to include effects associated with congestion, damage to roads, traffic accidents and noise. As to traffic accidents, values of lives are set equal to their production potentials. Time costs associated with congestion do not include costs due to time loss for public transportation and pedestrians.

2.6. Cost components not included

In the above description some of the more important cost elements associated with the use of fossil fuels are hopefully covered. A number of negative effects are, however, omitted, mainly due to lack of data.

Neither the direct impact on the national production potential nor the global effects of increased climate change is included. The World Commission of Economy and Development (WCED, 1987) recommended drastic reductions in use of fossil fuels in the industrialised countries for this reason, something which indicates that the costs are potentially large, although the Norwegian contribution to global warming is negligible in a national context.

Ozone near the ground level is probably a significant source of health damage, but this type of damage is not included in the above discussion. Recent research indicates that damage might occur at relatively low concentration levels. Also, ozone is reducing biological growth, a cost that is not included in this report except in the assessment of forest damage.

Material costs in this paper do not cover damage to cultural important buildings and monuments. Damage to concrete constructions from deposition of sulphur and ozone damage to rubber, plastic materials and textiles are not included either. Furthermore, costs of soiling, smell and lower visibility in a polluted atmosphere are neglected.

3. A summary of the assessment of marginal environmental costs

Table II presents a summary of the above discussion in the form of a model for calculation of the marginal costs associated with changes in emissions to air and use of transport fuels.

The calculated parameter values entering the model are presented in table III, which also contain estimates of the uncertainty intervals. Note that the estimates of marginal costs are based on an assumption of linearity of the damage within a limited range of emission variations. Also, constant real prices of environmental benefits are assumed, although they probably rise with income and scarcity of environmental goods and services.

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

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

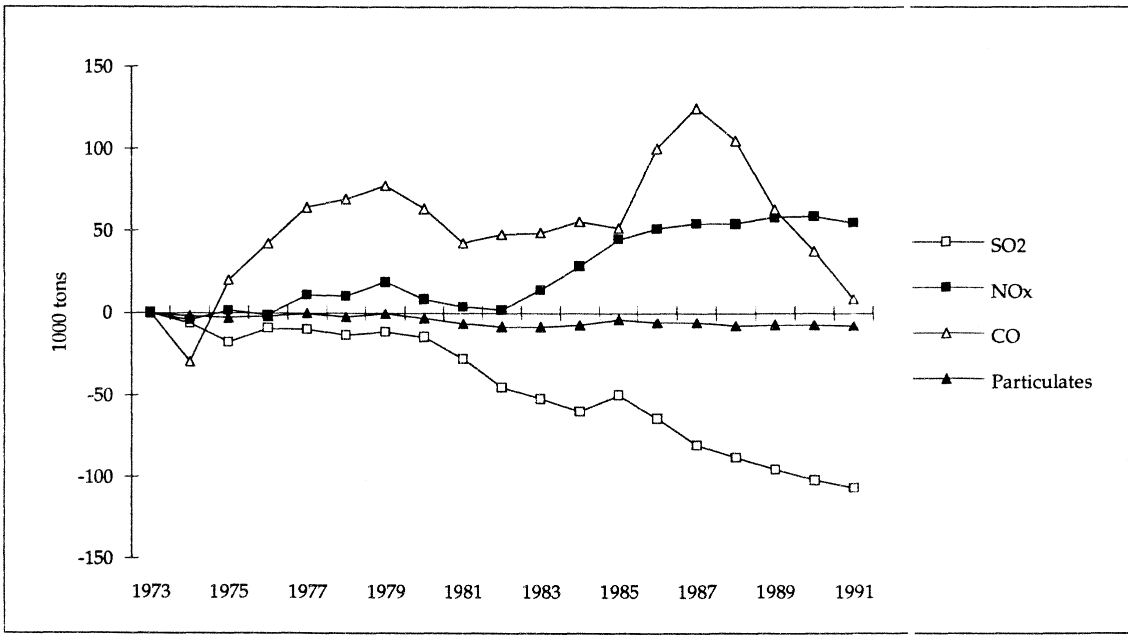
Table III. Model parameters. Marginal environmental and traffic costs in thousand 1990-NOK (b_j^i). Share of emissions causing health damage in per cent (a_j)

Type of costs	Parameter	Low	Medium	High
Acidification of water	b_1	0.11	0.19	0.31
Acidification of forests	b_2	0.41	0.49	0.51
Health damage from SO_2	b_3^{SO2}	59	155	259
	a_m^{SO2}	9	18	27
	a_s^{SO2}	3	7	11
Health damage from NO_x	b_3^{NOx}	194	555	1 070
	a_m^{NOx}	8	18	28
	a_s^{NOx}	3	6	10
Health damage from CO	b_3^{CO}	0.06	0.1	0.31
	a_m^{CO}	9	20	31
	a_s^{CO}	5	14	23
Health damage from particulates	b_3^{Prt}	194	555	1 070
	a_m^{Prt}	6	7	8
	a_s^{Prt}	8	17	26
Corrosion	b_4	0	4.2	8.4
Traffic accidents	b_5	660	1 530	4 370
Congestion	b_6	0	1 640	3 280
Damage to roads	b_7	0	2 050	4 090
Noise	b_8	440	760	1 080

4. Growth in environmental damage and external costs of road traffic from 1973

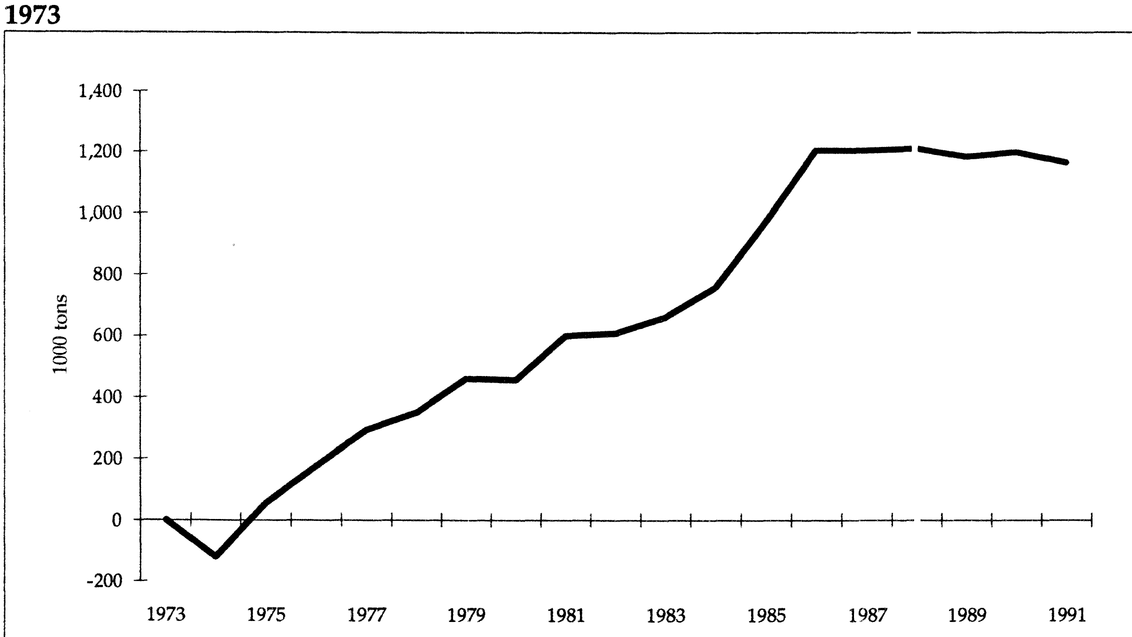
Figure 1 summarises the development in national emissions of SO_2, NO_x, CO and particulate matter over the period 1973-1991 in Norway.

Figure 1. Changes in emissions to air since 1973



In 1991, only the emissions of NO_x are significantly above the corresponding emission level in 1973. SO_2 emissions have been reduced by more than 100 thousand tons over the period, while no great changes have occurred in the emissions of CO and particulates, although the CO emissions were significantly above the 1973 level during most of the 1970's and 1980's. Figure 2 depicts the development in use of gasoline and auto diesel over the same period.

Figure 2. Changes in use of gasoline plus auto diesel since 1973



Together with information on the stock of buildings, the model outlined in the tables II and III, forms the basis for the estimated yearly change in benefits/costs in figure 3. For ease of exposition, the figure only shows costs by four aggregate groups of damage. Table IV provides a more detailed breakdown of the accumulated costs ascribed to changes in emissions and road traffic in 1991 relative to 1973.

Figure 3. Emission and traffic related costs. Changes since previous year.

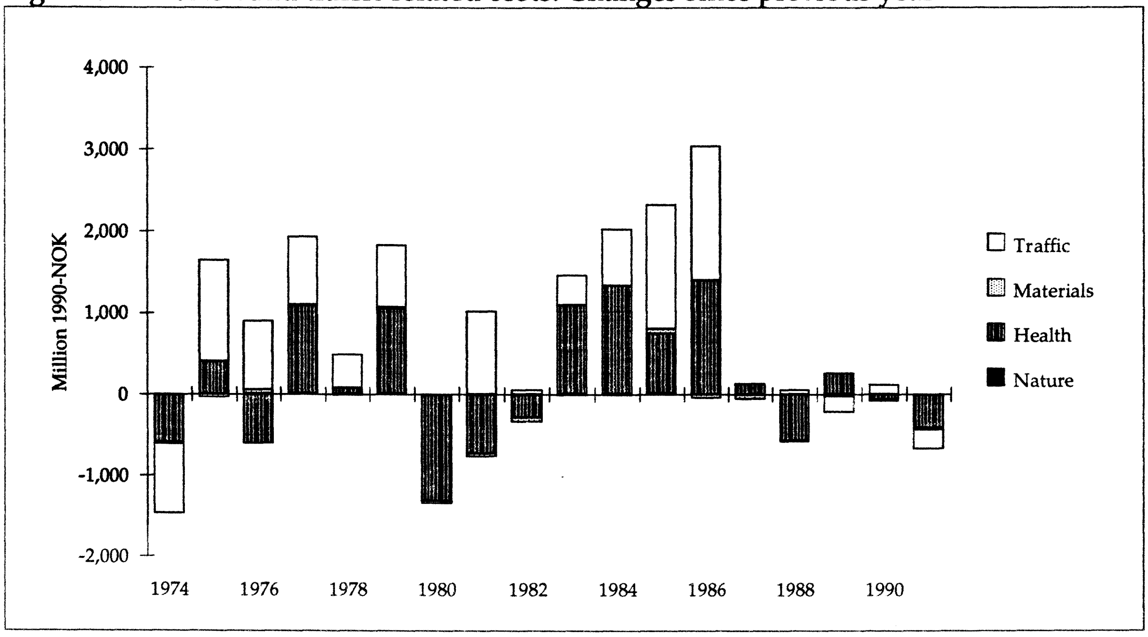


Table IV Accumulated costs in 1991 relative to 1973. Million 1990-NOK

Acidification of fresh water	-10
Acidification damages to forests	-25
Health damage of SO2	-1 173
Health damage of NOx	4 920
Health damage of CO	0
Health damage of particulates	-736
Corrosion damages	-218
Traffic accidents	2 086
Road congestion	2 295
Damage to roads	2 913
Noise from road traffic	920
Total	10971

From figure 3 we observe that

- annual changes in costs are almost exclusively related to changes in the non-emission related costs of road traffic and health damage from air pollution. Changes in the damage to nature included so far and corrosion damage due to changes in Norwegian emissions are negligible compared to traffic and health damage.

- most of the yearly changes in costs are positive indicating increased damage, although the trend the last five years is close to zero.

Table IV indicates substantial benefits from the reduction of SO_2 emissions, mainly related to reduced health damage. Unfortunately, this is more than offset by the increase in NO_x emission. Road congestion, damage to road and traffic accidents are all substantial elements in the aggregate 10 thousand million 1990-NOK cost increase estimated for the period from 1973 to 1991. The total cost increase represents somewhat more than 3 per cent of the corresponding increase in Gross Domestic Product (GDP) over the same period.

The above estimates are of course highly uncertain. In table III a range of values for the model parameters was indicated. This information on the uncertainty has been applied in a Monte Carlo simulation of the total cost increase from 1973 to 1991. The simulation is done under the assumption of independence among the parameters and uniform distributions over the respective uncertainty ranges. Figure 4 shows the frequency distribution of total accumulated change in cost in 1991 relative to 1973, while table V reports some summary statistics. Figure 4 also compares the simulated probability distribution with a normal distribution with the same average and standard deviation as observed in the sample.

Figure 4. Distribution of environmental costs in 1991 relative to 1973

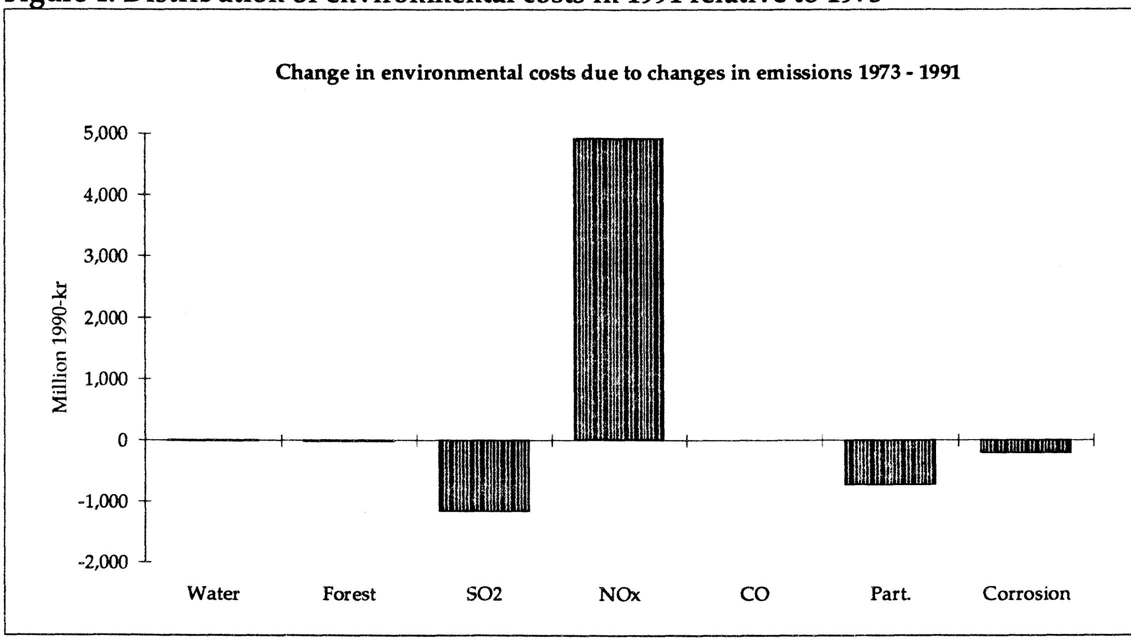


Table V. Summary statistics of Monte Carlo simulation. Billion 1990-NOK

Sample size	1 000
Standard deviation	4.03
Mean	12.61
Harmonic mean	11.14
Median	12.39
Quartiles - min. value	2.88
25 %	9.92
Median value	12.39
75 %	15.25
Max. value	24.66

Although the uncertainty is substantial, the conclusion is still that increased use of fossil fuels over the period 1973-1991 has inflicted substantial costs on the society.

Discussions on how to stabilise and even reduce greenhouse gas emissions are quite intense at the moment. A side effect of reducing these emissions is to reduce emissions of the more traditional pollutants considered in this paper: SO_2, NO_x, CO and particulate matter. Thus, to stabilise or reduce the growth in the emission of greenhouse gases will have additional benefits in addition to those accruing from a less severe climate change. The estimation of these secondary benefits is the subject of a companion paper (Alfsen and Glomsrød, 1992).

David Pearce has in a recent paper (Pearce, 1992) developed similar estimates of secondary benefits from carbon control for the United Kingdom. He concludes that "...the estimates of secondary benefits are remarkably similar between Norway and the UK despite the use of totally independent damage function estimates and emission coefficients." Although both his and our analyses are very simplistic, it is comforting to observe an agreement on the order of magnitude in the benefit assessments.

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