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Natural Resource Accounting and Analysis in Norway

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Abstract:
The paper briefly outlines the content and structure of the Norwegian natural resource accounts as these have been developed over the years. Initially, work on the natural resource accounts was motivated by a desire to improve the management of natural resources within a national context. Over time, it was gradually recognised that lack of systematically organised data is not the main obstacle to a satisfactory resource management in Norway. Therefore, more emphasis is now put on trying to integrate environmental and resource issues within the traditional economic planning tools, highlighting the linkages between economic development, natural resource use and environmental concerns. The integration secures consistency between economic analysis and analysis of important environmental and resource issues such as air pollution and energy use. In our view this provides better support for decision makers than the often suggested proposal of "correcting" GDP or other aggregates of the national accounts.

Examples of integrated environment-energy-economy models will be presented together with some empirical applications of these models. It will be shown that environmental control policies directed at one economic sector can have important repercussions for the rest of the economy. Thus, in order to capture the total economic effect of a change in policy, a general economy wide model should be used. Tentative calculations of secondary benefits associated with climate policies are also presented.

Overall, the aim of the paper is to illustrate the importance of organising the natural resource accounts in a manner that facilitates its usefulness for analytical purposes. This will enhance the probability that the linkages between economic, natural resource, and environmental issues are brought to the attention of the decision makers. Quite often it turns out that one can show, even with a limited set of data, that proper management of natural resources and the environment makes economic sense.

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1. Introduction

In the early 1970s concern for the management of natural resources in Norway was accompanied by several political conflicts. Thus, decades of intensive expansion of the hydro-power system gradually lead to increased opposition from conservationists seeking to preserve at least some of the more spectacular waterfalls. Oil and gas were discovered outside the Norwegian coast and, with rising petroleum prices, this augmented the concern for proper management of these valuable resources. Some of the fish stocks were over-exploited, threatening the resource base of the coastal population of Norway. Large reforestation programs had been initiated although production from already existing forests was not fully utilised. Agricultural questions, among them the question of the optimal degree of self sufficiency in agricultural products, were raised, and plans for the use of scarce arable land and soil were requested.

These concerns initiated work on natural resource accounting in Norway some twenty years ago. The aim was to ensure a better long term resource management by:

- providing new and better suited data for monitoring of resource use and long term management purposes,
- avoiding double efforts in data collection and analysis,
- providing data in a form compatible with traditional economic statistics to facilitate integrated analyses of natural resource and economic issues
- developing a standard procedure for presentation of data and analyses on natural resources and the environment.

Thus, initially, the natural resource accounts were perceived as tools for improving the resource management. However, not all types of natural resources fit naturally into an accounting framework. Typically, data on material resources where *quantity* is of prime importance is conveniently organised as accounts, while data on environmental resources, where the *quality* of the resource is of more concern, is better served by other types of data organisation[1]. Here, only the Norwegian material resource accounts and the emission inventories will be described in some detail. The reason is that these are the parts of the resource and environment data base that at present are utilised most systematically for analytical purposes.

The rest of the paper is organised as follows. In section 2 we briefly describe how the work on natural resource accounting is organised in Norway, and how this work has developed since it started in the 1970s. In section 3 the structure of the accounts is presented together with examples from the energy accounts for Norway. In section 4 we describe some elements of an integrated economy-energy-emission model and its data base, before we in section 5 present results from several studies based on this type of model. Section 6 briefly offers some concluding thoughts on the use of natural resource accounts.

2. Organisation of the work on the natural resource accounts

The work on the Norwegian natural resource accounting system was initiated by the Ministry of Environment in the early 1970s, and the system has since 1978 been operated and further developed by Statistics Norway (SN). Statistics Norway is also responsible for national accounting and development and operation of some of the economic planning models employed by the Ministry of Finance. Co-ordinating the work on the natural resource accounting with ongoing work on tools for economic planning has been useful for a number of reasons:

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[1] See for instance Alfsen et al. (1992a) and Alfsen and Sæbø (1993) on the topic of environmental indicators.

- Locating the work on natural resource accounting to SN has assured access to statistical expertise and closeness to primary statistics used in the development of the natural resource accounts.
- In SN, the resource accounting framework was naturally based on existing economic standards and sector classification schemes, thus ensuring general consistency in the sectoral classification of economic and resource related data and statistics. In particular, the linkage to the UN Standard of National Accounts (SNA) has made it possible to integrate important natural resource variables and relations within already existing macroeconomic models,
- Use of a common set of economic standards and models in the analysis of resource issues has facilitated the communication between the ministries responsible for the management of the economy and the ministries responsible for the management of the natural resources; e.g. the Ministry of Finance and the Ministry of Environment.

2.1. Historical development

In the initial phase of resource accounting, considerable efforts were made to establish resource accounts for *energy, fish* and *land use* (Alfsen et al. (1987), SN (1981), Lone (1987, 1988)). In addition, less detailed accounts were made for *minerals, forests* and *sand and gravel*. The accounts consisted of three sub-accounts covering

1. reserves
2. extraction, transformation and trade
3. domestic use of the resources

and were kept in *physical units*. In all parts of the accounts emphasis was put on consistency with the classifications and definitions of the national accounts. Later, based mainly on the energy accounts, - *inventories of emissions to air* have been established.

Thus, a relatively large number of resources were covered in the initial phase. The main reason for this was a generally growing concern for the scarcity and mismanagement of these resources, and a belief that one of the greatest stumbling blocks for a rational management was the lack of adequate and systematically organised data. These concerns have, however, changed over time.

The two oil price shocks of the 1970s and the reactions to these shocks seemed to indicate that there was no immediate danger of depletion of the non-renewable resources. It became clear that dooms-day prophecies brought forward by for instance the Club of Rome disregarded important regulating factors brought about by responses to resource prices. Thus, problems with the management of natural resources turned out to be different from those which originally motivated the establishment of the resource accounts.

It also emerged that the problems of attaining a rational management of natural resources were not primarily due to lack of data. Rather, political and bureaucratic bodies appeared to resist the introduction of new and partly unknown constraints and considerations in the existing planning and decision making procedures.

Finally, the effort necessary to develop and maintain a comprehensive accounting system was clearly underestimated in the first period.

This background, together with experiences with the government's use of the resource accounts, have resulted in *a stronger focus on a few economically and politically important issues*; namely management of Norway's considerable *energy resources*, and important environmental issues like *air pollution*, where several international protocols regulate national emission levels. The forest and fish accounts are, however, continued on a minimum basis, while accounting of land use and minerals at present has been discontinued.

Presently, there is a continuing effort to integrate resource and environmental issues into the *existing* economic planning procedures in Norway. This is seen as a more useful approach than striving for establishment of parallel and more or less separate resource and environmental planning procedures.

The integration is attempted carried out by linking data in physical units on exploitation and use of natural resources and the environment with economic data (e.g. the national account) and traditional economic models. Thus, over the years, the sectoral macroeconomic models employed by the Ministry of Finance for medium and long term economic projections have been disaggregated and extended to include energy and air pollution variables. Integrated forecasts are now routinely made of economic development, demand for energy and the consequences for emissions to air of several important polluting compounds[2] (i.e. sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), non-methane volatile organic compounds (NMVOC), particulate matter, lead (Pb), methane (CH_4) and nitrous oxide (N_2O)).

Summarising, the development in natural resource accounting in Norway has been from a broad coverage of many resource categories to a more selective approach with greater emphasise on analysis and integration of resource issues in economic planning.

3. The structure of the Norwegian resource accounts

The Norwegian resource accounts are kept in *physical units* and comprise the following three sub-accounts: i) Reserve accounts, ii) Extraction, conversion and trade accounts, iii) End use accounts. The meaning of the term *reserve* is clarified in Figure 1 below (McKelvey's box).

Figure 1. McKelvey's box

<table>
<tr><td rowspan="2"></td><td colspan="2">Physical resource base</td></tr>
<tr><td>Discovered</td><td>Undiscovered</td></tr>
<tr><td>Economic</td><td>Reserves</td><td rowspan="2"></td></tr>
<tr><td>Sub-economic</td><td>Resources</td></tr>
<tr><td>Non-economic</td><td colspan="2">Resources not likely to be economic in the future
or
not obtainable by present technology</td></tr>
</table>

By reserves is meant discovered resources that are economically extractable with today's technology. The reserves will vary from year to year due to extraction, price fluctuations, technological development and new discoveries. The overall structure of the material resource accounts is illustrated in Figure 2.

[2] See for instance the early attempt in the Government's Long Term Programme for the period 1974-1977 (Ministry of Finance, 1972), or the lastest application in the current Long Term Programme for the period 1994-1997 (Ministry of Finance, 1993). Other studies include Bye et. al. (1989), Moum (ed.)(1992) and the white papers NOU (1988) and NOU (1992) from the Green Tax Commission. Still other studies are cited later in this paper.

Figure 2. Structure of the material resource accounts

I. Reserve accounts	
Beginning of period:	Resource base Reserves (developed, non-developed) Total gross extraction during period Adjustments of resource base (new discoveries, reappraisals) Adjustment of reserves (new technologies, cost of extraction, transport, etc., resource price)
End of period:	Resource base Reserves (developed, non-developed)
II. Extraction, conversion and trade accounts (by sector):	
	Gross extraction - Use of resource in extraction sectors = Net extraction Import - Export =Net import Changes in stocks
For domestic use:	Net extraction + net import ± changes in stock
III. End use accounts (by sector):	
	Domestic use by economic sectors

Reserves of biotic resources are usually called *stocks*. In this case the stock accounts show how the stocks change due to recruitment and growth, revaluation (because of better knowledge), natural death and extraction (catch or harvest).

A couple of points is worth noting with regard to the structure illustrated above. *First*, the accounts consist of more than the reserves accounts. This is essential when it comes to using the accounts for management purposes. It is then important to know *who* are going to be affected by a change of policy. The end use account is essential for this kind of analysis. *Second*, although the accounts are kept in physical units, they are complemented with price information whenever *market prices* are available, allowing tables in monetary terms to be generated. *Third*, the sectoral structure of the extraction, conversion and trade accounts and the end use accounts follow the classification in SNA. This facilitates the inter linkage between the resource accounts and the national accounts. *Finally*, the accounts for the different resources differ with respect to details in the various parts of the accounts (I, II and III). Thus, a biotic resource like fish requires a relatively detailed reserve account with specification of age structure and localisation of the different fish stocks. The end use part of the accounts is, however, quite simple, since relatively few sectors use fish as an input factor in their production. For energy the situation is different, since energy is an important input factor in almost all sectors of the economy. This is illustrated in the three tables below, showing the energy accounts for Norway for the year 1990. Note that reserves have been subdivided into non-developed and developed reserves.

Table 1. Energy reserves account 1990

	Coal	Oil	Natural gas	Hydro power
	Mill.tonnes	Mill.tonnes	Bill. Sm^3	TWh
Non-developed reserves				
Beginning of period		203	896	42.7
Adjustments of resource base		18	0	-0.1
Planned developed		103	17	
Developed		-29	-4	-0.3
End of period		295	909	42.3
Developed reserves				
Beginning of period	13.3	779	365	107.8
Adjustments of resource base		90	-17	
Developed		29	4	0.3
Gross extraction	-0.3	-82	-28	
End of period	13.0	816	324	108.1
Developed and non-developed reserves at end of period				
	13.0	1,111	1,233	150.4

Table 2. Extraction, conversion and trade 1990

	Coal 1000 t	Coke 1000 t	Wood, waste, etc. 1000 toe	Crude oil 1000 t	Natural gas Mill. Sm^3	Other gases and LPG 1000 toe	Petrol 1000 t	Paraffin 1000 t	Middle distillates 1000 t	Heavy oil 1000 t	Elec-tricity GWh	District heating GWh
Extraction of coal												
Production	303											
Intermediate use									-4		-22	
Extraction of oil and gas												
Production				80,659	27,642	962	201					
Intermediate use					-2,037				-197	-14	-95	
Hydro power production												
Production											121,382	
Intermediate use							-3		-5		-1,331	
Primary production	303			80,659	25,605	962	198		-206	-14	119,934	
Import	713	901		1,623		1,121	642	102	827	593	334	
Export	-254	-119		-68,493	-25,380	-1,134	-2,564	-412	-3,610	-973	-16,241	
Norwegian purchase abroad								30	82	1,126	5,875	
Foreigners purchase in Norway								-30	-80	-44	-62	
Change in stocks	-13	-18		-1,473		-36		-12	-4	39		
Primary supply	749	764		12,316	225	913	-1,724	-320	-1,911	5,458	104,027	
Oil refineries												
Production		161				937	3,944	1,068	5,949	1,320		
Intermediate use				-12,742		-703	-211	-2	-115	-529	-448	
Thermal power												
Production											369	
Intermediate use									-2		-27	
Hydro power and district heating												
Production											97	1,413
Intermediate use	-21		-98						-2		-336	
Other supplies			989			80	54	14				
Losses											-7,237	-547
Statistical errors	26	-10		426	-225	-4	-274	-110	213	254	362	
Use outside the energy sectors	754	915	891			1,223	1,789	650	4,132	6,503	96,807	866
Domestic use	754	915	891			1,223	1,789	650	2,819	459	96,807	866
As raw material	595	890				1,112						
Domestic energy use	159	25	891			111	1,789	650	2,819	459	96,807	866

Table 3. Use of energy outside the energy sectors. 1990

	Coal 1000 t	Coke 1000 t	Wood, waste, etc 1000 toe	Other gases and LPG 1000 toe	Petrol 1000 t	Paraffin 1000 t	Middle distillates 1000 t	Heavy oil 1000 t	Electricity GWh
Total	754	915	891	1,223	1,787	650	4,132	6,503	96,807
Agriculture and fishing	5				16	1	640	19	680
Agriculture	5				12	1	164	5	680
Forestry					1		18		
Fishing					3		458	14	
Mining and quarrying				0			36	20	708
Metal ore mining				0			12	19	499
Other mining							24	1	209
Manufacturing	742	913	409	1,220	12	1	324	324	44,572
Manuf. of food, etc.	3	1	1	3	4		109	87	2,285
Manuf. of textiles, etc.				0			7	5	158
Manuf. of wood products			103	0	1		20	9	730
Manuf. of paper products	6		301	0			6	65	6,805
Printing, publishing etc.				2	2		3		403
Manuf. of ind. chemicals		178	4	1,177			7	49	5,169
Manuf. of chemical products	112	114		3	1		31	25	923
Manuf. of cement, etc.	120	10					4	4	197
Manuf. of other mineral prod.	17	10		5			26	28	563
Manuf. of iron and steel	70	2					5	18	655
Manuf. of ferro-alloys	413	433		0			4	1	7,453
Iron and steel founding	1			0			1		148
Manuf. of primary aluminium		151		1			47	6	14,431
Manuf. of other non-ferrous metals		14		17			2	20	2,210
Rolling and founding of non-ferrous metals				3			3		192
Other manufacturing				7	4		49	7	2,250
Construction					8		207		530
Wholesale and retail trade, etc.					189	2	178	1	5,995
Wholesale and retail trade					187	2	164	1	4,740
Hotels and restaurants					2		14		1,255
Transport and storage					72	405	2,201	6,132	1,449
Railway transport							32		640
Motor bus transport					1		106		
Taxi, etc.					19		12		
Other land transport					12		434		12
Ocean transport							1,314	6,045	
Coastal and inland water transport							276	87	
Air transport					3	405			
Supporting services					4		19		294
Post and telecommunication					33		8		503
Finance and insurance					54		18		1,504
Other private services					43	1	59	4	2,244
Public administration and defence					6	86	144	4	8,827
Public administration except defence					3		13		1,077
Education and research							26		2,630
Health and welfare institutions							36	4	2,874
Other public services					3	86	69		2,246
Private households	7	2	482	3	1,387	152	327	1	30,299

Note: Includes energy commodities used as raw material.

In addition to accounts for material resources like fish, forest and energy, related statistical information is collected for environmental resources. In particular, the energy account (end use account) is an important and necessary foundation for the *emission inventories*, which at present cover sectoral emissions of sulphur dioxide, nitrogen oxides, carbon monoxide and carbon dioxide, particulate matter, non-methane volatile organic compounds, lead, methane and nitrous oxide.

4. Use of the natural resource accounts for analysis

Natural resource accounting in Norway is not considered as a goal in itself, but rather as a way of providing systematised data for analytical purposes. Thus, information based on the energy accounts and the associated emission inventories have been integrated into more comprehensive analytical tools by expanding the macroeconomic planning models. These extended macroeconomic models are now used by the government and other administrative bodies on a routine basis. Some recent examples of their use are reported by the Green Tax Commission (NOU, 1992) and the government's Long Term Programme 1994-1997 (Ministry of Finance, 1993). Earlier studies include SIMEN (Studies of Industry, Environment and Energy Towards 2000, Bye et al., 1989), an analysis of climate policy problems on a national scale (Moum (ed.), 1992), and a white paper on structural adjustments of the Norwegian economy (NOU, 1988)

By integrating the resource and environmental data with economic models, several aims are achieved. *First*, consistency between economic planning, expected growth in energy use and the resulting emission to air is secured in the model based forecasts. *Second*, by providing output tables covering both economic, energy and environmental variables, the linkage between these policy areas is brought to the attention of the policy makers. *Finally*, by making a single modelling tool available to both the Ministry of Finance and the Ministry of the Environment (among others), communication among the different branches of the government is enhanced.

Typically, three types of questions are addressed by the integrated model:

1) What are the likely future developments with regard to economic growth, demand for energy and emissions to air? Are environmental targets compatibles with the economic goals?
2) How will a change of policy (e.g. introduction of environmentally motivated taxes or regulations) affect the projected development, both with respect to the economy and the environment?
3) How will future development in the state of the environment and availability of energy resource affect the economic development?

Below follows a brief description of some of the main elements of the model MSG-4, a general equilibrium model of the Norwegian economy that, in a slightly extended version, has been used extensively for analysis of air pollution problems. For further elaboration and details of the economic core model, see Johansen (1974), Bjerkholt et al. (1983), Offerdal et al. (1987), and Longva et al. (1985).

4.1. An economic core model

The Multi-Sectoral Growth (MSG) model was originally constructed to study the overall long-term prospects of the Norwegian economy with emphasis on the sectoral composition of economic growth. Later on, the interest widened to cover the long-term interactions between economic growth and energy supply and demand. The dimensions of the model, some *30 production sectors* and *40 commodities* (depending on model version), reflect a compromise between the ambition of applying detailed sector information and the Ministries' need for a manageable model.

In most industries the input aggregates - labour *(L)*, capital *(K)*, energy *(U)* and materials *(M)* - are substitutable according to neo-classical production functions. In addition, inter-fuel substitution is assumed between electricity *(E)* and fuel oil *(F)* within the energy aggregate *(U)*. The substitution responses are formally represented by Generalised Leontief (GL) cost functions (Diewert, 1971) as follows:

$$\frac{Q_j}{X_j} = h_j(t)\sum_k \sum_l \alpha_{kl} \sqrt{P_{kj} P_{lj}}\,; \quad k,l=K, L, M, U$$

$$P_{U_j} = \sum_k \sum_l \beta_{kl} \sqrt{P_{kj} P_{lj}}\,; \qquad k,l = E,F$$

where the indices k and l runs over the input factors, the Ps are prices of input activities, X_j is total output and Q_j denotes total cost in sector j, $h_j(t)$ describes Hicks neutral technical change, and the αs and βs are estimated parameters. The estimates are based on data from the National accounts for the period from the 1960s and onwards.

The development of the total production capacity of the economy is determined by the exogenous growth of the labour force, technical change, and rates of return to capital. The composition of production also affects the total productive capacity since sectors are not equally efficient. The model is closed by letting the level of household consumption be endogenously determined ensuring full capacity utilisation. Thus, total private consumption is what is left of production capacity over gross investments, government consumption, and net exports.

The model calculates the equilibrium prices of commodities and labour, and will trace out paths of balanced growth in the sense that there is a continuous balance between supply and demand of goods and factors of production within the limits of available capacity. Some price indices such as nominal wages, the prices of non-competitive imports, oil, gas, electricity, government fees and commodity taxes are exogenous to the model and determine the nominal price level.

The substitution parameters of the model are most properly interpreted as long-term elasticities. In an equilibrium model with no lags, as in MSG, economic agents react immediately to adjust their allocations to changes in prices or other incentives. In the real world, it necessarily takes time for economic agents to adapt to changed incentives. Thus, the model predicts a new equilibrium path when changed incentives have persisted long enough to allow agents to adjust.

4.2. Variations over the MSG model

Over the years several variants of the basic MSG-model have been developed. Some of the variants differ only as to which variables are treated as exogenous and endogenous. Thus, in the variant of the model described above (MSG-4E), the rate of return to capital is exogenous while amount of (real) capital is determined by the model. In another version of the model (MSG-4S) the opposite is the case. There are also variations on how external trade is treated. In one trivial modification the balance of trade is treated exogenously, while import shares are scaled up or down by a common endogenous factor. A more radical change is undertaken in a model variant (MSG-TAX) where product varieties and Armington relations are introduced to model the amount of external trade. Another variation is in how the private consumers are treated. In one model (MSG-5) several socio-economic consumer groups are introduced within a LES-system of consumer demand. Finally, a version of MSG called MSG-EE (EE for Energy and Environment) has been developed where transport activities and power production are modelled in more detail. In MSG-EE, production of commercial transport services has been disaggregated into five production sectors covering transport by road, air, rail and sea in addition to post and telecommunication. Transport (both own produced and commercially purchased) has also been introduced as a separate input factor in all production sectors, complementing the usual quartet of capital, labour, energy and materials. Power production in MSG-EE covers both production by hydro power and natural gas. Production and transmission/distribution of power are also treated as separate production activities.

4.3. The emission sub-model

Sectoral emissions of nine pollutants from four types of sources are presently calculated in post models to the economic core models. For some of the compounds (SO_2, NO_x and NMVOC) Norway has international obligations through conventions and protocols. These are compounds that, in addition to having local effects, also have regional consequences through acid rain and the formation of ground level ozone (O_3). Other compounds like carbon monoxide and particulate matter (technically particles with diameter less than 10 μm - PM_{10}) are local pollutants. Finally, there are compounds with mainly global effects in that they directly affect the radiation transfer of the atmosphere. Among these so called greenhouse gases we include CO_2, CH_4 and N_2O.

In the emission model, emissions from industries and private households due to *stationary combustion* are associated with the sectoral demand for fuel oils, *mobile combustion* emissions are associated with the demand for petrol, non-energy related *process emissions* are associated with demand for intermediate materials other than energy commodities, while *evaporation* is associated with both industry specific use of materials (proxy for use of solvents), total demand for gasoline (evaporation from storage and handling of gasoline) and private consumption of housing (proxy for use of paints, etc.), see table 4. Waste generation in private households is assumed to follow private consumption of food. Emissions from waste dumps (mainly methane) and incineration of waste are determined by exogenously given factors determining the relative amount of waste generated going to dumps and incineration, respectively.

Table 4. Sources and compounds covered by the emission sub-model

Type of sources	Associated activity variable
Stationary combustion	Demand for fuel oil *(FO)*
Mobile combustion	Demand for transport oils *(FT)*
Non-energy related processes	Demand for materials *(M)*
Evaporation	Various variables
Compounds	**Chemical symbol**
Sulphur dioxide	SO_2
Nitrogen oxides	NO_x
Carbon monoxide	CO
Carbon dioxide	CO_2
Non-methane volatile organic compounds	NMVOC
Lead	Pb
Particulate matter	PM10
Methane	CH_4
Nitrous oxide	N_2O

4.3.1. The generic procedure for calculating emissions

Emission coefficients are calibrated in a base year, and are projected over the forecasting period by taking into account the effects of planned and implemented environmental control policies such as emission standards for new vehicles, limits on sulphur content of heating oils, direct regulation of emissions from specified firms, etc. Abstractly, the calculation of the emissions from the various types of sources can be represented as follows.

$$E_t = \varepsilon_t \cdot C_0 \cdot A_t + E_t^0$$

$$C_0 = \frac{E_0}{A_o}$$

Here, E_t is the emission level in year *t* (with *t=0* designating the base year), while E_t^0 is an exogenous term. C_0 is a fixed emission coefficient determined in the base year. The variable A_t is an activity variable that varies according to the type of source considered (see table 4).

The time dependent parameter ε_t, is meant to take care of expected changes in emission intensities that are not taken into account by the economic model. For instance, stringent regulation of emissions from gasoline powered light vehicles in Norway imply that new cars must be fitted with catalytic converters. As the stock of cars is renewed, the emission intensity declines and this is reflected in a reduction in ε_t. Similarly, a long term plan to reduce the sulphur content of oil can be reflected in a declining ε_t. This parameter can also be used to take account of technological change affecting emissions in excess of the energy savings, etc. already captured by the economic model. Of course, any price effects associated with these changes should also be taken into account in the economic modelling.

It is worth noting that the sectoral emissions are projected by using *input factors* (heating oil, transport oils, intermediate deliveries) as activity variables. This implies that any technical change (factor specific or factor neutral) included in the modelling of the economic behaviour is also reflected in the calculation of the emissions. Thus, if technological progress reduces the need for input factors by, say, 10 per cent over a specific time period in a sector, the emission intensities, measured as emissions per unit real output, are also reduced correspondingly.

Table 5 shows examples of sectoral emission levels in a base year and projections to a future year. The table only summarises total emissions from all types of sources.

Table 5. Emissions in the base year 1988 and projected to the year 2000 by the model MSG-EE. Tonnes

	NMVOC		CO_2		NO_x		SO_2	
	1988	**2000**	**1988**	**2000**	**1988**	**2000**	**1988**	**2000**
11-Agriculture	3,082	1,970	740,008	538,560	5,456	2,421	913	228
12-Forestry	640	657	58,973	60,536	708	726	59	17
13-Fishery etc.	1,923	1,923	1,487,000	1,487,000	32,836	32,836	1,955	1,955
15-Prod. of consumer goods	366	489	731,997	745,977	2,336	2,935	3,466	2,229
25-Prod. of intermediate and investment goods	651	821	2,356,014	2,835,308	6,708	7,281	6,098	5,963
34-Prod. of pulp and paper	114	303	399,973	1,184,654	1,466	4,165	5,440	8,601
37-Prod. of industrial chemicals	832	700	1,867,984	1,712,055	5,346	2,420	6,947	5,150
40-Refining of petroleum products	4,998	8,315	990,003	1,647,043	1,680	2,795	3,123	4,993
43-Prod. of metals	1,396	1,515	4,971,940	4,922,917	7,603	7,687	19,718	16,861
45-Prod. of machines etc.	144	227	197,994	271,150	809	1,256	434	323
50-Building of ships and rigs	38	20	51,000	23,111	213	109	87	24
71-Prod. of electricity - hydropower			116,000	131,340				
710-Prod. of electricity - gaspower								
55-Construction	1,116	1,032	594,003	620,504	7,790	7,618	750	267
81-Retail and wholesale trade	5,797	3,225	1,271,985	1,582,864	11,860	8,673	1,061	685
64-Prod. and transport of oil and gas	82,944	114,741	4,871,999	7,760,245	26,587	42,349	358	243
60-Ocean shipping								
68-Drilling for oil and gas	588	390	309,999	205,637	6,420	4,259	792	422
75-Domestic transport - road	5,266	4,491	2,015,976	2,218,107	27,369	18,916	2,362	678
76-Domestic transport - air	491	563	1,111,990	1,275,451	3,214	3,686	142	163
77-Domestic transport - rail	74	92	91,999	114,323	493	613	117	43
78-Domestic transport - sea	1,045	1,170	1,268,985	1,420,420	27,993	31,333	7,525	4,033
79-Post and telecommunication	1,020	494	214,999	257,224	1,966	1,333	139	90
63-Banking and insurance	391	545	54,000	75,329	492	686	12	14
83-Housing services								
85-Other private services	2,389	1,221	680,993	813,957	3,501	2,208	534	309
92S-Defence	441	395	561,000	595,250	5,087	5,137	405	266
93S-Education and research	4	4	28,000	31,063	23	26	41	23
93K-Education and research	16	15	123,000	113,309	98	90	177	82
94S-Health service, etc.	2	2	19,000	19,055	20	20	86	60
94K-Health service, etc.	21	19	170,001	150,981	145	129	370	228
95S-Other public services	72	127	62,000	90,204	712	1,259	79	68
95K-Other public services	32	44	25,000	24,352	89	117	33	15
Private households	45,419	21,820	5,965,078	6,244,780	38,424	17,410	3,353	2,811
Land fills			45,000	45,000				
Combustion of waste	264	264	125,000	125,000	872	872	478	478
Handling of gasoline	9,375	10,077						
Handling of volatile compounds	34,000	34,000						
Total	204,950	211,672	33,578,891	39,342,702	228,314	211,366	67,053	57,320

4.3.2. Exceptions to the generic rule of emission projections

There are several exceptions to the generic projection rule described above. Some of the exceptions are of a permanent character, while others are only introduced occasionally in particular studies.

Exceptions to the generic rule that have a permanent character

Fishing is treated as a single economic activity in the model. However, in reality it consists of at least to very different activities; ocean fishing and rearing, activities with very different emission characteristics. Usually there are no reasons to believe that these activities will grow at the same rate. Historically, the growth in the rearing of fish has far outstripped the growth in the traditional fisheries. While the fishing fleet is a major emission source in Norway, in particular of NO_x emissions, breeding and rearing of fish have few if any air pollutants directly associated with it. A third source of emissions classified as coming from the fishing sector, is the liming of fresh water lakes (approximately 10 000 tonnes CO_2 per year). The emission generating activities within the fishing sector are all characterised by being very difficult to model in economic terms. Thus, usually the emissions from all types of sources in this sector are treated exogenously, typically by keeping them equal to emission levels in the base year. In 1988 the fishing sector's share of total emissions for some important compounds were as shown in table 6.

Table 6. The fishing sector's share of total emissions in 1988.

SO_2	NO_x	CO_2	NMVOC
3%	14.4%	4.4%	1%

Burning of wood for heating in the private households is a major source of emissions of particulate matter in Norway (approximately 12 out of nearly 21 thousand tonnes in 1988). However, the fuel wood is only seldom bought at the market. More often, it is harvested directly in forests, either owned by the household or freely available to the household. It is thus difficult to stipulate a price on this fuel, and correspondingly difficult to model the demand for fuel wood in economic terms. For this reason, emissions from burning of wood in the households are usually treated exogenously, either assuming a growth proportional with the population or keeping the emission levels at the base year level.

One of the economic sectors; Production of intermediate and investment goods (sector 25), is comprised of a large number of polluting activities. Some of these have deliveries to only one or a few other sectors. The emissions from these activities are more influenced by what is happening in the receiving sectors than in the aggregated sector 25. Therefore emissions from these activities are linked to the demand for input factors in the receiving sectors. Thus:

- Emissions from the production of anodes follow closely the use of the anodes. These emissions are therefore linked to the demand for intermediates in the sector Production of metals (43).
- Emissions from the production of cement are linked to a weighted average of the activity levels in the sectors Construction (55) and Production of riggs and ships (50).
- Emissions from the production of Leca (a building material) are linked to the activity level in the sector Construction (55).
- Process emissions of NMVOC from production of beer and bread are related to private consumption of food.
- Process emissions of NMVOC from the sectors Domestic road transport (sector 75) and Trade (sector 81) are related to the development in total gross demand for gasoline in the economy. These emissions are mainly from the storage and handling of the fuel.

Occasional exceptions to the generic rule

The above exceptions are a more or less permanent feature of the emission modelling. In other cases the modelling have changed from study to study. Among these non-permanent exceptions to the generic rule are the following.

Burning and storage of non-hazardous waste generate emission to air. Methane generated by the decomposition of organic materials is sometimes collected and used as fuel. This combustion also generate emissions to air. Sometimes the amount of waste generated is modelled as a function of private consumption of food and other non-durable goods and the activity levels in some waste intensive production activities. In other cases the amount of waste is given exogenously. In almost all cases the division of the waste among incinerators and waste dumps is given exogenously.

The economic modelling of the activity level in the petroleum sector is exogenous. Emissions from this sector is sometimes calculated on the basis of the generic rule, at other times it is treated exogenously.

Emissions from the production of coal is usually kept at a constant (base year) level.

The next three figures illustrate some historical emission levels and typical projections into the next century. The horizontal lines represent national targets (CO_2, NO_x) or international obligations (SO_2).

Figure 3. Emission of SO_2

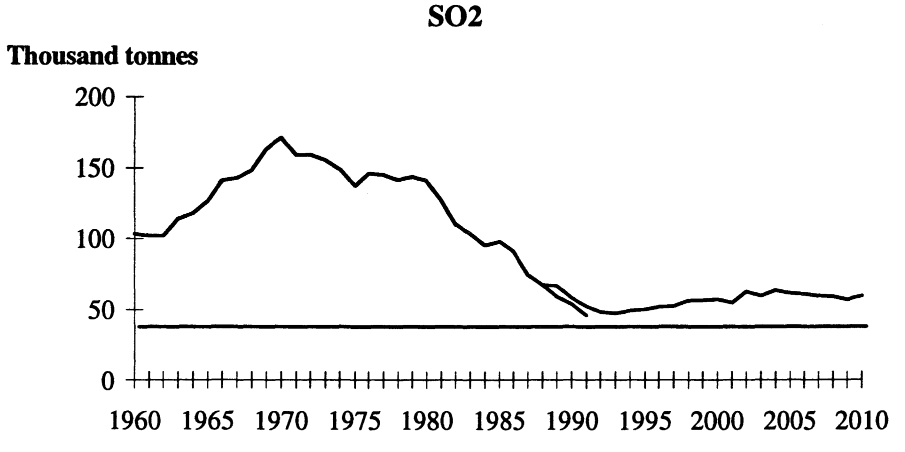


Figure 4. Emission of NO_x

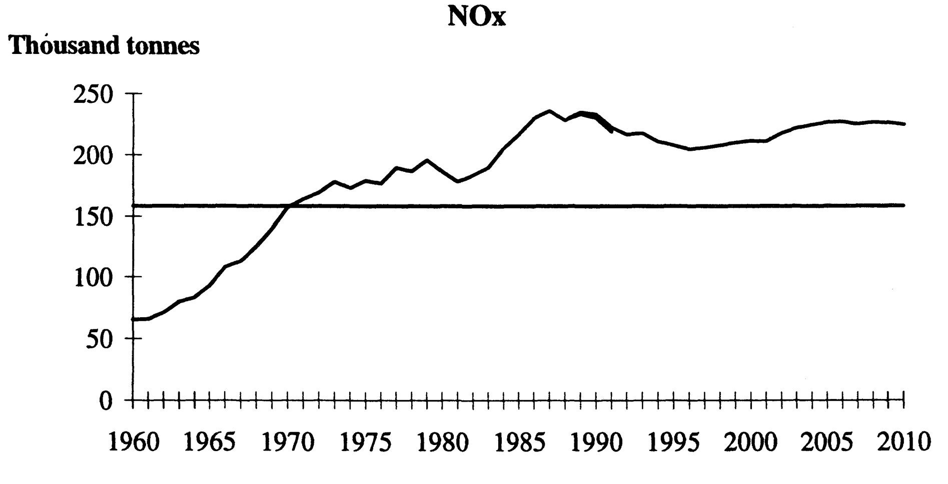
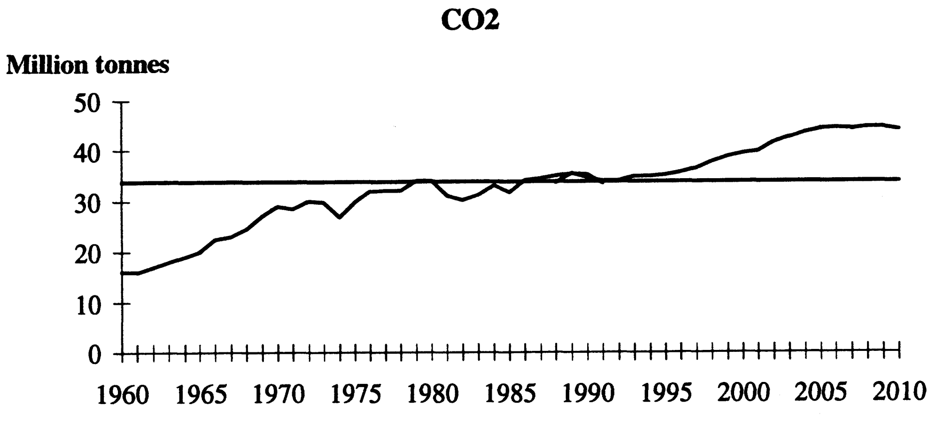


Figure 5. Emission of CO_2



4.4. Costs and benefits of environmental control policies

In traditional economic models the effect of environmental taxes and other regulations usually appears as reduced growth in macroeconomic indicators such as GDP, net production and private consumption. When environmental control measures, e.g. a carbon tax, nevertheless are contemplated in many countries, it must be due to a belief that the benefits of such measures more than make up for the costs. In this subsection we describe briefly one way of evaluating some benefits associated with reductions in *local* pollution levels of SO_2, NO_x, CO and particulate matter. The benefits covered are reduction in local 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. For a more detailed discussion of data and assumptions, we refer to Alfsen et al. (1992b) and Brendemoen et al. (1992).

4.4.1. Some marginal benefits of emission reductions

Two different types of benefits associated with a reduction in fossil fuel use are calculated. The first (denoted environmental benefits) is related to changes in emission levels of sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO) and particulate matter. These are pollutants harming e.g. human health, forests, fresh water lakes and certain types of capital equipment. In addition, the presence of these compounds reduces the welfare of the population by inflicting aesthetical damage to the natural environment. The second type of benefit is related to reduction in road traffic, and cover aspects such as congestion, accidents, damage to roads and noise from road traffic.

Environmental benefits

The economic cost of <u>damage to fresh water lakes</u> from deposition of sulphur and nitrogen in Norway is estimated on the basis of willingness-to-pay surveys carried out in the 1970s. <u>Damage to Norwegian forests</u> from sulphur deposition has been assessed by an official commission. Given an estimate of physical damage, the economic loss due to reduced timber production is relatively easy to assess. The estimation of loss in recreational value from damage to forests is roughly assessed in proportion to recreational loss from damage of fresh water lakes.

<u>Damage due to corrosion</u> of some building materials and machinery equipment has been estimated on the basis of data of capital exposure to atmospheric sulphur, cost of maintenance and replacement, and detailed physical damage functions (e.g. amount of material corroded under different atmospheric conditions).

Estimates of health damage due to air pollution are based on two official Norwegian reports on air pollution induced health damages and their costs in some Norwegian cities. These, in turn, build on international dose-response studies adjusted to correspond to Norwegian conditions.

Traffic related benefits

In the same reports marginal external costs of road traffic due to congestion, traffic accidents, damage to roads and noise are estimated. In the sub model we assume future road traffic to be proportional to the demand for transport fuels.

Multiplying the marginal cost of the various damage components with changes in emission to air of the relevant compounds and with the change in demand for transport fuels, yields a rough estimate of some of the direct benefits of environmental control policy compared to a baseline scenario. It is difficult to measure the economic cost of introducing a control policy correctly, but a rough indicator is the calculated reduction in GDP.

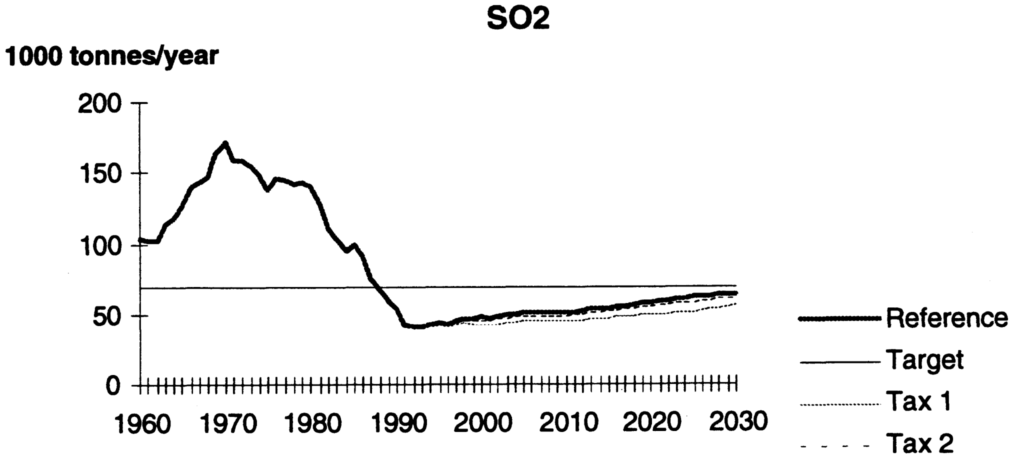
5. Some examples of empirical analyses

In this section we provide several examples of the use of integrated environment-energy-economy models. The first example is an analysis of the economic and environmental effects of the introduction of *carbon taxes*. The secondary benefit (i.e. secondary with respect to potential climate effects) of a specific carbon tax is presented in some detail, before an overview of secondary benefits and GDP losses in several studies is offered. The next example shows emission elasticities with respect to changes in the price of electricity and fuel oil, respectively. The final example illustrates that the indirect costs of an environmental control policy directed at a specific economic sector may be substantial.

5.1. Emission forecasts without and with a carbon tax

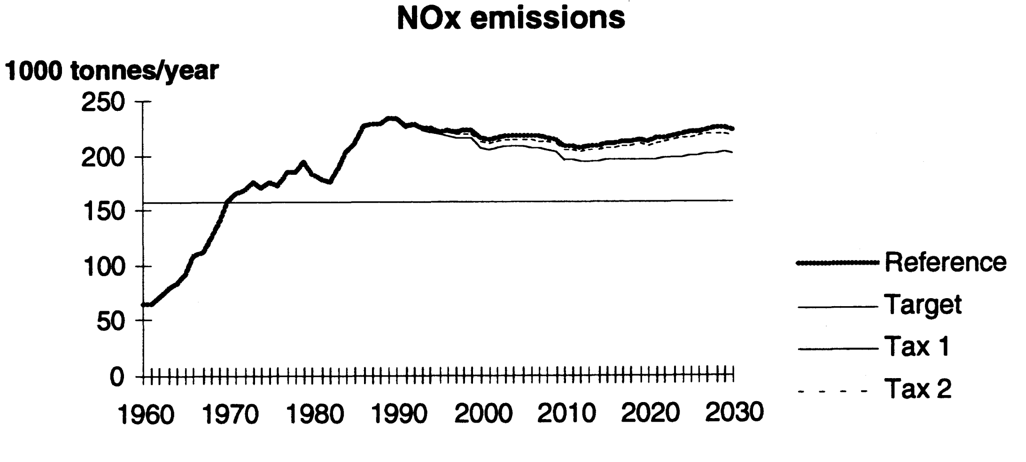
The figures 3-5 show historical development and projected values for the emission of SO_2, NO_x and CO_2 in Norway. The projections cover one reference alternative and two carbon tax alternatives. In the Tax-1 alternative the tax is of the order of $800/tC (1989-$) (corresponding to $93/barrel of oil) in year 2030, while the Tax-2 alternative assumes a much lower tax of $160/tC ($19/barrel of oil). In both cases the taxes are presumed to be part of an international agreement imposing similar taxes on all other industrialised countries and therefore affecting both economic growth in world markets and the price of important commodities like crude oil and natural gas. An important assumption in the calculations is that the trade balance of Norway should be unchanged from the reference alternative. Norway has national emission targets for all three compounds shown here. Although specified for different years, the targets are shown as horizontal lines in the figures.

Figure 6. Historical and projected emission level of SO_2 in Norway.



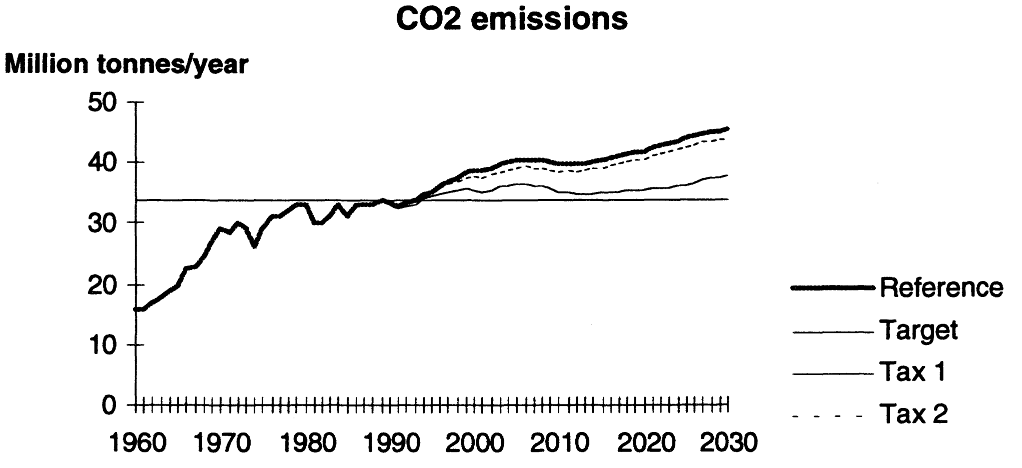
From the figure we note that the SO_2 emissions have declined substantially since the early 1970s. This is mainly due to vigorous use of administrative control measures and the close down of polluting industries. The decision to implement these control measures was to some extent influenced by an early analysis of expected future growth in SO_2 emissions carried out by use of an extended macroeconomic model (Ministry of Finance, 1972). Future emission growth is expected to be small, and no problems are envisaged with respect to the fulfilment of the national target even in the long run.

Figure 7. Historical and projected emission level of NO_x in Norway.



NO_x emissions have grown substantially over the years from 1960 to 1990. New control measures, such as catalytic cleaning of automobile exhausts, are expected to curb this growth in the future, but this is not enough to ensure a fulfilment of the national target even with a high carbon tax. However, a carbon tax is not likely to be the most efficient mean of reducing NO_x emissions.

Figure 8. Historical and projected emission level of CO_2 in Norway.



CO_2 emissions have also grown over the period from 1960 to 1990, although with a declining rate the last ten years or so. However, further expected growth makes is hard to achieve the national target, even with a high carbon tax.

It is obvious from the figures that the main problem for Norway of achieving its targets on air pollution is related to the emission of NO_x, unless new affordable technology offers for instance low NO_x combustion engines for use in ships and heavy vehicles.

5.2. The cost and some benefits of carbon taxes

Benefit estimates have been calculated according to the procedure briefly outlined in section 4. They are of course highly uncertain, and for this reason Monte Carlo simulations are carried out to map the effect of the uncertainty in the marginal cost figures on the final benefit estimate. The next two figures (6 and 7) illustrate the composition and probability distribution of the secondary benefit in year 2030 of introducing a carbon tax of approximately \$800/tC on all CO_2 emissions in Norway, assuming that similar measures are introduced by our most important trading partners also.

Figure 9. Environmental benefits due to reduced emission of local pollutants in year 2030. Million 1990-Nkr. Lower and upper limits correspond to the 25% and the 75% quartiles, respectively.

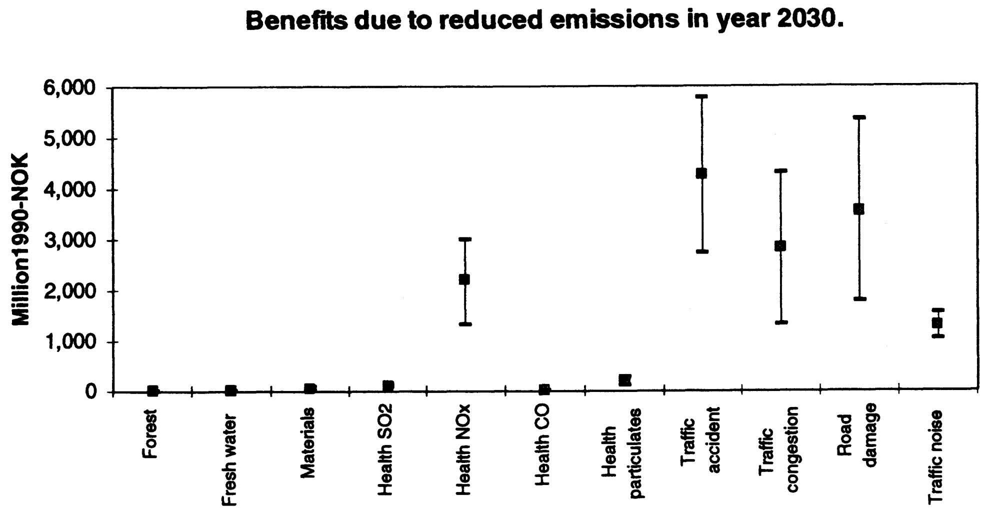
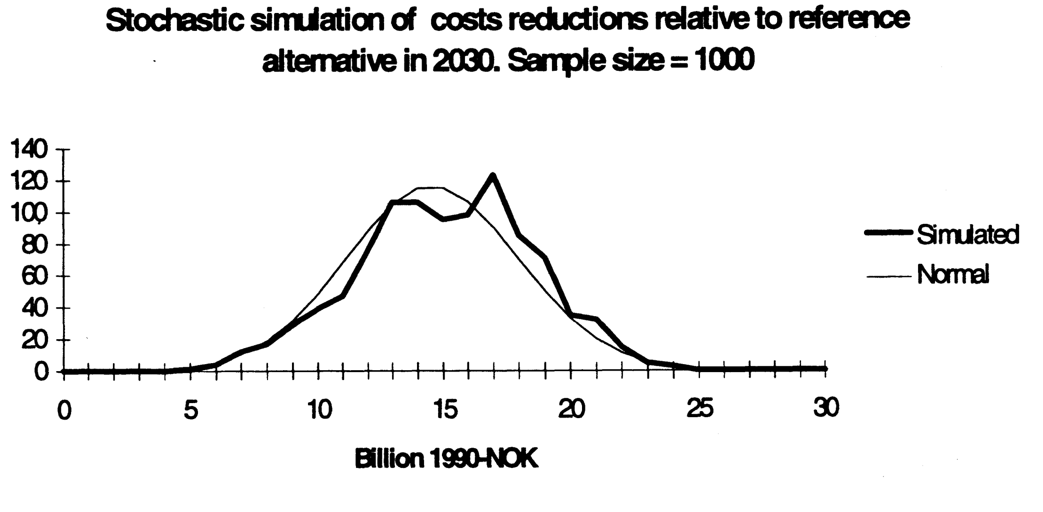


Figure 10. Probability density of the sum of environmental and traffic related benefits in year 2030. Billion 1990-Nkr.



It is worth noting that while the benefit is estimated to be between approximately 10 and 20 thousand million 1990-Nkr in year 2030, the calculated reduction in GDP is 34 thousand million Nkr in the specific example considered here. Thus, a sizeable fraction of the economic cost of introducing a carbon tax is recouped by the fact that emissions of local pollutants, like SO_2, NO_x, CO and particulate matter, are also reduced. Also note that these benefits are in addition to benefits that may accrue from a reduction in the greenhouse effect.

5.3. Costs and benefits in other SN studies

The results cited above is from just one out of a large number of more or less similar studies carried out in the SN over the years. Table 7 and figures 11 and 12 below summarises some of the results.

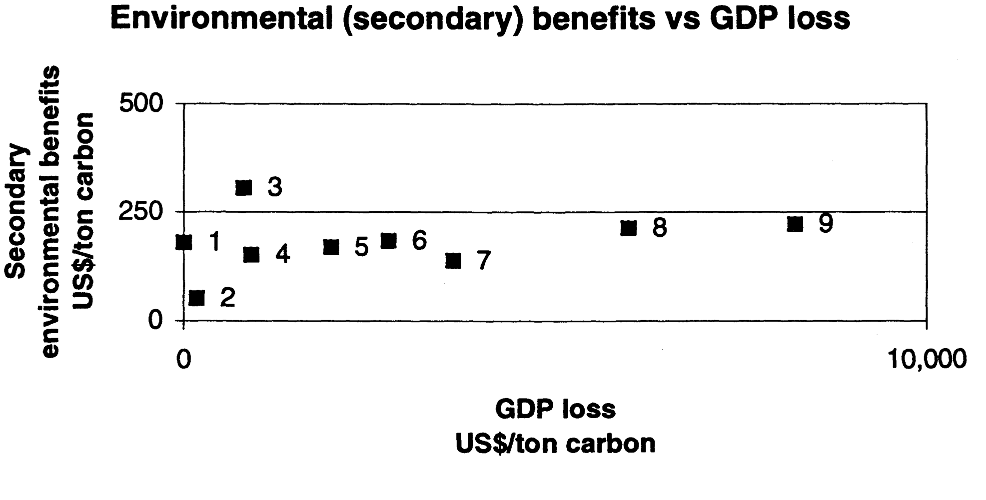
Table 7. Secondary environmental benefits versus loss in GDP in several studies of the effects of environmental taxes.

No.	Loss in GDP US$/tC	Secondary benefit Environment US$/tC	Traffic US$/tC	Total US$/tC	Benefit/ GDP ratio	Year	Model
1	2	179	309	489	300.00	2000	MODAG
2	177	52	74	126	0.71	2010	MSG-TAX
3	795	306	392	698	0.88	2000	MSG-TAX
4	897	151	228	379	0.42	2000	MODAG
5	1,974	169	255	424	0.21	2025	MSG-5
6	2,757	184	828	1,012	0.37	2030	MSG-5
7	3,634	138	228	366	0.10	2030	MSG-6
8	5,974	213	365	578	0.10	2030	MSG-4
9	8,219	222	256	478	0.06	2000	MODAG
10	37,672	1,426	1,630	3,056	0.08	2000	MODAG

The studies referred to in table 8 are based on different models employing different assumptions regarding how the tax is implemented (e.g. unilaterally or through an international agreement), world market reactions to the tax, etc. Also the time horizon of the studies varies from year 2000 to 2030. The results are therefore not strictly comparable.

Figure 11 and 12 depict graphically some of the information contained in table 8. Note that only environmental secondary benefits are reported in figure 11, i.e. transport related benefits are excluded, while these are included in figure 12.

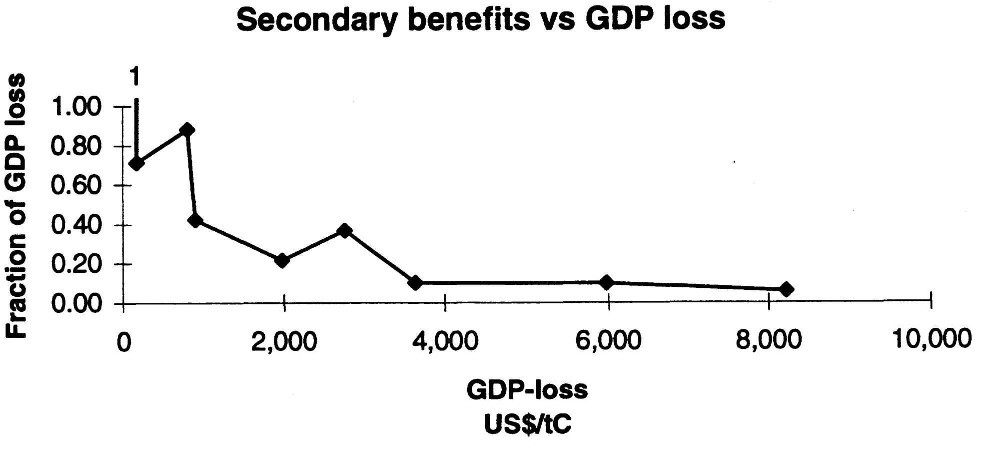
Figure 11. Secondary environmental benefits versus loss in GDP in several Norwegian studies of the effects of carbon taxes.



It is noteworthy that while estimates of GDP reductions (measured per ton carbon removed) vary over a wide range, the assessment of the local benefits associated with reduction in local pollutants only (i.e. neglecting the benefit from reduced road traffic), is in the range from $50 to $300, with most of the studies showing benefits between $150 and $200 when measured per ton carbon. This is of the same order of magnitude as found by Pearce (1992) in a separate study of secondary benefits from climate policies for the United Kingdom. Also it is of the same order of magnitude as the carbon tax calculated to be necessary in order to stabilise global CO_2 emissions (see for instance Cline (1992) for a summary of such studies. Burniaux et al. (1992) provides evidence of the global effects of a CO_2 tax, based on OECD's GREEN model). The variations both in benefit estimates and in the loss of GDP illustrate that many factors besides the strength of the policy measure (i.e. the tax rate) are involved in determining the final impact of the environmental policy. Thus, it is in general impossible to assign a single number to the cost of an environmental control policy without specifying in detail what other assumptions the projections are based on (e.g. impacts on world trade and world market prices of energy, other tax reforms, etc.). Finally, it is worth noting that the benefits of mitigated climate change due to the introduction of a carbon tax of this size, is in all cases estimated to be an order of magnitude *less* than the above range, see e.g. Nordhaus (1991a,b) and Cline (1992). Thus, the inclusion of the secondary local benefit estimates in the evaluation of climate policies, might be crucial to an evaluation of such policies.

Figure 12 depicts the size of the estimated secondary benefits measured as a fraction of the loss in GDP.

Figure 12. Environmental and traffic related benefits as fraction of loss in GDP in several studies.



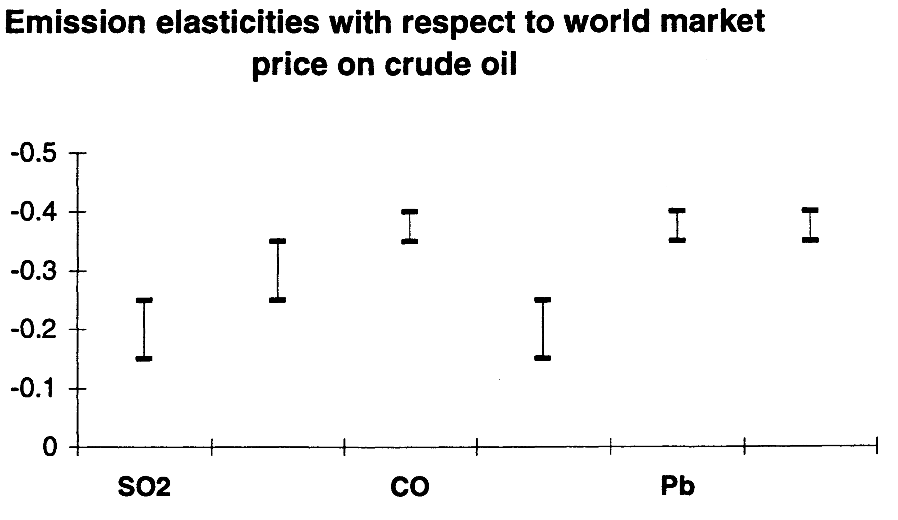
Study no.1, which falls outside the scale of the figure, refers to a highly optimistic case study where the impact on the Norwegian economy of an international carbon tax was very small due to only a small decrease in the price of petroleum products and a gain in competitiveness in the Norwegian hydro power based power intensive industries. Study no.3, which shows the next to highest ratio of benefits to GDP reductions, was based on a taxation rule that related the tax on fossil fuels to the marginal local damage from the use of this fuels. The "worst" case (study no. 9) when measured by the benefit/GDP-loss ratio, refers to a case where Norway on a unilateral basis stabilises its own CO_2 emissions by use of a carbon tax.

5.4. Emission sensitivity to energy prices

Any forecast is contingent on a number of uncertain assumptions. The future world market price on crude oil is crucial in this respect, due to its close link to emissions to air[3]. Figure 13 shows calculated emission elasticities for several compounds with respect to the oil price. In the model based calculation also effects on foreign trade from changes in the oil price is taken into account. Generally, emissions of compounds stemming mainly from transportation activities show the greatest sensitivity to changes in the oil price. For further discussion and references, see Alfsen (1991, 1992).

[3] The situation in Norway is somewhat special since the power system is 100% based on hydro power.

Figure 13. Emission elasticities with respect to the world market price on crude oil. Low and high estimates.



5.5. Emission tax on sulphur

In a study based on the MSG-4 model, the effects on economic activity and emissions to air of introducing a tax on sulphur emissions from the manufacturing industries were calculated (Alfsen, Hanson and Lorentsen, 1987). According to the model, which has empirically estimated relations with predominantly energy-capital complementarity, taxation of sulphur emissions reduces long term economic growth. Furthermore, the reduction in GDP inferred from the model calculation was considerably greater than the tax payment from the sectors directly affected by the tax. Although substitution possibilities can be expected to reduce the total impact of the tax on the economic results of a sector, the energy-capital complementarity leads to less investment when the price of energy increases, thus reducing the long term growth of that particular sector. Although taxation is a cost-effective mean to lower emissions from polluting sectors, the indirect allocation costs of the control policy should be recognised from the outset, as these costs may dominate the more easily calculated direct costs of the taxed sectors.

6. Conclusions

We have briefly outlined the structure of the Norwegian resource accounts and their historical development from the 1970s until today. Several empirical studies have been presented that illustrate the importance of considering both the indirect economic effects of environmental control policies and the impact it will have on several polluting compounds.

Over the years a pragmatic approach has been followed with emphasis on the use of the resource accounts for analytical purposes. The tools used are all based on slightly extended versions of disaggregated macroeconomic planning models already in use by governmental bodies. This has facilitated the introduction of environmental concern in the planning process in Norway. Furthermore, by using the same modelling framework for analyses of both economic and environmental policies, consistency in behavioural and other key assumptions are secured. Finally, linking physical resource accounts and environmental statistics to economy wide models provides for better and more comprehensive information on the value of natural resources and environmental services than available through more partial studies. For these reasons, we strongly recommend a strategy where resource and environmental issues through their physical characteristics are integrated into already operational economic planning tools. This in opposition to a strategy where new and separate models for resource and environmental analysis are developed in addition to existing models.

In Norway, future work will concentrate on updating and implementing the benefit relations in the economic models themselves, in order to capture the indirect economic benefits of environmental policies.

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