Working Paper 1993:10

# Cost efficient climate policy in a small country

*Cathrine Hagem*

ISSN: 0804-452X

Working Paper 1993:10

# Cost efficient climate policy in a small country

Cathrine Hagem

**Revised version published in The Energy Journal:**

Hagem, C. (1994): Cost-effective Climate Policy in a Small Country, The Energy Journal 15, 119-139.

ISSN: 0804-452X

# COST EFFICIENT CLIMATE POLICY IN A SMALL COUNTRY[a]

by

Cathrine Hagem[b]

**Abstract**
A unilateral action to curb $CO_2$ emissions in a small country or a group of countries has only a limited effect on global $CO_2$ emissions. However, it could be a first step toward a broader climate treaty. So far unilateral commitments have been aimed at reducing **national** consumption of fossil fuels. A country that produces and consumes fossil fuels can also influence the **global** $CO_2$ emissions by reducing its production. The total global effect of two different actions will depend on the supply and demand elasticities on fossil fuels and the countries share of global production and consumption. The cost of reducing national $CO_2$ emissions in Norway, through a reduction in fossil fuel consumption, is calculated in KLØKT (Moum (1992)). That cost is compared with an estimated cost of reducing the fossil fuel production in this paper. The calculation reveals that it could be less costly to reduce the production than the consumption, given that the effect on global $CO_2$ emissions is identical.

---

[a] I am indebted to Michael Hoel and Asbjørn Aaheim for valuable suggestions and comments.

[b] CICERO (Center for Climate and Energy Research, Oslo)

## 1. Introduction

Emission of carbon dioxide ($CO_2$) is an international climate problem, where the total global amount of emissions are of significance and not the geographical location of the sources. The benefit of a unilateral action to curb $CO_2$ emissions depends on the contribution to the changes in global discharge. A unilateral action taken by a single country will only have a limited effect on the global emissions. The reason for this is partly that no single country's discharge counts for more than approximately 25 per cent of global emissions. Reduced consumption can furthermore cause the international fuel prices to fall. The reduction in prices has the undesirable effect of giving other countries an incentive to increase their use of fossil fuels and partly offset the initial reduction. This effect of unilateral actions is often measured by the so called "leakage rate," which is the percentage by which resulting global reduction fall short of initial cutbacks. A small country's action to curb its own emissions will have a minimal impact on international fuel prices, and by that consumption in the rest of the world. This effect can, however, be significant in relation to the initial reduction.

Several authors have estimated carbon leakages resulting from climate agreements with limited participation. The results vary considerably. For example, Pezzey (1991) finds, by using the Whally-Wigle model (see Whalley and Wigle (1991), that a 20 percentage cut in EC-countries fossil fuel consumption cause a leakage rate of 80 per cent. Oliveira-Martins et al. (1992a), present simulated carbon-leakages in the GREEN-model. They find that a stabilization of $CO_2$ emissions in 2000 in EC-countries cause a leakage rate of only 11 per cent. Any calculation of the effect on international fuel prices will be highly dependent on how the world energy markets are modeled. Dean and Hoeller (1992) give a comparison of how the various global models work.

Different approaches to mitigate the price effect of reduced demand are discussed in Bohm (1993). He focuses in his article of the options of reducing supply in countries not participating in an international climate agreement. In Golombek, Hagem and Hoel (1993) it is studied how a differentiation of consumption and production taxes (per unit of carbon) between different types of fossil fuels can be used as a way to influence $CO_2$ emissions from nonparticipating countries. The purpose of this paper is to study the cost efficiency of a unilateral action in a small country that produces and consumes fossil fuels. It will be analyzed whether it is most efficient to reduce consumption or to reduce production, given that the impact on the global reduction of $CO_2$ emissions is the same in the two cases.

Small countries such as Finland, Sweden, the Netherlands and Norway have all taken unilateral actions in adopting carbon taxes. EC has as a target for the Community as a whole to stabilize the $CO_2$ emissions on 1990 level in year 2000. Unilateral commitments are so far all related to the $CO_2$ emissions on national basis or in a group of countries.

Any small country's unilateral action will only have a negligible effect on the total $CO_2$ emissions. Additionally, the country that undertakes the action must carry the entire cost. Consequently, unilateral action does not seem to be a likely policy for any country in the long run. Unilateral climate actions in a single country or a group of countries must be regarded as politically motivated, intended to encourage other countries to take actions. Such actions could be a first step toward a broader international climate treaty. Because it is the global amount of $CO_2$ emissions that is of significance, the benefit of a broader international climate agreement will be depending on the final effect on global emissions. It is thus relevant for any small country that takes action to curb its $CO_2$ emissions to evaluate the impact on global emissions. Furthermore, although the contribution is small, it seems reasonable that the country seeks to minimize the cost of achieving a certain target for their contribution to a reduction in the global warming potential.

In this paper I study the impact on global emission reduction of unilateral action in a small country. I compare the cost of reduced consumption of fossil fuels to the cost of reduced production of fossil fuels, given that the final effect on global emission reduction is identical.

There are several studies of macroeconomics effects of unilateral $CO_2$-control in small countries -see for example Bergman (1993) for Sweden, NEPP (1989) for the Netherlands, Glomsrød et. al. (1990) and KLØKT (Moum 1992) for Norway.

Norway produces and consumes fossil fuels and has a preliminary target to stabilize its $CO_2$ emissions on 1989-level within the year 2000. In the empirical part of this paper I will compare the cost of reduced consumption of fossil fuels in Norway to the cost of reduced production, given that the effect on global $CO_2$ emissions is identical. In the calculation it is assumed that only Norway takes action.

The model for determination of international fossil fuel prices is set up in section 2. It is shown how international fuel prices will be affected by a reduction in consumption of fossil fuels and by a lower production of fossil fuels.

In section 3 it is shown how a reduction in consumption of fossil fuels will affect the total global carbon emissions through international fuel prices. I will furthermore show how a similar reduction in global $CO_2$ emissions could be achieved by reduced production of one of the fossil fuels.

In the empirical section 4, the cost of reducing consumption is compared to the cost of reducing production. The total cost of achieving the national target of stabilizing $CO_2$ emissions in year 2000 on the 1989-level has been calculated in KLØKT. I estimate the final impact on <u>global</u> emission reduction of this policy, and the necessary reduction in fossil fuel production in order to achieve the same global discharge reduction. The cost of reducing fossil fuel production will depend on the fossil fuel prices and the amount necessary to achieve the identical reduction in global $CO_2$ emissions as achieved by imposing taxes on consumption. In section 5 I illustrate how changes in the assumptions of the model will influence the conclusion. Concluding comments are given in section 6.

## 2. The model

It is assumed that there is free international trade in all fossil fuels. This assumption is to a certain extent in conflict with actual markets structure. The gas market could more correctly be described as three regional markets (North-America, Asia-Japan and Europe). There is also a rather limited trade in coal. On the other hand it is possible that development of transport techniques could lead to more integrated fossil fuel markets in the future. I have assumed that all markets are competitive. This implies that cooperative behavior among OPEC-countries is not considered .The model used in this study is a static model, which means I have ignored the fact that fossil fuels are exhaustible resources. If oil, coal and gas are considered as exhaustible resources it would be best to use an intertemporal model to study the market equilibrium conditions in each period.

### Restriction on consumption

The small country is assumed to reach its target of national $CO_2$ emissions by introducing a tax on consumption of fossil fuel. The tax rate is set so that the total consumption of oil, gas and coal, denoted $y_1$, $y_2$ and $y_3$, in the small country will fulfill the target for national $CO_2$ emissions. The demand for oil, gas and coal in the rest of the world is assumed to be a function of all fossil fuel prices, denoted by $D_i(p_1,p_2,p_3)$ i = 1,2,3, while the supply of each of fuel is a function of the price of the fuel itself, $S_i(p_i)$. The supply functions include the supply from the small country. The market equilibrium condition for the international markets for the three fossil fuels; oil, gas and coal are;

$$
\begin{aligned}
&y_1+D_1(P_1,P_2,P_3)=S_1(P_1)\\
&y_2+D_2(P_1,P_2,P_3)=S_2(P_2) \qquad (1)\\
&y_3+D_3(P_1,P_2,P_3)=S_3(P_3)
\end{aligned}
$$

The three equations can be solved for the three fossil fuel prices, giving

(2)
$$P_j = f_j(y_1, y_2, y_3)$$

The $f_j$-functions will depend on all the supply and demand functions in (1). All price derivatives ($f_{ji}$) are functions of all supply and demand derivatives.

When all quantities of fossil fuels are measured in units of their carbon content, global carbon emissions (E) can be expressed either by total production of fossil fuels or by total consumption of fossil fuels.

(3)
$$\begin{aligned} E &= y_1 + y_2 + y_3 + D_1(P_1,P_2,P_3) + D_2(P_1,P_2,P_3) + D_3(P_1,P_2,P_3) \\ &= S_1(P_1) + S_2(P_2) + S_3(P_3) \end{aligned}$$

The total effect on global carbon emissions of a unit increase in $y_i$ is given by

(4)
$$\frac{\partial E}{\partial y_i} = \sum_{j=1}^{3} S_j' f_{ji}'$$

In (4) $\partial E/\partial y_i$ is expressed by the demand and supply derivatives. $\partial E/\partial y_i$ can alternatively be expressed in terms of elasticities. In (15), in Appendix A, $\partial E/\partial y_i$ is written as a function of the supply elasticities, direct price elasticities, cross price elasticities, fuel i's share of the total energy market and consumption of fuel i in the small country relative to total consumption.

In the special case when the cross price elasticities are zero, $\partial E/\partial y_i$ can be abbreviated to;

(5)
$$\frac{\partial E}{\partial y_i} = \frac{1}{1-(\frac{\delta_{ii}}{\sigma_{ii}})\cdot(1-\frac{y_i}{Y_i})}$$

where $\delta_{ii}$ (= $\partial D_{ii}/\partial p_i \cdot p_i/D_{ii}$) is the world's (exclusive the small country's) demand elasticity for fuel i. $\sigma_{ii}$ (= $\partial S_i/\partial p_i \cdot p_i/S_i$) is the world's (inclusive the small country's) supply elasticity for fuel i and $y_i/Y_i$ is the small country's share of total consumption of fossil fuel i.

When the cross price elasticities are zero and the small country's share of total consumption is close to zero, it is the ratio of direct price elasticity and elasticity of supply that is of significance for the final effect on global consumption.

**Restriction on production**

Global reduction in fossil fuel consumption could alternatively be achieved by decreased production of fossil fuel in the small country. The total effect of lower production will depend on to what extent other fuel producers increase their production. World total demand including the small country can be expressed by a common demand function $D_i^*(p_1,p_2,p_3)$ i = 1,2,3. While the functions $S_i^*(p_1)$ express world supply excluded supply from the small country, which is denoted $x_1$, $x_2$ and $x_3$.

Market equilibrium conditions for the three fossil fuels; oil, gas and coal are;

(6)
$$D_1^*(P_1,P_2,P_3)=x_1+S_1^*(P_1)$$
$$D_2^*(P_1,P_2,P_3)=x_2+S_2^*(P_2)$$
$$D_3^*(P_1,P_2,P_3)=x_3+S_3^*(P_3)$$

The three equations can be solved for the three fossil fuel prices, giving

(7)
$$p_j=g_j(x_1,x_2,x_3)$$

The total effect on global carbon emissions of a unit increase in $x_i$ is given by

(8)
$$\frac{\partial E}{\partial x_i} = 1+\sum_{j=1}^{3} S_j^{*\prime} g_{ji}^{\prime}$$

$\partial E/\partial x_i$ expressed in terms of elasticities is shown in (16) in appendix A.

In the special case when the cross price elasticities are zero, the terms $\partial E/\partial x_i$ can be abbreviated to;

(9)
$$\frac{\partial E}{\partial x_i} = \frac{1}{1-(\frac{\sigma_{ii}^*}{\delta_{ii}^*})\cdot(1-\frac{x_i}{X_i})}$$

where $\delta_{ii}^*$ (= $\partial D_{ii}^* / \partial p_i \cdot p_i / D_{ii}^*$) is the world's (inclusive the small country's) demand elasticity for fuel i. $\sigma_{ii}^*$ (=$\partial S_i^* / \partial p_i \cdot p_i / S_i^*$) is the world's (exclusive the small country's) supply elasticity for fuel i and $x_i/X_i$ is the small country's share of total production of fossil fuel i. It is assumed that the supply and demand elasticities in the small country are identical to the corresponding elasticities in the "rest of the world." The values of $\delta_{ii}$* and $\sigma_{ii}$* in (9) are thus identical to the values of $\delta_{ii}$ and $\sigma_{ii}$ in (5).

When the cross price elasticities are zero and the small country's share of total production is close to zero, it is the ratio of demand elasticity and the elasticity of supply that is of significance for the final effect on global consumption.

When the small country's share of world consumption <u>and</u> production is close to zero and the cross price elasticities are zero the relative effect on global emissions by reducing consumption compared to reduction in production is given by

(10)
$$\frac{\frac{\partial E}{\partial y_i}}{\frac{\partial E}{\partial x_i}} \approx -\frac{\sigma_{ii}}{\delta_{ii}}$$

The smaller global supply elasticity compared to the global direct price elasticity, the smaller is the global effect of reduced consumption of fossil fuels in the small country compared to a reduction in production.

**3. The global effect of national unilateral actions**

Assume that a national target of reducing the $CO_2$ emissions by Z units is achieved by reducing consumption of oil, gas and coal by respectively $dy_1$*, $dy_2$* and $dy_3$*. If all $dy_i$* are relatively small, an approximation of the final impact on global emission reduction (dE*) is given by;

(11)
$$dE^* \approx \frac{\partial E}{\partial y_1} \cdot dy_1^* + \frac{\partial E}{\partial y_2} \cdot dy_2^* + \frac{\partial E}{\partial y_3} \cdot dy_3^*$$

The global emission reduction dE* could alternatively be achieved by reducing production of either oil, gas or coal by approximately;

(12)
$$\partial x_i^* \approx \frac{dE^*}{\frac{\partial E}{\partial x_i}}$$

where $\partial E/\partial x_i$ is given by (8) (and (16)).

## 4. An empirical illustration

In this section I will compare the cost of two different climate policies; reduced consumption of fossil fuel in Norway and reduced production of fossil fuels. I will assume that the purpose of the climate policies is to contribute to the reduction in global $CO_2$ emissions. Reduced consumption of fossil fuels will, due to the effect on international fuel prices, result in a smaller reduction in global $CO_2$ emissions than the initial national reduction. I study whether the final reduction in global emissions could be achieved less costly by a decrease in the fossil fuel production in Norway. The starting point of the comparison of cost of the different climate policies is the KLØKT-calculations.

KLØKT presents a reference scenario for the Norwegian economy until year 2000 in order to study possible impacts on the economy of policies to reduce the national emissions of greenhouse gases. The effects of the already approved climate policies in the 1991 budget is taken into account in the reference scenario. The development of main economic characters is based on the medium term macroeconomic model MODAG. The emissions of $CO_2$ will increase from 35 million tonnes in 1989 to 43 million tonnes in year 2000. Fifty per cent of the increase in $CO_2$ emissions is caused by an increase in discharge from the oil producing sector due to growth in output.

A reduction of the $CO_2$ emissions by 8 million tonnes compared to the reference scenario in year 2000 is achieved by imposing a uniform tax of 800 1988-kroner per tonne $CO_2$ (i.e., 114 USD per tonne $CO_2$, or 418 USD per tonne carbon) on all use of fossils fuels. (This tax comes in addition to the already approved taxes on fossil fuels in the 1991 budget). The contributions from different fuels in this consumption tax scenario are shown in table 1.

A uniform tax on all fossil fuel use (per unit $CO_2$) is a cost efficient policy to reach a certain target for national emissions. It is however not a cost efficient way to achieve a given reduction in global emissions, cf. Golombek et. al. (1993). The "consumption tax policy" in this empirical illustration is the uniform tax policy suggested in KLØKT and thus not the cost-effective consumption tax policy given a target for global emission reduction.

The tax revenue is in KLØKT assumed to be transferred back to the private sector through a reduction in ordinary taxes and payroll tax.

This unilateral action to reduce $CO_2$ emissions cause an 1 per cent decrease in GDP in year 2000 compared to the reference scenario. A 1 percentage reduction in GDP correspond to 7.5 billion 1988-kroner (1.1 billion USD).

**Table 1. Contribution to reduction in $CO_2$ emissions in year 2000**

| **Contribution from:** | |
|---|---|
| Liquids | 2.8 |
| Natural gas | 1.4 |
| Solids | 3.8 |
| **$CO_2$-reduction in total** (Mill.tonnes $CO_2$) | 8.0 |

The reduction in discharge of $CO_2$ from natural gas is due to an assumed reduction in natural gas combustion in the production of oil and gas. According to a study by Christensen and Lindeberg (1990) the potential for a reduction in emissions from the production process is considerable. In KLØKT it is argued that a $CO_2$-tax will induce a more efficient energy use in the production of oil and gas. The gas production in MODAG is exogenously determined. The reduction in natural gas combustion in the oil and gas production will therefore not have any effect on the export of gas and thus neither on the international gas price. These assumptions imply that $\partial E/\partial y_2$ has to be set equal to 1, i.e., non of the reduction in $CO_2$ due to reduced gas combustion is offset by increased fossil fuel consumption in the rest of the world.

An approximation of the reduction in the global $CO_2$ emissions caused by the lower discharge in $CO_2$ ( table 1), is, according to (11), given by

$$(13) \qquad dE^* \approx \frac{\partial E}{\partial y_1} \cdot (-2.8) - 1.4 + \frac{\partial E}{\partial y_3} \cdot (-3.8)$$

where $\partial E/\partial y_1$ and $\partial E/\partial y_3$ are given by (4) (and (15)).

To calculate $\partial E/\partial y_1$ and $\partial E/\partial y_3$ it follows from (15) that one need figures for the following factors in year 2000: Own price elasticities, elasticities of supply, cross price elasticities, Norway's share of total production and consumption and the global production of the different fuels.

The elasticities used in the calculation are presented in table 2. All own price elasticities are equal to -0.80. All cross price elasticities are set to 0.10 The supply elasticities of coal are 2.00, which is greater than the common value of the supply elasticities of oil and gas (0.75). This assumption is due to the vast resources of coal. For a more detailed discussion about the choice of elasticities, see Appendix B. As the choice of elasticities has a decisive effect on the conclusion, a sensitivity analysis is presented in chapter 5.

**Table 2. Elasticities**

| | |
|---|---|
| **Consumption;** | |
| *Own price elasticities* | |
| all fuels | -0.8 |
| *Cross price elasticities* | |
| all fuels | 0.10 |
| **Production;** | |
| *Supply elasticities* | |
| oil | 0.75 |
| gas | 0.75 |
| coal | 2.0 |

World consumption of fossil energy in 2000 is based on an update for "Business-As-Usual" emission scenario prepared for IPCC (see emission scenario IS92a in Pepper et. al. (1992)). The production and consumption of fossil fuels in Norway are identical to the assumptions in the reference scenario in KLØKT. Figures for production and consumption of fossil fuels in Norway and world total in 2000 are presented in table 3.

**Table 3. Production and consumption of fossil fuels in 2000. (Mill tonnes $CO_2$)**

| Consumption | oil | gas | coal |
|---|---|---|---|
| Norway | 26 | 0 | 7 |
| World total | 10787 | 5237 | 10906 |
| **Production** | | | |
| Norway | 281 | 84 | 0 |
| World total | 10787 | 5237 | 10906 |

Inserting the figures from table 2 and 3 in (15) gives $\partial E/\partial y_1$ equal to 0.55 and $\partial E/\partial y_3$ equal 0.75. According to (13), the (approximately) final effect on global $CO_2$ emissions caused by the unilateral consumption tax policy presented in KLØKT is

**(14)** $$dE^* \approx 0.55\cdot(-2.8)\ -1.4\ +0.75\cdot(-3.8)=-5.3$$

A reduction of 8 million tonnes $CO_2$ in Norway will lead to a global reduction of 5.3 million tonnes. The carbon-leakage rate in the model is thus 35 per cent. The leakage is only caused by the reduction in oil and coal consumption, since the reduction in emission from gas combustion does not affect the supply of gas.

A decreased production in the oil sector will in itself cause a reduction in emissions from the oil producing sector. The discharge of $CO_2$ from the production process per million tonne produced oil and gas is however relatively small. In the reference scenario in KLØKT the discharge is set to 0.025 million tonnes $CO_2$ per millon tonne produced oil and gas (measured in $CO_2$-units). Some of the emission is further independent of small changes in the production level. In the calculation I have assumed that 50 per cent of the emission per tonne production is fixed.

In the reference scenario in KLØKT there is not assumed any development in the technology used in the oil sector. The consumption tax policy is assumed to lead to a higher energy efficiency and reduced flaring and thus lower discharge of $CO_2$ in that sector. The oil companies are assumed to improve the efficiency in gas turbine power generation both by normal replacement in existing installation and when constructing new ones. The cost of the reduced discharge from the oil producing sector is however not included in the calculated national cost of achieving the target for $CO_2$ emissions in year 2000.

Taxes on $CO_2$ emissions from the production and transport process have already been imposed on the oil companies operating in the North Sea. The tax was introduced in 1991 and accounts for 267 1988-kroner per tonne $CO_2$ emission from gas combustion. It is likely that this tax will lead to reduced gas flaring and a higher efficiency in the oil producing sector during a ten-years period. If that is correct, the $CO_2$ emission from the oil producing sector in the reference scenario in KLØKT is overestimated.

It is not obvious to what extent one should include reduced emission from the oil producing sector when calculating the necessary reduction in production to achieve the global decrease in discharge as calculated in (14). I have chosen two alternative calculations. In the first I assume the same reduction in emissions from the oil producing sector as assumed in the consumption tax policy in KLØKT. The reduced emission from combustion of gas in the production process is not assumed to affect the supply of gas. The reference scenario, regarding fossil fuel production, in my calculation is thus identical to the reference scenario in KLØKT. In the other calculation I assume that the oil sector uses the same production technology as in the reference scenario in KLØKT. The two different calculations lead to the following conclusions;

*Assuming the same decrease in discharge from the oil producing sector as in KLØKT, the production of oil has to be reduced by 8.5 million tonnes $CO_2$ units or the production of gas has to be reduced by 11.1 million tonnes $CO_2$ units to achieve the same global emission reduction as in the consumption tax policy (5.3 million tonnes of $CO_2$).*

*Assuming no decrease in discharge from the oil producing sector, the production of oil has to be reduced by 11.6 million tonnes $CO_2$ units or the production of gas has to be reduced by 15.1 million tonnes $CO_2$ units to achieve the same global emission reduction as in the consumption tax policy.*

The production of gas has to be reduced by a larger quantity than the production of oil to achieve the target for global $CO_2$ emission reduction. The reason for this is that gas represents a smaller part of world total fossil fuel consumption than oil. Gas accounts for about 18 per cent and oil for about 42 per cent of the assumed fossil energy consumption in 2000. A $CO_2$-unit decrease in gas production will represent a larger percentage decrease in total gas supply than a $CO_2$-unit reduction in oil supply will represent in the oil market. It follows from the assumption about the elasticities that the percentage price increase in the gas market, following from a unit reduction in supply, is larger than the percentage price increase on oil following from a unit decrease in the supply of oil. Since all cross price elasticities are equal, a reduction in the production of gas by one unit $CO_2$ has a larger impact on the prices on the other fuels, than a reduction in the supply of oil. In total, a reduction in gas production by one million tonnes $CO_2$-units in the small country is offset by an increase in fossil fuel production by 0.65 million tonnes in the rest of the world; the production of gas increases by 0.48 million tonnes and production of oil and coal by 0.17 million tonnes

($CO_2$-units). A reduction in oil production of one million tonne $CO_2$-units is offset by an increase in oil production in the rest of the world by 0.47 million tonnes and an increase in gas and coal production by 0.06 million tonnes.

The effect on international prices of unilateral actions is important for deciding the final contribution to the global $CO_2$ emissions. Even a very small change in international prices will greatly affect changes in the rest of the world's production compared with the reduction in the small country. The changes in the prices are however too small to have any significant effect on the small country's export revenue. A reduction in oil production by one million tonnes $CO_2$ units will increase the international oil price by 0.006 per cent and the gas price by 0.0004 per cent. A reduction in gas production by the same amount will increase the gas price by 0.0125 per cent and the oil price by 0.0008 per cent. The increase in export revenue due to the price increase is therefore of minor importance for the final cost of the policy. I have thus not considered the impact of price changes on the net export value of fossil fuels when comparing the cost of the different policy alternatives.

The cost of reducing the fuel production is set equal to the amount of reduced production multiplied by the prices in year 2000. I have thus chosen to calculate the maximum cost, i.e., I have not assumed any reduction in intermediate products, labor or capital due to the decrease in production. The reason for this assumption is partly that the necessary real capital for the estimated production in year 2000 is already built up or is under construction. The impact on the need for labor and intermediate inputs per unit reduced oil or gas production is furthermore difficult to estimate. By disregarding the possible impact on intermediate products, labor and capital, I have overestimated the actual cost of the reduced production policy.

The costs of reducing the production of either oil or gas to achieve a global $CO_2$-reduction of 5.3 million tonnes are shown in table 4 a and b. The costs will be dependent on the assumptions about the emissions from the production process as discussed above. The difference between the cost of reduced production of gas and oil is due to the differences in the necessary amount of reduction to achieve a global $CO_2$ reduction of 5.3 million tonnes and the differences in prices in year 2000. The prices of oil and gas in year 2000 are identical to the price assumptions in KLØKT.

**Table 4.a) Cost of reducing production when the decrease in discharge from the production process is as assumed in KLØKT.**

| | Price per tonne $CO_2$. | Reduction in production (mill.tonnes $CO_2$) | Reduction as percentage of reference scenario production | Total cost (billion 1988 - kroner) |
|---|---|---|---|---|
| oil | 316 kr. | 8.4 | 3.0 | 2.7 |
| gas | 346 kr. | 9.9 | 11.9 | 3.4 |

**Table 4.b) Cost of reducing production when there is no decrease in discharge from the production process.**

| | Price per tonne $CO_2$. | Reduction in production (mill.tonnes $CO_2$). | Reduction as percentage of reference scenario production | Total cost (billion 1988 - kroner) |
|---|---|---|---|---|
| oil | 316 kr. | 11.6 | 4.1 | 3.7 |
| gas | 346 kr. | 15.1 | 18.1 | 5.2 |

From table 4 a and b one can conclude the following;

*Reduced fossil fuel production is clearly less expensive than the cost of 7.5 billion 1988-kroner in lost GDP caused by the consumption tax policy.*

This conclusion holds regardless of what we assumed about the emissions from the production process. A reduction in oil production is less costly than a reduction in the production of gas. This is partly because gas has to be reduced by a larger quantity $CO_2$-units than oil to achieve the target for global emission reduction, as discussed above. Furthermore, the price of gas per unit of $CO_2$ is higher than the price of oil.

## 5. Sensitivity analysis

The main conclusion from section 4 is that a cost efficient climate policy in Norway implies a reduction in the production of oil rather than introducing uniform taxes on fossil fuel consumption.

This conclusion is first dependent on the calculated cost of consumption reductions. Secondly, it is dependent on the assumptions about prices on oil and gas in year 2000 and thirdly it is dependent on the elasticities used in our calculations.

The cost of reducing $CO_2$ emissions by eight million tonnes in Norway within the year 2000 is, in addition to KLØKT, presented in two other studies; in a report from the Norwegian committee for environmental taxes (see Miljøavgiftsutvalget (1991)) and in Bye, Bye and Lorentsen (1989). In the first study the cost is estimated to 1.6 per cent of GDP in year 2000 and in the latter to 1-2 per cent of GDP. Both studies are based on the same medium term macroeconomic model as in KLØKT.

An emission reduction of eight million tonnes $CO_2$ in KLØKT corresponds to approximately 18 per cent reduction from base line. Two studies of unilateral actions in Norway are based on different modified versions of the general equilibrium model MSG. Glomsrød et al. (1990), estimate the cost of a 26 percent reduction of emission to 2.7 percent of GDP in 2050. In a recent study by Johnsen et al. (1993) the cost of a 20 percent reduction in $CO_2$ emissions in Norway in 2020 is found to be 0.5 percent of GDP.

A GDP reduction of 1 percent of a unilateral reduction in $CO_2$ emissions of 18 per cent is thus in the lower range of the estimates for the Norwegian economy. However, the estimated costs of national $CO_2$ emission reduction vary considerably. Any conclusion drawn about cost efficient climate policy is thus highly dependent on the type of macroeconomic model, and of the specification of the model, used to estimate the impact of national $CO_2$ emission control.

The oil price assumption in my calculation is identical to the price used in KLØKT. An oil price above that level will have a direct effect on the cost. The assumed development in the oil price is in line with Radetzki (1991), while the price on gas is assumed to rise moderately (by around 10 per cent in constant prices) while Radetzki estimates a small decrease.

The conclusion about cost efficient policies is further dependent on the elasticities used in our calculations. Choice of elasticities affects the results in two ways. First it will affect the global $CO_2$ emissions caused by the initial consumption reduction in Norway, as shown in (11). Secondly it will affect the necessary reduction in production to achieve the global emission reduction target as shown in (12).

To examine the impact of the assumptions about the elasticities, I have computed "critical values" for some elasticities. These values are computed as follows; The starting point is the value of the elasticities as presented in table 2. One (or some) of the elasticities in the model is (are) increased until the cost of the production tax policy equals 7.5 billion kroner. The critical value is thus the value of the elasticity(ies) for which the cost of the reduced oil production policy is equal to the cost of the consumption tax policy, given that the other elasticities are as shown in table 2. When more than one of the elasticities are increased at the time, the critical value indicates the common critical value for the elasticities when they are increased simultaneously.

I have not assumed any decrease in discharge from the oil production process in the calculations, i.e., I have used the same assumptions as for the calculations in table 4b. Furthermore, since it is more costly to reduce gas production than to reduce oil production, I have restricted the analysis to the latter policy. Three different situations are examined. In the first situation, called A, I have increased the supply elasticities for oil, while the other elasticities are as shown in table 2. In situation B, I have increased the demand elasticity for oil. All demand elasticities are increased simultaneously in situation C. Finally, in situation D, I have increased all cross price elasticities simultaneously. In all situations, a decrease in the elasticities reduces the cost of the reduced oil production policy. It is thus only of interest to examine the effect of an increase in the elasticities to test the robustness of the conclusion about the most cost efficient climate policy. The critical values in the different situations are shown in table 5.

**Table 5. Values on elasticities for which the cost of reduced oil production is equal to the cost of the consumption tax policy.**

| | Elasticities increased | critical values |
|---|---|---|
| Situation A:<br><br>All elasticities except $\sigma_{ii}$ as in table 3 | $\sigma_{11}$ | 2.05 |
| Situation B:<br><br>All elasticities except $\delta_{11}$ as in table 3 | $\delta_{11}$ | -0.39 |
| Situation C:<br><br>All supply and cross price elasticities as in table 3. | $\delta_{ii}$<br><br>i = 1,2,3 | -0.46 |
| Situation D:<br><br>All supply and own price elasticities as in table 3. | $\delta_{ij}$<br><br>i = 1,2,3 j = 1,2,3 i≠j | 0.27 |

$\delta_{ii}$ is the demand elasticity for oil.
$\delta_{ij}$ (i = 1,2,3 j = 1,2,3 i≠j, ) are cross price elasticities
$\sigma_{ii}$ is the supply elasticity for oil.

The robustness of the conclusion regarding the less costly climate policy is dependent on the critical values for the elasticities. All critical values are significantly larger than the elasticities used in the model. The conclusion about reduced oil production being the less costly policy thus holds for elasticities in a relatively large interval around the elasticities presented in table 2. On the other hand, the discussion about elasticities in appendix B reveals that estimated cross price and own price elasticities vary considerably. The critical values for the cross price elasticities are for instance in the middle range, or even less, than many of the estimates reported by Bohi (1981), and in the upper range of the elasticities reported by Birkelund et al. (1993). Furthermore, as concluded in appendix B, own price elasticities less than the critical value of -0,36 can be justified.

To sum up, the conclusion about the less costly climate policy may be altered by other choices of elasticities, significantly diverging from the values I have used, but still justified by empirical observations.

## 6. Concluding comments

In this paper I have compared the cost of two different climate policies in a small country; a reduction in fossil fuel consumption achieved by imposing $CO_2$-taxes and a reduction in production of either gas or oil. It is shown how a national emission reduction caused by $CO_2$-taxes is partly offset by increased consumption of fossil fuels in the rest of the world. Assuming competitive markets, it is shown how a global $CO_2$ reduction alternatively could be achieved by reducing the production of fossil fuels.

The empirical illustration reveals that the reduced production policy may be less costly than the consumption tax policy. The conclusion is however highly dependent of the assumptions about the supply and demand elasticities, the international prices on fossil fuels and the estimated cost of the consumption tax policy.

I have based the comparison of the cost of the different policies on a 18 percent reduction in national emissions. It is reasonable to assume that the marginal cost of reducing $CO_2$ emissions is higher the larger percentage cutback in emissions. This is also the conclusion drawn in Johnsen et al. (1993). The cost of reduced oil production is in my calculation equal to corresponding decrease in the oil export revenue. A larger decrease in the reduction should thus not increase the cost per unit reduced oil production (disregarding the small effect on international fuel prices). A larger target for emission reduction is thus more likely to support the conclusion that reduced production is the less costly policy option.

**Appendix A.**

$\partial E/\partial y_i$ expressed in terms of elasticities;

$$
(15) \quad \frac{dE}{dy_i} = \frac{
\begin{aligned}
&\sigma_{ii}\cdot(\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{mm})+\sigma_{kk}\cdot(\frac{X_k}{X_i})\cdot(\delta_{mm}\cdot\delta_{ki}-\delta_{km}\cdot\delta_{mi})\\
&+\sigma_{mm}\cdot(\frac{X_m}{X_i})\cdot(\delta_{kk}\cdot\delta_{mi}-\delta_{mk}\cdot\delta_{ki})\\
&+\sigma_{kk}\cdot\sigma_{mm}\cdot(-\delta_{mi}\cdot(\frac{X_m}{X_i})\cdot(1+\frac{y_k}{Y_k-y_k})-\delta_{ki}\cdot(\frac{X_k}{X_i})\cdot(1+\frac{y_m}{Y_m-y_m}))\\
&+\sigma_{ii}\cdot\sigma_{kk}\cdot(1+\frac{y_k}{Y_k-y_k})\cdot(\delta_{mm})+\sigma_{ii}\cdot\sigma_{mm}\cdot(1+\frac{y_m}{Y_m-y_m})\cdot(\delta_{kk})\\
&-\sigma_{ii}\cdot\sigma_{kk}\cdot\sigma_{mm}\cdot(1+\frac{y_m}{Y_m-y_m})\cdot(1+\frac{y_k}{Y_k-y_k})
\end{aligned}
}{
\begin{aligned}
&(1-\frac{y_i}{Y_i})\cdot(\delta_{ii}\cdot\delta_{kk}\cdot\delta_{mm}-\delta_{ii}\cdot\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{im}\cdot\delta_{mi}\\
&\qquad -\delta_{mm}\cdot\delta_{ik}\cdot\delta_{ki}+\delta_{ik}\cdot\delta_{km}\cdot\delta_{mi}+\delta_{im}\cdot\delta_{ki}\cdot\delta_{mk})\\
&+\sigma_{ii}\cdot(\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{mm})\\
&+\sigma_{kk}\cdot(1-\frac{y_i}{Y_i})\cdot(1+\frac{y_k}{Y_k-y_k})\cdot(\delta_{im}\cdot\delta_{mi}-\delta_{ii}\cdot\delta_{mm})\\
&+\sigma_{mm}\cdot(1-\frac{y_i}{Y_i})\cdot(1+\frac{y_m}{Y_m-y_m})\cdot(\delta_{ik}\cdot\delta_{ki}-\delta_{ii}\cdot\delta_{kk})\\
&+\sigma_{ii}\cdot\sigma_{kk}\cdot(1+\frac{y_k}{Y_k-y_k})\cdot\delta_{mm}+\sigma_{ii}\cdot\sigma_{mm}\cdot(1+\frac{y_m}{Y_m-y_m})\cdot\delta_{kk}\\
&+\sigma_{kk}\cdot\sigma_{mm}\cdot(1-\frac{y_i}{Y_i})\cdot(1+\frac{y_k}{Y_k-y_k})\cdot(1+\frac{y_m}{Y_m-y_m})\cdot\delta_{ii}\\
&-\sigma_{ii}\cdot\sigma_{kk}\cdot\sigma_{mm}\cdot(1+\frac{y_k}{Y_k-y_k})\cdot(1+\frac{y_m}{Y_m-y_m})
\end{aligned}
}
$$

i = 1,2,3, k=1,2 3 and $k \neq i$, m = 1,2,3, $m \neq k$ and $m \neq i$

$\delta_{jj}$ (j = 1,2,3) is demand elasticity for respectively oil, gas and coal.

$\delta_{jr}$ (j = 1,2,3 r = 1,2,3 $j \neq r$) are the cross price elasticities

$\sigma_{jj}$ (j = 1 , 2 ,3) is the supply elasticity for respectively oil, gas and coal.

$X_j$ (j = 1,2,3 ) Total wold supply of respectivly oil, gas and coal

$Y_j$ (j = 1,2,3 ) Total world demand of respectivly oil, gas and coal

$X_j = Y_j$ (j = 1,2,3 ) Total world supply equals total world demand

$x_j$ (i = 1,2,3 ) Supply of respectively oil, gas and coal from the small country.

$y_j$ (j = 1,2,3 ) Demand for respectively oil, gas and coal from the small country.

$\partial E/\partial x_i$ expressed in terms of elasticities;

$$
(16)\quad \frac{dE}{dx_i} = 1 + \frac{
\begin{aligned}
&-\sigma_{ii}\cdot(\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{mm})+\sigma_{kk}\cdot(\frac{X_k-x_k}{X_i-x_i})\cdot(\delta_{mm}\cdot\delta_{ki}-\delta_{km}\cdot\delta_{mi})\\
&-\sigma_{mm}\cdot(\frac{X_m-x_m}{X_i-x_i})\cdot(\delta_{kk}\cdot\delta_{mi}-\delta_{mk}\cdot\delta_{ki})\\
&-\sigma_{kk}\cdot\sigma_{mm}\cdot(-\delta_{mi}\cdot(\frac{X_m-x_m}{X_i-x_i})\cdot(1-\frac{x_k}{X_k})-\delta_{ki}\cdot(\frac{X_k-x_k}{X_i-x_i})\cdot(1-\frac{x_m}{X_m}))\\
&-\sigma_{ii}\cdot\sigma_{kk}\cdot(1-\frac{x_k}{X_k})\cdot(\delta_{mm})-\sigma_{ii}\cdot\sigma_{mm}\cdot(1-\frac{x_m}{X_m})\cdot(\delta_{kk})\\
&+\sigma_{ii}\cdot\sigma_{kk}\cdot\sigma_{mm}\cdot(1-\frac{x_m}{X_m})\cdot(1-\frac{x_k}{X_k})
\end{aligned}
}{
\begin{aligned}
&(1+\frac{x_i}{X_i-x_i})\cdot(\delta_{ii}\cdot\delta_{kk}\cdot\delta_{mm}-\delta_{ii}\cdot\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{im}\cdot\delta_{mi}\\
&\qquad-\delta_{mm}\cdot\delta_{ik}\cdot\delta_{ki}+\delta_{ik}\cdot\delta_{km}\cdot\delta_{mi}+\delta_{im}\cdot\delta_{ki}\cdot\delta_{mk})\\
&+\sigma_{ii}\cdot(\delta_{km}\cdot\delta_{mk}-\delta_{kk}\cdot\delta_{mm})\\
&+\sigma_{kk}\cdot(1+\frac{x_i}{X_i-x_i})\cdot(1-\frac{x_k}{X_k})\cdot(\delta_{im}\cdot\delta_{mi}-\delta_{ii}\cdot\delta_{mm})\\
&+\sigma_{mm}\cdot(1+\frac{x_i}{X_i-x_i})\cdot(1-\frac{x_m}{X_m})\cdot(\delta_{ik}\cdot\delta_{ki}-\delta_{ii}\cdot\delta_{kk})\\
&+\sigma_{ii}\cdot\sigma_{kk}\cdot(1-\frac{x_k}{X_k})\cdot\delta_{mm}+\sigma_{ii}\cdot\sigma_{mm}\cdot(1-\frac{x_m}{X_m})\cdot\delta_{kk}\\
&+\sigma_{kk}\cdot\sigma_{mm}\cdot(1+\frac{x_i}{X_i-x_i})\cdot(1-\frac{x_k}{X_k})\cdot(1-\frac{x_m}{X_m})\cdot\delta_{ii}\\
&-\sigma_{ii}\cdot\sigma_{kk}\cdot\sigma_{mm}\cdot(1-\frac{x_k}{X_k})\cdot(1-\frac{x_m}{X_m})
\end{aligned}
}
$$

$i$ = 1,2,3, $k$= 1,2,3 and $k \neq i$, $m$ = 1,2,3 , $m \neq k$ and $m \neq i$
$\delta_{jj}$ ($j$ = 1,2,3) is the demand elasticity for respectively oil, gas and coal.
$\delta_{jr}$ ($j$ = 1,2,3 $r$ = 1,2,3 $j \neq r$) are the cross price elasticities
$\sigma_{jj}$ ($j$ = 1,2,3) is the supply elasticity for respectively oil, gas and coal.
$X_j$ ($j$ = 1,2,3 ) Total wold supply of respectivly oil, gas and coal
$Y_j$ ($j$ = 1,2,3 ) Total world demand of respectivly oil, gas and coal
$X_j = Y_j$ ( $j$ = 1,2,3 ) Total world supply equals total world demand
$x_j$ ($j$ = 1,2,3 ) Supply of respectively oil, gas and coal from the small country.
$y_j$ ($j$ = 1,2,3 ) Demand for respectively oil, gas and coal from the small country.

It is assumed that the supply and demand elasticities in the small country are identical to the corresponding elasticities in "the rest of the world." $\delta_{jr}$ (j=1,2,3 and r =1,2,3) and $\sigma_{jj}$ (j =1,2,3) in (15) and (16) are thus identical.

**Appendix B**

In this appendix I discuss the choice of elasticities.

**Supply elasticities**

Global models developed to estimate impacts of climate policy use different supply elasticities. The carbon based supply elasticity is set to 0.5 in the Whally-Wigle model (see Whalley and Wigle (1991)). According to Burniaux et al. (1992), both oil and coal supply elasticities are 1.0 in the model developed by Edmonds and Barns (1990).

In GREEN the upward supply elasticity of coal ranges between 4-5 and the downward elasticity is infinite. The downward supply elasticity of oil in the energy-exporting LDCs is phased out from 3 to 1 over the period 1990 - 2050 and the downward supply elasticity of gas ranges between 3-4 and the upward elasticity is zero (see Oliveira-Martins (1992b)).

I have chosen elasticities within the range of these models. The supply elasticities of oil and gas are set to 1.0, while the supply elasticities of coal are set to 2.0. A higher supply elasticity of coal can be explained by the vast resources of coal: An increase in the price of coal by 1 per cent may induce a large increase in the supply.

**Demand elasticities**

There are several studies estimating own price elasticities for fossil fuel in the literature. There are however more difficult to find estimated cross price elasticities. Furthermore, most of the estimates are based on data from developed countries.

Al-Sahlawi (1989) surveys estimated price elasticities on gas for the industrial, residential and commercial sector. Bohi (1981) surveys estimated long-run own price elasticities and cross price elasticities on all fossil fuels based on data from USA. In Pindyck (1979 a and b) long-run own price elasticities and cross-price elasticities for residential demand and industrial demand are estimated for nine and ten OECD-countries, respectively. Furthermore, Birkelund, Gjelsvik and Aaserud (1993) estimate long- run elasticities and cross price elasticities for four european countries (France, Great Britain, Italy and West -Germany)

Most of the long-run elasticities on gas demand reported by Al-Shalawi are in the range of -0.5 to -2.0. Bohi concludes in his survey that the own price elasticity for gas is close to -0.5 in the residential sector and near -1.0 in the commercial sector. He further concludes that the elasticity is uncertain in the industrial sector where the estimates in the literature he surveys are in the range of -0.45 to -1.5. Pindyck's estimates of own price elasticities for gas in the industrial sector range from -0.41 to -2.34, while residential demand elasticities range from -1.28 to -1.95. Birkelund et al. estimate the own price elasticities on gas for the four european countries to be in the range of -0.75 to -1.75

Bohi reports own price elasticities for oil in the residential and commercial sector in the range from -1.1 to -1.76. The corresponding elasticities in the industrial sector are in the range from -0.8 to -2.82. Pindyck estimates the own price elasticities for oil in the range of -0.06 to -1.17 in the industrial sector and in the range of -1.10 to -1.38 in the residential sector. Birkelund et al. estimate the direct price elasticity for oil in the end use sectors in the four european countries ranging from -0.6 to -1.0, with an average of -0.70.

Bohi reports own price elasticities on coal in the range of -0.49 to -2.07 in the industrial sector. Pindyck estimates the corresponding elasticities in the range of -1.29 to -2.24, and the own price elasticities in the residential sector between -1.0 and -1.12. Birkelund et al. find coal elasticities to be in the range of -1.0 to -1.25.

As the literature on demand elasticities in developed countries indicate, the estimates on direct price elasticities vary substantially. All choices of elasticities ranging from (e.g.) - 0.40 to -2.20 can be justified.

The conventual wisdom seems to be that fuel demand is less elastic in developing countries, although some studies estimate the energy demand elasticities to be larger in the developing countries, cf. Fiebig, Seale and Theil (1987).

Given the moderate level of knowledge, I have in this paper chosen identical own price elasticities for all fuels. They are all set to -0.8.

**Cross-price elasticities**

The magnitudes of cross price elasticities are very uncertain as well. Most of the cross price elasticities in Pindyck (1979 a and b) are negative. Furthermore, several of the positive cross price elasticities are larger than one. Bohi (1981) provides a range of positive cross price elasticities for all fossil fuels;.The elasticity of the oil price on the demand for natural gas ranges from 0.14 to 0.58 whereas the opposite elasticity ranges from 0.75 to 1.42. The elasticity of the coal price on the demand for natural gas ranges from 0.15 to 0.45, whereas the opposite elasticity ranges from 0.75 to 1.27. The elasticity of the oil price on the demand for coal ranges from 0.14 to 3.06 whereas the opposite ranges from 0.14 to 1.01.

In Birkelund et al. the cross price elasticities are considerably smaller. Most of the cross price elasticities are in the range of 0.01 to 0.30. We have chosen the size of the cross price elasticities in the line with Birkelund et al. All cross price elasticities are set to 0.10.

I have assumed that all elasticities are constant in the area examined.

**References**


Al-Sahlawi, M.A. (1989): The demand for natural gas: A survey of price and income elasticities." The Energy Journal, vol.10, No 1.

Bergman, L. (1991): "General Equilibrium Effects of Environmental Policy: A CGE-Modeling Approach". Environmental and Resource Economics, 1:43-61, 1991

Birkelund, H., E. Gjelsvik and M. Aaserud (1992): Carbon/energy taxes and the energy market in Western Europe". Discussion paper No 81, 1993 from Central Bureau of Statistics, Oslo

Bohi, D.R. (1981): Analyzing demand behaviour - a study of energy elasticities. John Hopkins University Press.

Bohm, P. (1993): "Incomplete International Cooperation to Reduce $CO_2$ Emissions: Alternative Policies." Journal of Environmental Economics and Management 24, 1993

Burniaux, J-M., J. P. Martin, G. Nicoletti and J. Oliveira Martins (1992): GREEN- a multi-sector, multi-region general equilibrium model for quantifying the costs of curbing $CO_2$ emissions: A technical manual", Working paper No 116 from Economics department, OECD.

Bye, B., T. Bye and L. Lorentsen (1989): "SIMEN- Studies of Industry, Environment and Energy up to year 2000." Discussion paper no. 12 1989, Central Bureau of Statistics, Oslo.

Christensen, T. and E. Lindeberg (1990): "Forbedret energiutnyttelse på produksjonsplattformer". Rapport 90.150, Institutt for kontinentalsokkelundersøkelser og petroleumsteknologi.

Dean, A. and P. Hoeller (1992): "Costs of reducing $CO_2$ emissions: Evidence from six global models.", Working paper No 122 from Economics department, OECD

Edmonds, J.A. and Barns (1990): "Estimating the marginal cost of reducing global fossil fuel $CO_2$ emissions", mimeo, Pacific Northwest Laboratory, Washington, D.C.

Fiebig, D.G., J. Seale and H. Theil (1987): The demand for energy. Evidence from a cross-country demand system". Energy Economics, July

Glomsrød, S., H. Vennemo and T. Johnsen (1990): "Stabilization of emissions of $CO_2$: A computable genaral equilibrium assessment." Discussion paper no 48, 1990. Central Bureau of Statistics, Oslo.

Golombek, R., C. Hagem and M. Hoel (1993): "Efficient incomplete international climate agreements". Working paper 1993:4 from CICERO, University of Oslo.

Johnsen, T.J., B.M. Larsen and H.T. Mysen (1993): " Costs of reducing $CO_2$ emissions in Norway", paper presented at the international conference of IAEE 1993.

Moum, K (eds.) (1992):" Klima, Økonomi og Tiltak (KLØKT)", Rapporter 92/3, Central Bureau of Statistics, Oslo

Miljøavgiftsutvalget (1991): "Mot en mer bærekraftig utvikling: Prinsipper og forslag til bedre prising av miljøe". Delutredning fra Miljøavgiftsutvalget.

Oliveira-Martins, J., J-M. Burniaux and J.P. Martin (1992a): "Trade and the effectiveness of unilateral $CO_2$ abatement policies: Evidence from GREEN". Paper presented at the Fondazione Eni Enrico Mattei conference on "The international Dimension of Environmental Policy, Milan 1992.

Oliveira-Martins, J., J-M. Burniaux, J.P. Martin and G. Nicoletti (1992b): "The costs of reduced $CO_2$ emissions: A comparison of carbon tax curves with green", Working paper No. 118, 1992 from Economics department, OECD.

Pepper, W., J. Leggett, R. Swart, J. Wasson, J. Edmonds and I. Mintzer (1992): "Emission Scenarios for the IPCC. An Update".

Pezzey, J. (1992): "Analysis of unilateral $CO_2$ control in the European Community and OECD". The Energy Journal, Vol 13,Number 3.

Pindyck, R.S. (1979a): Interfuel substitution and the industrial demand for energy. An international comparison". Review of Economics and Statistics, May.

Pindyck, R.S. (1979b): International comparisons of the residential demand for energy". European Economic Review, 13.

Radetzki, M. (1991): "Price prospects in Western Europe for international traded fossil fuels until 2000". Natural Resources Forum, November 1991.

Whalley, J and Wigle, R. (1991): "The International Incidence of Carbon Taxes", in R. Dornbusch and J.M. Poterba (eds.): Global Warming: Economic Policy Responses, MIT Press