Norwegian Gas Sales and the Impacts on European CO_2

Elin Berg*, Pal Boug** and
Snorre Kverndokk**

NOTA DI LAVORO 9.98

JANUARY 1998
ENV – Environmental Economics

*Norsk Hydro, Stabekk, Norway
**Research Department, Statistics Norway

We are indebted to Kjell Arne Brekke for useful discussions, to Torstein Bye, Ådne Cappelen, Øystein Olsen and Knut Einar Rosendahl for comments on earlier drafts and to Mohamed Hazza for research assistance. This work was supported financially by the Norwegian Ministry of the Environment.

Address for correspondence:

Snorre Kverndokk
Research Department
Statistics Norway
P.O. Box 8131 Dep.
0033 Oslo
Norway
Fax: +4722864963
E-mail: snk@ssb.no

SUMMARY

This paper studies the impacts on Western European CO_2 emissions of a reduction in Norwegian gas sales. Such impacts are due to changes in energy demand, energy supply, and environmental and political regulations. The gas supply model DYNOPOLY is used to analyse the effects on Russian and Algerian gas exports of a reduction in Norwegian gas supply. The effects on the demand side and the effects of committing to CO_2 targets are analysed using the energy demand model SEEM. If Western European countries commit to their announced CO_2 emissions targets, reduced Norwegian gas sales have no impact on emissions. The consumption of oil and coal will increase slightly, while total energy consumption will go down. Also, a reduction in Norwegian gas sales have only minor impacts on the CO_2 emissions from Western Europe when no emissions regulations are considered.

Key words: Gas sales, Energy consumption, CO_2 emissions, Environmental regulations

JEL: Q31, Q41

NON TECHNICAL SUMMARY

Norway is a large producer and exporter of natural gas to Europe, and is currently supplying almost 10 per cent of the natural gas consumption in Western Europe. An energy policy which changes the Norwegian gas sales may therefore have impacts on CO_2 emissions from Western Europe. In Norway it has been a large discussion over the last few years on the climate impacts of Norwegian gas sale. In this paper we, therefore, study the effects of a reduction in the Norwegian gas sales to Western Europe on the region’s energy use and CO_2 emissions.

The environmental impacts from Norwegian gas sales may be classified in three different categories; demand effects, supply effects and effects via regulations. On the *demand side*, we have two effects. First, if a reduction in Norwegian gas sales gives a higher gas price in Western Europe, the consumers will turn their energy demand away from gas towards other sources of energy which are relatively less expensive. Since oil and coal are more polluting fuels that gas, this substitution effect increases CO_2 emissions. Second, we have the income effect which will lead to energy savings and thus lower CO_2 emissions as a higher gas price makes energy more expensive relative to other factors of production such as labour, capital and material inputs. Environmental impacts through the demand effects of reduced Norwegian gas sales are thus uncertain.

A change in Norwegian gas sales may also have *supply effects* through reactions from other gas producers and producers of alternative energy sources. As mentioned above, a higher price of gas may increase the demand for oil and coal. The impact of this substitution effect depends on the supply curves. For instance, the increase in consumption of oil and coal, and thus the increase in carbon emissions, will be higher if the supply curves for these fuels are horizontal than if the supply curves are upward sloping. The slope of the supply curve for gas is also important for this substitution effect. With a vertical gas supply curve the reduced Norwegian gas sales will not be replaced by increased supply from other producers. On the other hand, if the supply curve for gas is horizontal the reduction in Norwegian gas sales will be exactly matched by an increase in the production from other gas suppliers, and the gas price remains unchanged. However, with an increase in the supply from other producers such that the total gas supply is the same, there may still be environmental impacts. The outcome depends on the leakage from the delivery and transportation system for gas. The distance from the markets and the quality of the pipelines of the different gas suppliers are important.

Finally, *political regulations* in consumer countries may also be important for the environmental effects of Norwegian gas sales. If for example a country has committed to stabilise CO_2 emissions, this will be effectuated regardless of the Norwegian gas sales policy. A change in Norwegian gas sales will, therefore, not influence the CO_2 emissions from the country.

The gas supply model DYNOPOLY is used to analyse the effects on Russian and Algerian gas exports of a reduction in Norwegian gas supply. The effects on the demand side and the effects of committing to CO_2 targets are analysed using the energy demand model SEEM.

Our results indicate that if Western European countries commit to their announced CO_2 emissions targets, reduced Norwegian gas sales have no impact on emissions. The consumption of oil and coal will increase slightly, while total energy consumption will go down. Also, a reduction in Norwegian gas sales have only minor impacts on the CO_2 emissions from Western Europe when no emissions regulations are considered.

January 1998

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by

Elin Berg, Pål Boug and Snorre Kverndokk

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Keywords: Gas Sales, Energy Consumption, CO_2 Emissions, Environmental Regulations
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Acknowledgements: We are indebted to Kjell Arne Brekke for useful discussions, to Torstein Bye, Ådne Cappelen, Øystein Olsen and Knut Einar Rosendahl for comments on earlier drafts and to Mohamed Hazza for research assistance. This work was supported financially by the Norwegian Ministry of the Environment.
Address: Research Department, Statistics Norway, P.O. Box 8131 Dep., 0033 Oslo, Norway.
Corresponding author: Snorre Kverndokk, e-mail: snk@ssb.no, fax: +4722864963.

Non-technical abstract

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Finally, *political regulations* in consumer countries may also be important for the environmental effects of Norwegian gas sales. If for example a country has committed to stabilise CO_2 emissions, this will be effectuated regardless of the Norwegian gas sales policy. A change in Norwegian gas sales will, therefore, not influence the CO_2 emissions from the country.

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Our results indicate that if Western European countries commit to their announced CO_2 emissions targets, reduced Norwegian gas sales have no impact on emissions. The consumption of oil and coal will increase slightly, while total energy consumption will go down. Also, a reduction in Norwegian gas sales have only minor impacts on the CO_2 emissions from Western Europe when no emissions regulations are considered.

1. Introduction

Global warming is recognised as a severe threat to the world, see, e.g., IPCC (1996). Carbon dioxide (CO_2) is the main greenhouse gas, and the main source for CO_2 emissions (70-75 per cent of all CO_2 emissions, see Halvorsen et al. 1989) is the combustion of fossil fuels; natural gas, oil and coal. However, the carbon content of the three fossil fuels differ, with coal as the most polluting and natural gas as the cleanest fuel with regards to CO_2 emissions per energy unit (see, e.g., Marland 1982). Thus, the composition of energy use, not only total consumption, has an impact on CO_2 emissions.[1]

Norway is a large producer and exporter of natural gas to Europe, and is currently supplying almost 10 per cent of the natural gas consumption in Western Europe (see BP 1996). An energy policy which changes the Norwegian gas sales may therefore have impacts on the CO_2 emissions from Western Europe. In Norway it has been a large discussion over the last few years on the climate impacts of Norwegian gas sale. In this paper we, therefore, study the effects of a reduction in the Norwegian gas sales to Western Europe on the region's energy use and CO_2 emissions.

The environmental impacts from Norwegian gas sales may be classified in three different categories; demand effects, supply effects and effects via regulations. The *demand effects* may be divided into two separate effects. The first is due to the substitution between different sources of energy. If a reduction in Norwegian gas sales gives a higher gas price in Western Europe, the consumers will turn their energy demand away from gas towards other sources of energy which are relatively less expensive. Since oil and coal are more polluting fuels that gas, this substitution effect increases CO_2 emissions, ceteris paribus. The other effect is the income effect which will lead to energy savings and thus lower CO_2 emissions as energy has become more expensive relative to other factors of

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[1] In this study we do not consider other polluting emissions from the combustion of fossil fuels.

production such as labour, capital and material inputs. Environmental impacts through the demand effects of reduced Norwegian gas sales are thus uncertain.

A change in Norwegian gas sales may also have *supply effects* through reactions from other gas producers and producers of alternative energy sources. As mentioned above, a higher price of gas may increase the demand for oil and coal. The impact of this substitution effect depends on the supply elasticities. For instance, the increase in consumption of oil and coal, and thus the increase in carbon emissions, will be higher if the supply curves for these fuels are horizontal, i.e., infinitely elastic, than if the supply curves are upward sloping. The slope of the supply curve for gas is also important for this substitution effect. With a vertical gas supply curve the reduced Norwegian gas sales will not be replaced by increased supply from other producers, and we get the greatest increase in the price of gas. On the other hand, if the supply curve for gas is horizontal the reduction in Norwegian gas sales will be exactly matched by an increase in the production from other gas suppliers, and the gas price remains unchanged. However, with an increase in the supply from other producers such that the total gas supply is the same, there may still be environmental impacts. The outcome depends on the leakage from the delivery and transportation system for gas. The distance from the markets and the quality of the pipelines of the different gas suppliers are important. If for example Norwegian gas is replaced by increased imports from Russia, the environmental effects will probably be negative due to the higher emissions connected with the transportation of Russian gas to the Western European market.

Finally, *political regulations* in consumer countries may also be important for the environmental effects of Norwegian gas sales. If for example a country has committed to stabilise CO_2 emissions, this will be effectuated regardless of the Norwegian gas sales policy. A change in Norwegian gas sales will, therefore, not influence the CO_2 emissions from the country. However, as fossil fuel prices and the composition of the country’s energy consumption may change, the costs of lowering emissions may vary accordingly. At the moment many countries reconsider their earlier commitments. Therefore, as the Norwegian gas policy may influence the country's costs of stabilising emissions, a reduction in Norwegian gas sales may have an impact on the probability of the country to keep its previously announced target.

As the above discussion indicates, it is difficult from theory to determine how a reduction in Norwegian gas sales will influence energy demand and CO_2 emissions in Western Europe.[2] In this paper we try to quantify some of these effects through numerical simulations. We present a detailed analysis of both the supply and demand side of the Western European gas market. First, the supply side is analysed in DYNOPOLY, a dynamic oligopoly model of the European gas market (see, e.g., Berg 1995a, 1995b and Brekke et al. 1991). Second, the demand effects for 13 Western European countries are studied in the energy demand model SEEM (see, e.g., Birkelund et al. 1994, Alfsen et al. 1995 and Brubakk et al. 1995). The two models are connected through the gas price. The impacts are analysed in the situation where no environmental regulations are present, and also under the restriction that all countries fulfil their announced emissions targets. Our results indicate that when there are no binding restrictions, reduced Norwegian gas sales will lead to a slight reduction in European CO_2 emissions. However, the emissions reduction will be quite modest as the lower supply of gas to some extent is replaced by increased consumption of oil and coal. In the case where countries have binding emissions targets, the CO_2 emissions are unaffected by reduced Norwegian gas sales, however, the composition of the energy is altered. In this paper we focus on the energy use of the four large energy consumers; Germany, France, Italy and United Kingdom. In addition to changes in CO_2 emissions from the consumer countries, we also calculate the effects on emissions from production, transportation and distribution of gas.

Previous analyses include Berg (1995a) and ECON (1994, 1995). Berg (1995a) uses the DYNOPOLY model in an analysis of supply effects in the European gas markets similar to the supply side analysis presented in this paper. ECON (1994,1995) reports results from simulations on their energy demand model ECON-ENERGY which has a similar structure as SEEM.. They study the effects of a reduction in Norwegian gas sales of 10 million ton oil equivalents (mtoe) in 2010 to Germany, Netherlands, Belgium and France. First, a negative shift in the supply curve is considered. However, the supply side is modelled ad hoc as three different scenarios. Second, a negative shift in the demand function, as a result of energy security, is studied. ECON concludes that as long as the supply curve is not vertical, a reduction in the Norwegian gas supply will increase CO_2 emissions. This result is mainly driven by leakages in Russian pipelines and an increase in domestic energy production based on coal due to energy security considerations.

The remainder of the paper is organised as follows. Section 2 presents the models DYNOPOLY and SEEM. The results from the numerical simulations are presented in Section 3 and the paper ends with conclusions in Section 4.

2. Description of the models

2.1. The DYNOPOLY model[3]

DYNOPOLY is a dynamic oligopoly model of the European natural gas market. The model focuses on strategic investments in an imperfect competition environment. Some of the first attempts to model the European gas market can be found in Boucher and Smeers (1985, 1987). These studies rely on perfect competition mechanisms. Models explicitly dealing with the imperfect competitive nature of the European gas market were initiated by Mathiesen et al. (1987). A first departure towards dynamic models was undertaken by Haurie et al. (1988) who consider a multistage development of the European gas market in an uncertain environment and search for open loop Cournot solutions. In Brekke et al. (1991) the restriction to an open loop equilibrium is removed.

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[2] These emissions also include CO_2 emissions in connection with imported gas from Algeria and Russia.

[3] For a more thorough documentation of the DYNOPOLY model, see, e.g., Brekke et al. (1987), Brekke et al. (1991) and Bjerkholt and Gjelsvik (1992).

DYNOPOLY computes closed loop feedback equilibrium and it is thus possible to take account of strategic investments.

In DYNOPOLY there are three major suppliers to the market: Norway, Algeria and Russia. The strategic variable is investment projects to increase production capacity. United Kingdom and the Netherlands are not modelled as players in the game, but their production is included in the exogenous indigenous production of the demand region in the model. The reason is that the Netherlands has already made most of its heavy investments, and production will decrease into the next century. United Kingdom has limited reserves and is not likely to become a large exporter.

Each player in the model has up to three discrete, irreversible investment projects which must be undertaken in a specified order. The time horizon (1995-2075) is divided into five year periods. At the beginning of each period the players can choose whether or not to invest in one or more of the remaining options. There is a five year time lag in investment so the they will first be operative in the following period. The moves are made simultaneously, and only previous investments are known when players make their decisions. The production capacity (or rather the export capacity to Western Europe) of a player in any given period is equal to the initial production capacity plus all investment projects undertaken in previous periods. Hence, the model does not take into account the depletion of production fields. Within each five year period the price of natural gas and the profits of the three players are determined in a short run Bertrand game for given capacities, the solution to which implies that all players produce at full capacity.

The players are assumed to have perfect information and they choose their investment profiles so as to maximise discounted cash flows over the time horizon. An important feature of the model is that the players are aware that their current actions have important implications in future periods and they take account of the fact that their own actions have an impact on the actions of the other players. Thus the model focuses on the strategic elements of the optimal investment profile. A strategic investment is defined as an investment where the only incentive for advancing the investment is pre-emption, i.e., to render the other players' investments unprofitable. Undertaking an investment increases the market share of the producer, but causes a fall in the overall price. The other producers will foresee this price fall and might postpone new investments. The result is a fight for market shares and an investment may thus be profitable according to strategic considerations even though it is not profitable according to the standard present value criterion. The model computes the subgame perfect maximin/Nash solution.[4] In equilibrium the players will balance the profits from discouraging other suppliers by making an investment, against the profits from restricting supply by postponing the investment.

2.1.1. Numerical assumptions in DYNOPOLY

The demand region in DYNOPOLY comprises the 13 Western European countries in SEEM. However, demand is calculated at a central point in Western Europe, and the model does not take account of the regional aspect of the gas market. As mentioned above, all players produce at full capacity. The price of gas is then determined by the equation of demand and total supply in the model. This may be interpreted as a situation with third party access (TPA).[5] Net demand for natural gas (D), which is equal to the total demand less the indigenous production of natural gas from the demand region (Q), is assumed to be a function of the end user price of natural gas (P_G) which is the producer price plus a (constant) margin that covers transmission and distribution costs as well as taxes and profits to the transmission companies. Demand also depends on the price of oil (P_O) and

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[4] The model is solved by dynamic programming. However, this procedure does not ensure a unique equilibrium. Therefore, we introduce a modified subgame perfect equilibrium, called a subgame perfect maximin/Nash solution, where we assume that the maximin solution will be chosen in multiple equilibria situations. The maximin solution entails that a player maximise his profit given that the other players choose the worst possible actions. However, the experience with the model so far indicates that the lack of a unique solution in the subgames is very rare.

[5] TPA ensures access to the transmission pipelines by paying a specified tariff to the owner of the pipeline. This enables gas producers and end users to enter contracts of gas deliveries using the transmision companies only as a transportation service. In the European gas industry today there is a diversity of institutional framework, with monopolies co-existing with deregulated markets. United Kingdom has already adopted a system of regulated TPA, however, on the continent gas is mostly sold under long term take-or-pay contracts. The price of gas is set according to the market value principle which entails that the price is set so that gas can compete with the best energy alternative of the customer, e.g., oil, coal or nuclear power. However, the EU Energy Commission plans to create a single European gas market through TPA and unbundling. So far the process has been slowed down by the opposition from large companies in the industry, and the gas directive currently under discussion is relatively modest compared to the original draft directive put forward in 1992.

coal (P_C) and on the gross domestic product (Y) of the demand region. We assume constant demand elasticities (e1, e2, e3 and e4).

$$D_t = AP_{Gt}^{e1}P_{Ot}^{e2}P_{Ct}^{e3}Y_t^{e4} - Q_t \tag{1}$$

The direct price elasticity is set equal to -0.75 which is the average direct price elasticity for gas in the major consumer countries in SEEM. The cross price elasticities for oil and coal are assumed to be 0.365 and 0.103 respectively based on earlier simulations on the SEEM model. The income elasticity is set equal to 0.5. The development in future oil and coal prices correspond to the estimates in SEEM which are based on predictions from IEA (1996), see Paragraph 2.2.1. The annual growth in GDP is assumed to be 2.5 per cent. GDP and the price of oil and coal are set equal to one initially. The initial import price is $88/toe which is the European Union cif price of natural gas in 1994, reported in BP (1995). The gross margin, defined as the difference between the end user price and the import price on natural gas, is in a previous study calculated to be $227/toe in 1993 (in 1991 US dollars)[6] on average for Germany, France and Belgium (see Berg 1995b). Thus when the calculated gross margin is added, the initial end user price is $315/toe. The model is calibrated to fit observed values in 1994 in the first five year period (1995-2000). It is also calibrated such that supply in DYNOPOLY fits demand for gas in SEEM.[7]

Total supply of gas in the model is the sum of the exogenous indigenous supply from the demand region and the supply from the three players Norway, Algeria and Russia. Initial production of the three players are set equal to their reported exports to the demand region in 1994 according to BP (1995). Indigenous production in the first period is then determined residually (164 billion cubic meter per year, bcm/year) such that total consumption in the demand region equals observed 1994

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[6] Unless otherwise noticed, all prices and costs are measured in 1991 US dollars.

[7] The discrepancy between supply and demand in the two models is about 1-7 per cent in the reference scenario (with a supply surplus).

consumption according to BP (1995).[8] Indigenous production is assumed to be almost unchanged in the first two periods, but from 2000 it is assumed to decrease at a rate of approximately 20 per cent over each five year period due to limited natural gas reserves. The supply from the three players depends on the timing of their investments and is determined endogenously. Below we give a brief presentation of the investment projects available to the three players. We assume that all players use the same discount rate of 10 per cent p.a.

The initial production capacity of Norway is set equal to the Norwegian gas exports to Western Europe in 1994 which according to BP (1995) was about 27 bcm. However, at the beginning of 1995 Norway had entered long term contracts for delivery of large quantities of natural gas to Western Europe into the next century. Thus we assume the initial capacity increases to 60 bcm/year from 2000 onwards to meet deliveries under existing contracts.[9] The deliveries under these contracts involve large investments in field development and pipeline construction. However, since these investments are required by contract, we do not consider them as part of the competition for market shares as described by the model, and hence they will not be listed as strategic investment options for Norway. Beyond the level of 60 bcm/year from 2000 we assume that Norway has two investment projects to further increase production capacity, see Table 1. Both projects concern the development of gas fields in the North Sea area. Each of them will add 10 bcm/year to the initial production capacity so that Norway, after having exhausted these options, will have a production capacity of 80 bcm/year. The first project comprises field development and investment in a new pipeline to either France or Belgium[10], while the second project assumes that gas is delivered through the existing Frigg pipeline to St. Fergus in Scotland.[11]

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[8] The indigenous production in the model in the first period is about 8 per cent lower than the production in Western Europe (excluding Norway) in 1994 according to BP (1995).

[9] Norway has signed several new gas contracts since 1995. In 2005 Norwegian gas producers will have delivery obligations in the order of 70 bcm, see Norwegian Ministry of Petroleum and Energy (1997). However, contracts signed after 1995 are not included in the initial capacity of Norway in the DYNOPOLY model.

[10] Today Norwegian gas is transported to the continent through the pipelines Norpipe and Europipe to Emden and through Zeepipe to Zeebrugge. Including the Norfra pipeline to Dunkerque, which is due to be completed in 1998, the export capacity of Norway to the continent will be about 60 bcm/year. The Norwegian Ministry of Petroleum and Energy has also approved the plan for installation and operation of another pipeline, Europipe II from Kårstø to Emden,

Table 1. Strategic investment projects for Norway

	Capacity addition	Production costs[1)]	Investment costs
Alt.1 Low investment level	10 bcm	22.91 $/toe	4.800 bill$
Alt.2 High investment level	10 bcm	25.73 $/toe	1.120 bill$

1) The production costs include operating costs of pipelines and compressor stations for gas delivered to a specified point. Estimates of production and investment costs are based on informal industry information. Our estimate of the transportation costs is based on the estimated tariff for transporting gas from the St. Fergus terminal to Bacton on the United Kingdom National Transmission System, then through the planned Interconnector pipeline to Zeebrugge and finally to the German border on Belgian Distrigaz's system, reported in World Gas Intelligence (1994).

Algerian exports to Western Europe in 1994 was about 28 bcm according to BP (1995) which we take to be the initial capacity in the first period. However, Algeria has already begun work on several investment projects to increase the export capacity to Western Europe by the turn of the century. As in the case of Norway these investments are not subject to the investment game depicted by DYNOPOLY. Rather we assume that from 2000 Algerian export capacity increases to 56 bcm/year. In addition to these 56 bcm/year, Algeria has two strategic investment projects, see Table 2. Both projects concern the building of compressor stations on existing pipelines. The first concerns the installation of compressor stations on the Maghreb-Europe pipeline to Spain and will add 10 bcm/year to the initial transport capacity on this pipeline. The second refers to compressor stations on the Transmed pipeline to Italy and will increase capacity by another 6 bcm/year.

Table 2. Strategic investment projects for Algeria[1)]

	Capacity addition	Production costs	Investment costs
Alt.1 Compressor stations on Maghreb-Europe	10 bcm	64.13 $/toe	1.669 bill$
Alt.2 Compressor stations on Transmed	6 bcm	64.96 $/toe	1.001 bill$

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which will add approximately 18 bcm/year to the export capacity. The planned start up of the installation of Euopipe II is 1999.

[11] Since 1992 there has been a conflict between Norway and United Kingdom about the interpretations of the Frigg treaty. This has lead to the cancellation of Norwegian gas contracts with British buyers as Norway has been denied the right to transport gas thorugh the Frigg pipeline apart from the initial Frigg deliveries. However, this conflict now seems to be solved, see for example Oil & Gas Journal (1997). The Frigg pipeline has a transport capacity of 7.3 bcm/year to the gas terminal in St. Fergus in Scotland.

1) Estimates are based on various sources: News information, BP (1994) and Petroleum Economist (1994).

Russian gas exports to Western Europe in 1994 was about 64 bcm according to BP (1995). We assume that this initial production (export) capacity increases to 70 bcm/year from 2000 onwards. The former Soviet Union has huge reserves of natural gas and about 85 per cent of these reserves are found in Russia. It is not likely that the amount of reserves will be a limiting factor in Russian gas exports in the near future, see, e.g., Stern (1995)[12]. We therefore concentrate on pipeline projects rather than field development projects for Russia, see Table 3. Of the new Russian pipeline projects, the Yamal pipeline is receiving most of the media attention. The Yamal project now encompasses such a wide variety of production and transmission options that it is difficult to distinguish how many lines are being discussed, running from which fields to which destinations, see Stern (1995). We have, somewhat arbitrarily, split the project into two sections where each «stage» receives half the estimated costs of investment, ignoring the economies of scale for multiple pipelines. We also include a third Russian investment project which concerns the building of a pipeline from North Tyumen to the German border with a capacity of 30 bcm/year.

Table 3. Strategic investment projects for Russia[1)]

	Capacity addition	Production costs to the German border	Investment costs
Alt.1 Yamal Stage I	26 bcm	57.96 $/toe	7.066 bill$
Alt.2 Yamal Stage II	26 bcm	57.96 $/toe	7.066 bill$
Alt.3 Upgrading of existing pipelines	30 bcm	61.07 $/toe	6.724 bill$

1) Estimates are based on various sources: News information and BP (1994).

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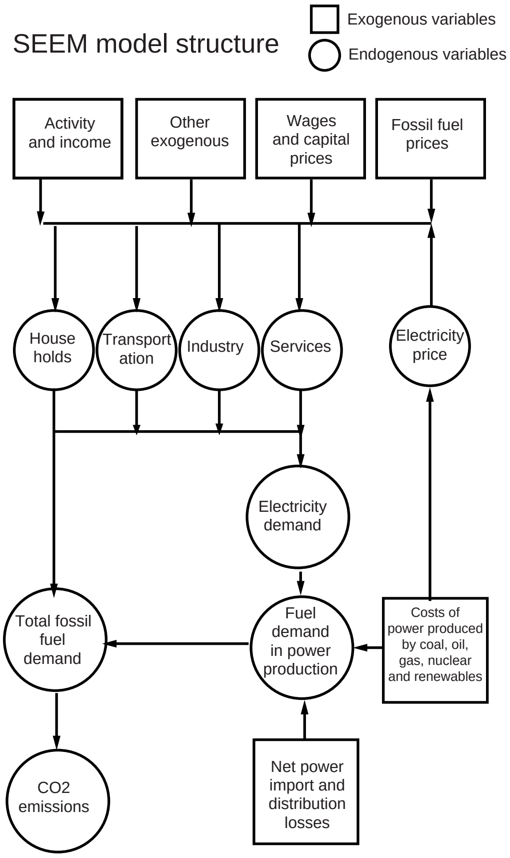
[12] Stern argues that a «bubble» of Russian gas production capacity of more than 30 bcm in 1994, remained unproduced because of lack of markets, both domestic and foreign. Further, he thinks it is likely that this bubble will increase to around 40 bcm by the end of the year 2000. Stern argues that falling internal demand will make possible the delivery of significant increments of Russian gas to Europe.

2.2. The SEEM model [13]

SEEM is a multisectoral energy demand model for 13 Western European countries. These are the four major consumers Germany, France, Italy and United Kingdom, the four largest Nordic countries Denmark, Sweden, Finland and Norway, in addition to Spain, Austria, Belgium, the Netherlands and Switzerland. Together these countries covered around 80 per cent of total primary energy consumption in Europe in 1995 (BP 1996). Several models in the literature have treated Western Europe as one demand region when analysing future energy demand and related environmental issues, see, e.g., the global models Global 2100 (Manne and Richels 1992) and GREEN (Burniaux et al. 1992). SEEM differs from these models in that each country is individually modelled and simulated. Earlier studies employing the SEEM model include Birkelund et al. (1994) and Alfsen et al. (1995).

Figure 1.



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[13] A more detailed documentation of the model can be found in Brubakk et al. (1995), Boug (1995) and Kolsrud (1996).

Each country is treated as a separate block in the sense that neither trade between countries nor supply of primary energy is modelled. Furthermore, the model is partial in the sense that fossil fuel prices and production activity are exogenously given. However, the supply of electric power is modelled, and prices and quantities of electricity are thus endogenously determined. In each country, five sectors are modelled: Power production, Industry, Services, Households and Transportation. Transportation is further subdivided into passenger, freight and air transport. Figure 1 depicts the model structure of each country.

In the first step the model determines the demand for coal, oil, gas and electricity in the end user sectors based on exogenous information on technology and economic activity in addition to prices of fossil fuels, labour, and capital. Each supply curve in the end user sectors is assumed to be horizontal. The end user fossil fuel prices are calculated according to the following identity:

$$P = (P^{CIF} + M + T^{E} + T^{C})(1 + T^{VAT}), \tag{2}$$

where P^{CIF} is the import price (cif), M is the gross margin, T^{E} is the excise energy tax, T^{C} is a carbon tax, and T^{VAT} is the rate of value added tax. The «import price» for electricity corresponds to the costs in producing the power. Noticeably, the impact of the import price and the carbon tax on the end user price is greater the smaller the gross margin and energy taxes are.

The electricity generation sector provides the required domestic production of power, given exogenous information on net power import and distribution losses. An important underlying assumption is that total supply equals total demand for electricity. Electricity is produced by thermal power plants using coal, gas or oil as inputs, nuclear power plants or by plants using renewables. The different thermal power plants’ share of total electricity generated depends on their relative costs in producing the power, which are functions of fuel and technology related costs. These shares together with exogenously given fuel efficiencies in turn determine the demand for the different fuels used in power production. Based on the production costs of electricity, margins and taxes, SEEM determines electricity end user prices in all sectors. Adding the use of fossil fuels in the end user sectors to fossil fuel inputs in thermal power production, total demand for each fossil fuel is derived by country. In a sub model emission coefficients for CO_2 are linked to the consumption of coal, oil and gas in all sectors in order to estimate CO_2 emission.[14]

Energy demand in all sectors are modelled according to variants of the fuel-share model, see Sato (1967), Brown and Heien (1972), and Berndt and Christensen (1973). The starting point of the fuel-share model is a neo-classical macro production function of the form

$$Y = F[K, L, E(c, o, g, el)] \tag{3}$$

where Y is production, K is capital, L is labour and E is an energy aggregate composed of coal (c), oil (o), gas (g) and electricity (el). The notion of the energy aggregate function means that energy is produced by use of the different energy inputs, and that the optimal combination of these is independent of the other inputs in the production function (weak separability). Besides, it is assumed that the fuel shares are independent of the level of production Y (homotheticity property). The assumptions of weak separability and homotheticity allow the optimisation problem to be carried out in two steps: First, at the lower level, a calculation of the cost-minimising combination of energy inputs for a given level of aggregate energy use, and second, at the upper level, a calculation of the cost-minimising combination of the aggregates K, L and E for exogenous levels of production Y. This stepwise optimisation procedure is also utilised for sectors in which energy demand is derived from the consumer side of the economy, like the household and the passenger transport sector. Equation (3) will then express a utility function rather than a production function with an aggregate

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[14] Note that only anthropogenic emissions of CO_2 from fossil fuel combustion are calculated.

of «all other goods» replacing capital and labour as arguments. The optimisation problem is solved by maximising this utility subject to the consumers budget constraint.

In general, we do not explicitly specify the objective function F(·), but instead postulate behavioural functional forms for the energy aggregate, E, resulting from cost minimising and utility maximising behaviour. The energy aggregate is either specified as a Cobb-Douglas or a CES (Constant Elasticity of Substitution) function. Parameters representing the behaviour of the sectors (i.e., demand elasticities) are either estimated by Statistics Norway or adopted from the literature (Pindyck 1979, Abodunde et al. 1985, and Wavermann 1992). Estimations and calibrations of the energy use and prices to the base year of 1991 are based on data from IEA (1993a,b). The time horizon of the model includes the final year 2020.

2.2.1. Numerical assumptions

The final impact on energy demand in each country of a change in an exogenous variable depends on the following aspects: (i) the magnitude of the exogenous shift, (ii) demand elasticities in each sector, (iii) fuel shares by sector in the base year and (iv) sector shares of total energy demand in the base year. Underneath, we present the most important numerical assumptions underlying the energy demand and CO_2 emissions analyses. These are based on predictions made by IEA (1996) and considerations made by Statistics Norway. Unless otherwise noticed, the assumptions apply to all scenarios and countries.

We assume that the ongoing European integration process will result in positive overall effects on economic productivity and income in EU and the present EFTA countries. Thus, we set a 2.5 per cent annual growth in economic activity in all sectors throughout the simulation period. This is in line with the predictions for OECD-Europe in IEA (1996).

The optimal import price of gas from DYNOPOLY is used as an exogenous input in the SEEM model. To ensure consistency between the models with regards to the gas import price evolution, the

European Union import price of 88$/toe in 1994 (BP 1995) is used in both models in 1995. The gas import price in 1991 of around 128$/toe in all SEEM countries explains the huge fall in the price from 1991 to 1995. Likewise, we specify the development in future oil and coal import prices on predictions in IEA (1996). Hence, the average oil import price in the SEEM area of around 143$/toe in 1991 is assumed to rise steadily throughout the simulation period after a huge drop from 1991 to 1995. The average coal import price of around 33$/toe in 1991 is on the other hand assumed to remain constant.

Autonomous energy saving is supposed to capture non-price induced technological improvements and structural changes that contribute to reductions in energy consumption. We assume this to be 0.5 per cent annually on average from 1991 to 2020 in the household, industry and the service sector. The fuel efficiencies in the power and transport sector are, however, set to 0.7 and 0.8 per cent annually on average throughout the simulation period.

As part of the economic integration, all scenarios assume that a harmonisation of energy taxes takes place to avoid fiscal inequalities. More specifically, the excise tax for each fuel in each of the economic sectors in SEEM is harmonised towards the corresponding unweighted average in the four major energy consumers: Germany, France, United Kingdom and Italy. The harmonisation is based on the energy tax structure in 1991, and takes place gradually from 2000 to 2010.

We use carbon taxation as an instrument to achieve national CO_2 targets, and apply the CO_2 targets for EU of stabilising the emissions at the 1990 level by the year 2000, as reported by the European Commission under the Convention of Climate (cf. Norwegian Ministry of the Environment 1994-1995). However, given the uncertainty about the attainment of these targets and the outcome of an international agreement, we assume the relevant year for attainment of the targets is 2010. The imposed carbon tax is set according to the carbon content of each fossil fuel, and carbon coefficients are taken from Manne and Richels (1990). To achieve the national CO_2 targets the carbon tax is introduced in 2000 and is fixed in successive years until 2010. Note that the carbon tax is superimposed on the existing excise tax systems. Also, in the simulations we disregard any effects of the tax on economic growth and its composition and only consider substitution effects among the energy carriers.

The substitution possibilities from gas to oil and coal are represented by cross price elasticities of about 0.15 and 0.33 on average in the four major countries, respectively. Generally, the substitution possibilities are relatively small in the industry sector, which may be justified on the ground of environmental considerations that discourage new plants based on oil or coal to be built.[15] No substitution possibilities from gas to oil exist in the transport sector[16] and the substitution towards electricity is small in the end user sectors. The direct price elasticity and the income elasticity for gas are about -0.75 and 0.90 on average, and vary less across sectors in the four major countries than the cross price elasticities. Energy demand responses for all fuels are thus dominated by direct price effects and income effects and less cross price effects.[17]

3. Results from the model simulations

3.1. Effects on the supply side

We present the simulation results in the DYNOPOLY model for the five year periods up to 2020 which correspond to the time horizon in SEEM.

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[15] For instance, the British government has signalled that they will continue to reduce the subsidies to the coal industry in order to give incentives for the industry to use gas instead (cf. the Norwegian Ministry of the Environment 1994-1995). Germany has also announced their intentions to reduce the coal subsidies before 2000 to lower the CO_2 emissions.

[16] Note, that coal is not used in the transport sector in any of the countries in SEEM.

[17] The moderate cross price effects can be attributed to the fact that they consist of two opposite price effects; one positive price effect which increases demand for competing fuels as they become relatively cheaper than the fuel that faces the price increase, and one negative price effect which decreases energy demand as such as the fuel price increase itself makes energy relatively more expensive than other production factors and commodities in the economy.

3.1.1. Reference scenario (RS)

Norway and Algeria experience a large (exogenous) increase in their initial capacity from 1995 (or rather 1994) to 2000. Still, these countries are the first to invest in new projects. However, they do not do so until 2005 and due to the time lag in investments, these projects do not come on stream until 2010, see Table 4. Norway enters both investment projects while Algeria launches the first project in 2005, and follows up with the second investment in 2010. Russia is the last to enter the stage and invests in the first two projects in 2015 and 2020.[18]

Table 4. Simulation results in DYNOPOLY. Reference scenario (RS)

Period	**Investments made[1)]**			**Capacity bcm/year**			**Indigenous production**	**Total supply**	**Import price $/toe**
	Nor	**Alg**	**Rus**	**Nor**	**Alg**	**Rus**			
1995	0	0	0	27	28	64	164	283	88
2000	0	0	0	60	56	70	165	351	58
2005	2	1	0	60	56	70	140	326	134
2010	2	2	0	80	66	70	112	328	183
2015	2	2	1	80	72	70	90	312	264
2020	2	2	2	80	72	96	72	320	305

1) The columns list the number of aggregate investment projects each player has undertaken. The investments are operative, i.e., they increase the production capacity, in the following period.

The large increase in contracted supply in 2000 may in part explain the late arrival of the first investments. In fact, the increase in total contracted supply from 283 bcm/year in 1994 to 351 bcm/year in 2000 leads to a drop in the import price of natural gas in the model from 88$/toe to 58$/toe. In February 1997 the average European border price is 115.6 1997$/toe, see World Gas Intelligence (1997), which is considerably higher than our simulated import price in 2000. The main reason for the falling price in DYNOPOLY is the large exogenous increase in supply from all three players from 1995 to 2000. The investment behaviour of the players and the rapid depletion of indigenous reserves combined with an increasing demand for gas, leads to a steadily increasing price of gas after 2000. One derives at the end user price by adding the profit margin, which is assumed to remain constant at 227$/toe.

None of the investments in the reference scenario are strategically motivated. Thus, the investments are not entered before they are profitable according to standard present value calculations in order to pre-empt other players' projects.

3.1.2. Reduction scenarios

To study the effect on the price of gas of a reduction in the Norwegian gas exports to Western Europe, we consider the following scenarios:

S1) The initial capacity of Norway is reduced by 10 bcm/year from 2000 onwards, which amounts to nearly 17 per cent of the Norwegian initial capacity in 2000 and almost 3 per cent of the total supply in that same period (if no investments are made in the first period). The interpretation of this is that Norway from 2000 fails to deliver gas under contracts that are already signed.

S2) The initial capacity of Norway is reduced by 20 bcm/year from 2000 onwards, with the same interpretation as in S1. The percentage reductions in Norwegian capacity and total demand in 2000 are hence doubled to almost 33 and 6 respectively.

A problem with the approach in S1 and S2 is that Norway as a player in the model may in early periods counteract the effect of the reduction policy which can be thought of as imposed by the Norwegian government. This can be achieved by moving the investment projects forward in time. However, when the investment options are exhausted, Norway will eventually produce less gas than in RS, but the timing of the effect of reduced Norwegian gas exports can be influenced by the investment behaviour of Norway and is thus determined endogenously in the model. S1 and S2 may

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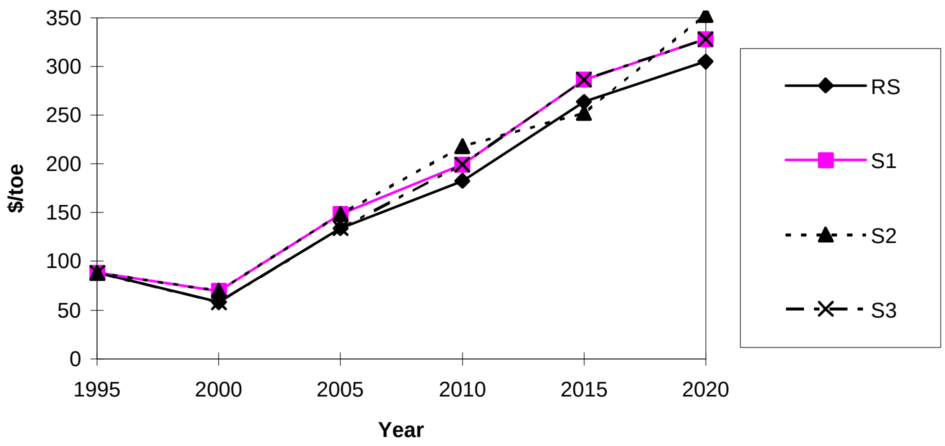
[18] The last of the Russian projects is not entered until in 2035. However, in this analysis we are only interested in the

therefore be interpreted as counterfactual scenarios, i.e., they describe the energy consumption and CO_2 emissions if Norway initially had less export capacity (fewer gas contracts). We have therefore also looked at a third reduction scenario.

S3) Norway has the same initial capacity as in RS, but only one investment project that can increase production capacity with another 10 bcm/year. This may be interpreted as a result of a political decision. In this scenario Norway observes existing contracts, but is given less leeway to increase capacity and capture new contracts in the game for market shares depicted by the DYNOPOLY model. The effect of this policy does not appear until the period where the second investment project would come on stream in RS.[19]

The import prices of natural gas in the reference and reduction scenarios are given in Figure 2 below, while total supply of gas to Western Europe is presented in Figure 3.

Figure 2. The import price of natural gas in DYNOPOLY. RS and S1-S3



In S1, the investment behaviour of the players is unchanged compared to RS. This means that the reduction in Norwegian gas sales is not replaced by increased production from any of the players and

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time horizon from 1995 to 2020 which is the time horizon in SEEM.

total supply of gas is reduced by 10 bcm/year from 2000 onwards. This gives a rise in the import price of about 20 per cent in 2000 and 7-10 per cent in later periods. The increase in the end user price to consumers is much more modest because of the large and constant gross margin.[20]

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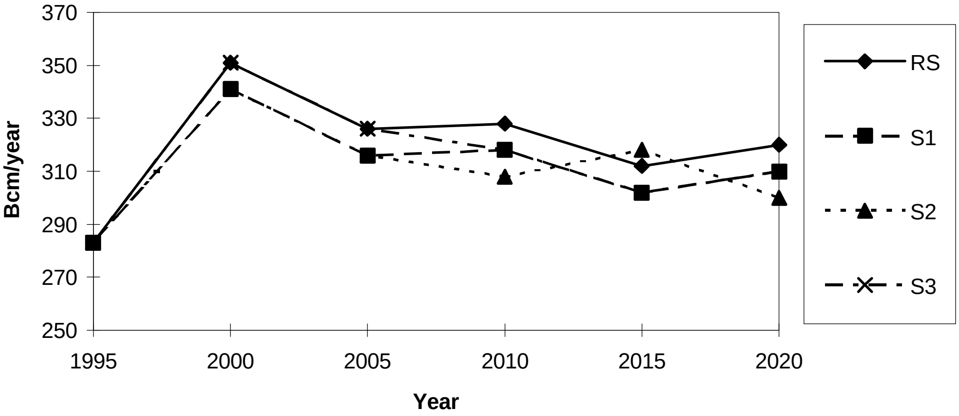
[19] We also looked at a fourth alternative (S4) which is a combination of S1 and S3 where both the initial production capacity of Norway is reduced by 10 bcm/year from 2000 onwards and the second investment project is eliminated. However, as it turned out, the price and total supply of gas in scenario S2 and S4 were identical.

[20] The effects of an *increase* in Norwegian gas exports of 10 bcm/year from 2000 are not entirely symmetric. Compared to RS, Norway in this case delays the introduction of the two investment projects until 2010. Total supply in 2010 is thus 10 bcm *lower* than in RS. However, in all other periods from 2000 to 2020 total supply increases with 10 bcm/year.

Figure 3. Total supply of gas to Western Europe in DYNOPOLY. RS and S1-S3



When the Norwegian gas exports are reduced by 20 bcm/year from 2000 onwards in S2, both Algeria and Russia move their investments forward in time and thus partly offset the effect of the Norwegian reduction in the earlier periods. The first Algerian investment is now implemented in 1995 and is strategically motivated to prevent Norway from entering the two projects in 2000, and also to prevent Russia from accelerating investments. As a result, total supply is reduced by only 10 bcm/year in 2000 and 2005. The effect on the import price of gas is hence as in S1 until 2010. Only in 2010 and 2020 we do see the full effect of the Norwegian reduction of 20 bcm/year. In these periods the price is about 20 and 15 per cent higher compared to RS. In 2015, however, Russian gas from the first stage of the Yamal project is brought on stream one period earlier than in RS and adds 26 bcm to the total supply to Western Europe. This leads to a *decrease* in the import price of 4 per cent.

In S3 where Norway is left with only one investment project, the investment behaviour of the players is again unaltered.[21] Hence the total supply and the price of gas is the same as in RS until the time

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[21] It may be tempting to interpret the results in S1 and S3 as there being a low elasticity of supply in the Russian and Algerian gas exports to Western Europe. However, these results might be generated by two important features of the DYNOPOLY model. First, the investment opportunities of the players consist of large, irreversible and lumpy investment projects which must be undertaken in a specified order. Second, the nature of the short run game implies that the players produce at full capacity. These two characteristics of the model limit the possibilities of the players to respond to (smaller) changes in market conditions, e.g., a reduction in Norwegian gas sales. And also, as sensitivity analyses show, with different assumptions about some key parameters in the model, a 10 bcm/year reduction may lead to supply reactions from both Algeria and Russia.

when the second Norwegian project were supposed to come on stream, i.e., in 2010. From 2010 the effects are thus identical to those described in S1 since the second project, which is now removed from the set of Norwegian investment opportunities, would have brought an additional 10 bcm/year to the market.

To conclude, a reduction in the Norwegian gas exports of 10 bcm/year leads to an increase in the import price of gas between 7 and 20 per cent. The percentage increase in the end user price to consumers will be considerably smaller due to a high and constant gross margin. The impact of this price increase on energy consumption and CO_2 emissions in Western Europe will be investigated in Paragraph 3.2. using the SEEM model.

3.1.3. Sensitivity analyses in DYNOPOLY

As there is much uncertainty surrounding the parameters in DYNOPOLY, we carried out sensitivity analyses for RS and S1 to test the robustness of the results. Changes in the *discount rate* of the three gas producers lead to small alterations in the results, as relatively large increases in production and investments costs are required to alter the investment behaviour of the players. Some other findings are presented below.

An *income elasticity* of demand of 0.4 instead of 0.5, corresponding to a lower GDP growth rate in the model, gives lower prices and higher supply in RS, except in 2010. A reduction in the Norwegian gas exports of 10 bcm/year from 2000 will also have a greater percentage impact on the import price of gas in this case. On the other hand, with an income elasticity of 0.9, the price of gas is increased (between 34 and 45 per cent in RS) even though both Algeria and Russia invest earlier to meet the increased demand. Changes in the *direct price elasticity* also influence the price path of gas in DYNPOPOLY. With a direct price elasticity of -0.9, demand is more elastic and the same changes in supply now require a smaller adjustment in the price to equilibrate supply and demand. The price path is thus smoother in RS, and the impact on the price of a reduction in Norwegian exports of 10 bcm/year is also smaller. With a direct price elasticity of -0.5, the opposite is true. Finally, reducing the *oil cross price elasticity* to 0.15, implying less substitution between the two fossil fuels, the overall result in RS is a fall in the price of gas between 8 and 46 per cent in all periods. The Norwegian reduction policy has a larger impact on the gas price in this case, especially in 2000 and 2005.

We assume a decrease in the *indigenous production* in the demand region by approximately 20 per cent over each five year period after 2000. More optimistic estimates of the gas reserves in this region (i.e., reduction rates of 15, 10 or 5 per cent) lead to lower gas prices and higher total supply. However, the effect of increased indigenous production is partly offset by the postponement of investment projects by the three players.[22] In RS, the import price is between 10 and 20 per cent lower in most periods. With higher indigenous production, the reduction policy from Norway gives a higher percentage increase in the import price of gas, especially in the first two periods.

To conclude, the results in DYNOPOLY appear to be quite dependent on the specific parameter values in the model, especially parameters in the demand function. As there is much uncertainty surrounding these parameters the results should be interpreted with caution. It is difficult to identify a clear pattern for the effects of reduced Norwegian gas sales, but the no response policy of the players to the 10 bcm reduction does not seem to be a stable outcome. However, the parameter assumptions in DYNOPOLY have only a modest impact on simulated energy demand and CO_2 emissions in the SEEM model, see Paragraph 3.3.2 below.

3.2. Effects on energy demand and CO_2 emissions

In this section we study the impacts of reduced Norwegian gas exports on energy demand and CO_2 emissions in Western Europe in the next decades. First, we present the results when no environmental restrictions and CO_2 taxes are present, and second, we discuss the effects of environmental regulations. In the presentation below we focus on the four major consumers

Germany, United Kingdom, Italy and France, as they represented about 55 per cent of total primary energy use in Europe and 51, 72 and 90 per cent of total Russian, Norwegian and Algerian gas export in 1995 (BP 1996). Although the simulation period ends in 2020, we present results for 2000 and 2010 as these years are of great interest in the current CO_2 emissions debate.

3.2.1. Energy demand

A reduction in Norwegian gas exports is assumed to influence the gas price in such a way that all countries face the same alterations in the import price. Furthermore, we disregard any shift in the demand functions due to preferences for security in energy deliveries, assuming none of the importing countries to be too much dependent upon one gas supplier.

From Table 5 we see that total energy consumption decreases when the Norwegian gas sales are restricted and the gas price is increased. The reduction in gas consumption is substantially larger than the total increase in oil and coal consumption as a result of strong direct price effects and small energy substitution effects. For instance, reduced Norwegian gas sales by 10 or 20 bcm/year (from 2000 onwards) leads to a 3 per cent decrease in gas consumption in year 2000 compared to RS, while total oil and coal consumption increases by 0.3 per cent only. The energy composition in S1 and S2 are identical in year 2000 as the gas price is also identical. In 2010, the gas price is about 20 per cent higher in S2 than in RS. As a result, demand for gas is reduced by as much as 5.5 per cent and the substitution effect amounts to a 0.5 per cent increase in demand for oil and coal. Overall, this means energy savings of nearly 1 per cent in S2 in 2010. In S3, the demand effects are even more moderate than in S1. In fact, no demand effects are observed in 2000 as the total supply and the gas price is unchanged compared to RS until 2010.

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[22] In two cases the total supply is *decreased* in period 2010 due to the delayed introduction of the first Norwegian and Algerian projects.

Table 5. Energy demand in SEEM, total demand (1991 and RS) and changes (S1-S3). Mtoe

		2000				2010			
	1991	RS	S1	S2	S3	RS	S1	S2	S3
Total Western Europe:									
Oil	433.6	518.1	1.0	1.0	0.0	606.0	1.7	2.4	0.8
Coal	270.9	274.0	1.2	1.2	0.0	329.7	1.2	2.3	1.1
Gas	220.3	296.7	-8.9	-8.9	0.0	285.0	-9.7	-15.7	-5.8
Energy	924.8	1088.9	-6.7	-6.7	0.0	1220.6	-6.8	-11.0	-3.9
4 major energy consumers[1]:									
Oil	311.4	372.1	0.8	0.8	0.0	437.6	1.4	1.9	0.6
Coal	211.5	214.2	0.7	0.7	0.0	255.0	1.0	1.7	0.8
Gas	165.2	220.9	-6.1	-6.1	0.0	217.5	-7.3	-11.8	-4.1
Household	69.0	86.9	-1.0	-1.0	0.0	100.7	-1.4	-2.6	-1.0
Service	20.6	25.8	-0.3	-0.3	0.0	28.8	-1.0	-1.4	-0.3
Industry	52.4	75.8	-3.3	-3.3	0.0	60.4	-3.8	-5.5	-1.7
Transport[2]	2.3	2.9	0.0	0.0	0.0	4.1	0.0	0.0	0.0
Power	20.9	29.5	-1.5	-1.5	0.0	23.5	-1.1	-2.3	-1.1
Energy	688.1	807.2	-4.6	-4.6	0.0	910.1	-4.9	-8.2	-2.7

1) Germany, United Kingdom, Italy and France.
2) Alterations are less than 0.05.

The same energy demand picture is seen if we consider the four major energy consuming countries in total. These countries account for around 70-75 per cent of total reduction in gas and energy consumption, while the shares of total increase in oil and coal range from 60-80 per cent. The largest reduction in gas demand is in the industry sector in 2000 and 2010, but the reduced demand in the household and power generating sectors are also quite considerable. In addition to the gas shares in each sector, the relationship between the import price and the end user price of gas is important in explaining the results. A given percentage increase in the import price involves a lower percentage increase in the end user price due to other price components such as margins and taxes (see Equation 2). 1 per cent increase in the import price of gas rises the end user price in the industry sector by around 0.7 per cent on average. Gas delivered to the power sector faces a price increase corresponding to 0.9 per cent of the import price increase, while the corresponding price increase is only 0.25 per cent in the household and the service sector. The gas demand in the household sector is however reduced, mainly due to the gas share of about 40 per cent initially.

The reduced gas demand in the service sector is to a large extent replaced by oil, and no significant energy saving is realised. Both oil and coal are the alternatives for gas in the power sector. Oil replaces about 25 per cent of total reduction in gas demand and coal about 40-50 per cent, leaving the remaining share as energy savings. Even though a part of the gas demand is replaced by oil in the household sector, energy saving plays a dampening role. No significant replacement from oil or coal is seen in the industry sector in the major countries. Hence, these energy savings are most substantial, amounting to 70 per cent of total energy savings in the major countries.

3.2.2. CO_2 emissions

A reduction in Norwegian gas supply to the continent may alter the CO_2 emissions. These changes are divided into the following categories: (i) emissions in consuming countries through changes in the energy composition, and (ii) emissions in connection with production and transportation of oil, coal and gas. Alterations in the composition of gas deliveries to Western Europe may change the emissions from the transport systems for gas, due to differences in distance from the producers to the market and energy efficiency in the pipelines. Changes in emissions may also arise from the transport systems for oil and coal as these energy carriers may replace Norwegian gas.

For category (i) the alterations in CO_2 emissions are based on the results presented in Paragraph 3.2.1.[23] For category (ii) we rely on assumptions made in ECON (1994, 1995). Hence, we assume that 4 per cent of total gas transported from the Norwegian continental shelf is consumed on the production spot and in the transport systems. Energy consumption related to gas deliveries from

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[23] The emission factors employed in terms of million tonnes CO_2 (MtC) per million tonnes oil equivalents of energy use (Mtoe) are 2.201 for gas, 3.1 for oil and 3.844 for coal. The factor for oil is taken from SFT (1990), while the corresponding relative carbon coefficients of 0.71 for gas, 1 for oil and 1.24 for coal are taken from Manne and Richels (1990).

Russia and Algeria amounts to 12 and 6 per cent of transported quantity, respectively, while the consumption related to import of oil and coal amounts to 4 and 2 per cent of transported quantity. Table 6 presents the alterations in CO_2 emissions.

Table 6. Western European CO_2 emissions, total emissions (1991 and RS) and changes (S1-S3). MtC

		2000				2010			
Category	1991	RS	S1	S2	S3	RS	S1	S2	S3
Emissions from SEEM	2870.2	3312.6	-11.8	-11.8	0	3773.1	-11.4	-18.4	-6.0
Prod. and transport[1)]	70.7	95.9	-0.7	0	0	109.8	-0.6	-1.3	-0.7
Total	2940.9	3409.6	-12.7	-12.2	0	3884.4	-12.2	-20.0	-6.9
Germany	866.7	936.1	-1.2	-1.2	0	1038.2	-1.5	-2.7	-0.6
U. Kingdom	543.7	615.8	-2.8	-2.8	0	658.6	-2.3	-3.6	-1.4
France	343.1	422.0	-2.0	-2.0	0	478.7	-1.1	-2.3	-1.2
Italy	388.4	489.1	-1.9	-1.9	0	640.1	-3.2	-5.0	-1.3
4 major countries	2141.9	2463.0	-7.9	-7.9	0	2815.6	-8.1	-13.6	-4.5

1) The calculations of emissions from the transport and distribution systems for oil, coal and gas are based on ECON (1994, 1995). Emissions related to import of oil and coal are calculated from the consumption figures from SEEM and import shares from BP (1992, 1996). Note that the import shares in 1995 are used in 2000 and 2010. In the calculation of emissions related to the production and transportation of gas we make use of the results from DYNOPOLY. The estimates for 1991 are based on BP (1992).

The CO_2 emissions slightly decrease in Western Europe under the different reduction scenarios. In both S1 and S2 emissions are reduced by somewhat less than 0.4 per cent in year 2000 compared to RS. In 2010 the corresponding emissions reduction is about 0.3 per cent in S1 and 0.5 per cent in S2. The most significant emissions changes are found in the energy consuming countries. More than 90 per cent on average of the reduction in global CO_2 emissions is attributed to this emission category. As previously discussed, this is due to energy saving. The emissions reductions from the Norwegian continental shelf range from 8 to 16 per cent of total CO_2 reductions. Since the Norwegian gas export is reduced by 20 bcm/year from 2000 onwards in S2, the reductions in the emissions from the production spot and the transport systems are doubled compared to S1. Despite some apparent changes in the composition of total deliveries of gas to Western Europe, the alterations in the emissions from the energy transport systems are negligible. As predicted by DYNOPOLY, Russian gas export is unaltered by the Norwegian policy in all cases in 2000 and 2010. Hence, emissions related to Russian gas deliveries are also unchanged compared to RS. This is also the case for Algeria, except in S2 in 2000 where the disappearance of the Norwegian gas is partly replaced by Algerian gas supply. Thus, the emissions from transport of the Algerian gas increase by 1.5 MtC in S2 in year 2000.

Alterations in CO_2 emissions in the four major countries amount to about 70 per cent on average of total emission reductions in the SEEM area. United Kingdom is the main contributor to this in 2000 under S1 and S2, while Italy is the main contributor in 2010. In S3 the contributions are more evenly spread among the four countries. Figures 4-7 decompose total alterations in CO_2 emissions from each country on the different sectors under S1.

While reduced Norwegian gas sales induce lower CO_2 emissions in all four countries, the sectoral alterations differ. The emissions from the industry sector are however significantly reduced in all countries. Also in all countries the emissions from the transport sector are unaltered. This is mainly explained by low gas consumption initially (see Table 5) in addition to small substitution possibilities among the energy carriers in this sector. *Germany* faces the largest reduction in CO_2 emissions in the industry sector due to significant energy savings and small substitution towards oil and coal. The opposite happens in the household and service sectors giving higher emissions. Substitution, mainly towards coal, is also seen in the power sector. However, this impact on emissions is not large enough to offset the impact from reduced gas demand, and the emissions decrease slightly. Except from a slight increase in the power sector, all sectors in *United Kingdom* get lower emissions. Significant substitution possibilities exist in both the household and service sector. However, the oil and coal consumption is low initially, such that the emission alterations in these sectors are dominated by reduced gas demand. The emissions increase somewhat in the power sector since the gas demand is mainly replaced by coal. *France* experiences a considerable increase in the emissions in the service sector in 2010 as the substitution towards oil is remarkable in this sector. As in United Kingdom, the emission reduction in the household sector is explained by small consumption shares of oil and coal initially. No alterations in the emissions are found in the power sector since electricity production in thermal power plants is based on oil and coal. Finally, the development in the sectoral CO_2 emissions in *Italy* coincides with the results for United Kingdom. The emissions go down in all sectors except for the power sector (and transport), where small energy saving effects are dominated by considerable substitution effects, mainly towards oil.

Figure 4. Alterations in CO_2 emissions in Germany. S1

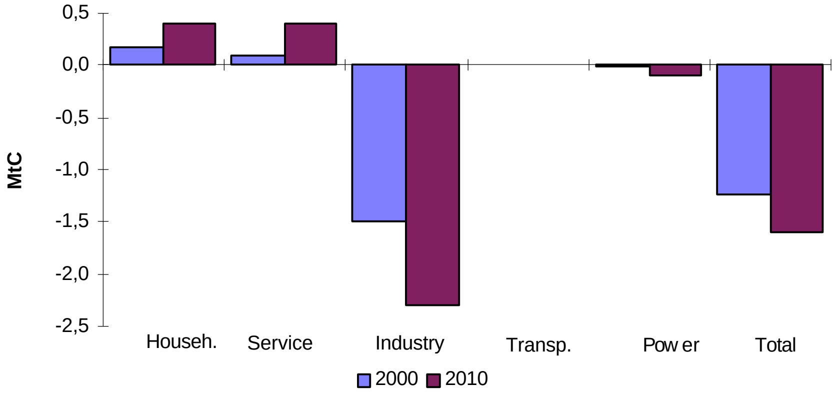

Figure 5. Alterations in CO_2 emissions in United Kingdom. S1

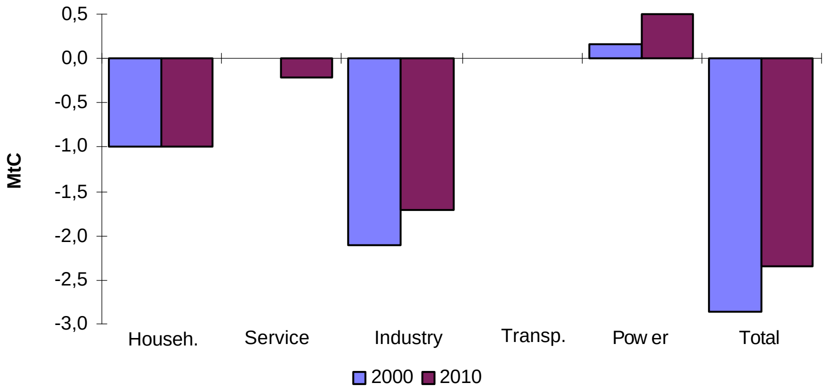

Figure 6. Alterations in CO_2 emissions in France. S1

Figure 7. Alterations in CO_2 emissions in Italy. S1

As a comment to the results, the SEEM model assumes horizontal supply curves, giving greater substitution from gas towards oil and coal, and thus higher emissions, compared to the case of upward sloping supply curves. Hence, the calculations based on SEEM may underestimate the reductions in the emissions caused by reduced Norwegian gas sales to the continent.

The sensitivity analysis on the DYNOPOLY model revealed that the investment behaviour of the players in the model and thus the endogenously determined gas price were to a large extent sensitive to changes in the specific parameter choices. However, the emission results above are not very sensitive to different choices of gas import price paths. Overall, the emission levels associated with the different price paths from the sensitivity analysis in DYNOPOLY deviate from the emission levels reported in Table 6 by about -1 to +1 per cent. It is also interesting to note that an *increase* in Norwegian gas sales of 10 bcm/year from 2000 has only minor impacts (giving a slight increase) on Western European CO_2 emissions.

3.2.3. Environmental regulations

Given the concern about the possible threat of climate change, many governments, including a majority of the EU member states, have announced their intention to return greenhouse gas emissions to 1990 levels by the year 2000. Table 7 provides a summary of CO_2 targets and expected attainment for EU in total and for the four major energy consumers (cf. Norwegian Ministry of the Environment 1994-1995). Among the most important existing strategies on the national or the EU level in order to fulfil these targets are programs that promote energy improvements and lower use of exhaustible energy resources. A combined carbon/energy tax is not yet included in these strategies. The European Commission has, however, proposed a carbon tax that is intended to be introduced in 2000.

Table 7. Emissions targets. CO_2 emissions in MtC

	CO_2 emissions target	CO_2 emissions in 1990	Expected attainment of CO_2 emissions target
EU in total[1)]	Stabilisation of emissions at 1990-level by 2000	3141	Small possibilities to meet the target
Germany	25-30% reduction in emissions from 1990-level by 2005	1032	Uncertain whether the target will be met
United Kingdom	Stabilisation of emissions at 1990-level by 2000	587[2)]	Expected to meet the target
France	Stabilisation of emissions per capita at 1990-level by 2000[3)]	367	Expected to meet the target
Italy	Stabilisation of emissions at 1990-level by 2000	424	Not clarified

1) Exclusive Greece and Luxembourg. 2) Emissions from the petroleum sector are included in the estimates. 3) This target gives room for about 13 per cent increase in total CO_2 emissions from 1990 to 2000. Hence, total CO_2 emissions in 2000 must not exceed 415 MtC when the per capita target is translated into a target for total CO_2 emissions.

Source: Norwegian Ministry of the Environment (1994-1995)

Despite these strategies, it is expected that EU in total will not meet its CO_2 target. With reasonable economic assumptions and with no specific environmental regulations undertaken, simulations on SEEM support this, and predict that total CO_2 emissions in 2000 and 2010 will be between 157-172 MtC and 615-632 MtC above the target. The simulations also show that none of the major energy consuming countries are able to meet its national CO_2 targets without an energy policy aimed to stabilise or reduce emissions.

We assume that a carbon tax is introduced in 2000 to fulfil the national CO_2 targets by 2010. Due to the small differences in total CO_2 emissions across the scenarios, we concentrate on RS and S1. Table 8 shows the carbon taxes necessary in each country to achieve the targets.

Table 8. CO_2 emissions, targets and carbon taxation in 2010[1)]

		Emissions with no CO_2 tax		Emissions with CO_2 tax		CO_2 tax in RS and S1		
	Target	RS	S1	RS	S1	Oil	Coal	Gas
Germany	722-774	1038	1037	775	774	340	422	241
U. Kingdom	587	659	656	587	585	65	81	46
France	415	479	478	414	413	100	124	71
Italy	424	640	637	426	424	415	515	295

1) Emissions are measured in MtC and the carbon tax is measured in 1991$/toe.

Assume that all countries have committed themselves to stabilise the emissions at 1990 level by 2010. Thus, a change in Norwegian gas sales will not affect the emissions from the country. However, as the gas price changes, the composition of the energy consumption and the abatement costs may change. As seen above, the alterations in the energy composition due to reduced Norwegian gas sales are too small to give any significant effects on the CO_2 emissions. Thus, the simulated carbon taxes turned out to be identical in RS and S1. The magnitude of the carbon taxes is however substantial, especially in Germany and Italy, as these countries have the most restrictive

CO_2 targets in 2010. The alterations in energy demand are also rather large with this level of taxation. Table 9 shows that Germany, as a major oil and coal consumer, reduces the energy demand with almost 25 per cent with CO_2 taxes. The reduction in Italy is even higher (32 per cent) since oil with a consumption share of about 60 per cent is heavily taxed. This consumption share is also the reason why oil is reduced relatively more than coal in this country. United Kingdom and France, on the other hand, face a much more moderate reduction in energy demand (about 10 per cent) as these countries are closer to meet their targets. As with no taxes, the energy composition alters somewhat the when Norwegian gas sales are reduced. Strong energy saving effects and less dominant substitution effects towards oil and coal due to a higher gas price still apply as the explanations for the energy composition alterations.

Table 9. CO_2 taxes and changes in energy composition in 2010. Mtoe

		Germany		U. K.		France		Italy	
		RS	S1	RS	S1	RS	S1	RS	S1
Composition with no CO_2 tax	Oil	130.4	130.8	80.1	80.1	94.7	95.4	132.4	132.7
	Coal	131.1	131.7	77.1	77.4	27.0	27.0	19.8	19.9
	Gas	59.1	56.9	51.8	50.3	36.9	35.4	69.7	67.7
	Energy	320.6	319.3	209.0	207.7	158.6	157.8	222.0	220.3
Composition with CO_2 tax	Oil	117.4	117.6	74.5	74.5	87.9	88.5	92.0	92.1
	Coal	79.3	79.5	64.5	64.7	17.5	17.5	7.6	7.6
	Gas	48.4	47.4	48.8	47.7	33.8	32.7	50.6	49.9
	Energy	245.0	244.5	187.9	186.9	139.1	138.6	150.1	149.5
Reduction due to CO_2 tax	Oil	13.0	13.2	5.6	5.6	6.8	7.0	40.4	40.7
	Coal	51.8	52.2	12.6	12.6	9.6	9.5	12.2	12.3
	Gas	10.7	9.5	2.9	2.6	3.2	2.7	19.2	17.8
	Energy	75.6	74.9	21.1	20.8	19.5	19.2	71.8	70.8

4. Conclusions

In this paper we have studied the impacts on Western European energy demand and CO_2 emissions of a reduction in Norwegian gas sales by 10 or 20 bcm/year from 2000. The effects on the supply side are simulated using the gas supply model DYNOPOLY. This model considers a game between Norway, Algeria and Russia. These suppliers engage in a fight for market shares using investment projects as the strategic variable. In our main reduction scenario (S1), Algeria and Russia will not replace Norwegian gas, and hence the total gas supply will decrease accordingly. However, the results in DYNOPOLY are sensitive towards changes in exogenous parameters. It is also a limitation of the model that the strategic decisions of the players concerns the introduction of large discrete investment projects. Since it is optimal for the players to produce at full capacity when a new investment project is undertaken, there may be large jumps in the supply of gas. The results should therefore be interpreted with caution.

The optimal gas import price from DYNOPOLY in the different scenarios is introduced into the energy demand model SEEM to study the effects on energy demand and CO_2 emissions in Western Europe. In addition to CO_2 emissions from consumer countries we also take into account changes in the emissions through the transport and distribution system. According to our results, a reduction in the Norwegian gas sales gives a slight increase in the consumption of oil and coal while the consumption of gas is somewhat reduced. The results indicate a reduction in CO_2 emissions, however, the effect appears to be modest.

Besides the effects on the demand and supply side, political regulations may also be important. If, for example, a country has a binding CO_2 emissions target, it will be kept no matter how the Norwegian gas policy is. Thus, if all countries commit to their announced CO_2 emissions target, a reduction in Norwegian gas sales will have no effect on CO_2 emissions. The consumption of oil and coal will increase slightly, but the total energy consumption will go down. On the other hand, if the country has not committed to a CO_2 emissions limit, but only has preferences for a better environment, the Norwegian energy policy may have greater impacts on CO_2 emissions. For instance, the country may for environmental reasons choose to rely on imported gas instead of building a new thermal power plant based on coal, even if the electricity from gas does not lower the price for the consumers. As the electricity price has not decreased, there is no reason to expect the total energy consumption or CO_2 emissions to increase. A reduction in Norwegian gas sales may in this situation prevent such choices from being made. However, a country may also have production and consumption targets for, e.g., coal. Thus, there will not be a substitution towards gas even if the country imports gas, and it is likely that the energy consumption will increase as a result of gas imports. A reduction in Norwegian gas may in this case lead to lower total energy consumption. This discussion illustrates the importance of the institutional framework and political regulations for the environmental effects of a reduction in Norwegian gas sales.

References

Abodunde, T., F. Wirl and F. Koestl (1985): Energy Demand Elasticities: A reassessment, *OPEC Review* **9**, 163-186.

Alfsen, K., H. Birkelund and M. Aaserud (1995): Impact of an EC carbon/energy tax and deregulating thermal power supply on CO_2, SO_2 and NO_x emissions, *Environmental and Resource Economics **5***, 165-189.

Berg, E. (1995a): Miljøvirkninger av norsk gass-salg - En tilbudssideanalyse (Environmental Impacts of Norwegian Gas Sales - A supply Side Analysis), *Sosialøkonomen* **11**, 18-25.

Berg, E. (1995b): Utviklingen på det europeiske gassmarkedet (Developments in the European Gas Market), *Økonomiske Analyser* **nr. 4**, Statistic Norway.

Berndt, E. R. and L. R. Christensen (1973): The Internal Structure of Functional Relationships: Separability, Substitution and Aggregation, *Review of Economic Studies* **40**, 403-410.

Birkelund, H., E. Gjelsvik and M. Aaserud (1994): The EU carbon/energy tax: Effects in a distorted energy market, *Energy Policy **22***, 657-665.

Bjerkholt, O. and E. Gjelsvik (1992): Common Carriage for Natural Gas: the Producers' Perspective, in Hope, E. and S. Strøm (eds.): *Energy Markets and Environmental Issues: A European Perspective,* Scandinavian University Press.

Boucher, J. and Y. Smeers (1985): Gas trade in the European Community during the 1970's. A model analysis, *Energy Economics* **7** (2), 102-116.

Boucher, J. and Y. Smeers (1987): Economic Forces in the European Gas Market - A 1985 prospective, *Energy Economics* **9** (1), 2-16.

Boug, P. (1995): User's Guide: The SEEM-model Version 2.0, Documents 95/6, Statistics Norway, Oslo.

BP (1992): *BP Statistical Review of World Energy*, London.

BP (1994): *Review of World Gas*, London.

BP (1995): *BP Statistical Review of World Energy*, London.

BP (1996): *BP Statistical Review of World Energy*, London.

Brekke, K. A., E. Gjelsvik and B. H. Vatne (1987): A Dynamic Supply Side Game Applied To The European Gas Market, Discussion Paper **22**, Statistics Norway.

Brekke, K. A., E. Gjelsvik and B. H. Vatne (1991): A Dynamic Investment Game - The Fight for Market Shares in the European Gas Market, unpublished manuscript, Statistics Norway.

Brown, M. and D. Heien (1972): The S-Branch Utility Three: A Generalization of the Linear Expenditure System, *Econometrica* **40**, 737-747.

Brubakk, L., M. Aaserud, W. Pellekaan and F. von Ostvoorn (1995): SEEM - An Energy Demand Model for Western Europe, Reports 95/24, Statistics Norway.

Burniaux, J. M., J. P. Martin, G. Nicoletti and J. Oliveira Martins (1992): GREEN - A Multi-Region Dynamic General Equilibrium Model for Quantifying the Costs of Curbing CO_2 Emissions: A Technical Manual, Working Paper 116, OECD Economics Department.

ECON (1994): Redusert gasseksport fra Norge, virkninger på globale CO_2 utslipp (Reduced gas export from Norway, impacts on global CO_2 emissions), Rapport 331/94, ECON Senter for økonomisk analyse.

ECON (1995): Virkninger på globale CO_2 utslipp av norsk gasseksport (Impacts on global CO_2 emissions of Norwegian gas export), Rapport 340/95, ECON Senter for økonomisk analyse.

Halvorsen, B., S. Kverndokk and A. Torvanger (1989): Global, regional and national carbon dioxide emissions 1949-86 - Documentation of a LOTUS Database, Working paper 59/89, Centre for Applied Research, Oslo.

Haurie, A., Y. Smeers and G. Zaccour (1988): Dynamic Stochastic Nash-Cournot model with an application to the European gas market, in *Gas Trade for Western Europe, final report contract EN3M-0020-B*, DG XII, Commission of the European Communities, Brussels.

IEA (1993a): *Energy Balances in the OECD Countries*. 1960-1991, OECD/IEA, Paris.

IEA (1993b): *Energy Prices and Taxes*, OECD/IEA, Paris.

IEA (1996): *World Energy Outlook*, OECD/IEA, Paris.

IPCC (1996): *Climate Change 1995 - The Science of Climate Change*, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

Kolsrud, D. (1996): Documentation of Computer Programs that extend the SEEM-model and provide a Link to the RAINS-model, Documents 96/1, Statistics Norway, Oslo.

Manne, A. S. and R. G. Richels (1990): CO_2 Emission Limits: An Economic Cost Analysis for the USA, *The Energy Journal* **11** (2), 51-74.

Manne, A. S. and R. G. Richels (1992): Buying Greenhouse Insurance - The Economic Costs of CO_2 emission Limits, MIT Press, Cambridge, Massachusetts.

Marland, G. (1982): The Impact of Synthetic Fuels on Global Carbon Dioxide Emissions, in W. C. Clark (ed.) *Carbon Dioxide Review: 1982*, Clarendon Press, Oxford.

Mathiesen, L., K. Roland and K. Thonstad (1987): The European Natural Gas Market: Degrees of Market Power on the Selling Side, in R. Golombek, M. Hoel and J. Vislie (eds): *Natural Gas Markets and Contracts*, North-Holland.

Norwegian Ministry of the Environment (1994-95): Om norsk politikk mot klimaendringer og utslipp av nitrogenoksider (NO_x) (On Norwegian Policy to avoid Climate Changes and Emissions of Nitrogen Dioxides), St. meld. 41, 1994-95.

Norwegian Ministry of Petroleum and Finance (1997): *Norwegian Petroleum Activity*, Oslo.

Oil & Gas Journal (1997): U. K., Norway settle Frigg treaty squabble, *Oil & Gas Journal*, May 5, p. 58.

Petroleum Economist (1994): Energy Map of Algeria, Petroleum Economist Energy Map Series No. **26**.

Pindyck, R. S. (1979): The Structure of World Energy Demand, MIT Press, Cambridge, Massachusetts.

Sato, K. (1967): A Two-level Constant Elasticity of Substitution Production Function, *Review of Economic Studies* **34**, 201-218.

SFT (1990): Klimagassregnskap for Norge. Beskrivelse av utslippsmengder, drivhusstyrke og utlippsfaktorer (Greenhouse Gas Inventory for Norway. Emission Amounts, Global Warming Potential and Emission factors), Rapport, Statens Forurensningstilsyn (The Norwegian Pollution Control Authority), Oslo.

Stern, J. (1995): *The Russian Natural Gas «Bubble»- Consequences for European Gas Markets,* The Royal Institute of International Affairs, Energy and Environmental Programme, London.

Wavermann, L. (1992): Econometric Modelling of Energy Demand: When are substitutes Good Substitutes?, in Hawdon, D. (eds.): *Energy Demand: Evidence and Expectations*, Surrey University Press, New York.

World Gas Intelligence (1994): What's New Around The World. United Kingdom, January 14., p. 11-12.

World Gas Intelligence (1997): European Border Prices, February 14., p. 5.