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Norwegian Gas Sales and the Impacts on European CO₂ Emissions

Abstract:

This paper studies the impacts on Western European CO₂ emissions of a reduction in Norwegian gas sales. The impacts are due to changes in energy demand and energy supply, but environmental and political regulations also play an important role. 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 CO₂ targets are analysed using the energy demand model SEEM. If the Western European countries commit to keeping their announced CO₂ emissions targets, regardless of the costs associated with this, a reduction in Norwegian gas sales will have no impact on emissions. However, the consumption of oil and coal will increase slightly, while total energy consumption will go down. A reduction in Norwegian gas sales also seems to have only minor impacts on the CO₂ emissions from Western Europe in the situation where no emissions regulations are considered.

Keywords: Gas Sales, Energy Consumption, CO₂ Emissions, Environmental Regulations.

JEL classification: D92, L13, Q31, Q38.

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1. Introduction

The global warming problem is recognised as a severe threat to the world, see, e.g., IPCC (1996). Carbon dioxide (CO₂) is the main greenhouse gas, and the main source for CO₂ emissions (70-75 per cent of all CO₂ 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 CO₂ emissions per energy unit (see e.g., Marland 1982). Thus, the composition of energy use, not only total consumption, has an impact on CO₂ emissions. In this study we do not consider other polluting emissions from the combustion of fossil fuels.

Norway has established itself as 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 CO₂ emissions from Western Europe. In this paper we study the effects of a reduction in the Norwegian gas sales to Western Europe on the region's energy use and emissions of CO₂.

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 results in a higher price of gas 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 than gas, this substitution effect will lead to an increase in CO₂ emissions, ceteris paribus. The other effect is the income effect which will lead to energy savings and thus lower CO₂ emissions as energy has become more expensive relative to other factors of production such as labour, capital and material inputs. The environmental impacts through the demand effects from a reduction in Norwegian gas sales are thus uncertain.

A change in Norwegian gas sales may also have *supply effects* through supply reactions from other gas producers and producers of alternative energy sources such as oil, coal and nuclear power. 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 elasticity of supply for oil and coal. The increase in consumption of oil and coal, and thus the increase in carbon emissions, will be higher if the supply curves for oil and coal 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 in determining the magnitude of this substitution effect. With a vertical supply curve for gas the reduced Norwegian gas sales will not be replaced by increased supply from other producers and we will see 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 there will be no change in the gas price. However, with an increase in the supply from other producers such that the total gas supply is unchanged, 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 in connection with the transportation of Russian gas to the Western European market.

Finally, the existence of *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 CO₂ emissions, this will be effectuated regardless of the Norwegian gas sales policy. A change in Norwegian gas sales will then have no influence on the total CO₂ emissions from the country. However, as fossil fuel prices and thus 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. On the other hand, if a country has not committed to a certain CO₂ emissions limit, but only has preferences for a better environment, the Norwegian energy policy may have greater impacts on the level of total CO₂ emissions.

As the above discussion indicates, it is difficult from theory to determine how a reduction in Norwegian gas sales will influence energy demand and emissions of CO₂ in Western Europe.¹ 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 the dynamic oligopoly model of the European gas market DYNOPOLY (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.

¹ These emissions also include CO₂ emissions in connection with imported gas from Algeria and Russia.

1995 and Brubakk et al. 1995). The two models are connected through the price of gas. The impacts are analysed both in the situation where no environmental regulations are present and under the restriction that all countries fulfil their announced CO₂ emissions targets. Our results indicate that when there are no binding restrictions, a reduction in the Norwegian gas sales will lead to a slight reduction in the European CO₂ emissions. However, the emissions reduction will be quite modest as the reduction in the supply of gas to some extent is replaced by increased consumption of oil and coal. In the second case, when the countries have binding emissions targets, the CO₂ emissions are unaffected by the reduced Norwegian gas sales, however, the composition of the energy use may be altered. In the paper we focus on the energy use of the four large energy consumers; Germany, France, Italy and United Kingdom. In addition to the changes in CO₂ emissions from the consumer countries, we also calculate the effects on emissions from the 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) report results from simulations on their energy demand model ECON-ENERGY which has a structure similar to the SEEM model. ECON looks 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. The supply side is modelled ad hoc with three different scenarios; a vertical, horizontal and elastic (supply elasticity = 1) supply curve. Second, a negative shift in the demand function, as a result of energy security, is also studied. The effects on CO₂ emissions are split into three; (i) emissions from Norwegian gas production, (ii) emissions in the consuming countries and (iii) emissions from the transport and distribution system. ECON concludes that as long as the supply curve is not vertical, a reduction in the Norwegian gas supply will increase CO₂ 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 numerical 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 numerical models

2.1. The DYNOPOLY model²

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. 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 elimination of the Netherlands and United Kingdom as players may be defended on the grounds 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 of natural gas.

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 investments will first be operative in the following period. The moves are made simultaneously, and only previous investments are known when they 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

² 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).

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 of 80 years. 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. In a Nash equilibrium each player's strategy must be an optimal response to the strategies of the other players. The concept of subgame perfect equilibria was first introduced by Selten (1965).³ 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, thus the model does not take account of the regional aspect of the gas market. As mentioned above, the solution to the short run Bertrand game in prices implies that 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

³The 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 lack of a unique solution in the subgames is very rare.

situation with third party access (TPA).⁴ 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 producer price plus a (constant) margin which is assumed to cover transmission and distribution costs as well as taxes and profits to the transmission companies. In addition to the end user price of natural gas (P_G), demand also depends on the price of oil (P_O) and coal (P_C) and on the gross domestic product (Y) of the demand region. We assume constant demand elasticities (e_1 , e_2 , e_3 and e_4).

$$(1) \quad D_t = AP_{Gt}^{e_1} P_{Ot}^{e_2} P_{Ct}^{e_3} Y_t^{e_4} - Q_t$$

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 corresponds 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)⁵. 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). Also the model is calibrated such that supply in DYNOPOLY fits the total demand for gas in SEEM.⁷

⁴ 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 transmission 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.

⁵ According to BP (1995) this estimate is based on information supplied by Gas Strategies.

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).

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 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 in the demand region. The supply from the three players depends on the timing of their investments and is determined endogenously in the model. In the following we give a brief presentation of the investment projects available to the three players. We assume all players use the same discount rate of 10 per cent p.a.

The initial production capacity of Norway is set equal to the level of 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 DYNOPOLY 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 investment projects concern the development of gas fields in the North Sea area. Each investment project will add 10 bcm/year to the initial production capacity so that Norway, after having exhausted these investment 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 The second project

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 the year 2005 Norwegian gas producers will have delivery obligations in the order of 70 bcm, see Norwegian Ministry of Petroleum and Energy (1997). However, contracts that are 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, which will add approximately 18 bcm/year to the export capacity. The planned start up of the installation of Europipe II is 1999.

assumes that gas is delivered through the existing Frigg pipeline to St. Fergus in Scotland and thus the project does not include the construction of a new pipeline.¹¹

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) and we take this to be the initial capacity of Algeria 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 the DYNOPOLY model and will not be defined among the strategic investment projects for Algeria. Rather we assume that from 2000 Algerian export capacity increases to 56 bcm/year. In addition to these 56 bcm/year we assume that Algeria has two strategic investment projects, see Table 2. Both projects concern the building of compressor stations on existing pipelines. The first project 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 project refers to compressor stations on the Transmed pipeline to Italy which will increase capacity by another 6 bcm/year.

Table 2. Strategic investment projects for Algeria¹

	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\$

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

¹¹ Since 1992 there has been a conflict between Norway and United Kingdom about the interpretation of the Frigg treaty. This has led to the cancellation of Norwegian gas contracts with British buyers as Norway has been denied the right to transport gas through the Frigg pipeline apart from the initial Frigg deliveries. However, this conflict now seems to be solved, see for example Oil & Gas Journal (1997).

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. Rather analysts are talking about a Russian «Gas Bubble», see Stern (1995)¹². We have therefore chosen to 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.¹³ 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 have also included 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 Russia¹

	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 North Tyumen	30 bcm	61.03 \$/toe	6.724 bill\$

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

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.

¹³ Stern (1995) divides the Yamal projects into four stages, starting from the customer and building backward to the reserve base at the Yamal Peninsula. The first stage is the Polish section of the pipeline laying two 56 inch pipelines from the Belarus border through Poland to the German border. The second stage includes the building of two 56 inch lines from Torzok to the Belarus border. Three 56 inch lines will be built from Ukhta to Torzok at the third stage of the project, and the last stage will finally link this new export transport system to the vast natural gas reserves at the Yamal Peninsula.

2.2. The SEEM model¹⁴

SEEM is a multisectoral model of the demand side of the energy markets in each of 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. Examples are 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. The demand structure of the ECON-ENERGY model (ECON 1990,1994,1995) is very similar to SEEM. These models differ mainly with respect to the region classification in that ECON-ENERGY only considers Germany, France, the Netherlands, Belgium and Denmark within the region of OECD Europe. Earlier studies employing the SEEM model include Birkelund et al. (1994) and Alfsen et al. (1995).

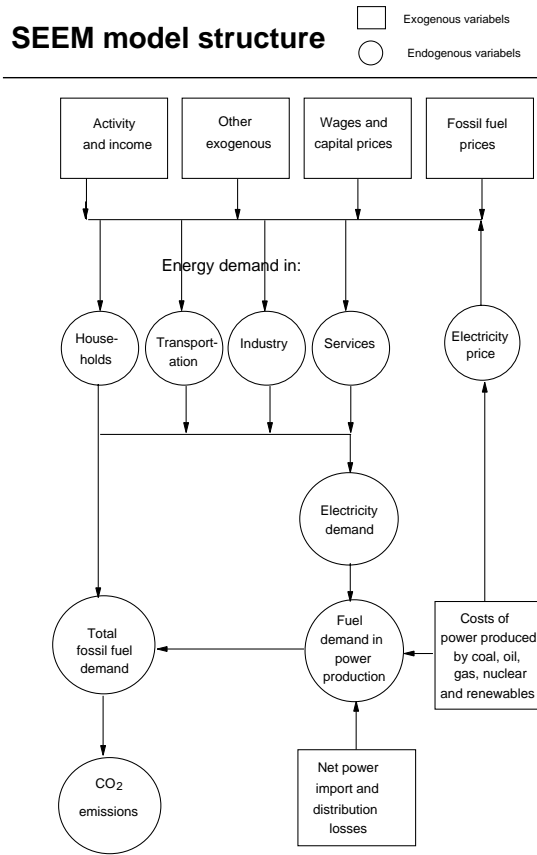
Each country is treated as a separate block in the sense that neither trade between countries nor supply of primary energy is modelled. Furthermore, the model is partial in the sense that fossil fuel prices and production activity in the economies are exogenously given. However, the supply of electric 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 a 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 on 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:

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

¹⁴ The presentation of the SEEM-model is restricted to a rather brief and descriptive outline. A more detailed documentation of the model can be found in Brubakk et al. (1995), Boug (1995) and Kolsrud (1996).

Figure 1.



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 relevant 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 is and the smaller other energy taxes are.

The electricity generation sector then 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 emission¹⁵.

Energy demand in all sectors are modelled according to variants of the fuel-share model. This representation draws upon the early work of Sato (1967), Brown and Heien (1972), and Berndt and

¹⁵Note that only anthropogenic emissions of CO_2 from fossil fuels are calculated. CO_2 emissions from both biomass/wood combustion and industrial (non-combustion) processes are not included.

Christensen (1973). The starting point of the fuel-share model is a neo-classical macro production function of the form

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

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 $E(\cdot)$ means that energy is produced by use of the energy inputs coal, oil, gas and electricity, 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 E , and second, at the upper level, a calculation of the cost-minimising combination of the aggregates K , L , 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 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 $F(\cdot)$, 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 the International Energy Agency (IEA 1993a,b). The time horizon for the simulations with 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 major model 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 CO₂ emissions analyses. The assumptions 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 continue more or less according to the time schedule laid out in the Maastricht Treaty. Due to resulting positive economic perspectives, we further assume that EU will be joined by the present EFTA countries around the turn of the millennium. The integration process will result in the completion of all objectives of the internal market, and a moderate, but positive overall effect on economic productivity and income in EU is expected. Based on these considerations, we assume a 2.5 per cent annual growth in economic activity in all sectors comprised by SEEM throughout the simulation period. This assumption is in line with the predictions for OECD-Europe in IEA (1996).

As indicated in the introduction, DYNOPOLY and SEEM are linked through the gas price, i.e., the optimal import price of gas from the DYNOPOLY model 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 as the actual price in both models in 1995. The gas import price in 1991 of around 128\$/toe in all SEEM countries explains the huge negative growth rates from 1991 to 1995. Likewise, we specify the development in future oil and coal import prices based on predictions in IEA (1996). Hence, the average imported oil price in the SEEM area of around 143\$/toe in 1991 is assumed to rise steadily throughout the simulation period after a huge drop in the price from 1991 to 1995. The average imported coal price of around 33\$/toe in 1991 is on the other hand assumed to remain constant.

It is common practice in numerical simulations of future energy demand to assume energy efficiencies that are independent of economic growth and energy prices. Such efficiencies are supposed to capture non-price induced technological improvements and structural changes that contribute to reductions in the energy consumption. We assume the autonomous energy saving 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 assumed to be 0.7 and 0.8 per cent annually on average throughout the simulation period.

In SEEM energy tax policies may be introduced as either direct energy taxes or carbon taxes in SEEM (cf. Equation 2). As part of a complete economic integration, all scenarios assume that a harmonisation of energy taxes takes place to avoid fiscal inequalities across the member states. More specifically, the excise tax for each fuel in each of the economic sectors in SEEM is harmonised towards the corresponding unweighted average tax levels in the four major energy consumers: Germany, France, United Kingdom and Italy. The harmonisation is based on the energy tax structure in 1991, and is assumed to take place gradually over the period from 2000 to 2010.

In this paper we also consider carbon taxation imposed on energy consumption as an instrument to achieve national CO₂ targets. We apply the CO₂ targets for EU of stabilising the CO₂ emissions at the 1990 level by the year 2000, as is 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, which are to be discussed further in Kyoto in Japan in December 1997, we assume the relevant year for attainment of the targets is 2010. The imposed carbon tax is a tax based solely on the carbon content of each fossil fuel, such that coal as the most polluting fuel with regards to CO₂ emissions per energy unit is most heavily taxed. For instance, a carbon tax of 100\$/toe for oil implies a tax of 124\$/toe and 71\$/toe for coal and gas, respectively (carbon coefficients are taken from Manne and Richels 1990). To achieve the national CO₂ targets the carbon tax is assumed to be introduced in 2000, and then to be 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.

An increased gas price due to a reduction in the Norwegian gas supply changes the energy composition towards those carriers that face lower or no price increase. These substitution effects vary across sectors and countries, depending among other things on the equipments already installed in the production and the choice of fuel when new capacity is built. The substitution possibilities in SEEM from gas to oil and coal are represented by cross price elasticities of around 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.¹⁶ No substitution possibilities from gas to

¹⁶ 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 a cleaner industry using 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 reduce the CO₂ emissions.

oil exist in the transport sector¹⁷ 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 to a less degree 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 to a more moderate degree by cross price effects.¹⁸

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.

3.1.1. Reference scenario

In DYNOPOLY we assume that Norway and Algeria will experience a large (exogenous) increase in their initial capacity from 1995 (or rather 1994) to 2000. Still, Norway and Algeria are the first to invest in their 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. Algeria 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 2020.¹⁹

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 investment projects each player has undertaken in a given period. The investments are operative i.e., they increase the production capacity, in the following period.

¹⁷ Note, that coal is not used in the transport sector in any of the countries in SEEM.

¹⁸ 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.

¹⁹ The last of the Russian projects is not entered until in 2035. However, in this analysis we are only interested in the time horizon from 1995 to 2020 which is the time horizon in SEEM.

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 the respective periods. Our initial import price in 1995 is set equal to the European cif price in 1994 reported in BP (1995). In February 1997 the average European border price is 115.6 1997\$/toe according to World Gas Intelligence (1997), which is considerably higher than our simulated import price in 2000. The reason is that since the price in DYNOPOLY is determined by Equation (1), this implies that when there is a large exogenous increase in supply from all three players from 1995 to 2000 the price must fall. For the same reason, the investment behaviour of the players, 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 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. This means that 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

We are interested in the effect on the price of gas of a reduction in the Norwegian gas exports to Western Europe. We have looked at 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.

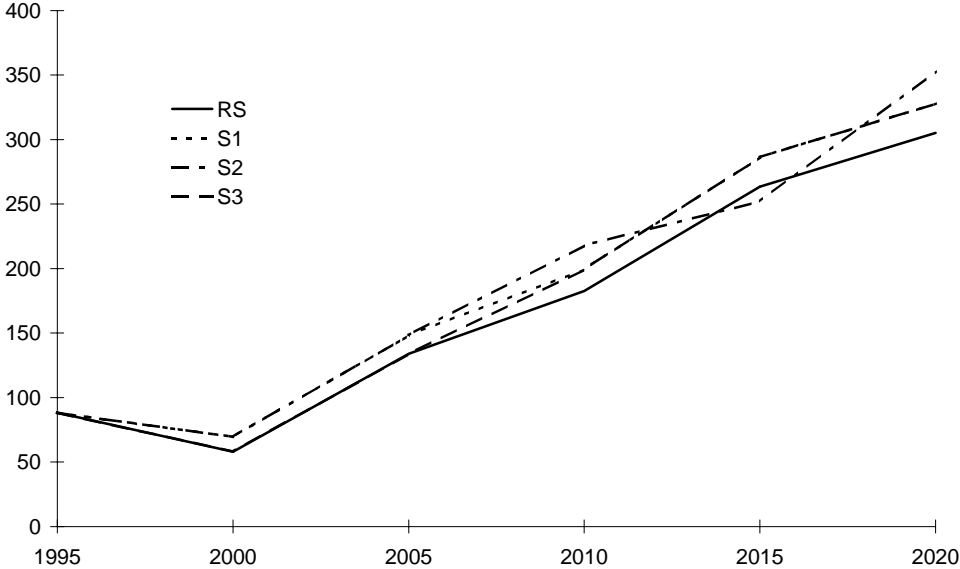
A problem with the approach in S1 and S2 is that Norway as a player in the model may in early periods counteract the effect of the reduction policy which can be thought of as imposed by the Norwegian government. This can be achieved by moving the investment projects forward in time.

However, when the investment options are exhausted Norway will eventually produce less gas than without the reduction policy, but the timing of the effect of the reduction in Norwegian gas exports may be influenced by the investment behaviour of Norway and is thus determined endogenously in the model. S1 and S2 may therefore be interpreted as counterfactual scenarios, i.e. they describe the energy consumption and CO₂ 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 further investment project to 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.²⁰

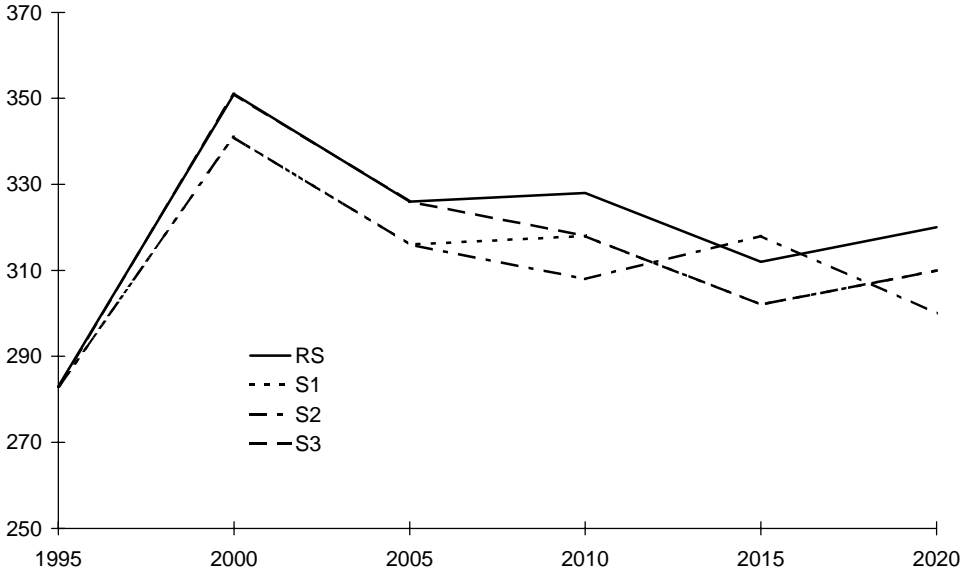
The import prices of natural gas in the reference and reduction scenarios are given in Figure 2 below. The corresponding levels of total supply of gas to Western Europe are presented in Figure 3.

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



²⁰ We also looked at a fourth alternative which considered 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 so we only present scenario S2.

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



In S1, where the Norwegian gas exports are reduced by 10 bcm/year compared to RS, the investment behaviour of the players is unchanged. This means that the reduction in Norwegian gas sales is not replaced by increased production from any of the players and thus total supply of gas is reduced by 10 bcm/year from 2000 onwards. This leads to an increase 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.²¹

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 it is strategically motivated to prevent Norway from entering two projects in 2000, and also to prevent Russia from moving up investments. As a result the total supply is reduced by only 10 bcm/year in the periods 2000 and 2005. The effect on the import price of gas is hence as in S1 until 2010. Only in 2010 and 2020 do we see the full effect of the Norwegian reduction of 20 bcm/year. In these periods the price is increased about 20 and 15 per cent 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

²¹ 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.

the total supply to Western Europe. This leads to a *decrease* in the import price of 4 per cent compared to RS.

In the third scenario we consider, S3, where Norway is left with only one investment project, the investment behaviour of the players is again unaltered.²² Hence the total supply and the price of gas is unchanged compared to RS until the time 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 investment opportunities open to Norway, would have brought an additional 10 bcm/year to the market.

To conclude we see that 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 CO₂ emissions from Western Europe will be investigated in section 3.2. using the SEEM model.

3.1.3. Sensitivity analyses in DYNOPOLY

As there is much uncertainty surrounding the parameters in the DYNOPOLY model we carry out sensitivity analyses to test the robustness of the model results. The results in RS and S1 presented in the preceding paragraphs appear to especially sensitive towards changes in the parameters in the demand function. Changes in the discount rate of the three gas producers only lead to small alterations in the results, and relatively large increases in production and investments costs are required to alter the investment behaviour of the players. Some of the findings are presented below.

With a lower *income elasticity* of demand of 0.4, which correspond to a lower GDP growth rate in the DYNOPOLY model, we get lower prices and higher supply, except in 2010, than in RS. 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

²² 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.

is increased (between 34 and 45 per cent compared to 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 the DYNPOPOLY model. With a direct price elasticity of -0.9 demand is more elastic compared to RS 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 than 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, with a lower *oil cross price elasticity* of 0.15, which implies less substitution between the two fossil fuels than in RS the overall result is a fall in the price of gas in all periods between 8 and 46 per cent. The Norwegian reduction policy has a larger impact on the gas price in this case, especially in the 2000 and 2005.

In RS we assume a rapid decrease in the *indigenous production* in the demand region as production is assumed to decrease by approximately 20 per cent over each five year period after 2000. More optimistic estimates of the gas reserves in the demand region (corresponding to reduction rates of 15, 10 or 5 per cent instead of the 20 per cent in RS) 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 in the model.²³ The effect on the import price compared to RS is in most periods between -10 and -20 per cent. With higher indigenous production the reduction policy from Norway also gives rise to a greater 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 the parameters in the demand function. As there is much uncertainty surrounding these parameters the results should be interpreted with caution. The effects of a reduction in the Norwegian gas sales are also seen to be sensitive towards changes in the parameters of the model. It is difficult to identify a clear pattern, but the no response policy of the players to the 10 bcm reduction in Norwegian gas exports does not seem to be a stable outcome. However, these changes in parameter assumptions in DYNOPOLY have only a modest impact on simulated energy demand and CO₂ emissions in the SEEM model, see paragraph 3.3.2.

²³ In two cases the total supply *decreases* in period 2010 due to the delayed introduction of the first Norwegian and Algerian projects.

3.2. Effects on energy demand and CO₂ emissions

The purpose of this section is to compare the three scenarios of reduced Norwegian gas exports to Western Europe with the reference scenario along two dimensions: the impacts on energy demand and on CO₂ emissions in the next decades. First, we present the impacts on energy demand and CO₂ emissions when no environmental restrictions and CO₂ taxes are present. Second, we discuss the effects of environmental regulations. In the presentation of the simulation results from SEEM we focus on results for 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 around 51, 72 and 90 per cent of total Russian, Norwegian and Algerian gas export in 1995, respectively (BP 1996). Although the simulation period ends in 2020, we focus on the main results in 2000 and 2010 as these years are of most interest with respect to CO₂ emission levels and the attainment of national CO₂ targets.

3.2.1. Energy demand

We are interested in analysing the effects on energy demand of a reduction in Norwegian gas exports. A reduction in the Norwegian gas exports is assumed to influence the gas price for Europe, in such a way that all countries face the same alterations in the imported price of gas. Furthermore, we only consider energy demand effects as a result of shift in the gas supply from Norway. 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 in the model area decreases when the Norwegian gas sales are restricted and the gas price is increased. The reduction in the consumption of gas 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, respectively. For instance, a reduction in 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. Simulated alterations in energy composition in S1 and S2 are identical in year 2000 due to the fact that the supply effects, and thus the gas price evolution, are unaltered across these scenarios in that period. Only in 2010, do we experience significant supply effects of the Norwegian reduction of 20 bcm/year in that the gas price is about 20 per cent higher than in RS. As a result, demand for gas in 2010 is reduced by as much as 5.5 per cent and the substitution effect amounts to a 0.5 per cent increase in total demand for oil and coal. Overall, this means a total demand effect of nearly 1 per cent in energy savings in S2 in 2010. For the reduction scenario S3 in which Norway has the same

initial capacity as in RS, but only one strategic investment project of another 10 bcm/year, the demand effects are even more moderate than the effects experienced in S1. In fact, no demand effects are observed in 2000 as the total supply and the price of gas is unchanged compared to RS until 2010.

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

	1991	2000				2010			
		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 consumers¹:									
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
Househ.	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
Transp 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 when 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 reduction in gas demand is mainly experienced in the industry sector in both 2000 and 2010. The contributions to the reduced gas demand from the households and power generating sector are also quite considerable. In addition to the gas shares in each economic sector, the relationship between the import price and the end user price of gas is important in explaining these results. Normally, 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. This is taken care of in the model simulations through Equation 2. A 1 per cent increase in the import price of gas increases the end user price in the industry sector by around 0.7 per cent on average, while the price increase is only 0.25 per cent in the household and the service sector. Despite the small impact from the import price on the end user price, the reduced gas demand in the household sector is mainly explained by its gas share of around

40 per cent, initially. Gas delivered to the power sector normally faces a price increase corresponding to 0.9 per cent of the import price increase.

The total reduction in gas demand in the service sector is to a large extent replaced by oil, such that no significant energy savings are realised in this sector. Both oil and coal are the alternatives for gas in the power sector. Oil replaces around 25 per cent of total reduction in gas demand and coal around 40-50 per cent, leaving the remaining share as energy savings in this sector. Even though a part of the total reduction in gas demand is replaced by oil in the household sector, the energy saving effects play a dampening role in this sector. No significant replacement from oil or coal is seen in the industry sector in the major countries. Hence, the energy savings are most substantial in this sector. Roughly speaking, the energy savings in the industry sector amount to 70 per cent on average of total energy savings in the major countries in total.

3.2.2. CO₂ emissions

We have argued that a reduction of the Norwegian gas supply to the continent may alter the CO₂ emissions. We divide these changes into the following emission categories: (i) emissions in the 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 total deliveries of gas to Western Europe may change the emissions from the transport systems for gas, due to differences in the distance from the producers to the market, and the energy efficiency in the pipelines. Corresponding alterations in CO₂ emissions may also arise from the transport systems for oil and coal as these energy carriers may replace Norwegian gas supply.

For category (i) the alterations in CO₂ emissions are based on the results presented in paragraph 3.2.1 as emissions are proportional to energy consumption. The emission factors employed in terms of million tonnes CO₂ (MtC) per million tonnes oil equivalents of energy use (Mtoe) are 2.201 for gas, 3.1 for oil and 3.844 for coal.²⁴ For the category (ii) we have to rely on assumptions made in other studies (see ECON 1994 and 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 Russia and Algeria amounts to 12 and 6 per cent of

²⁴ The emission factor of 3.1 for oil as a reference for the other fuels 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). Note, that there is no variation in factors between the sectors, because it is the carbon content of each fuel, and not the combustion technology, that determines the emissions.

transported quantity, respectively, while energy consumption related to import of oil and coal amounts to 4 and 2 per cent of transported quantity. Table 6 presents the alterations in CO₂ emissions based on these assumptions.

Table 6. Western European CO₂ emissions, total emissions (1991 and RS) and changes (S1-S3). MtC

Category	1991	2000				2010			
		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
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 energy consumers	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).

It is evident that CO₂ emissions slightly decrease in the model region under different assumptions about the reduction in the Norwegian gas sale to the continent. In both S1 and S2 emissions are reduced by somewhat less than 0.4 per cent in year 2000 compared to the RS. In 2010 the corresponding emissions reduction is about 0.3 per cent in S1 and in excess of 0.5 per cent in S2. The most significant alterations in the emissions are simulated in the energy consuming countries. More than 90 per cent on average of the reduction in global CO₂ emissions is attributed to this emission category. As previously discussed, the reason for this is that the energy saving effect due to increased gas prices is stronger than the substitution effect towards more polluting energy products. The reductions in the emissions from the Norwegian continental shelf range from 8 to 16 per cent of total CO₂ 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 the DYNOPOLY model, the Russian gas export is unaltered by the Norwegian gas export in all cases in year 2000 and 2010. Hence, emissions related to gas deliveries from Russia are also unchanged compared to RS. This is also the case for gas deliveries from 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 going from RS to S2 in year 2000.

Alterations in CO₂ emissions in the four major countries amount to around 70 per cent on average of total emission reductions in the SEEM area. United Kingdom is the main contributor to these alterations in year 2000, while Italy is the main contributor in year 2010 when the Norwegian gas sales are reduced by 10 or 20 bcm/year from 2000 onwards. In S3 the contributions are more evenly spread among the four major countries. The figures 4-7 decompose total alterations in CO₂ emissions from each country into sectoral alterations in the case of S1.

While reduced Norwegian gas sales induce lower total CO₂ emissions in all four countries, the figures show that sectoral alterations are different across the countries. The emissions from the industry sector are however significantly reduced in all countries. Another common denominator is that the emissions from the transport sector are unaltered. This is mainly explained by low gas consumption initially (see Table 5) in addition to the fact that small substitution possibilities among the energy carriers exist in the transport sector. Germany faces the largest reduction in CO₂ emissions in the industry sector due to significant energy saving effect and small substitution towards oil and coal. The opposite effects are the case in the household and service sector, and result in increased emissions in these sectors. Substitution, mainly towards coal, is also seen in the power sector. However, this negative impact on the emissions is not large enough to offset the positive impact from the reduced gas demand, and the emissions decrease slightly in this sector. Except from a slight increase in the power sector, all sectors in United Kingdom face reductions in the 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 reduced gas demand in this sector 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. The emission reduction in the household sector is, as in United Kingdom, 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 in France is based on oil and coal, and not on gas. Finally, the development in the sectoral CO₂ emissions in Italy coincides with that simulated for United Kingdom. The emissions go down in all sectors except from the power sector (and transport). Small energy

saving effects are dominated by considerable substitution effects, mainly towards oil, in the power sector. Hence, the emissions increase somewhat in this sector in Italy.

Figure 4. Alterations in CO₂ emissions in Germany. S1

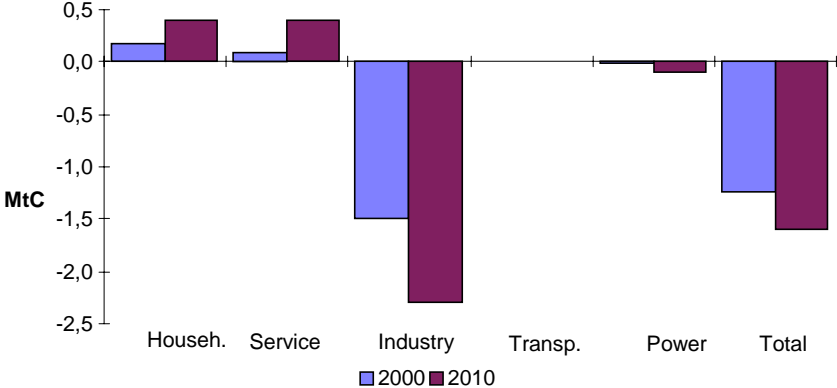


Figure 5. Alterations in CO₂ emissions in United Kingdom. S1

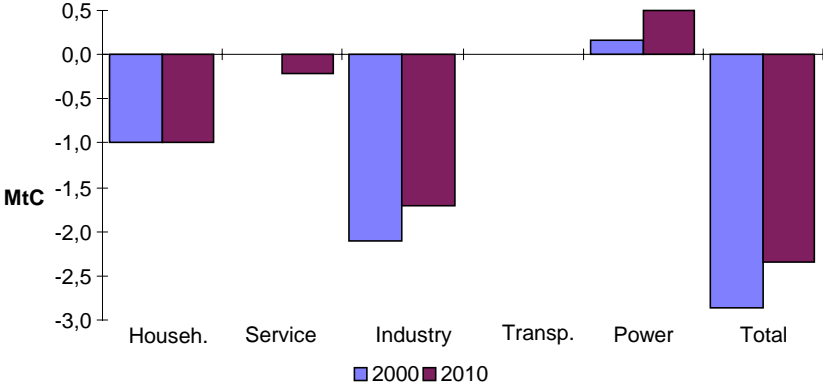
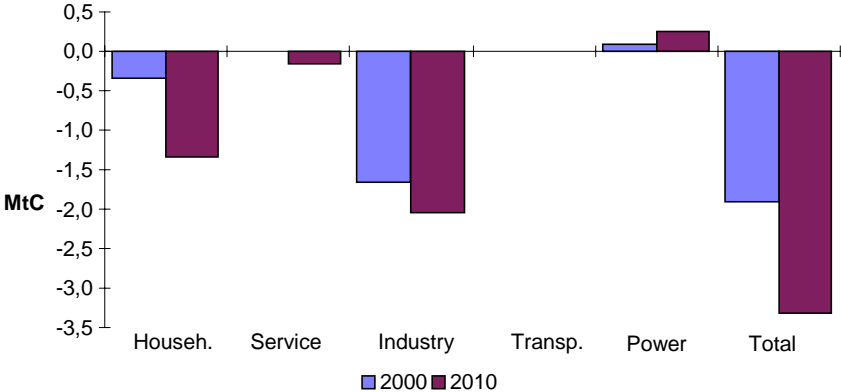


Figure 6. Alterations in CO₂ emissions in France. S1



Figure 7. Alterations in CO₂ emissions in Italy. S1



It is worth noting that the SEEM model assumes horizontal supply curves. This results in greater substitution from gas towards oil and coal, and thus higher emissions, compared to the substitution effects and the estimated emission levels in 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 as input in the SEEM model. Overall, the emission levels associated with the different price paths from the sensitivity analysis on the

DYNOPOLY model deviate from the emission levels reported in Table 6 by around -1 to +1 per cent. It is also interesting to notice that an *increase* in Norwegian gas sales of 10 bcm/year from 2000 has only minor impacts (slight increase in emissions) on Western European CO₂ emissions.

3.2.3. Environmental regulations

Given the concern about the environmental impacts of energy consumption, and more specifically, the possible threat of global climate change, many governments, including a majority of the EU member states, have announced their intention to return greenhouse gas emissions to the 1990 levels by the year 2000. Table 7 provides a summary of national CO₂ targets and expected attainment of these targets for EU in total and for the four major energy consumers that have reported under the Convention of Climate (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 include programs that promote energy improvements and decreased use of exhaustible energy resources. A combined carbon/energy tax is not yet included in these strategies. The European Commission has, however, proposed a compulsory carbon tax that is intended to be introduced in 2000.

Table 7. Emissions targets. CO₂ 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 the 1990-level by 2000	3141	Small possibilities to meet the target
Germany	25-30% reduction in emissions from the 1990-level by 2005	1032	Uncertain whether the target will be met
United Kingdom	Stabilisation of emissions at the 1990-level by 2000	587 ²	Expected to meet the target
France	Stabilisation of emissions per capita at the 1990-level by 2000 ³	367	Expected to meet the target
Italy	Stabilisation of emissions at the 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 CO₂ emissions from 1990 to 2000. Hence, total CO₂ emissions in 2000 must not exceed 415 MtC when the per capita target is translated into a target for total CO₂ emissions.

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

Despite these strategies, it is expected that the EU in total will not meet its CO₂ target. With reasonable economic assumptions and with no specific environmental regulations undertaken (i.e., no commitments to CO₂ targets and no CO₂ taxes), simulations with the SEEM model support this expectation and predict

the total CO₂ emission levels in 2000 and 2010 to be in the ranges of 157-172 MtC and 615-632 MtC above the EU stabilisation target. The simulations illustrate that none of the four major energy consuming countries are able to meet their national CO₂ targets without a specific energy policy aimed to stabilise or reduce the emissions. Thus, this study supports the view that an effective energy policy is called for in order to stabilise CO₂ emissions in Western Europe in the future.

In this study we assume that a fixed carbon tax based solely on the carbon content of each fuel is needed to be introduced in 2000 to fulfil the national CO₂ targets by 2010. Due to the small differences in total level of CO₂ emissions across the scenarios, we concentrate on the reference scenario and reduction scenario S1. Table 8 shows the simulated magnitude of the carbon taxation that is necessary in each country to achieve the national CO₂ target.

Table 8. CO₂ emissions, targets and carbon taxation in 2010¹

	Target	Emissions with no CO ₂ tax		Emissions with CO ₂ tax		CO ₂ tax in RS and S1		
		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 levels are measured in MtC and the carbon tax is measured in 1991\$/toe. The carbon coefficients are taken from Manne and Richels (1990).

We now want to look at the impacts of Norwegian gas under the assumption that all countries have committed themselves to stabilise the emissions at the 1990 level by 2010. When a country has committed itself to a CO₂ target, a change in Norwegian gas sales will not affect the emissions from that country. However, as the gas price changes, the composition of the energy consumption and the costs of lowering the emissions may change. We focus on RS and S1. Not surprisingly, the simulated carbon taxation turned out to be identical in both scenarios. We have seen in the discussion above that the alterations in the energy composition due to reduced Norwegian gas sales are too small to give any significant effects on the CO₂ emissions. The magnitude of the carbon taxation is however substantial, especially in Germany and Italy, as these countries are simulated to have the most restrictive CO₂ targets in year 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, faces a reduction in the energy

demand of almost 25 per cent with CO₂ taxes. The reduction in Italy is even higher (32 per cent) since oil with a consumption share of around 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 (around 10 per cent) as these countries are closer to meet their CO₂ targets in year 2010. As in the case of no taxes, the energy composition alters somewhat when the Norwegian gas sales are reduced and each country is committed to fulfil its CO₂ targets. Strong energy saving effects and less dominant substitution effects towards oil and coal due to increased gas price still apply as the explanations for the energy composition alterations.

Table 9. CO₂ 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 CO₂ 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 three suppliers engage in a fight for market shares using investment projects as the strategic variable. In this model a change in Norwegian gas policy may induce large discrete jumps in the total supply of gas. In our main reduction scenario (S1), however, Algeria and Russia will not replace the reduction in Norwegian gas sales and hence the total gas supply will decrease accordingly. However, the results in DYNOPOLY are sensitive towards changes in exogenous parameters in the

model. It is also a limitation of the model that the strategic decisions of the players in the model 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, this may lead to large jumps in the supply of gas in the model. 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 CO₂ emissions in Western Europe. In addition to calculating the CO₂ emissions from the consumer countries we have also taken into account changes in the emissions through the transport and distribution system. According to our results a reduction in the Norwegian gas sales will lead to a slight increase in the consumption of oil and coal while the consumption of gas is somewhat reduced. The results indicate a reduction in emissions of CO₂, however, the effect appears to be modest.

It should be mentioned that demand responses in such models are highly dependent on the particular elasticities chosen. And in addition to the effects on the demand and supply side, there are political regulations which will have important impacts on the results. If, for example, a country has a binding announced CO₂ emissions target, this will be kept no matter what the Norwegian gas export policy is. So if all countries commit to keeping their announced CO₂ emissions targets, a reduction in Norwegian gas sales will have no effect on CO₂ 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 certain CO₂ emissions limit, but only has preferences for a better environment, the Norwegian energy policy may have greater impacts on the level of total CO₂ emissions. For instance, the country may for environmental reasons choose to rely on imported gas instead of building a new thermal power station 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 CO₂ emissions to increase. A reduction in Norwegian gas sales might in this situation prevent such choices from being made. However, a country may also have production and consumption targets for certain fossil fuels like for instance coal. In this case, 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 therefore in this case lead to an decrease in 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.

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