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Energy demand, carbon emissions and acid rain

Consequences of a changing Western Europe

Statistics Norway

Statistisk sentralbyrå

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Abstract

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Energy demand, carbon emissions and acid rain
Consequences of a changing Western Europe

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Employing a multisector energy demand model of thirteen Western European countries (SEEM) together with the RAINS model developed by IIASA, we in this report address the question of how much the European economic and political integration process matter for future development in energy demand, emissions to air of key pollutants and transboundary transport of sulphur and nitrogen. We do this by comparing two simulation scenarios; one scenario based on the assumption of further European integration versus another scenario where fragmentation is assumed to prevail. Both scenarios cover the period from 1991 to 2020. The focus of the report is on consequences for future demand for fossil fuels, emissions of CO_2, SO_2 and NO_x, and transport and deposition of sulphur and nitrogen.

Average annual growth in GDP in the integration scenario is 2.3 per cent, while demand for energy, emissions of CO_2, SO_2 and NO_x, and nitrogen deposition all show average annual growth rates from 1.7 to 1.9 per cent. Deposition of sulphur grows at the slightly lower rate of 1.4 per cent per year in this scenario. In the fragmentation scenario all growth rates are reduced by 0.5-0.7 percentage points, except the rate of annual average growth in SO_2 emissions which is reduced by 0.8 percentage point. The results vary considerably, however, over countries, sectors and fuel types.

Keywords: Energy demand, emissions to air, economic growth, SEEM, acid rain, Western-Europe.

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Contents

1. Introduction

European integration has been on the agenda for a long time. Whether this momentum towards greater integration can be kept up also in the next few decades is however uncertain. The problem addressed in this report is how this uncertainty might affect its energy markets and how this in turn could affect emissions of carbon dioxide (CO_2), and emissions, transport and deposition of the two most important acid compounds; sulphur dioxide (SO_2) and nitrogen oxides (NO_x).

The strategy followed is first to describe how further integration or lack of integration (fragmentation) can affect the economic development of 13 countries in Western Europe. This description is of an ad hoc nature and is treated as exogenous input to this analysis. Based on alternative growth paths, we employ a Sectoral European Energy Model (SEEM) to calculate likely impacts on the energy markets, where basically three types of primary energy goods are treated endogeneously; gaseous fuels, liquid fuels and solid fuels[1]. Supply and demand of electricity based on thermal power production is also modelled in SEEM.

Other types of energy technologies, e.g. nuclear power and alternative energy technologies, are treated as exogenously given. Secondly, based on projected energy demand, emissions of the greenhouse gas carbon dioxide (CO_2) is calculated by the SEEM model[2], while IIASA's RAINS model is utilised in calculating emissions, atmospheric transport and deposition of SO_2 and NO_x. The inputs to the RAINS model are the energy consumption paths generated by the SEEM model.

Given this strategy, the rest of the report is organised as follows. The next section briefly describes the structure and working of the SEEM model[3]. Section 3 then comments on the economic assumptions used in the two scenarios of further European integration and European fragmentation, respectively. Simulation results based on these alternative economic development paths are given in section 4, while section 5 concludes. The appendix contains a set of detailed country tables covering emissions to air and deposition of SO_2 and NO_x.

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[1] Studies based on a previous version of the model have been published by Birkelund et al. (1993, 1994) and Alfsen et al. (1995).
[2] The topic of CO_2 emissions in a changing Europe is discussed in detail in Boug and Brubakk (1996).
[3] The model is documented in detail in Brubakk et al. (1995), Boug (1995) and Kolsrud (1996).

2. The SEEM model

2.1. Model structure

The Sectoral European Energy Model (SEEM)[4] is a simulation model for energy demand projections for 13 countries in Western Europe. The model consists of separate model blocks for each of the following countries:

- Four major energy consumers: Germany, France, United Kingdom, and Italy;
- Four Nordic countries: Denmark, Sweden, Finland and Norway;
- Five other countries: Spain, the Netherlands, Belgium, Austria, and Switzerland.

Together, these countries consumed about 90 per cent of the total energy use in the OECD Europe in 1991.

Neither inter-country trade nor supply of primary energy is modelled within SEEM. Supply of electric power is, however, part of the model. In each country there are five sectors: manufacturing industries and service industries (hereafter referred to as industry and services), households, transport[5] and power production. Energy commodities covered in SEEM are coal, oil, gas, electricity and various transport fuels. Demands for nuclear and renewable fuels are treated as given in the model.

The model is partial in the sense that it determines the demand for energy based on exogenous prices, taxes and production and consumption activity levels (cf. figure 2.1). Hence, we focus on the demand side of the energy markets, with the assumption that demand equals realised consumption. However, both the demand and the supply side of the Electricity generating sector is included in the model. Cost minimising behaviour is assumed for all sectors using energy.

The choice of behavioural functional forms and parameters, and the quantitative methodology, were chosen considering the data and resource limitations.

Furthermore, model transparency and the scope for implementation and simulation on a Personal Computer were important design criteria.

Parameters representing the behaviour of the sectors included in the model are estimated on empirical data or calibrated on research results published in international journals. For all estimations and the calibration of the energy use and prices to the base year (1991), data from the International Energy Agency (IEA, 1993a, b) were used.

We have formulated the model equations directly at the sector level by adopting a "top down" modelling approach. However, the macro-level producer or consumer that we study, is assumed to behave according to microeconomic considerations. In fact, the neo-classical micro model often seems more meaningful at the sector level than at the individual level. In particular, continuous substitution possibilities are perhaps more realistic at a sectoral level. These substitution possibilities are premises for cost minimising and utility maximising behaviour, which are crucial assumptions when deriving the fuel demand functions.

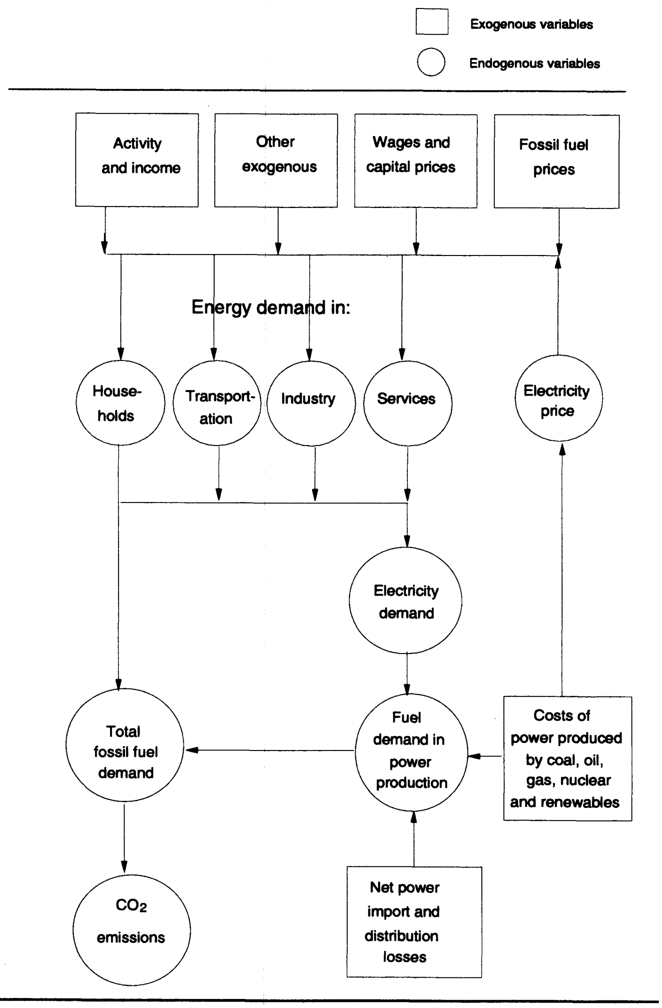
Figure 2.1 depicts the structure of the model block for one country. In a first step the model determines the demand for coal, oil, natural gas and electricity in the end user sectors, based on exogenous information on activity levels, income, and technology, in addition to production factor prices.

In the electricity generation sector the need for domestic production of power is derived, given an exogenous matrix of net power import and a constant percentage of distribution losses. The electricity requirements can be produced in several ways: By thermal power plants using coal, oil or natural gas as inputs, by nuclear power plants and/or by plants using renewables (now mainly hydro power).

[4] SEEM version 2.0 has been developed in co-operation with the Netherlands Energy Research Foundation ECN.

[5] Fuel demand for transport purposes has been grouped into one sector.

Figure 2.1. SEEM model structure



The different technologies' share of the total electricity generation depends on their relative costs of production. Based on the production costs of electricity, margins and taxes, the model calculates 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 yields the total demand for each fossil fuel. In a submodel, demand for coal, oil and natural gas are converted into estimates of CO_2 emissions.

Table 2.1 gives a list of the countries, sectors and fuels covered by the model together with their model codes.

2.2. The sector models

In SEEM, the *industry* sector is described by a two-level fuel-share model. The upper level determines the cost minimising combination of the three aggregate production factors; capital, labour and energy, while the lower level determines the cost minimising combination of the different fuels included in the energy aggregate, i.e. the optimal proportion (fuel shares) of coal, oil, natural gas and electricity. At both levels Cobb-Douglas production functions have been used. To allow for sluggish adjustment of capital input to price changes, demand is lagged according to a partial adjustment hypothesis. Hicks-neutral technical progress is specified at the upper level. The fuel demand equations at the lower level are calibrated using information about the cost shares of the different fuels. At the upper level the calibration is based on elasticities found in other studies.

Table 2.1. Model specifications and codes

Stationary sectors		**Fuels in mobile sectors**	
EL	Electricity production	BD	Diesel for buses
HO	Households	GA	Gas
IN	Manufacturing industries	GO	Gasoline
SE	Service industries	RE	Electricity for rail
ST	Stationary consumption (=EL+HO+IN+SE)	RD	Diesel for rail
FC	Final consumption (=ST-EL)	DI	Diesel
		EL	Electricity
Mobile sectors		OI	Oil
TP	Passengers transport		
TF	Freight transport	**Countries**	
FA	Air freight	AU	Austria
MO	Mobile consumption (=TP+TF+FA)	BE	Belgium
		BR	Germany
Fuels in stationary sectors		CH	Switzerland
NUC	Nuclear fuel	DK	Denmark
REN	Renewable fuels	FR	France
COA	Coal	GB	United Kingdom
OIL	Oil	IT	Italy
NGS	Natural gas	NL	The Netherlands
ELE	Electricity	NO	Norway
		SF	Finland
		SP	Spain
		SW	Sweden

For *service industries* we have estimated a fuel-share model similar to that of the industry sector by postulating Constant Elasticity of Substitution (CES) production functions for the energy aggregates. We allow for a nested model in *three* levels (compared to two in the industry sector) for countries with substantial use of all four energy sources, i.e. coal, oil, gas and electricity. At the upper level, electricity and an aggregate of oil, gas and coal are separate inputs. This implies a hypothesis that the use of electricity contributes to production in a profoundly different way compared to fossil fuels. While the latter are used for space heating mainly, electricity is mostly used in appliances like computers and lighting for which energy substitution is impossible. The energy demand functions at the upper level are log-linear, with calibrated parameters. At the intermediate level, the fossil fuel aggregate is produced by a CES technology utilising an aggregate of oil and gas, and of solids. At the lower level the oil and gas aggregate is produced, also by a CES technology. The intermediate and lower level parameters are estimated.

The *household* sector model is equal to the services sector model, except that at the upper level «private consumption» and «prices of other goods» substitute for the production activity level and factor costs others than energy costs as explanatory variables, respectively. Also in the households, electricity and fossil fuel prices are variables which determine the households' demand for electricity and fossil fuel aggregate at the upper level. The modelling and parametrisation of the lower levels are similar to the service sector model.

The *transport* sector model is divided into *passenger transport*, *freight transport*, and *air transport*. Fuel efficiencies in the transport sectors are based on linear penetration of new technologies.

Air transport is treated separately because most air transport is combined passenger and freight transport. Demand for fuel (kerosene) is modelled as a function of the price of kerosene and gross domestic production.

For *passenger transport* both private and public transport are considered; more specifically cars (gasoline, gasoil and gas), trains (electricity and gasoil) and busses (diesel) are distinguished. At the upper level of the passenger transport model total demand for person kilometres is a function of consumer expenditures and a transport price index. At the lower level the demand for transport is split into the different modes in proportions depending on fuel prices and capital prices of the respective modes. This determines demand for person kilometres by transport mode. Given figures for car occupancy and efficiency, the corresponding fuel use is then computed.

The *freight transport* is modelled at the upper level by assuming that the development of domestic production determines total demand for tonnes kilometres. Given exogenous assumptions on mode shares and fuel efficiency, the demand for the different fuels are then calculated.

In the *electricity generation* model the domestic power production requirements are determined by adding end user electricity demand (i.e. total demand from industry, services, households and transportation), net import (exogenous) and distribution losses. Electricity can be produced by different technologies relying on different energy sources - coal, oil, natural gas, nuclear and renewables. The shares of electricity produced by different fossil fuels are determined by the relative costs of the different plants, which are a combination of fuel costs and technology related costs. This in turn determines demand for the different fuels, given fuel efficiency in different plants. As in the transport model, the fuel efficiency is based on the assumption of a linear penetration of new technologies.

The *fuel price* module computes sectoral end user prices for the different fuels. The end user prices are divided into import prices, gross margins and taxes. For electricity, the «import price» corresponds to the electricity generation price calculated by the average unit costs of producing electricity domestically. Gross margins for all fuels include costs and profits in transformation, distribution, retailing, etc. Taxes are divided into fuel specific taxes, carbon taxes and a value added tax.

2.3. Model input and output

Table 2.2 summarises the main SEEM model input and output. The list reflects the menu for topics and policy questions that the model user can study by simulating SEEM.

Table 2.2. SEEM inputs and outputs

MODEL INPUT:	MODEL OUTPUT:
Cost variables	**Fuel demand**
Fuel import prices	Coal
Fuel gross margins (costs and profits in transformation, distribution, retailing, etc.)	Oil products (light and heavy oil, gasoline, diesel, kerosene)
	Natural gas
Fuel taxes (excise taxes, carbon taxes, VATs)	Electricity
Capital costs	
Labour costs	**Electricity production**
Activity/income variables	**End user prices**
GDP	For all fuels and sectors
Industry production	Electricity generation costs
Services production	
Private consumption	**Energy intensities**
	Total and by sector
Technologies	
Technologies in Transportation and Power generation (investment costs, fixed and variable costs, efficiency, availability)	**Activity variables**
	Demand for kilometres
Autonomous energy saving in Industry, Services and Households	
	CO_2 emissions
Net power import	Total and by fuel and sector
Fuel substitution possibilities	
Demand sensitivity	

3. Integration or fragmentation? A brief description of alternative economic scenarios

In this section we describe the economic development scenarios used as input to the SEEM model simulations, starting with the integration scenario.

3.1. Ongoing Western European Integration (IS)

This scenario is based on the assumption that the ongoing European integration process will continue more or less according to the time schedule in the Maastricht treaty. Because of perceived positive economic perspectives we assume that the EU will be joined by Switzerland and Norway around the turn of the century. Hence, the integration process concerns all 13 Western European countries. Furthermore, we assume an association of all Central and Eastern European countries around year 2000, improving trade possibilities and access to foreign investments. In fact we assume that all proposals mentioned in the Maastricht Treaty are fully implemented by the year 2000. The integration process will result in the completion of the all objectives of the internal market, so free movement of all goods, persons and capital will be realised.

We expect that the completion of the internal market will have a moderate, but positive, overall effect on economic productivity and income in EU. Funds for structural improvements in the Southern European EU countries presumably will contribute to a more equal development pattern.

We expect that the European Monetary Union will result in a single currency (ECU) and the establishment of a Central bank before the year 2000. A stable monetary situation without continuously changing exchange rates will be reached at that time, increasing economic prospects further.

Already political decisions in the field of environmental protection, public health and consumers' protection are made on Communal level. With respect to environmental policy, we assume more attention will be given to «continental» issues, e.g. Eastern European problems. Economic and social cohesion, high-tech industry and research are subjects given high priority by the Community. EU will co-ordinate these policies Europe-wide with a minimum of national interference and obstacles.

Of crucial importance to the issue analysed in this report is that an energy tax harmonisation is assumed to take place in the model countries. The tax is harmonised towards the average tax levels presently found in the four largest countries; Germany, France, United Kingdom and Italy.

Table 3.1 summarises the main effects of continued integration on some key variables.

Table 3.1. Assumed influence of further integration on some key factors in Western Europe (EU+EFTA) compared with present situation

Integration	GDP	Ind. production	Prod. cost	Competitive strength (EC)	Employment	Labour cost	Trade balance EC-World	Energy prices	Interest rate	Prosperity	Innovation	Environment
-Internal market	++	++	–	++	++	—	+	—	–	++	++	++
-Monetary	++	+	—	++	+	—	++	–	—	+	+	0
-Social	0	+	0	0	–	++	0	0	+	+	+	0
-Political	0	+	–	++	+	0	++	0	0	+	++	++

++ significant positive effect (higher). + small positive effect (higher). 0 no clear effect. – small negative effect (lower).
— significant negative effect (lower).

3.2. Western European Fragmentation (FS)

This scenario is based on the assumption that the EU integration is halted from now on. National disagreements dominate further EU unification, resulting in a more fragmented Western Europe.

Large innovative powers and competition mainly from the Asian Pacific region will push Western Europe into a relatively backward position. As a result, we assume that overall average economic growth in Western Europe is lower than in the integration scenario, and also results in greater differences in growth between Western European countries than in the integration scenario.

Completion of the internal market will not progress further. Instead increasing protectionism in specific sensitive sectors such as agriculture, coal mining, gas distribution, and electricity generation in many EU-countries might be expected. National intervention in energy markets will prevail. Also permanent or even increasing inequalities in the national taxation systems will occur over the next decades. Some countries will suffer more, however, from this halt in the integration process, and see their economic growth declining more than others. Particularly, we expect Finland, UK and southern member states Italy and Spain to suffer most in this situation.

No energy tax harmonisation is assumed to take place in this scenario.

The European Monetary Union will become a dead letter and not realised. As a result of monetary uncertainties, cross-country investments will decline and international trade will stagnate and thus hamper overall economic growth performance in all Western European countries. A summary of the main effects of fragmentation is given in table 3.2

3.3. Model inputs

3.3.1. Economic growth

The above qualitative description of some possible effects of integration or fragmentation in Europe on economic growth is of course both brief and incomplete. It provides, however, some motivation for the economic growth rates shown in table 3.3. In the table, the average annual growth of GDP, production in Industries and Services, and Private consumption are shown. Together with information on energy prices and autonomous technical change described in the following subsections, this constitutes some of the key input into the SEEM model.

Table 3.2. Assumed influence of fragmentation on some key factors in Western Europe (EU+EFTA) compared with present situation

Fragmentation	GDP	Ind. production	Prod. cost	Competitive strength (EC)	Employment	Labour cost	Trade balance EC-World	Energy prices	Interest rate	Prosperity	Innovation	Environment
- Internal market	—	—	+	—	–	+	+	++	+	—	–	–
- Monetary	–	—	+	–	–	+	–	+	++	–	0	0
- Social	—	–	–	0	+	—	0	0	–	—	0	0
- Political	–	0	0	—	–	0	+	–	–	—	–	–

++ significant positive effect (higher). + small positive effect (higher). 0 no clear effect. – small negative effect (lower).
— significant negative effect (lower).

Table 3.3. Average annual growth in economic activity. 1991-2020. Per cent

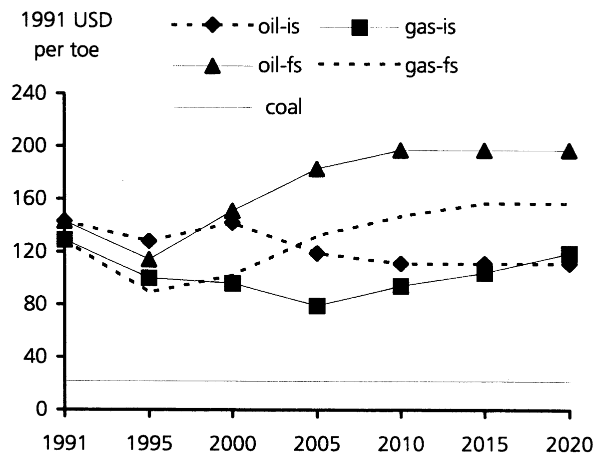
	GDP		Industry production		Services production		Private consumption	
	IS	FS	IS	FS	IS	FS	IS	FS
Austria	2.4	2.1	2.4	2.1	2.5	2.2	2.5	2.0
Belgium	2.3	1.9	2.3	1.9	2.4	2.0	2.4	1.8
Denmark	2.2	1.8	2.1	1.6	2.3	1.9	2.2	1.6
Finland	2.3	0.5	2.3	0.5	2.4	0.5	2.3	0.5
France	2.3	1.9	2.3	1.9	2.4	2.0	2.3	1.8
Germany	2.3	2.1	2.3	2.1	2.4	2.2	2.4	2.0
Italy	2.6	1.7	2.5	1.7	2.7	1.8	2.6	1.6
Netherlands	2.2	1.8	2.1	1.6	2.3	1.9	2.2	1.6
Norway	2.4	2.0	2.4	2.0	2.5	2.1	2.5	1.9
Spain	2.6	1.7	2.5	1.7	2.7	1.8	2.6	1.6
Sweden	2.3	1.6	2.3	1.6	2.4	1.5	2.4	1.4
Switzerland	2.3	2.1	2.3	2.1	2.4	2.2	2.4	2.0
United Kingdom	2.2	1.0	2.1	1.1	2.3	1.0	2.1	1.0
Average	2.3	1.7	2.3	1.7	2.4	1.8	2.4	1.6

3.3.2. Energy prices

In the integration scenario we assume that a successful economic transition in Russia will take place and that this will keep oil and gas prices low. Together with the structural developments in Western Europe this will lead to decreasing gas prices. At about 2005 the gas price is expected to be uncoupled from the oil price. However in the fragmentation scenario, we assume a monotonic, but modest, increase in oil and gas prices, due to lack of new investments and thus exports from Russia. After about 2015 the resulting gas prices reach values above oil prices from the Middle East.

Figure 3.1 shows the development in oil and gas import prices according to the two scenarios. We assume that the coal import price for EU countries will remain stable at the present price level in both scenarios.

Figure 3.1. Fossil fuel import prices. Average over SEEM countries



3.3.3. Autonomous efficiency improvement

Our assumptions on autonomous efficiency improvement are rather conservative in both scenarios, due to relative low prices in the integration scenario and a lack of co-operation in the fragmentation scenario. In general, efficiency improvement in IS is expected to be larger than in FS, because of higher economic growth, thus inducing faster turnover and more competition. Furthermore, it is expected that industry is more efficiency oriented, thus more improvement can be realised here than in services or households.

In southern countries like Spain and Italy it is expected that the starting situation lags behind Western European averages. Therefore, in these countries annually realised efficiency improvements can be relatively higher, particularly in industry. Summarising, table 3.4 shows the country averages of the autonomous efficiency improvements adopted in the simulations.

Table 3.4. Annual change in autonomous technical efficiency. 1991-2020. Per cent

	Industry	Services	Households
IS	0.6	0.4	0.4
FS	0.3	0.2	0.2

4. Simulation results

4.1. Energy demand

In the presentation of the simulation results, we first concentrate on demand for the endogenously determined fossil fuels. Nuclear and renewable energy use are mostly exogeneously given in the two scenarios.

The development in fossil fuel consumption can be summarily explained by changes in:

- economic activity
- technological improvements
- fuel import prices
- fuel taxes

The relative impacts of these factors in going from the integration (IS) to the fragmentation (FS) scenario is shown in table 4.1.

Table 4.1. Impacts on energy consumption of various factors in going from IS to FS

	Oil	Gas	Coal	Total
Economic growth	–	–	–	–
Technology	+	+	+	+
Fuel import prices	—	–	+	—
Fuel tax harmonisation	+	–	0	0
Total	—	—	+	—

(+ indicates higher fuel demand in FS than in IS)

Since we have assumed a higher economic activity growth in IS than in FS (approximately 2.3 per cent per year vs. 1.7 per cent), this tends to lower the demand for all fuels in FS compared to IS. This is marked by "–" in the table. The technology assumptions work the opposite way. We have assumed higher (autonomous) energy savings and fuel efficiency improvements in the integration scenario (see table 3.4), implying that, at constant fuel prices, the energy intensity will become higher in FS, i.e. more fuel is used per output ("+" in the table). Roughly speaking, the activity effect and the technology effect tend to more or less offset each other when it comes to the overall effect on total fuel demand.

From figure 3.1 it is clear that the oil and gas prices are lower in the integration scenario than in the fragmentation scenario, resulting in lower oil and gas consumption in FS than in IS. The price differences are especially high for oil from 2005, so the effects have time to work out completely despite lag effects in the model. This results in a double "–" for the oil demand difference between FS and IS in the table. Although the coal import price stays constant in both scenarios, it is more favourable compared to oil and gas prices in the FS scenario. Thus, the fuel price effect is that coal demand is higher in FS than in IS.

The fourth major difference in input between the scenarios is the tax harmonisation implemented in the integration scenario. Due to extremely high taxes on natural gas used in households in some countries where gas consumption is high (Italy is the main example), removal of the harmonisation leads to reduced gas consumption at the aggregate level. The effect on oil is opposite (but weak), mainly because some of the large countries today have gasoline taxes slightly below the average of the four big countries. Overall, the effect of the tax harmonisation must be considered to be weak.

Summing up the separate effects, as shown by the bottom line of the table, the net effect of the different scenario inputs is that the demand for oil, gas and total energy demand, is higher in the IS scenario than in the FS scenario. Altered input assumptions could of course change these results. For instance, a higher rate of technology improvement in the integration scenario would reduce the gap between total fuel demand in IS and FS.

The figures 4.1 - 4.3 show the simulated time paths of aggregated demand for natural gas, oil and coal in the integration (IS) and fragmentation scenarios.

Figure 4.1. Demand for gas. Thousand tonnes oil equivalents (ktoe)

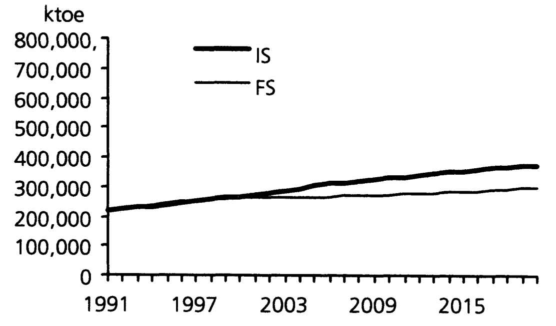


Figure 4.2. Demand for oil. Thousand tonnes oil equivalents (ktoe)

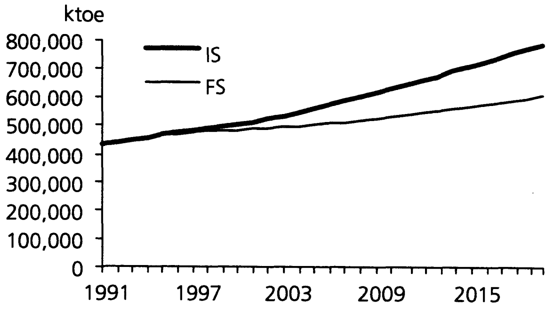
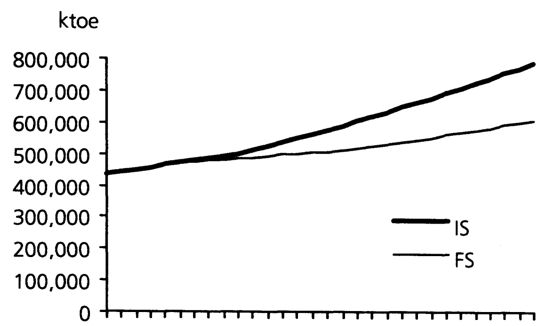


Figure 4.3. Demand for coal. Thousand tonnes oil equivalents (ktoe)



From the figures and table 4.2 below, we note that in the integration scenario oil demand is expected to show the fastest growth, closely followed by gas. Coal demand show only half the growth rate of the two other fossil fuels. In considering the effects of fragmentation, we note a reduction in the growth rate of oil and gas of almost 1 percentage point, while demand for coal actually increases slightly. The explanation for this is that under the adverse economic conditions in the fragmentation scenario and without a deregulation of the national coal industries, the coal price is competitive with the other fuels. Also, since electricity demand drops in the fragmentation scenario relative to the integration scenario, less investments are made in thermal power supply, postponing the introduction of gas fired power plants.

Table 4.2. Average annual growth in energy demand 1991-2020. Per cent

	Gas	Oil	Coal	Total
IS	1.9	2.1	1.0	1.8
FS	1.1	1.2	1.1	1.1

Total fossil fuel demand shows an average annual growth in the integration scenario of 1.8 per cent. In the fragmentation scenario the growth rate is 1.1 per cent. Thus, fossil fuel demand growth is lower than the economic growth in both scenarios, but energy use is reduced relatively more than economic activity in going from the integration to the fragmentation scenario. Table 4.3 shows the fossil energy demand by countries in the base year (1991) and annual average growth over the period 1991 - 2020 in the integration and fragmentation scenarios.

We note that the demand for fossil fuels grows faster in the southern countries, Italy in particular, than in most of the other countries in the integration scenario. The south, together with Finland, are also hardest hit (i.e. show the largest reductions in energy use) by fragmentation.

Germany, Italy, United Kingdom, the Netherlands and France are the main countries with respect to demand for gas. Their shares of demand in 1991 range from 23 per cent for Germany down to 12 per cent for France. Oil demand is also dominated by the four large countries (demand shares varying from 24 per cent for Germany to 15 per cent for United Kingdom), while coal demand is dominated by two countries only; Germany with a demand share of 42 per cent in 1991 and United Kingdom with a share of 24 per cent.

In the integration scenario Italy and France show growth in demand for gas above the average growth rate, while Germany, United Kingdom and the Netherlands have growth rates well below the average. The same pattern is also found in the fragmentation scenario, but here the spread between the highest and lowest growth rates is much narrower.

With respect to oil, we find in the integration scenario that demand in Italy again is expected to be well above the average at 2.1 per cent per year, while Germany and United Kindom have growth rates well below the average. Turning to the fragmentation scenario, we find that oil demand in Germany and France are just sligthly reduced, giving them growth rates above the

Table 4.3. Fossil fuel demand in 1991 (ktoe) and average annual growth rates 1991-2020

	1991 (ktoe)			Annual average growth 1991-2020 IS (Per cent)			Annual average growth 1991-2020 FS (Per cent)		
Country[a)]	Gas	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal
AU	5,096	9,545	4,299	2.1	2.1	1.6	1.6	1.8	1.8
BE	8,430	15,188	9,584	1.4	0.7	1.0	0.8	0.6	1.2
BR	49,959	104,365	112,695	1.4	1.4	0.9	1.0	1.3	1.1
CH	2,038	12,628	722	1.5	1.7	1.0	1.4	1.6	1.2
DK	1,512	7,340	7,687	1.0	1.8	1.5	0.4	0.9	1.0
FR	26,396	68,025	19,286	2.1	1.9	1.7	1.6	1.4	1.7
GB	41,615	65,458	64,834	1.4	1.3	0.8	0.4	0.2	0.7
IT	47,352	73,505	14,654	2.7	3.5	1.5	1.5	1.5	1.9
NL	30,248	12,433	8,370	1.6	1.4	0.7	1.1	0.9	1.0
NO	-	8,060	854	.	1.8	1.3	.	1.3	1.5
SF	2,352	8,600	5,983	1.4	0.9	1.1	-0.2	-0.1	0.2
SP	4,833	37,456	19,144	1.2	2.9	1.2	0.6	1.4	0.8
SW	507	10,962	2,745	1.2	2.5	2.1	0.6	1.0	0.9
Total	220,338	433,566	270,856	1.9	2.1	1.0	1.1	1.2	1.1

a) Country codes are explained in table 2.1.

average level, now at 1.2 per cent annually. Although oil demand in Italy is reduced considerably from the integration scenario, the growth in demand here is still above the average level. Demand for oil in United Kingdom is reduced to a very small growth rate of only 0.2 per cent per year on average.

The growth in total demand for coal is dominated by the development in Germany and UK, which both show growth of almost 1 per cent per year in the integration scenario. In going to the fragmentation scenario, the growth rate in Germany increases slightly due to slower replacement of older power plants, while the growth is marginally reduced in UK.

Table 4.4 shows the fossil fuel shares in 1991 and 2020 in the integration and fragmentation scenarios. We note that the share of gas in total fossil fuel demand is almost constant at ¼ both in 1991 and in 2020 (both scenarios). Oil increases its share from somewhat below ½ to somewhat above ½ from 1991 to 2020 in the integration scenario. Coal reduces its share correspondingly from almost $^1/_3$ to almost ¼. In the fragmentation scenario the shares in year 2020 are equal to the shares prevalent in 1991.

Table 4.4. Fuel shares in total demand for fossil fuels in 1991and 2020. Per cent

	Gas	Oil	Coal
1991	24	47	29
IS-2020	25	51	24
FS-2020	24	47	29

The sectoral demand for fossil fuels shown in table 4.5 indicates that the growth rates are more equal across sectors than across fuel types or countries, cf. table 4.3. However, with an annual average growth rate in total demand of approximately 2 per cent, we find that energy use for transportation and household demand for fossil fuels in the integration scenario grow some-

Table 4.5. Demand for fossil fuels by sector in 1991 (ktoe) and average annual growth in the integration and fragmentation scenarios over the period 1991-2020

	1991 (ktoe)			Annual average growth 1991-2020 IS (per cent)			Annual average growth 1991-2020 FS (per cent)		
Sector[a)]	Gas	Oil	Coal	Gas	Oil	Coal	Gas	Oil	Coal
EL	35,938	46,980	197,153	1.6	3.2	0.9	1.2	1.0	1.0
HO	84,435	56,091	14,236	2.2	1.6	1.7	1.2	0.8	1.1
IN	69,307	49,363	55,539	1.4	2.0	1.2	0.6	0.0	1.1
SE	26,769	40,093	3,928	1.9	1.2	3.0	1.6	1.3	2.5
ST	216,449	192,527	270,856	1.8	2.1	1.0	1.1	0.8	1.1
FC	180,511	145,546	73,703	1.9	1.9	1.4	1.1	1.2	1.2
MO	3,889	241,040	-	2.3	2.1		1.2	1.4	
Total	220,338	433,567	270,856	1.9	2.1	1.0	1.1	1.2	1.1

a) Sector codes are explained in table 2.1.

what faster than demand from the other sectors. In comparison, industry shows a growth rate of 1.5 per cent. In the fragmentation scenario we note that demand from the service sector remains relatively unaffected by the scenario assumptions, and displays only a slight decrease relative to the integration scenario.

The difference in oil demand between IS and FS is largest in the electricity generation sector. This is mainly explained by the low taxes in the integration scenario, and thus heavily decreasing prices in the electricity sector. Furthermore, especially in the UK and Italy, a major difference between activity growth is assumed, resulting in a large demand for electricity in IS.

The gap in oil demand in the industry sector between IS and FS is also rather large. This can be explained by low tax rates combined with relatively high elasticities.

For sectoral gas demand the services sector shows only a small difference between IS and FS. This is due to high taxes which dampen the differences in gas import prices between the two scenarios. In the household sector the tax rates are also relatively high. However, reaction on energy demand is much larger, because income elasticities in that sector are much greater than in the service sector.

The sectoral demand for coal is dominated by the electricity generating sector. In contrast to the other fuels, demand for coal is slightly increased in going from the integration to the fragmentation scenario. As mentioned before, this is mainly due to a slower replacement of old coal fired power plants in the fragmentation scenario.

4.2. Emissions to air

4.2.1. Emission of CO_2

Emissions of CO_2 are determined by the carbon content of each fuel. The emission factors employed in this study are as follows: Gaseous fuels: 2.4, liquid fuels: 3.1 and solid fuels: 3.9, all measured in (metric) tonnes of CO_2 per tonnes oil equivalents (t.o.e.). Figures 4.4 - 4.6 show emission levels in 1991 and in year 2020 in the two scenarios from groups of countries[6], by fuel types and by sectors. Average annual growth in CO_2 emissions are 1.7 per cent in the integration scenario and 1.1 per cent in the fragmentation scenario. Total CO_2 emissions grow somewhat slower than total demand for fossil fuels, since both oil and gas (with relatively low emission coefficients) grow faster than demand for coal (with a relatively high emission coefficient). In the integration scenario Germany reduces its share of emissions, while Italy increases its share. In the fragmentation scenario the 1991-shares are more or less restored in 2020, expect for United Kingdom which reduces its share from 19 per cent to 16 per cent in both scenarios.

With respect to type of fuel, we find that the share of oil related emissions, and to a much smaller extend the gas related emissions, increase in the integration scenario, while the base year shares are restored in the fragmentation scenario in 2020.

Electricity generation and transport are the dominating sectors with respect to CO_2 emissions. Since transport activities are assumed to grow relatively fast in both scenarios, its share increases from 26 per cent in 1991 to 29 per cent in year 2020 in the integration scenario and 28 per cent in the fragmentation scenario. Electricity generation reduces its share from 34 per cent in 1991 to 31 and 33 per cent in year 2020 in the IS and FS scenarios, respectively.

Figure 4.4. Emissions of CO_2 by group of countries

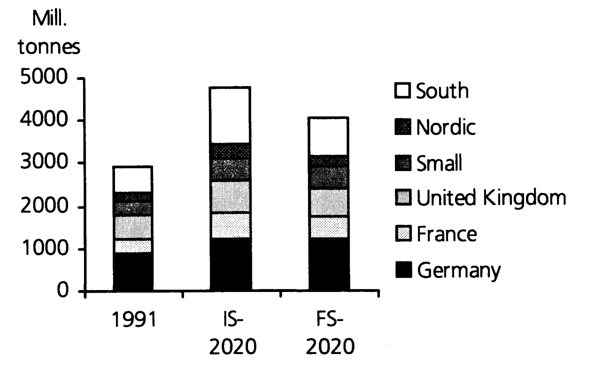
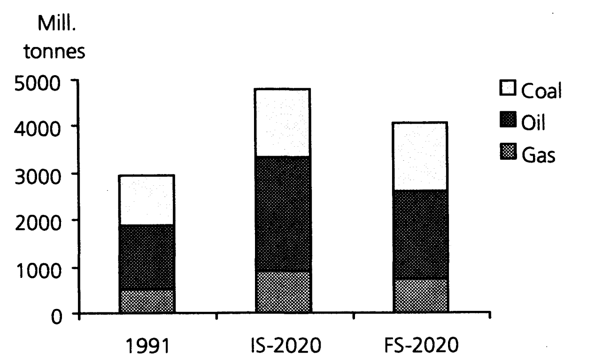


Figure 4.5. Emissions of CO_2 by type of fuels



[6] The country aggregates are defined by the following labels: Austria, Switzerland, Belgium and the Netherlands are the «Small» countries. The «South» countries consist of Italy and Spain, while the «Nordic» countries are Denmark, Finland, Sweden and Norway.

Figure 4.6. Emissions of CO_2 by sectors

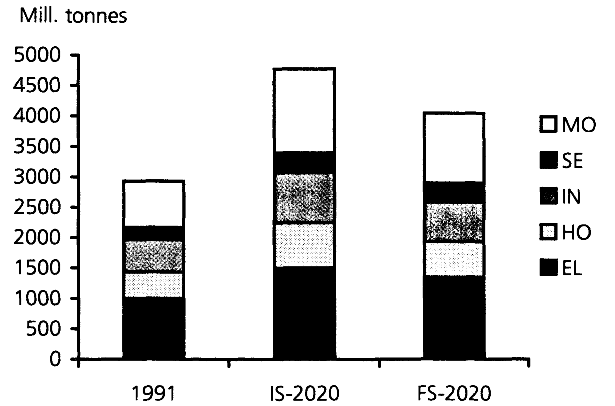
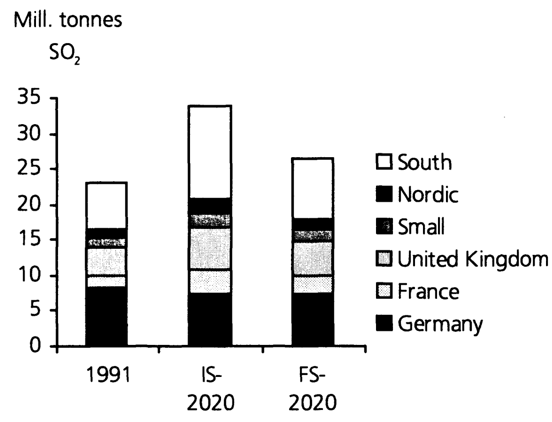


Figure 4.7. SO_2 emissions in 1991 and 2020 by country groups



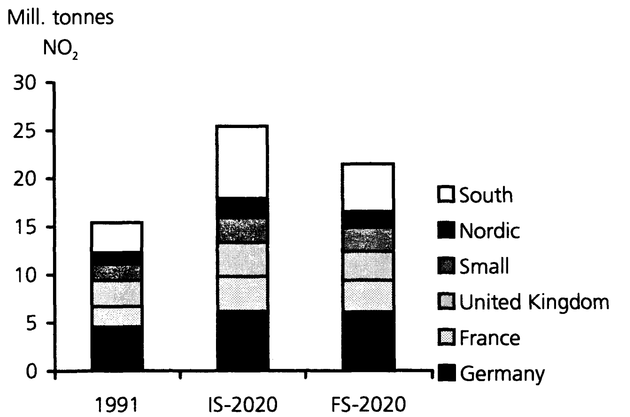
4.2.2. Emissions of SO_2 and NO_x

Unlike CO_2 emissions, the emission of SO_2 and NO_x depends on how the fossil fuels are burned (combustion technology) as well as the amount of cleaning of exhaust gases that takes place. These emissions will therefore not necessarily follow the pattern of fossil fuel demand. Also, in the case of sulphur emissions, these are dominated by the demand for coal which is more sulphurous than the other fossil fuels.

As mentioned above, we calculate the emissions of SO_2 an NO_x by inserting energy trajectories from the SEEM model into IIASA's RAINS model (Alcamo et al. 1990, Kolsrud, 1996). The simulated SEEM figures are suitably transformed to take into account differences in definitions of sectors and fuels between the two models. Utilising the technology assumptions incorporated in the Official Energy Pathway (OEP) scenario of RAINS, we can then calculate SO_2 and NO_x emissions and also use the atmospheric transport module to find the deposition pattern associated with our energy scenarios[7].

Total SO_2 emissions are growing at an annual average rate of 1.3 per cent in the integration scenario versus only 0.5 per cent in the fragmentation scenario, see figure 4.7. These comparatively low growth rates are due to the fact that SO_2 emissions from Germany are declining in both scenarios. This is explained by the forecasted large reduction in coal used in the eastern part of the country. The other big contributer to SO_2 emissions is the southern block, i.e. Italy and Spain.

Figure 4.8 NO_x emissions in 1991 and 2020 by country groups



High economic growth rates in the integration scenario lead to high emissions. In 2020 their combined emission share is almost 40 per cent, up from 28 per cent in the base year 1991. Even in the fragmentation scenario, where their economic growth is closer to the average growth of all countries, Italy and Spain increase their share of SO_2 emissions from 28 per cent to 32 per cent.

Total NO_x emissions grow more in line with total energy demand, see figure 4.8. While SO_2 emissions were determined by the use of coal and oil primarily in the power producing sector, transport oil use is an important determinant for the NO_x emissions. The southern countries also in this case increase their shares of emissions from 20 per cent in 1991 to 30 per cent in 2020 in the integration scenario and more modestly to 23 per cent in the fragmentation scenario.

Further information on the SO_2 and NO_x emissions are given in the tables 4.6 and 4.7. Both oil and coal use contribute significantly to the SO_2 emissions. The coal use is not much affected by neither integration nor

[7] As explained in Alfsen et al. (1995) and Kolsrud (1996), SEEM does not provide values for all the energy variables entering the RAINS model. In addition, the Official Energy Pathway scenario of the RAINS model, that provides the technology parameters relevant to the SO_2 and NO_x emission calculations, has a time horizon to year 2000. After this time, we have kept the technology parameters constant in our simulations. This allows us to study the partial effects of changing energy consumption pattern, and to interpret the results in purely economic terms. Furthermore, the energy variables not provided by SEEM are forecasted using total demand for solid, liquid and gaseous fossil fuels simulated by SEEM as relevant indicators.

fragmentation, and coal emissions grow in both scenarios at a modest average rate close to 0.1 per cent per year. Oil contributes more to SO_2 and NO_x emissions in the future than in 1991 in both scenarios, but most prominently in the integration scenario. From table 4.7 we note that most of the SO_2 emissions are coming from the power producing sector, and that this is the case also in the future in both scenarios although other sectors' contribution are likely to grow somewhat.

Table 4.6. Shares om emissions in 1991 and average annual growth rates from 1991 to 2020 in the integration (IS) and the fragmentation (FS) scenarios by fuel type. Per cent

	SO_2 emissions	Average annual growth 1991-2020		NO_x emissions	Average annual growth 1991-2020	
	Shares 1991	IS	FS	Shares 1991	IS	FS
Gas	-	-	-	5	1.7	1.0
Oil	36	2.9	1.0	71	2.2	1.4
Coal	61	0.1	0.2	20	0.7	0.8
Other[a]	4	0.2	0.0	3	-0.1	-0.1
Total	100	1.3	0.5	100	1.7	1.2

[a] Other includes emissions from non-combustion processes and from use of alternative technologies.

The use of oil is the most prominent cause of NO_x emissions in the SEEM countries, in particular for transport purposes. The dominant role of transport is likely to increase in the future.

Table 4.7 Shares om emissions in 1991 and average annual growth rates from 1991 to 2020 in the integration (IS) and the fragmentation (FS) scenarios by RAINS' sectors. Per cent

	SO_2 emissions.	Average annual growth 1991-2020		NO_x emissions.	Average annual growth 1991-2020	
	Shares 1991	IS	FS	Shares 1991	IS	FS
Conversion	8	2.9	1.2	2	2.3	1.2
Power prod.	68	1.0	0.4	21	1.1	0.7
Domestic	10	1.4	0.4	5	1.8	1.1
Traffic	3	2.6	1.6	65	2.1	1.5
Industry	11	1.7	0.3	6	1.5	0.7
Total	100	1.3	0.5	100	1.7	1.2

4.2.3. Deposition of SO_2 and NO_x-

Deposition of sulphur and oxidised nitrogen is calculated using the above emission figures and the transport matrices for 1991, as given by Sandnes (1993). The SEEM countries only constitute a subset of the countries covered by RAINS and the transport matrices. Here we only consider the contribution to depositions in the SEEM countries coming from the SEEM countries. Table 4.8 shows the average annual growth rates. The figures 4.9 and 4.10 show the deposition of oxidised sulphur and nitrogen in groups of SEEM countries coming from these same groups in 1991 and in 2020.

Table 4.8. Average annual growth rates in deposition of oxidised sulphur and nitrogen. 1991-2020. Per cent

	SO_2	NO_x
IS	1.4	1.8
FS	0.5	1.2

Figure 4.9 Sulphur deposition in 1991 and 2020

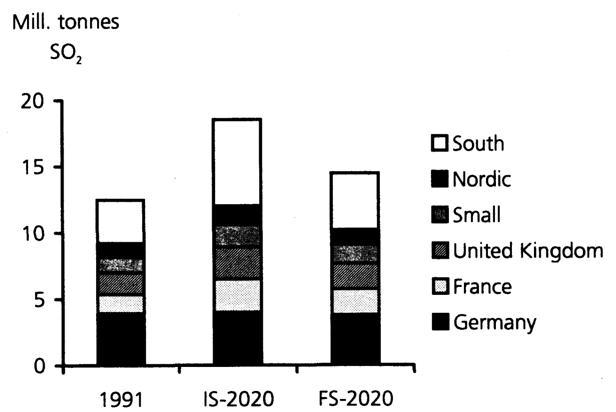


Figure 4.10 Nitrogen deposition in 1991 and 2020

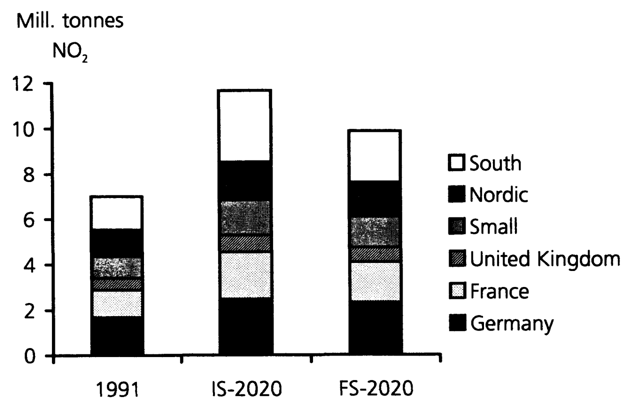


Table 4.9 show how the ratio between depositions and emissions develop from 1991 to 2020 in the two scenarios.

Table 4.9 The ratio between deposition and emission of oxidised sulphur and nitrogen in the integration (IS) and fragmentation (FS) scenario by country groups

	SO_2			NO_2		
	1991	IS-2020	FS-2020	1991	IS-2020	FS-2020
Germany	0.48	0.54	0.51	0.37	0.40	0.38
France	0.87	0.77	0.76	0.58	0.57	0.54
United Kingdom	0.40	0.39	0.40	0.19	0.21	0.21
Small	0.86	0.83	0.77	0.57	0.60	0.55
Nordic	0.84	0.74	0.81	0.95	0.86	0.93
South	0.52	0.50	0.51	0.47	0.42	0.46
Total	0.54	0.55	0.55	0.45	0.46	0.46

Overall, we find the ratios of deposition to emission to be larger for sulphur than for nitrogen with relatively more of the sulphur emissions being deposited in the SEEM countries. France, the small countries in central Europe and the Nordic countries receive more than 80 per cent of the amounts they emit. At the opposite end of the scale we find that United Kingdom, Germany and the southern countries of Italy and Spain receive about half or less of what they emit. With regards to nitrogen, the Nordic countries receive the most relative to their own emissions, while United Kingdom is the largest contributor to depositions in other SEEM countries.

In the integration scenario we find that Germany receives relatively more SO_2 compared to its emissions, while the opposite is the case for France and the Nordic countries. Only small changes in the deposition/-emission ratios are experienced by the other country groups. With respect to nitrogen, the most prominent changes over time in the integration scenario are the reductions in relative depositions in both southern and Nordic countries.

Going from the integration to the fragmentation scenario, we find a decline in the relative deposition of both sulphur and nitrogen in the small country group, while the relative deposition increases in the Nordic group.

5. Conclusion

Several models in the literature have analysed energy scenarios for Western Europe, e.g. Global 2100 (Manne and Richels, 1992), GREEN (Burniaux *et al.*, 1992) and ECON-ENERGY (Haugland *et al.*, 1992). However, in these models Western Europe is treated as one block. In contrast, the SEEM model is more detailed, since it models energy demand and emissions to air from each of the countries covered. The SEEM model is also unique in that it allows for a linkage to the RAINS modelling system.

The SEEM simulations in this paper have been based on two exogenously given economic growth scenarios with the following main features:

- The economy shows only modest growth in the integration scenario, strongest in the southern part of Europe. The growth rate is even lower in the fragmentation scenario. The southern countries experience the largest reduction in economic growth, while the growth in Germany is almost unaffected in going from the integration to the fragmentation scenario.

With respect to the issues addressed in this paper, i.e. the effect of integration or fragmentation in Europe on future energy demand, emissions to air and deposition of acid compounds, the simulations indicate that:

- Overall the demand for fossil fuels grows at an average annual rate of 1.8 per cent in the integration scenario and 1.1 per cent in the fragmentation scenario. Average annual growth in demand for oil and gas in the integration scenario is around 2 per cent per year, while demand for coal grows at a rate close to 1 per cent per year. In the fragmentation scenario the demand for coal is slightly higher, while the average annual growth in demand for oil and gas is reduced to approximately 1 per cent.

- Growth in CO_2 emissions follows the growth in overall demand for fossil fuels. The power generating sector and transport are the two most contributors to CO_2 emissions, each with an emission share of around 30 per cent.

- SO_2 emissions are dominated by oil and coal use in the power generating sector. Italy, United Kingdom and Germany are the largest contributers. The average annual growth in total SO_2 emissions in the integration and the fragmentation scenarios are 1.3 and 0.5 per cent, respectively. The stronger growth in the integration scenario is due to higher demand for oil.

- NO_x emissions are more evenly distributed among the countries, and is strongly dominated by emissions from transportation. This is also the sector with the strongest economic growth. Overall we find that the average annual growth in NO_x emissions are close to the growth in demand for fossil fuels and CO_2 emissions, i.e. 1.7 and 1.2 per cent in the integration and the fragmentation scenario, respectively.

- With regard to depositions of SO_2 and NO_x, they follow the emission pattern quite closely, with slow or no growth in sulphur deposition in Germany and relatively high growth in the southern countries. Growth in nitrogen depositions are more evenly distributed among the countries.

With respect to further work, we would like to point out the following. The data used for estimating and calibrating elasticities and other parameters in the model can always be improved. Furthermore, the model's treatment of energy trade is simplistic. Finally, being a partial energy model, SEEM lacks explicit modelling of the linkages to economic growth. Further work in all of these areas could improve the ability of the model apparatus to address the many future challenges facing EU and neighbouring countries in Europe in the years ahead.

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Appendix: Country tables

Table A.1 Emissions of SO_2, NO_x and CO_2. Level in 1991 and per cent average annual growth 1991-2020 in the integration (IS) and fragmentation (FS) scenarios

Emissions	kt SO_2	Average annual growth 1991-2020		kt NO_2	Average annual growth 1991-2020		Mt CO_2	Average annual growth 1991-2020	
	1991	IS	FS	1991	IS	FS	1991	IS	FS
Austria	348	2.0	1.8	332	2.1	2.0	59	2.0	1.8
Belgium	538	1.0	0.6	480	1.0	1.0	105	1.0	0.9
Denmark	334	1.7	0.8	284	1.6	1.0	56	1.6	0.9
Finland	506	1.1	0.3	312	1.0	0.1	56	1.0	0.0
France	1,641	2.4	1.5	2,089	1.9	1.6	349	1.9	1.5
Germany	8,225	-0.4	-0.4	4,579	1.0	1.0	883	1.2	1.1
Italy	3,761	3.4	1.6	1,737	3.2	1.7	399	3.1	1.6
Netherlands	393	1.5	0.9	639	1.3	1.0	144	1.3	1.0
Norway	90	0.6	0.4	287	2.1	1.9	28	1.7	1.3
Spain	2,563	0.7	-0.2	1,359	2.9	1.5	202	2.2	1.1
Sweden	311	2.1	0.3	325	2.0	1.1	46	2.4	1.0
Switzerland	79	1.2	1.1	242	1.8	1.8	47	1.6	1.6
United Kingdom	4,132	1.3	0.6	2,728	0.9	0.3	556	1.1	0.5
Total	22,921	1.3	0.5	15,393	1.7	1.2	2,929	1.7	1.1

Table A.2 Deposition of SO_2 and NO_x. Thousand tonnes in 1991 and per cent average annual growth 1991-2020 in the integration (IS) and fragmentation (FS) scenarios

Deposition	kt SO_2	Average annual growth 1991-2020		kt NO_2	Average annual growth 1991-2020	
	1991	IS	FS	1991	IS	FS
Austria	502	1.6	1.0	414	1.9	1.4
Belgium	279	1.2	0.8	140	1.4	1.1
Denmark	151	1.0	0.5	100	1.2	0.9
Finland	319	1.0	0.2	245	1.3	0.8
France	1,482	1.9	1.1	1,230	1.9	1.4
Germany	6,463	0.8	0.7	1,677	1.4	1.2
Italy	1,876	3.2	1.4	844	2.6	1.6
Netherlands	321	1.2	0.8	181	1.3	1.0
Norway	230	0.9	0.4	337	1.3	1.0
Spain	1,378	0.8	-0.1	696	2.7	1.5
Sweden	380	1.2	0.3	458	1.4	1.0
Switzerland	268	2.1	1.1	231	2.0	1.5
United Kingdom	1,639	1.3	0.6	526	1.1	0.7
Sum	15,286	1.4	0.8	7,078	1.8	1.2

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