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Carbon/energy taxes and the energy market in Western Europe

by

*Hugo Birkelund, Eystein Gjelsvik and Morten Aaserud**

Research Department
Natural Resources Division

ABSTRACT

The paper analyzes carbon taxes as proposed by the EC in a multisector energy demand model of nine West-European countries. The simulations show that the taxes are insufficient to stabilize CO_2 emissons. Furthermore the taxes have to rise along with the growth in fossil fuel demand. Inter fuel substitution is hampered by distortion of fuel prices by taxation at the outset (in the reference path) and by other priorities, particularly those imposed on the power generation sector. Thus, efficient carbon taxation superimposed on the existing price structure requires adjustments of interference in energy markets distorting prices and investments.

* *We are grateful to the Norwegian state oil company Statoil, who initiated and financed the development of the model presented in this paper*

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1. Introduction

The European Community, EC, works for the time being on a plan to stabilise CO_2 emissions throughout the EC by year 2000 on the basis of the 1990 levels. A significant part of the package consists of a carbon/ energy tax to be implemented from 1993 on. This paper analyses the impacts of the EC tax proposal in the Western European energy markets using a multisector demand model.

For Norway, there are two aspects of the carbon emissions abatement strategies that are of particular national interest. *First,* both government and parliament has set out ambitious targets for carbon emission abatement, and urged for international cooperation such that abatement efforts become globally efficient. The ambitions have been followed up in practical policy, by introducing national carbon taxes from 1990, that by 1992 has reached a level above the proposed EC carbon tax[1]. Thus far from being free riders, Norway has together with some other Nordic and European countries started practical measures in order to stop the historical growth in CO_2 emissions.

The *second* important aspect for Norway is connected to our country's role as a gas and oil exporter. The petroleum industry is by far the most important economic sector in Norway, earning 10 - 15 per cent of national income, of which around 40 per cent are pure rents. If carbon abatement becomes international policy (which is a national political goal), Norway is certain to loose oil export income. But as a gas exporter to the European markets, the net impact is ambiguous, as gas is the least of the "bad" fossil fuels. Gas should take market shares from coal and oil in the inter fuel markets, and the substitution effect may dominate the negative impact on fossil energy demand.

Alfsen et al (1989) studied the substitution potential in a "what if substitution of gas for oil and coal were fully exploited" setup in the European markets. They found that gas consumption would increase and that emissions would be reduced by 28 per cent in 1985. In order to analyze the economic viable substitution, an inter fuel substitution model is needed. Thus, the Central Bureau of Statistics (CBS) has developed a model of this type for nine West European countries, including the four major energy consumers Germany (West)[2], France, Italy and UK, the Netherlands as a major gas country, and the four major Nordic countries.

These countries are chosen for a number of reasons. First, these countries together take between 80 and 90 per cent of Norway's oil and gas exports as of 1991. Second, these countries consumed about 80 per cent of the OECD Europe total energy use

[1] See section 4.1.2

[2] We wanted to rely on knowledge of the markets, and have excluded the eastern part of Germany, as our model cannot easily describe an economy in transition

in 1989. Furthermore, a main share of long distance air pollution in Norway stems from the model region.

The outline of this paper contains of a brief model description, the construction of a reference path for energy demand, and an analysis of the implementation of the proposed EC carbon tax scheme. Our results indicate that for Norway, as a gas and oil exporter and an eager proponent for sustainable development, there is no double gain from the EC tax. On the contrary, Norway stands to loose as a petroleum exporter, while the tax is inefficient with respect to carbon abatement. The main reasons for this are:

1. the tax is too low compared to existing fuel price levels to make fuel prices rise sufficiently.
2. the tax is superimposed on an existing price and tax structure that disfavours substitution of gas for coal.
3. the energy demand structure in Europe does not allow much substitution as oil dominate in the transport sectors where the price impact is small.
4. since the electricity generation industries are subject to national planning and goals that include other aims besides cost efficiency, there is a limited potential for gas penetration in the power sector.

However, it should be emphasized that the design of the tax can be adjusted to reduce the impact of the first factor above, thus improving the carbon abatement efficiency. Second, the electricity generation sector can be more cost efficiently governed, thus reducing factor 4, and improving both carbon abatement and gas penetration. But unless one is willing to adopt drastic and costly measures in the transportation sector, there is not much to do to eliminate factor 3.

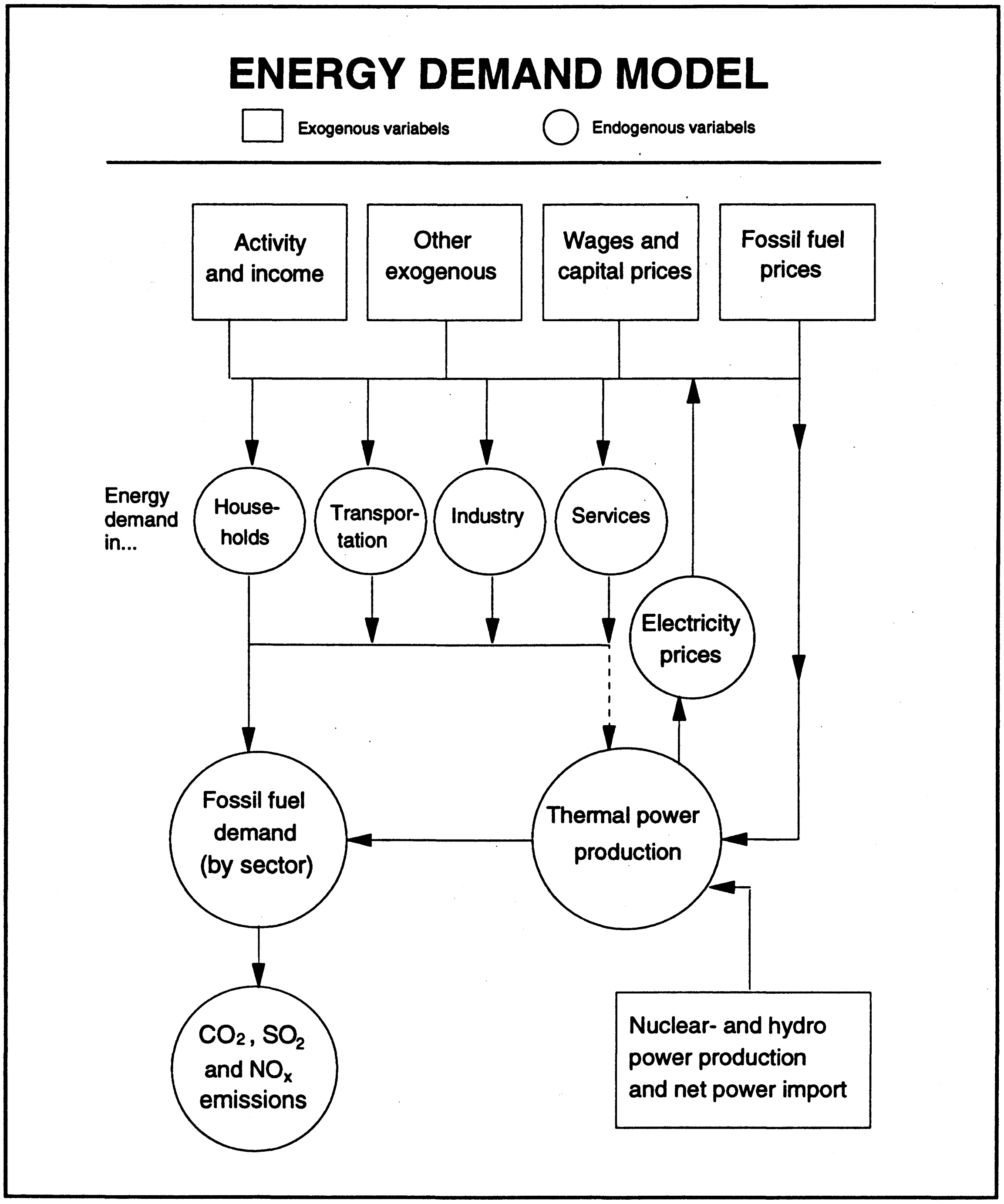
2. The model

2.1 Main features

Each country is treated as a separate block in a pure demand model, i.e. we are not concerned about the supply of primary energy. There are six sectors included, comprising the energy end use sectors: manufacturing industries and service industries (in the following Industry and Services), Household, Transportation and Other (agriculture, fisheries etc.) as well as the Power production sector. The electricity generation sector supplies electricity as price takers using a markup mechanism. Thus prices and quantities of electricity are endogenous.

Figure 2.1 depicts the structure of each country model. The squared boxes marks exogenous input.

Figure 2.1 Model structure



In the first step the model determines the demand for solids, oil, natural gas and electricity in the end user sectors. The electricity generation sector then derives the need for domestic production of thermal power, given a set of plans for power production by renewable and nuclear sources. Based on costs in thermal power production the model calculates electricity prices in all sectors, based on the supply functions. The model is thus simultaneous in the electricity market, where the equilibrium set of prices is defined when supply equals demand for electricity. Adding the end use of fossil fuels in industry, households, services and transportation to fossil fuel inputs in thermal power production, total demand for fossil fuel is derived by country.

In a sub model emission coefficients for CO_2 are linked to the consumption of solids, oil and natural gas in all sectors in order to calculate the CO_2 emissions.

2.2 Brief outline of the sector models

This presentation is restricted to a brief outline. A full documentation is given in Birkelund et al (1993). Table 2.1 indicates how each sector is modelled.

Table 2.1 Sector models

Sector	Model type/ Functions	Method	Source
Industry......................................	Fuel Share Cobb Douglas	Calibrated	CBS
Households.................................	Discrete Cont. Choice - Dynamic	Estimated/ Calibrated	CBS/Lawrence Berkeley Lab.
Transport.................................... (7 sectors)	Structural and reduced form	Calibrated	CBS/Oxford Inst. Energy Economics/a.o.
Services.......................................	Fuel Share - CES	Estimated/ Calibrated	CBS
Power...	Fuel Share Cobb Douglas	Calibrated/ Simulated	CBS/IEA
Other..	Exogenous	-	CBS/IEA

Tabel 2.1 indicates model specifications, data source and method (estimated or calibrated) by sector. Choice of model specification and method of parameter estimation was beased on the folowing guidelines:

1. Use a simple well established theory (fuel share)
2. Data friendly and user friendly functional forms (CES, Cobb Douglas)
3. Utilisation of international literature and previous estimation in our own institution (CBS) in order to calibrate parameters.

One reason why we decided on calibration as a main method is that our own and international experiences indicate that estimations of important parameters seem to vary significantly among different model specifications and data sources. Often, models that fit data best do not satisfy important theoretical presumptions, such as concavity of cost functions and symmetry, This might imply wrong signs of elasticities. We have chosen to rely on rasonable assumptins from theroy, thus ensuring reasonable simulation properties. The other side of the coin is that we do not use models that fit history best.

A number of industries are lumped into one **industry** sector[3]. We have chosen a simple fuel share model with two levels specified as Cobb Douglas. The lower level determines the cost minimizing combination of the energy aggregate, and the upper level determins the costminimizing combination of the capital, labor and energy aggregate. On the lowest level we calibrated using fuel consumption cost shares. On the upper level we calibrated using elasticities found in other studies[4]. Hicks neutral technical progress is specified on the upper level. To allow for lags in the adjustment of capital to price changes, demand is lagged according to a partial adjustment hypothesis.

For **service industries** we have estimated a fuel share model similar to that of the industry sector. We postulate a CES function with weak separability between at least two levels. However, we allow for a nested model in *three* levels for countries with substantial use of all four energy carriers. The case of Germany (West) illustrate the structure, see figure 2.2. On the upper level, electricity and the aggregate of oil, gas and solids are separate inputs, i.e. the full energy aggregate is neither separable nor homothetic. 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 on the upper level are loglinear, with calibrated parameters. On the intermediate level, the fossil fuel aggregate is produced by an aggregate of oil and gas, and of solids separately. The production function is specified as Constant Elasticity of Scale (CES). On the lower level the oil and gas aggregate is produced by the two fuels oil and gas in a CES technology. The intermediate and lower level parameters are estimated.

Household demand is modelled by Discrete Continuous Choice (DCC). The discrete part of the model corresponds to the choice of fuel used for space heating in both existing and new dwellings, while the continuous part determines the level of energy demand, given the system choice. Transitions among fuels make the model dynamic, and a specific parameter reflects the degree of "habit persistence" held by consumers. The set of independent variables includes both structural and economic components such as fuel prices and private consumption expenditures.

The model has been estimated on cross section data for 7 European countries in Bartlett et al (1987), where the model is outlined in detail. However, some

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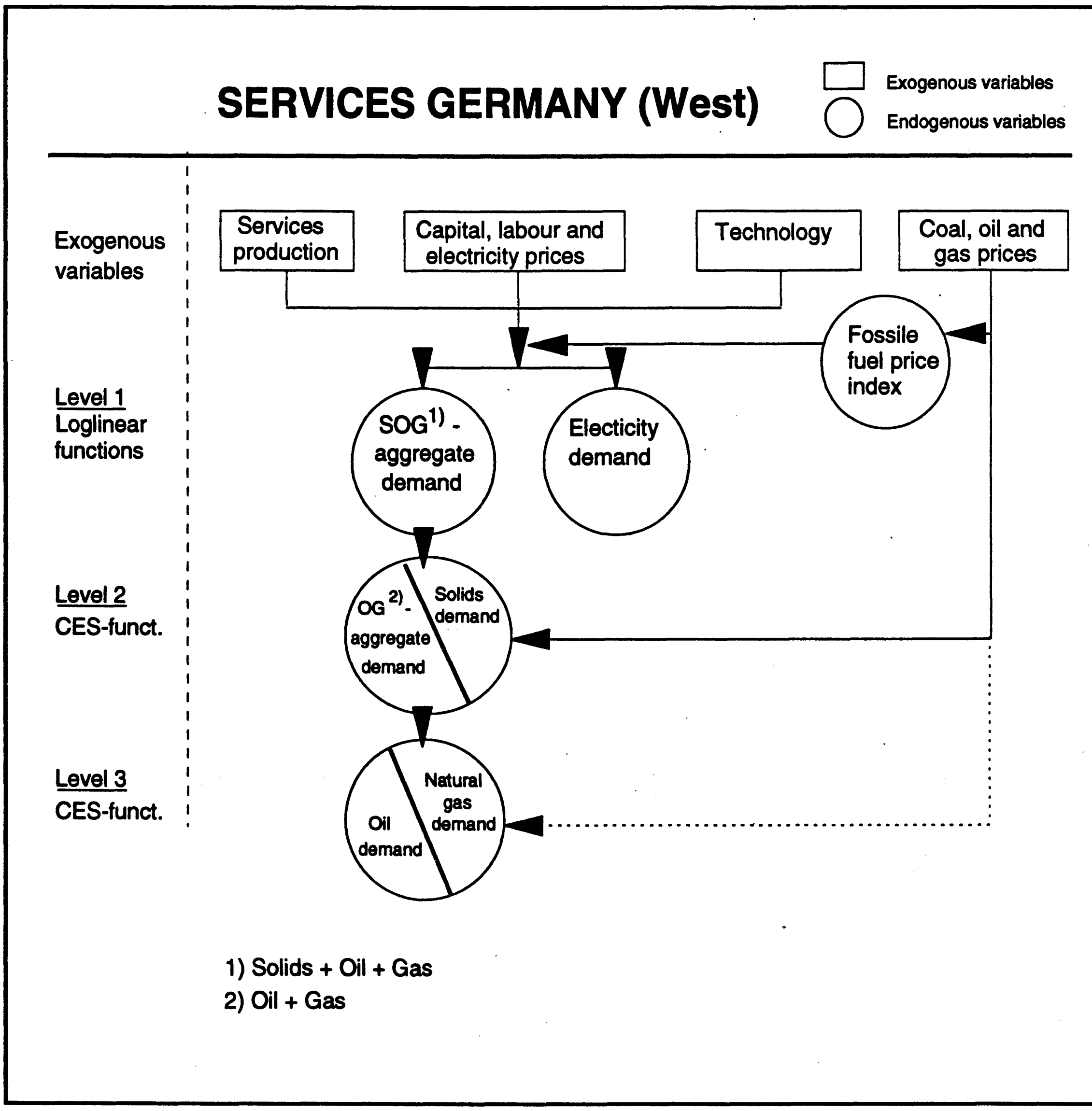
[3] Disaggregation into a number of sub sectors would be preferable, but neither our data nor time- and software constraints allow for sub division.

[4] See Birkelund (1990)

parameters in the implemented version have been calibrated, in order to bring the direct fuel price elasticities in line with those estimated in a study by Chern et al (1983). The household model for Norway is based on the Linear Expenditure System and estimated by Haug (1992).

Figure 2.2 Model structure. Services



The **transportation** sector is divided into four main groups; Road transportation, rail, domestic shipping (international shipping excluded), and aviation. This structure takes into account that energy use and emissions vary between the sectors, making each group fairly homogeneous for our purposes. The road transportation is split up in passenger and non-passenger transportation. Furthermore, the vehicles can be driven by gasoline or auto diesel.

Loglinear demand functions for each of the four road transportation segments are defined in the model. For each segment the amount of road transportation services demanded, T, is produced by suppliers in a two step cost minimizing procedure. First, the optimal combination of vehicles (capital) and average distance per vehicle (utilization) for a given T is found. In the second step, a cost minimizing combination of fuel and other variable inputs per vehicle is found. Autonomous technical change is allowed for in the relation for fuel use per vehicle.

The cost share parameters on the lower level are based on three surveys Dahl (1986), NOS (1980) and Eidhammer (1984) and are set equal for all countries. Using these estimates, the parameters on the upper level are given country specific values such that the total fuel price and income elasticities equal those estimated in Dargay (1990).

The demand for fuel in aviation and for electricity in rail transportation are specified as estimated loglinear functions, with GDP and fuel prices as arguments. The fuel consumption forecasts in rail transportation and internal navigation are exogenous to the model.

The **electricity generation** model focuses on the supply of thermal power. By adding end user demand for electricity to the exogenously forecasted net export and the calculated transfer and distribution losses, we derive total domestic power production requirements. Deducting the exogenously forecasted supply of hydro, nuclear and other power yields residual demand for thermal power, covered by either existing plants or new capacity. New capacity requirements is defined by the gap between the demand for thermal power and the remaining capacity from the previous period. In this model version, we assume no substitution possibilities in incumbent capacity, thus disregarding dual fuel systems. New capacity fossil fuel input shares are functions of relative marginal fuel costs.

The fuel shares are specified as Cobb Douglas functions. Parameter values are adjusted such that official plans for domestic power sectors, as reported in IEA (1988) are ensured.[5] This means that the reference path may differ significantly from a cost minimizing composition of fuel demand for the given set of fuel prices and capital costs. The reference path reflects the priorities of national energy policies as of 1988, which have probably changed by now. These priorities may mirror security of supply (an IEA favorite), protection of national industries (such as coal in Germany and nuclear in France), conflicting industry interests as well as cost considerations. The IEA (1988) projections imply a large expansion of coal combustion.

The **Norwegian power system** is based exclusively on hydro power. Consequently hydro power is endogenous and thermal power production from the different fossil fuels is subject to exogenous projections. The determination of hydro power production is based on long term marginal cost, *LTMC*, of expanding the hydro

[5] In general, the electricity demand forecasts made by the individual government are not equal to the reference scenario. Because of this the reference path diverges from the official plans reported in *IEA (1988)*.

power system described in Johnsen (1991). Electricity prices are calculated as a function of *LTMC,* taxes and residual markups.

For the other countries we have assumed that changes in the **electricity prices** are based on changes in the thermal power production costs. Furthermore we have assumed constant returns to scale, implying that electricity prices are determined by calculating the average costs based on fuel and capital inputs and prices in thermal power production, adding sector specific markups and taxes.

In the **emission sub-model** only the anthropogenic emissions of CO_2 from fossil fuels are calculated. We have not included the CO_2 emissions from biomass/wood combustion assuming that there is a zero net flux of CO_2 to the atmosphere from this activity in this part of the world because of sustainable yield. Emissions from industrial (non-combustion) processes has not been included. The emission factors in terms of millions metric tons (mt) CO_2/mtoe energy input are 2.4 for natural gas, 3.1 for oil, 3.9 for hard coal and 4.6 for brown coal (SFT (1990) and Calander et al. (1988)). There is no variation in factors between the sectors, because it is mainly the fuel and not the combustion technology that determines the emissions.

When calibrating the model, OECD data were mainly used for energy prices, taxes and quantities as well as for activity and income levels.

Before turning to the model simulations, it is useful to point out some important model properties. The final impact on energy demand of a change in an exogenous variable depend on the following aspects.

1. The magnitude of the exogenous shift (GDP growth rate, relative price change)
2. Price and income elasticities
3. Fuel shares by sector
4. Sector shares of total energy demand

Since a change in a variable works simultaneously through the model structure 2-4, it is sometimes difficult to single out explanations of a particular impact. In the following discussion we will point to dominating factors whenever possible.

Table 2.2 shows simulated average long term elasticities by fuel and sector aggregated over the model region. Note that the elasticities are total elasticities, i.e. impacts of the power sector equilibrium model are included. The *direct price elasticity* of oil in the end use sectors is lower than those of coal and gas, because most of the oil demand comes from transportation where the price elasticity is low due to lack of inter fuel competition. Similarly, the high *income elasticity* in transportation drives the total income elasticity of oil upwards to 1.15, compared to 0.75 for gas and coal, and 0.9 for electricity. The latter is somewhat higher than for other stationary fuels, due to high income elasticity of electricity consuming appliances in households and services. *Cross price elasticities* are small in most end use sectors, except for households and services, making total cross price effects small. The elasticity of electricity with respect to the price of coal is slightly negative, due to the dominating coal share in power generation. Higher coal prices thus increase electricity prices, and the negative impact on power demand dominates the substitution effect in the end use sectors. The table also shows that the direct price elasticities in power generation are small, since we have assumed that only new capacity is price sensitive.

Table 2.2. Simulated long term elasticities. Average for the whole model region

Demand for		Price			
Sector	Fuel	Coal	Oil	Natural gas	Activity
End user sectors in total	Solids	-1.05	0.05	0.15	0.75
	Oil	0.03	-0.70	0.15	1.15
	Natural gas	0.10	0.30	-1.20	0.75
	Electricity	-0.12	0.01	0.10	0.90
Thermal power production	Solids	-0.30	0.06	0.25	1.30
	Oil	0.15	-0.45	0.23	1.15
	Natural gas	0.16	0.05	-0.30	1.30

3. The reference path

The base run assumptions for the key exogenous variables are based on forecasts from studies made by Data Resources Institute (DRI), Central Bureau of Statistics in Norway (CBS) and Energy Technology Systems Analysis Program (ETSAP). The reference scenario should not be interpreted as an official energy demand forecast by the CBS. It is designed as a business as usual scenario, serving as a reference point for different policy scenarios in our analysis.

3.1 Assumptions

3.1.1 Activity variables

For all countries except Norway we have used real GDP and private consumption expenditures forecasts from DRI 1991 Country Reports. Based on the GDP forecasts and historical data on production by sector we have adjusted industry, services and "other sectors" forecasts such that growth rates for production in services and the industry sector are somewhat higher respectively lower than the GDP rates, while private consumption more or less keeps up with the GDP growth. The similar forecasts for the activity variables in Norway are taken from a study with the Norwegian macro model MODAG, see Bowitz and Storm (1991).

Table A.1 in the appendix shows forecasts by country. The real GDP growth rates for the period 1990-1995 vary between 3.3 per cent per year for Germany (West) and Norway to below 2 per cent for UK, Sweden and Finland whose low figures (1.8, 1.5 and 1.3 respectively) reflect the recession in the beginning of the nineties. For these countries the growth forecasts are somewhat higher in the period 1995-2000 where the average yearly GDP growth rates are within the range of 2.3-3.3 per cent, with Sweden and Germany (West) as the extremes. In the period 2000-2010 the forecasts for almost all countries are slightly lower, ranging from 1.6 (Sweden) to 2.6 (UK, France and Finland) per cent.

3.1.2 Energy prices

Real electricity prices are calculated in the price model, as outlined in section 2.2. Real end user prices for fossil fuels, P^E, are calculated according to the following identity:

$$P = (P^{CIF} + M + T^E + T^C) \cdot (1 + T^{VAT}) \qquad (1)$$

where:

P^{CIF}	is the CIF (or import) price
M	is the gross margin, including costs and profits in transformation, distribution, retailing etc.
T^C	is the carbon tax
T^E	are other excise energy taxes
T^{VAT}	is the relevant Value Added Tax rate

Prices, margins and taxes are measured in 1988 USD per toe. Forecasts of T^E and T^{VAT} are set constant at 1990 levels throughout the simulation period. Forecasts of P^{CIF}, which are consensus forecasts taken from ETSAP (1991), are shown in table A.2 in the appendix. The carbon tax, T^C, equals zero in the base run.

The gross margins for fossil fuels have been unstable during the 1980's, particularly for oil products. Fluctuations in M may reflect business cycles, cost differences, price discrimination and market power as inter fuel competition varies by market segment. By lack of better information, we let the margins move linearly from their observed values in 1990 to their 1986-1990 average values in 1995. From 1995 the gross margins are constant.

The forecasted percentage growth in end user prices tend to be higher the

a) higher the forecasted growth in the CIF price is (Crude oil and natural gas).
b) smaller the gross margin is (Heavy fuel oil to industry and electricity generation)
c) smaller the excise taxes are (Coal to all sectors, fuels to industry and electricity generation)

d) smaller the 1990 gross margin is relatively to the 1986-1990 mean gross margin. (This relationship will only influence the P^E growth rates in the period 1991-1995.).

3.1.3 Capital and labour costs

We simply assume that all capital costs, whether it refers to industry equipment or cars in the transportation sector, will be constant in real terms in the simulations, while real labour costs follow the real GDP growth rate.

3.1.4 Technical progress

In all sectors technical progress is autonomous. Based on Bowitz and Storm (1991) we have assumed the percentage autonomous energy saving per year for each country equal to 0.75 in the manufacturing industry, 1.1 in services and 0.7 in households. Based on verbal information from Institute of Transport Economics (TØI) in Norway we have assumed a 30 per cent autonomous fuel efficiency gain in transportation in all countries from 1988 to 2010.

3.1.5 Power production plans

Supply forecasts of nuclear, hydro and other power are based on official plans for development of new capacity as reported in IEA (1988). Note that such plans beyond year 2000 often are based on trends designed to meet expected growth in demand for electricity. Net exports are set constant at their 1988 levels throughout the period. Forecasts of electricity production from nuclear and renewable sources are listed in table A.3 in the appendix.

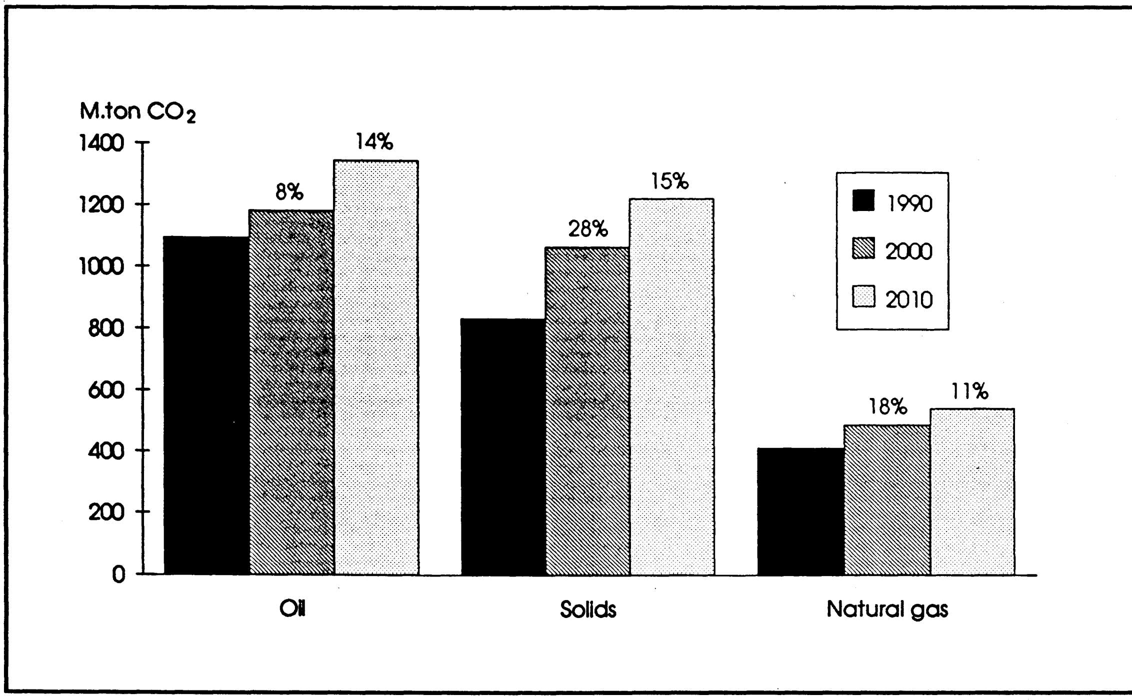
3.2 Reference simulation results

Although the simulation period ends in 2010, we will also focus on some of the reference simulation results by the *year 2000*. These results, i.e. the emission and energy picture by the turn of the century, are important in next chapter's discussion focusing on carbon taxes as a measure to stabilize the carbon emissions by the *year 2000* at the 1990 level.

3.2.1 CO_2 emissions

The carbon dioxide emissions in the model area rise by 17 per cent from 1990 to 2000, when it equals 2733 million metric tons CO_2. As indicated in figure 3.1 the emission from solids, mainly coal used in the power sector, grow by 28 per cent in the period, while the growth rates for oil and natural gas based CO_2 emissions are 8 and 18 per cent, respectively. The moderate increase in emissions from oil combustion is due to decreasing emissions from the stationary sectors. Despite the growth in emissions from solids, oil is still the main contributor to CO_2 emissions in 2000, with a share of 43 per cent. Solids are close behind with a share of 39 per cent, leaving the remaining 18 per cent for natural gas.

Figure 3.1 CO_2 emissions from solids, oil and natural gas. Reference scenario. 1990, 2000 and 2010. Million metric tons CO_2



The power and transport sectors are the main contributors to the CO_2 emissions, 32 and 27 per cent, respectively in 1990. Their shares even increase to 35 and 29 per cent in 2000 respectively. The power production and transport emissions grow by 27 and 25 per cent, respectively, in the period. The growth in household and services emissions is more moderate, about 11 per cent, while industry emissions actually drop by 5 per cent in the period.

As CO_2 emissions are proportional to consumption of the different fuels by sector, we can shed more light on the pattern in the simulated emissions by looking at the energy consumption patterns.

3.2.2 Aggregate energy consumption by fuel and sector

Driven by economic growth, end use demand for all fuels increases in the base simulation, see figure 3.2. Electricity demand increases by 47 per cent from 1988 to 2010, averaging 1.8 per cent a year. The end use demand for natural gas and solid fuels increase by 32 and 27 per cent over the period, while oil demand initially drops, but from 1992 rebounds for a total growth of 27 per cent from the base year level in year 2000.

The oil demand growth is mainly due to a steady increase in the transportation sector demand for petroleum products. This is indicated in figure 3.3, which shows energy consumption by end use sectors, historically and simulated.

Furthermore, figure 3.3 indicates that the transportation sector, facing a 65 per cent increase in energy consumption over the simulation period, is by far the most energy consuming end user sector by 2010. The energy consumption in the industry sector is roughly constant in the reference simulation, making it the second ranked energy end user sector by 2010. In fact, energy consumption in households almost equals that of the industry sector by 2010. The energy use in households and services grow by 30 and 33 per cent respectively during the simulation period.

Figure 3.2 Energy end use by fuel. Reference scenario. 1980-2010. Mtoe

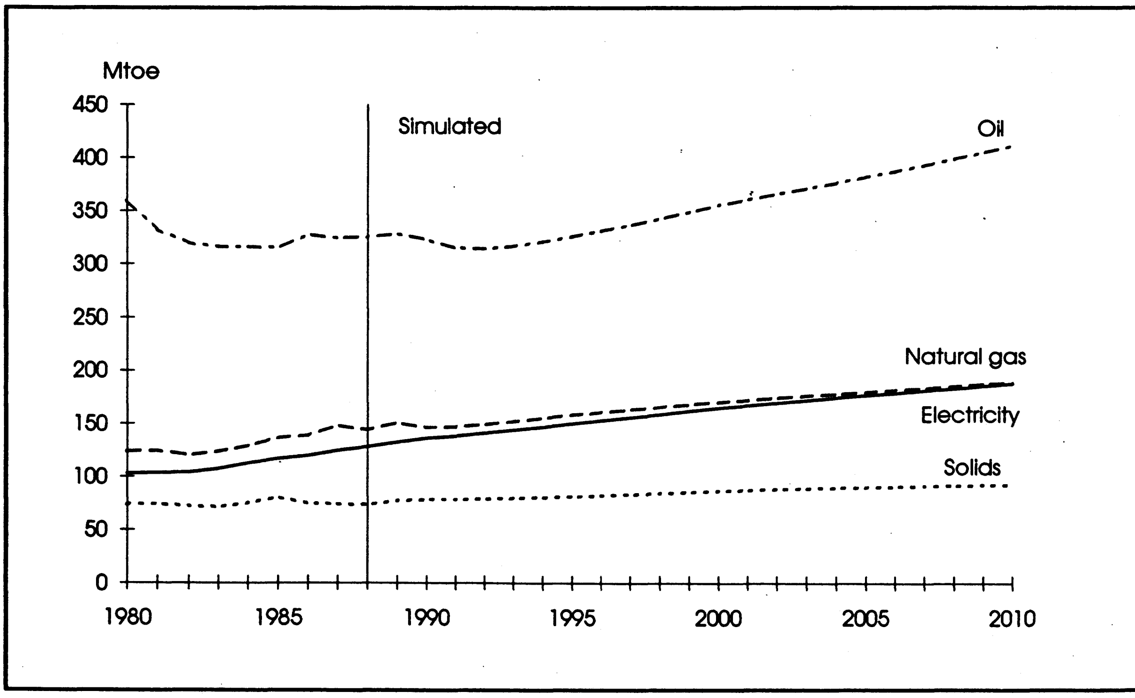
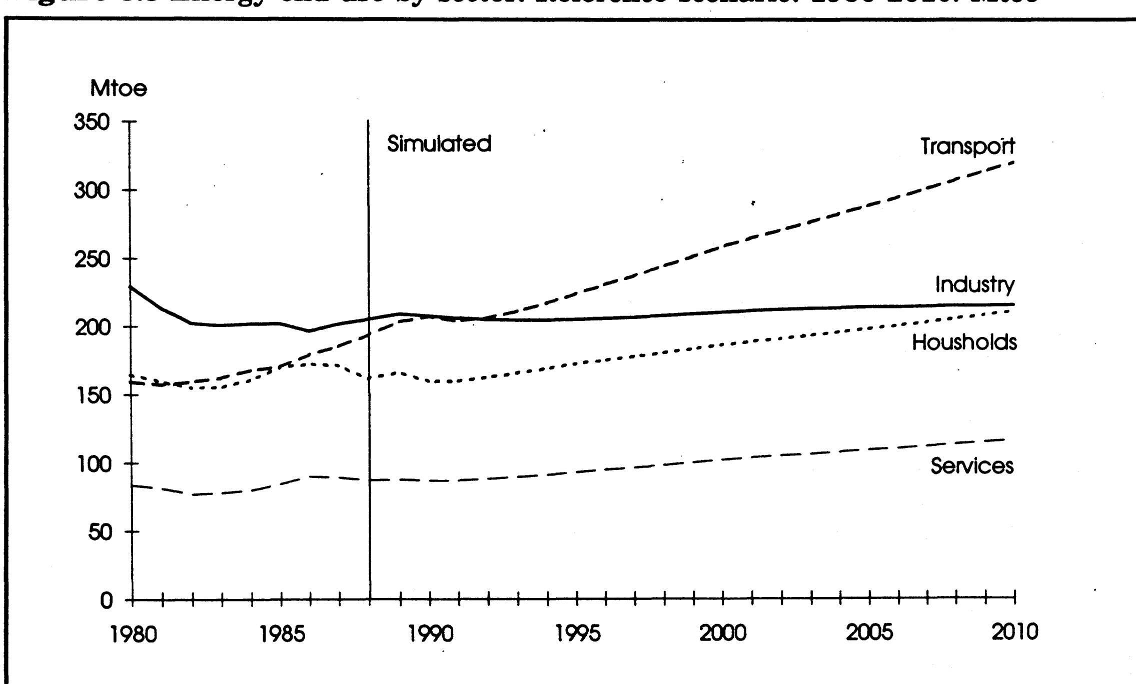


Figure 3.3 Energy end use by sector. Reference scenario. 1980-2010. Mtoe



3.2.3 Energy end use by sector

The factors behind these energy use patterns by sectors can be analyzed further by looking at each sector separately. The figures 3.4-8 show the historic and simulated consumption of each fuel in the industry, household, services, transportation and thermal power sector, respectively.

Due to a high price growth on oil products early in the 1990s and a prolonging of the trend, oil consumption in industry decreases briskly through the first half of the simulation period. As the price growth dilutes, oil consumption levels out after 2000 and is relatively stabile at 23 mtoe, which is 45 per cent lower than at the beginning of the simulation. The oil share of total energy consumption decreases from 34 per cent in 1980 to 21 and 11 per cent in 1988 and 2010 respectively.

The moderate price growth on coal and electricity enhances their competitiveness. The consumption of electricity and solids increases by 35 and 22 per cent respectively. This makes electricity and solids the dominant energy sources in industry by 2010 with market shares of 34 and 31 per cent respectively. Suffering from high price forecasts throughout the simulation period natural gas consumption in the model area as a whole declines moderately from the 1988 level.

The fall in oil consumption is more than offset by growing use of other energy sources, such that total energy requirement in the industry sector grows by 5 per cent from 1988 to 2010.

Figure 3.4 Energy demand. Industry. Reference scenario. 1980-2010. Mtoe

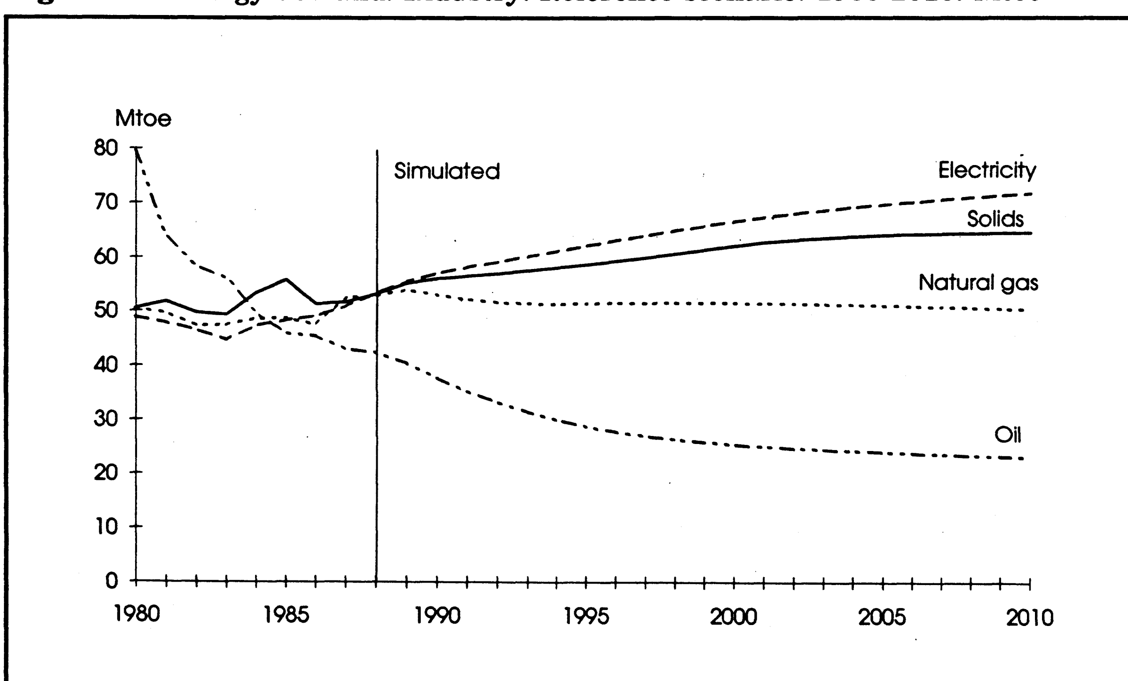
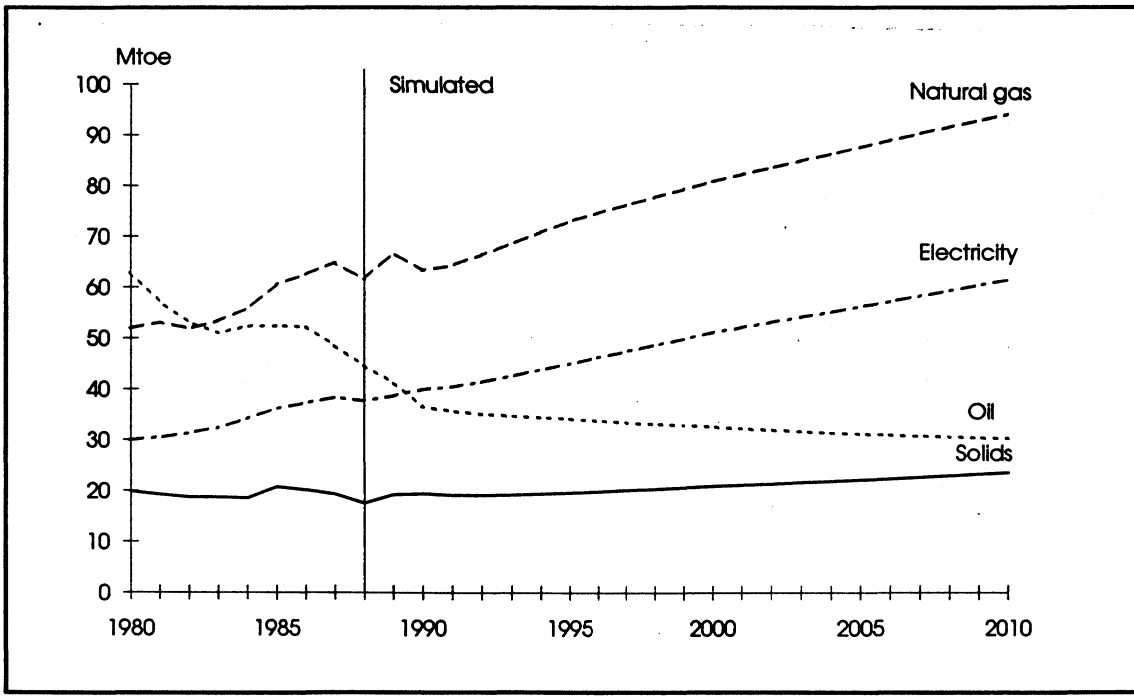


Figure 3.5 Energy demand. Households. Reference scenario. 1980-2010. Mtoe



Oil consumption in **households** declines by 32 per cent through the simulation period. Figure 3.5 shows a steeper decline in the first years. This is partly due to a sharp rise, both absolutely and relatively, in light fuel oil price for households. But the decline is also related to the transition mechanism arising from the fact that the probability of choosing oil space heating systems for new dwellings are lower than for those of the existing stock. The probabilities for existing dwellings will move towards those for new dwellings because the model allows for transition of systems in the existing dwelling stock. Also, the "demographic" mechanism, i.e. fuel system choices of new dwellings become part of the existing stock as time goes by, affects the outcome. The transition process is driven by the relative fuel prices, reflected in the choice probabilities, but dampened by transition costs and habit persistence.

This transition mechanism is also a major force behind the growth in the natural gas and electricity consumption in this sector. The effect is stronger in the beginning of the period, when the differences in fuel choice probabilities are larger. The rise in the natural gas and electricity consumption from 1988 to 2010 is 54 and 63 per cent, respectively. The growth in electricity consumption is partly related to increased use of assessories. There is a slight growth in the consumption of solids in households, partly due to decreasing coal prices relative to other fuels.

During the 1980's natural gas became the dominant fuel in the household sector, and by the end of the simulation period its share of total fuel consumption amounts to 44 per cent. Oils share falls from 28 per cent in 1988 to only 14 per cent in 2010. Thus, oil is passed by electricity which increases its share steadily from 23 per cent in 1988 to 29 per cent in 2010.

Figure 3.6 Energy demand. Services. Reference scenario. 1980-2010. Mtoe

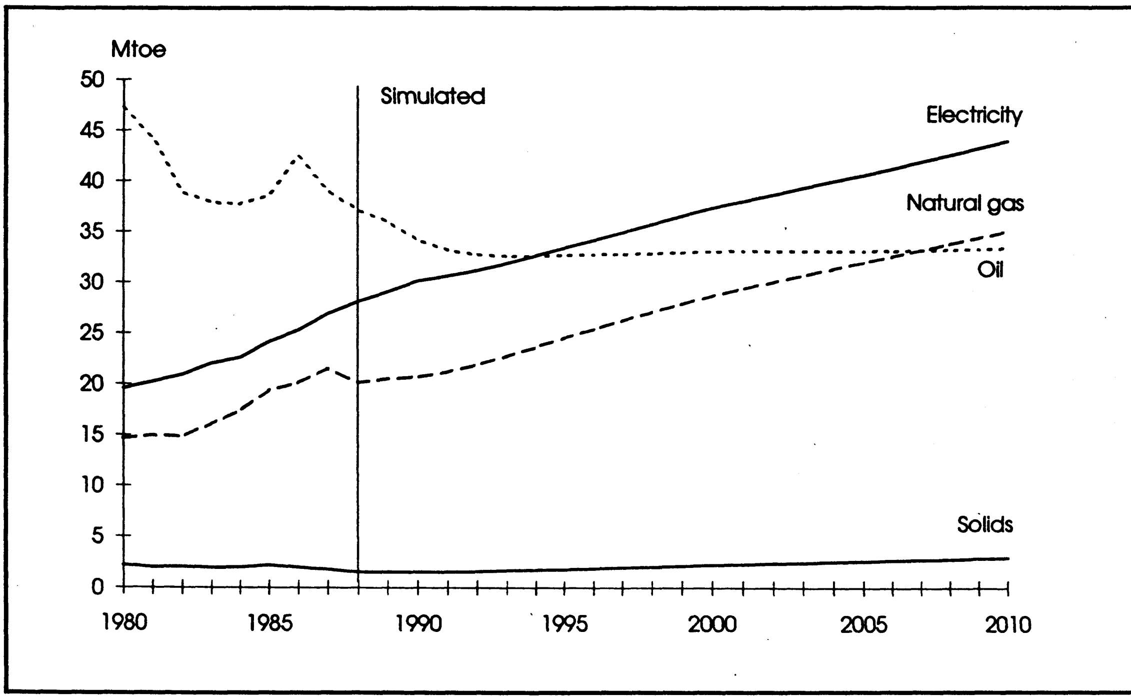


Figure 3.7 Energy demand. Transport. Reference scenario. 1980-2010. Mtoe

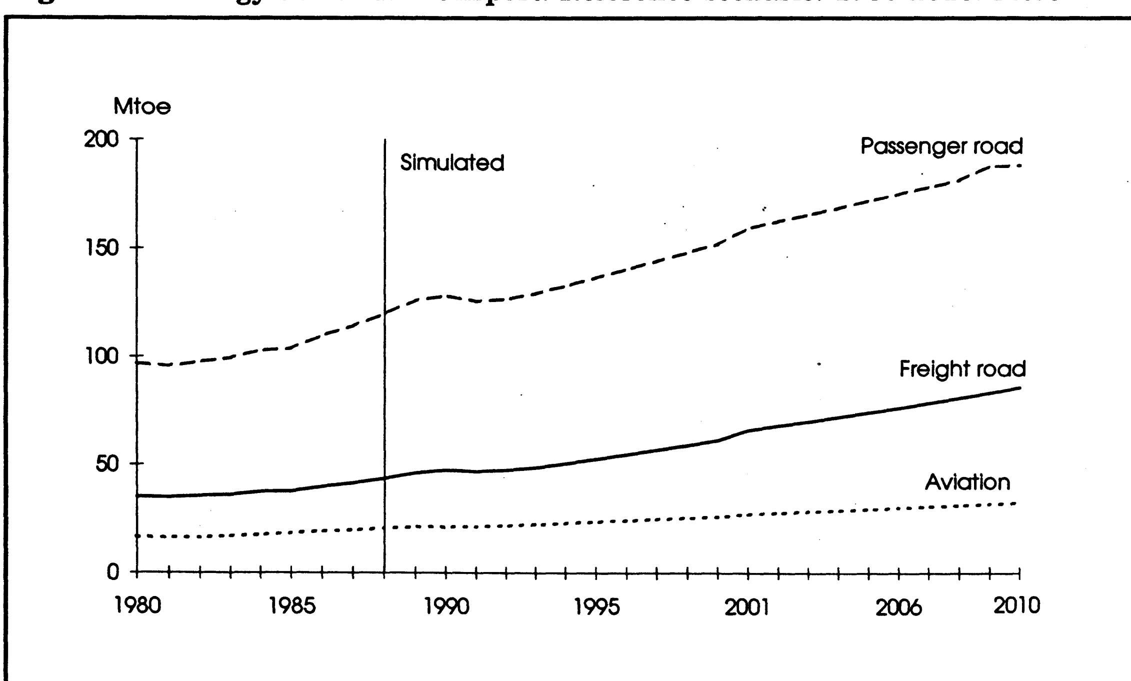


Figure 3.6 indicates that the energy use in the **services** sector developes similarly to the energy use in the households. The oil consumption decreases while consumption of the other fuels increase. The fall in the oil consumption levels out in 1993, thus making the total reduction over the simulation period only 10 per cent. The growth in consumption of natural gas, solids and electricity amounts to 75, 93 and 57 per cent, respectively.

Electricity replaces oil as the dominant fuel in the beginning of the simulation period. By the end of the period also natural gas consumption exceeds the oil consumption. Electricity, natural gas and oil shares are 38, 30 and 29 per cent respectively by 2010.

Consumption of oil products in **transportation** is closely related to the growth in real GDP and private consumption. As seen above, the percentage rise in gasoline and diesel prices in the base run is moderate due to large margins and taxes on these products. Therefore, the autonomous energy saving rather than fuel prices dampens the growth in the activity and income driven fuel consumption.

Figure 3.7 shows fuel consumption in the three most dominant transportation segments - passenger and freight transportation on roads and aviation. In all segments there is a steady, almost parallel, growth - both throughout the 1980's and the simulation period. The passenger vehicle group is the dominant fuel user in transportation, with a share of 60 per cent in 2000. The highest growth in fuel consumption, however, is in non-passenger road transportation, averaging 3.5 per cent annually before 2000 and 3 per cent in the period 2000-2010. In this sector the increase in use of the main fuel, auto diesel, somewhat exceeds the growth in gasoline consumption. The differences in the base run growth rates are mainly due to differences in income elasticities. The elasticities are higher for diesel than for gasoline vehicles and higher for freight than for passenger vehicles.

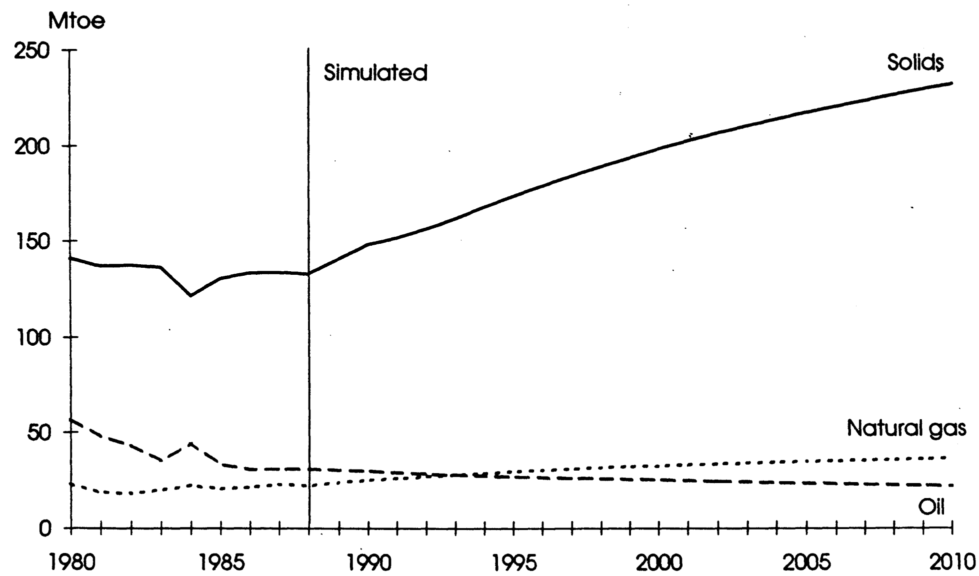
3.2.4 Energy use in power generation

The fuel input in power generation is important for the total energy use as many countries base their power generation on conventional thermal power. Thus, the thermal power share of carbon emissions amounted to 30 per cent in 1988 within the model region.

Figure 3.8 displays the historical and reference path for the aggregated power sector. As shown in figure 3.2, total electricity demand increases from 127 mtoe to 187 mtoe throughout the simulation periode. This corresponds to an annual growth rate of 1.8 per cent. The growth in electricity demand calls for an increase in thermal **power production** as planned annual growth in nuclear and hydro capacity averages only 1,6 per cent throughout the simulation period. 38 mtoe, or 55 per cent of the total increase in electricity requirement of 70 mtoe is produced in conventional thermal power plants.

In line with the IEA projections, the incremental supply of thermal power results in a growing use of solids and natural gas. In our reference scenario solids and natural gas consumption grow by 75 and 64 per cent respectively from 1988 to 2010. Being by far the dominant fuel in electricity production at the start of the simulation, solids consumption increases by 100 mtoe throughout the simulation period. The consumption of natural gas intersects oil consumption in 1994 and reaches a level of 36 mtoe by 2010. Despite the expansion of the power systems, the consumption of fuel oil declines 28 per cent. This reflects that the role of oil as a base load fuel declines rapidly.

Figure 3.8 Energy demand. Thermal power production. Reference scenario. 1980-2010. Mtoe



There are large variations between countries. Countries with a higher than average growth in thermal power production, like Sweden, UK and France, expand their production capacity in all fuel types. The Netherlands' ambition to reduce their dependence on natural gas in power production results in a 50 per cent decline in their natural gas consumption in this sector. This calls for a boost in coal consumption as coal must cover both growing electricity demand and the reduced production of gas power. The strain on coal fired utilities in Netherlands eases as nuclear production is introduced towards the end of the 1990s. In contrast, the Italians reduce their oil dependence in power production, at 57 per cent in 1988, with increasing use of natural gas and coal. In 2010 the picture of the Italian power sector is changed considerably with the market share of oil reduced to 9 percent, and the market share of solids and natural gas swollen to 53 and 38 percent respectively.

3.2.5 Primary energy consumption

Finally, for the record, we summarize the results of the end use demand and fuel demand in power generation in figure 3.9, showing total primary energy consumption. Since carbon emissions are proportional to primary energy consumption, we refer to the comments in section 3.2.1.

The growth in fuel demand is dampened by rises in real fuel prices and autonomous technological progress. Thus, energy intensities as measured by the ratio of total energy use to activity/income by sector steadily decline in all sectors in the reference scenario, see figure 3.10.

Figure 3.9 Primary energy consumption. Reference scenario. 1980-2010. Mtoe

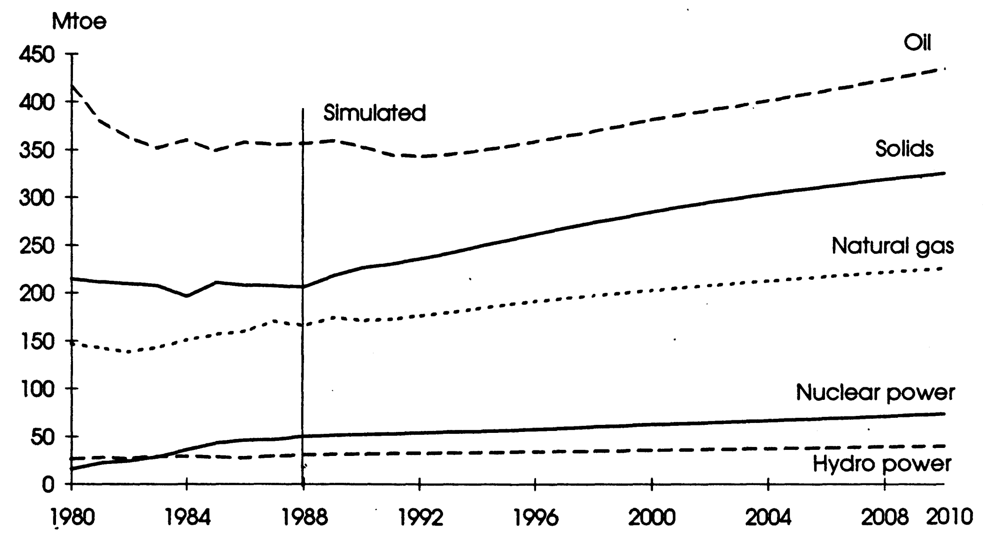
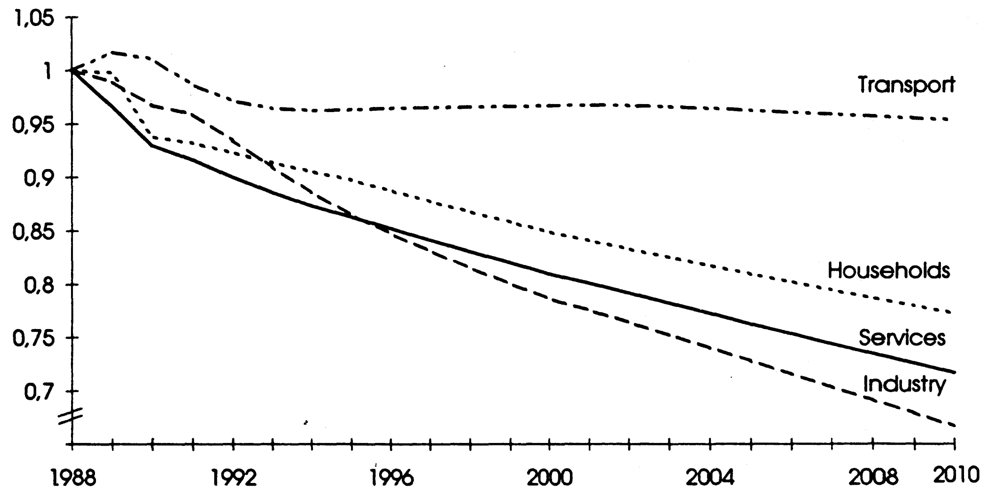


Figure 3.10 Energy intensities by sector. Reference scenario. 1988-2010. Index, 1988=1



The decline is very moderate in the transportation sector, reflecting high income elasticities offsetting the brisk technological progress. In the industry sector, where the substitution of non energy production factors for energy are highest, the fall in energy intensity is most rapid. The energy intensity in the services and household sectors develops similarly, with a 24-28 per cent decline over the simulation period.

4. The carbon and energy tax scenarios

4.1 Background and assumptions

On May 13 1992 the European Commission adopted a wide-ranging plan to stabilize CO_2 emissions in the Community in the year 2000 at 1990 level, see Europe Information Service (1992). The array of instruments the Commission is proposing to introduce comprises a non-fiscal part and a fiscal part in the form of tax[6]. In this paper we focus on the impact of the fiscal measures on CO_2 emissions.

4.1.1 Activity and other exogenous variables

A key characteristic of the tax proposition is revenue neutrality, meaning that the tax will be fully compensated by tax incentives or cuts in taxes or other public charges. Assuming strict revenue neutrality, the impact on GDP is estimated to be modest.[7] This justifies constant forecasts for goods and services production and income in all scenarios. Also for other exogenous variables including fuel import prices and other energy taxes we have assumed the same values in the tax scenarios as in the reference case. This is, of course, a debatable presumption, as oil and hence other energy prices might be changed if such a dominant consumer as EC superimposes new taxes. In this paper, however, we focus on the demand side.

4.1.2 Tax scenarios

The proposed EC tax is a tax based partly on an energy component and partly on a carbon component, where the energy component of the tax should not exceed 50 per cent. A $3 per barrel tax would be introduced on in 1993 with an additional $1 per

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[6] The plan comprises draft Directives on *carbon/energy/CO_2 tax, energy efficiency (SAVE), renewable forms of energy (ALTENR)* and a draft Decision on *monitoring the levels of CO_2* emitted by the Member States.

[7] A number of studies have considered the impact of carbon taxes on GDP. The estimates for Europe seem to be in the range of 1-3 per cent loss depending on the speed of tax implementation. The costs are lower if capital adjustments are allowed to take place. Thus, *DRI (1992)*, NOU (1992) and Agostini et al. (1992) show higher adjustments costs for stabilization within year 2000, while the long term equilibrium models, allowing for long term (2010-2020) stabilization such as Manne and Richels (1991) and Berniaux et al. (1991) with OECD GREEN, are in the lower range. The models also show higher production losses for energy intensive industries, in the 3 per cent range if taxes are global (OECD GREEN) and much higher losses if taxes are unilateral, due to capital mobility.

barrel in successive years until 2000. After year 2000 the carbon/energy tax is to be kept at its 2000 level.[8]

Our analyses contains two carbon/energy tax scenarios:

1) The carbon component of the tax is 50 per cent, i.e. both the tax per carbon unit and the tax per energy unit equals $5 per barrel oil by year 2000. Hereafter this is referred to as the EC tax scenario as it is the most likely alternative.
2) The carbon component of the tax is 100 per cent, i.e. the tax per carbon unit equals $10 per barrel oil by year 2000, while the tax per energy unit equals zero.

Obviously, the latter alternative is most efficient with respect to with respect to CO_2 abatement, as alternative 1) does not satisfy the necessary condition for efficiency that tax rates are proportional to emission coefficients. Thus, alternative 1) increases the deadweight loss for a given level of abatement. Given the emission coefficients this implies the following combined carbon/energy tax in year 2000 in the respective scenarios:

Table 4.1 Carbon/energy taxes per toe in year 2000. 1988 US$

Fossil fuel	Base run	50% carbon tax (EC tax)	100% carbon tax
Coal	$0	$78	$88
Oil	$0	$68	$68
Gas	$0	$59	$49

4.2 Impacts of taxation

4.2.1 Impacts on relative end user prices

According to the EC tax proposal, T^C is superimposed on the existing excise duty system in the model through equation (1). While the import prices on the various fuel types, see P^{CIF} in equation (1), roughly are at the same level throughout the model region, the gross margin, energy excise taxes and value added tax vary a lot. This is the main reason for the discrepancy in end user prices between countries at the sector level.

Consequently, the percentage increase in end user prices, P^E, due to an implementation of a fixed tax component, varies between sectors and countries. Obviously the

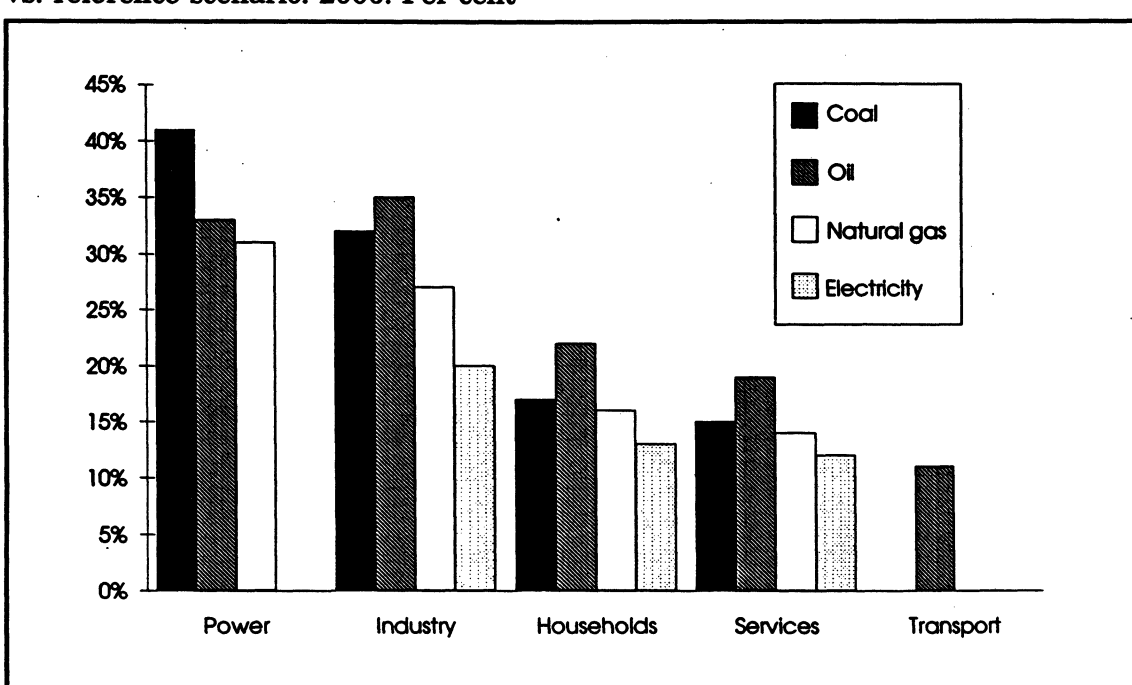
[8] The EC plan has several exemptions and limitations. Hydro power plants with a capacity of less than 5 MW are not to be taxed. Firms where energy's cost share of total cost are considerable, will get tax reductions. Furthermore, the EC Comission proposes sector-specific voluntary agreements. These parts of the EC plan are not included in our analysis, parly because the exemptions and limitations seem somewhat unclear yet and partly due to insufficient data.

lower the initial price level, the higher the percentage increase in the end user price will be.

The end user prices are relatively low in the power and industry sectors and high in households, the services and transportation sectors due to high margins and taxes on energy in these sectors. Therefore, the implementation of the carbon/energy tax means a relatively high price increment in the industry and power generating sectors and relatively moderate price rises in households, services and transportation. In paeticulary the impacts on automotive fuels are small, ranging from 6 per cent on gasoline in Italy, which had the highest automotive fuel prices amongst the countries in 1988, to 11 per cent on diesel in UK and Germany (West). The carbon/energy tax induced increase in fuel prices in households and services sectors by 2000 are higher, ranging from 12 per cent impact on electricity to 20-30 per cent on solids.

In some sectors and countries (Germany) there is a combination of a relatively high coal price and a low oil price. Although the energy/carbon tax on coal is highest, its relative weight in the coal price is lower than that of the oil price in some cases. It follows that the coal/oil price ratio decreases when introducing the carbon/energy tax. Thus, the tax enhances the competitiveness of coal, despite the fact that the CO_2 emissions, and thus the tax, per TOE are higher for coal than for oil. This will, of course, lead to substitution of a worse pollutant for a more harmless pollutant. This pattern is depicted in figure 4.1, showing the relative impact on end user prices in 2000 by implementation of the carbon/energy tax in Germany (West).

Figure 4.1 Changes in energy prices and demand. Germany (West). EC tax scenario vs. reference scenario. 2000. Per cent



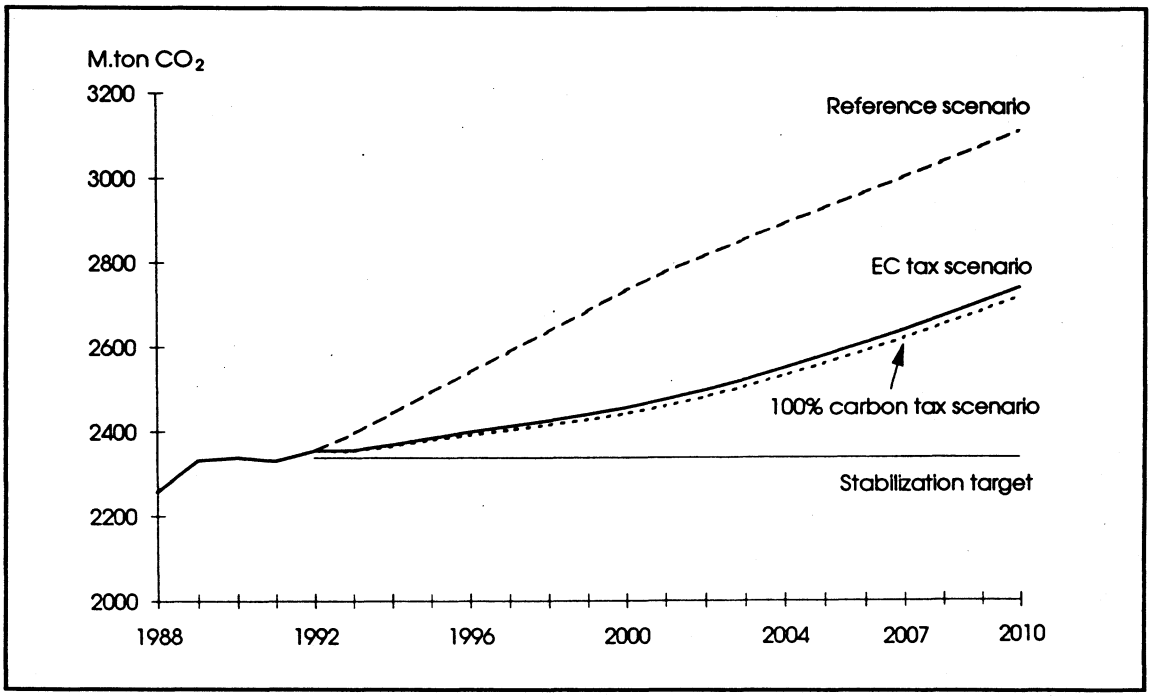
The carbon/energy tax inflates electricity prices as increasing fuel prices in thermal power production increase the average production cost in this production. On the Norwegian electricity price we have added only the energy component of the energy/carbon tax as hydro power does not generate CO_2 emissions.

Finally it should be noted that because import prices are rising and the tax level stays constant *beyond year 2000*, the relative price shifts decline. This implies that the substitution mechanism is reversed somewhat after 2000.

4.2.2 Impacts on CO_2 emissions

Figure 4.2 reports the simulated carbon dioxide emissions in the reference, EC tax and the 100 per cent carbon tax scenario. The emissions in the EC tax scenario is 10 per cent lower than the emissions in the reference scenario in 2000. This is insufficient to meet the target of stabilizing the emissions at the 1990 level[9], which requires a 15 per cent reduction from the 2000 base run level. Implementation of a 100 per cent carbon tax, as shown in table 4.1, does not help much. Such a tax reduces the CO_2-emissions by 11 per cent in 2000.

Figure 4.2 CO_2 emissions. Reference, EC tax and 100 per cent carbon tax scenario. 1980-2010. Million metric tons CO_2



The figure demonstrates that there are minor differences between the impacts of the two tax regimes. The main reason for this is that the differences between the two taxes are too small to make substantial impacts on the end use price levels. The

[9] Note that the 1990 carbon dioxide emissions level is simulated in our analysis.

natural gas prices in the 100 per cent carbon tax scenario are between 1 and 5 per cent lower than those in the EC tax scenario, while the coal prices are between 1 and 3 per cent higher. As the oil price is the numeraire when designing the two tax regimes, the tax impact on the oil prices is, of course, the same in the two scenarios. The small differences in the impacts on fuel prices lead to only minor changes in fuel consumption. The consumption of solids drops by 2 per cent while the natural gas consumption increases by 2 per cent in 2000. Compared to the EC tax scenario the 100 per cent carbon tax scenario thus gives slightly reduced CO_2-emissions from solids. However, this is partly offset by a small increase in emissions from natural gas.

Even though the effect is small, this confirms the a priori arguments about the efficiency of the two tax alternatives. Note that the two principles set out in the EC proposal, revenue neutrality and additivity of energy taxes, imply that only taxes on other inputs or direct taxes are allowed to decrease. The ceteris paribus effect of carbon taxation would increase if the principle of revenue neutrality allowed for a change in existing energy taxation, but carbon emissions would obviously increase if oil excise taxes were reduced.

Due to the small differences between total level of CO_2 emissions in the two tax scenarios we restrict further discussion to impacts of the EC tax scenario.

Figure 4.2 also shows that with the carbon/energy tax level constant from 2000 and onwards the CO_2 emissions increase steadily after the turn of the century, due to growth in income and production activities. Thus if a long term stabilization is sought by tax measures, the tax has to rise also beyond year 2000. This simply reflects that the shadow price of the emission constraint increases over time as energy demand increases.

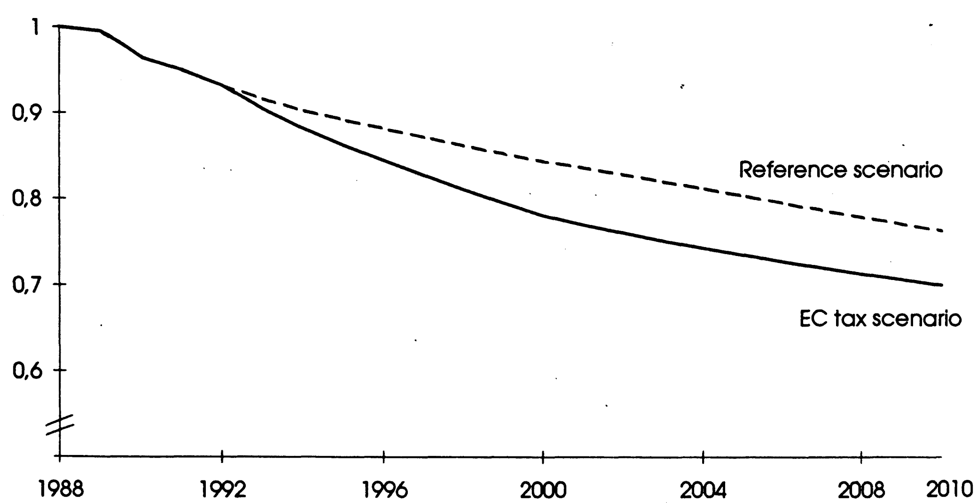
However, it should be emphasized that the plan adopted by the European Commission on May 13 1992 also suggests supplementary remedies in addition to the carbon/energy tax, and that those measures combined with a carbon/energy tax could be sufficient to stabilize the emissions, by 2000 and afterwards.

The EC tax impact on emissions from the different fuels varies. Compared to the reference scenario in 2000, the solid fuel emissions are reduced by 16 per cent, while the reduction in emissions from oil and natural gas consumption are 5 respectively 8 per cent only. It seems to be a paradox that the impact is least on emissions from oil, which faces a higher energy tax than natural gas. However, one big component of oil based emissions comes from the transportation sector, where the increase in fuel prices, and thus the emission reductions, are quite small due to a high price level before introducing the carbon/energy tax. Moreover, there are no inter fuel substitution possibilities in transportation.

4.2.3 Impacts on energy demand

The main effect of the carbon/energy tax is a reduction in energy intensities, as shown in figure 4.4. By year 2000 the energy intensity is reduced by 6 per cent.

Figure 4.3 Energy intensities. Reference and EC tax scenario. 1988-2010. Index, 1988=1



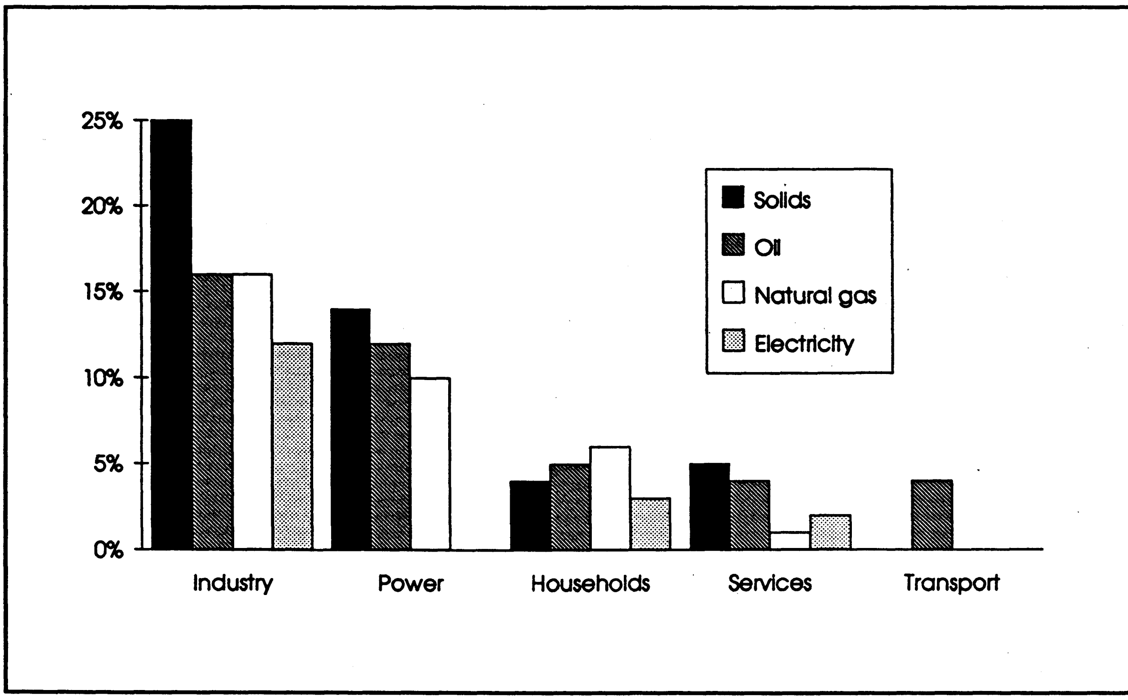
Although the EC tax changes relative prices, it is not sufficient to induce large substitution of fuels with low carbon content for those with higher carbon content. Table 4.2 presents the different sources' share of total energy requirement in the two scenarios in 2000.

Table 4.2 Fuel shares. Reference and EC tax scenario. 2000. Per cent

	Reference scenario	EC tax scenario
Solids	29.5	27.0
Oil	39.4	40.8
Natural gas	21.0	21.1
Nuclear	6.5	7.0
Hydro etc.	3.7	4.0

The EC tax impact differ between sectors. Figure 4.4 shows per cent reductions in fuel demand by sector by year 2000.

Figure 4.4 Per cent reductions in fuel demand by sector. EC tax scenario vs. reference scenario. 2000



The EC tax have a substantial impact on the fuel consumption in the **industry** sector. Compared to the reference scenario the tax reduces total consumption of energy by 22 per cent in 2000, mostly due to the substantial price increase, which leads to a substitution of capital and labor for energy. The confluence of low relative impact on price ratios from the EC tax and low cross fuel price elasticities makes the inter fuel substitution effect negligible.

The tax stabilizes the use of electricity in the industry sector at the 1993 level during the period of tax implementation. In the same period the fossil fuels consumption decline rapidly. While natural gas and oil continue to decline at a moderate pace after year 2000, the use of electricity and solids resume a moderate growth after the implementation is completed. Facing the highest EC tax solids takes the largest reduction and consumption is reduced to 44,5 mtoe by 2010, 16 per cent lower than its 1988 level. Throughout the simulation period consumption of solids was reduced by 31 per cent followed by oil and gas with a 20 per cent reduction. Electricity consumption is reduced by 16 per cent, but is still 13 per cent above its level in 2010.

The EC taxes have relatively small effect on total fuel consumption in the **household, services** and **transportation** sectors. The reductions in total energy demand compared to the reference scenario are 5, 3 and 4 per cent respectively in 2000. The small impact is due to various reasons.

First, as discussed in section 4.2.1 the impact on the end user prices is smaller in these sectors than in industry and power production, reflecting higher fuel price levels initially. *Second,* in households and services some of the cross price elasticities are high. Thus, the cross price effects often dampen the direct price effects. The effect on solids in service-sector in Germany (West) illustrate this point. The direct long term price elasticity for this fuel is -2.68. However, the cross price elasticities of oil, gas and electricity prices on solids demand are 1.72, 0.70 and 0.05 respectively - adding up to 2.47, which almost equals the direct price elasticity. And as the relative price increases are of the same magnitude for all fuels in the services in Germany (West), the total cross effect on solids demand will nearly outweigh the direct impact from the solids price increase. Thus the total reduction in demand for solids is as low as 1 per cent. *Finally,* the demand for electricity used for appliances in households is relatively insensitive to price changes.

The household and services sectors responds to the EC tax through reductions in energy intensities rather than changes in the fuel shares. As indicated in figure 4.4 the small substitution in households goes in the "wrong" direction. The EC tax impact on natural gas demand exceeds the impact on oil demand. Furthermore, the per cent reduction of oil demand exceeds the decrease in solids demand. This is due to effects similar to those in services, referred to above. First, the EC tax does not change relative fuel prices significantly, due to different fuel price levels initially. Second, the combination of moderate direct and high cross price elasticities is such that it favours solids and disfavours natural gas, relatively speaking.

Table 4.3 Fuel shares in households and services. Reference and EC tax scenario. 2000. Per cent

	Households		Services	
	Ref.	EC tax	Ref.	EC tax
Solids	11.3	11.3	2.2	2.1
Oil	17.5	17.5	32.7	32.1
Natural gas	43.6	43.0	28.3	28.7
Electricity	27.6	28.9	36.9	37.9

The reduction in fuel use in all four road transportation sectors is only about 5 per cent in 2000, and even lower in aviation, 2 per cent. However, when it comes to electricity consumption, in rail transport, the impact of the taxes are bigger, 10 per cent in 2000. The differences reflect variations in the direct price elasticities.

In the reference scenario **thermal power** generation gains market shares, and by 2010 the thermal share almost equal the renewable and nuclear share. The EC tax inflates electricity prices in all sectors, and the following 6 per cent reduction of electricity demand is covered by decline in thermal power alone, since it is the residual supplier. The decline of thermal power is 13 per cent, thus, the market share decrease from 52 per cent in the reference scenario to 43 per cent in the EC tax scenario in 2010. The reduction in solids and oil consumption is 14 and 12 per cent respectively. The substitution towards natural gas is not sufficient to outweigh the decreasing demand for thermal power. Thus, natural gas consumption decreases by 10 per cent over the simulation period.

This result contradicts expectations in the natural gas and power industries. Our result is influenced by the choice of calibration, see section 2.2.[10] Recall that by assumption fuel substitution possibilities exist only in the new thermal power plants, which represent only a small part of the total capacity. Changes in marginal shares of individual energy sources, and thus substitution in new power plants, can therefore be relatively large without causing any significant short term substitution in the power system as a whole. The effects of changed marginal shares accumulates as old facilities are shut down and new plants using other fuels take their place. This time consuming process makes the substitution effect relatively insignificant in the short term and inferior to the scale effect caused by the reduced electricity demand.

It could be argued that a carbon/energy tax would accelerate the turnover in power plants that experience the largest relative cost increase. This would enlarge the substitution towards natural gas in power production. We have chosen not to alter the rate of depreciation in the various scenarios.

Interfuel substitution in thermal power production applies to the whole model area except Norway where thermal power production is negligible. But interfuel substitution in the end use sectors increases the electricity demand in Norway ceteris paribus. In the EC tax scenario a 34$/toe energy tax is imposed on the electricity prices in all sectors. The direct price increase dominates the demand shift, leaving the electricity demand below the level in the base run scenario.

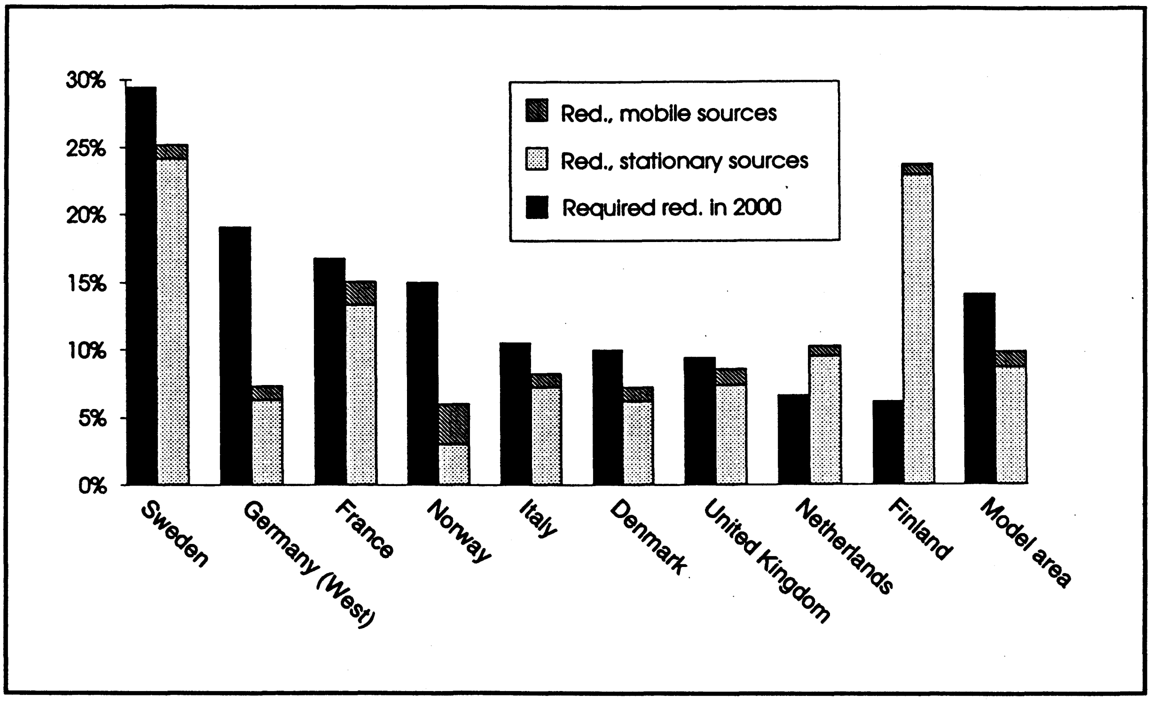
4.2.4 Impacts on CO_2 emissions and energy demand by country

Although the EC stabilization target is a multilateral effort, it is also interesting to see how each country perform according to unilateral targets. The left hand bars in figure 4.5 report percentage required reduction in total CO_2 emissions to reach national stabilization at 1990 level in each country by 2000 - if emissions develop as indicated in our reference scenario. The right hand bars show contributions from stationary and mobile sources to emissions reductions in 2000 in the EC tax scenario, all in relative measures. The required reduction bars are ranked in descending order. The bars labelled "EU" show weighted average for the model area.

The figure exhibits large differences. We first examine the total growth in CO_2 emissions by country, looking for the factors behind the left bars, as large required reductions corresponds to high growth in CO_2 emissions from 1990 to 2000 in the base run scenario.

[10] A study of a cost efficient calibration of the power model is forthcoming.

Figure 4.5 Required and simulated reductions in CO_2 emissions by country. EC tax scenario vs. reference scenario. 2000. Per cent



CO_2 emissions growth 1990-2000 by country (left hand bars)

The rapid CO_2 emission growth in Sweden after 1990 are mainly caused by the surge in thermal power demand which largely hails from no increase in hydro power production and decline in nuclear power production. While hydro power potential is limited as remaining rivers are sheltered from development, nuclear power stations retirement rates are more exposed to shifting political winds.

Germany (West) and France however, expand their hydro and nuclear capacity further, thus restricting the growth in thermal power demand and CO_2 emissions. Nevertheless the total CO_2 emissions grow rapidly in these countries, due to high growth in real GDP and private consumption.

In Norway CO_2 emissions from stationary sources decrease moderately from 1990 to 2000. This is related to the transition from oil to electricity in households and industry. Total CO_2 emissions grow, however, as fuel demand in transportation increase.[11]

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[11] Note that the model does not include emissions from oil and gas extraction, which are large in Norway and UK, and expected to increase significantly in Norway. Thus, including the offshore sector NOU (1992) finds it particularly costly to stabilize carbon emissions by 2000. The required emission reduction is almost 30 per cent in the study, which is based on macroeconomic model (MODAG) simulations for Norway.

In countries with low CO_2 emissions growth industry emissions decline whereas emissions from transportation increase slowly. Main explanations are high fuel prices in industry as well as low activity and consumption forecasts.

Finland and the Netherlands expand their nuclear power capacity, restricting the growth in emissions from power production to 16 and 7 per cent respectively, resulting in the lowest CO_2 emissions growth of all countries. Moreover, forecasted activity growth in Finland is low.

EC tax impact on CO_2 emissions by country (right hand bars)

The right hand bars in figure 4.5 show percentage CO_2 emission reductions by year 2000 in the EC tax scenario. To explain variations in country responses to the EC tax we focus on variations in either of the aspects 1-4 set out in section 2.2.

Large reductions in industry and thermal power emissions and small reductions in transport emissions are common to all countries. This is mainly due to variations by sector in the tax impact (aspect 1 and 2). However, country variations in the tax impact are mainly due to differences in the energy structure (aspects 3 and 4). This explains why per cent emissions reductions are biggest in Sweden, Finland, and France.

Most of the reductions in Sweden and France comes from power production. There is a complex array of reasons. *First*, it should be noted that the relative reduction in demand for electricity are somewhat higher than elsewhere. (Recall that thermal power is the marginal residual supplier in the model.) *Second*, thermal power share of total power supply is small in both countries. Thus, the per cent reduction in thermal power and emissions are large: 55 per cent in France and somewhat less in Sweden. For Sweden even a *third* reason contributes. In spite of the small thermal power share, it contributes 40 per cent of total emissions, due to the high demand for electricity in Sweden.

The thermal power production also partly explains the results for Finland. Furthermore, emission reductions in the energy intensive industries in Finland amount to about 45 per cent of total reductions. The EC tax impact on industry coal prices in Finland is large. This has a significant impact on CO_2 emissions from the sector, due to high simulated coal shares in 2000.

Germany (West), Italy, Denmark, UK and the Netherlands have lower than average per cent emission reductions. One reason for this, is high household shares of CO_2 emissions. Recall from section 4.2.1 that the EC tax impact on fuel prices in households is rather small. The impact is low in Norway due to low emissions reductions from transportation, which is the main emission sector. This result is in line with the NOU (1992) study.

Hoeller et al. (1991 p 95, chart 1) reports an interesting regression of carbon emissions per unit of GDP on average prices of fossil fuels per tons of emission. The curve is sharply rising and convex in the price, indicating that countries with high prices initially (Norway, Sweden, France and Italy) will have the smallest impact of a uniform additional tax. Our result contradict the hypothesis for Sweden and France, for the reasons set out above. Even though the result for Sweden is dependent on the assumed nuclear phase out, and impacts are dependent on a number of assumptions, our model demonstrates that the impact of the national energy structures are important. The impact on Norway and Italy are in line with the hypothesis.

Required vs. simulated reductions

The EC tax is insufficient for all countries except the Netherlands and Finland to meet national stabilization by year 2000. This is seen by comparing simulated to required emission reductions, i.e. the differences between the two bars in figure 4.6. The country variations in meeting national stabilization levels emphasizes the obvious fact that when stabilizing total CO_2 emissions for a group of countries by imposing a common measure, the measure will be more than sufficient for national stabilization in some countries while insufficient in others. This fact may have an impact on willingness to join an agreement on a common target, as Finland has little incentive to join, while Germany should be eager to join.

Evidently, either less optimistic forecasts on economic growth and private consumption, or higher production of nuclear and renewable power, or higher fossil fuel prices in the reference path would make many of the included countries come closer to national stabilization through implementation of the planned EC energy/carbon tax.

5. Summary, conclusions and need for further research

A carbon/energy tax as designed by EC is insufficient for stabilization (base year 1990) of CO_2 emissions by the year 2000, unless it is combined with other abatement strategies. In order to stabilize emissions beyond 2000, the combination of abatement strategies, notably the fiscal tax have to rise along with the growth in fossil fuel demand that follows from income and activity growth. These results are in line with a number of other studies.

A fuel tax based on equal shares of carbon emission and energy content reduces oil and gas demand by 5 and 8 per cent respectively by the year 2000. The smaller reduction in oil demand is due to the high share of transportation demand, where price effects and flexibility is low such that the impact of the EC tax is low. Even if the carbon share of the tax increases to 100 per cent, thereby reducing the burden on gas, the gas demand impact is -6 per cent. The substitution effect in the model is insufficient to alter the qualitative result.

Haugland et al (1992), DRI (1990), and Berniaux et al (1991) got the same result for simulations on the European OECD area, but the latter had a smaller impact on gas than oil. Agostini et al (1992), using a calibrated short term inter fuel substitution model, got increasing gas demand. They found very high direct gas price elasticity in the power sector, and high cross price elasticities of gas with respect to oil and coal, which partly explain their result. They also got increasing gas demand in the industry sector.

The Haugland et al study explain their results by referring to the lack of impact on relative prices, and conclude that uniform taxes levied on the existing price structure is inefficient. It is beyond the scope of this paper to elaborate on this, but we note that the existing price and tax structure is very heterogeneous, and that this fact strongly affects the impacts in our model. However, the price changes work through an energy consumption structure that is heterogeneous. The structural impact is also strong, and cannot be eliminated by price and excise tax harmonization, but only moderated.

We agree to the argument that the existing tax structure makes *additional uniform carbon taxes* (*AUCT*) inefficient with respect to carbon emission abatement. In the presence of fiscal constraints and other externalities, this argument is not sufficient to conclude that *AUCT* is inoptimal. Analyzing the transport sector, Newbery (1992) argues that *AUCT* is optimal, if existing taxes reflect optimal road user charges. But the result depends on the crucial assumption that the marginal congestion externality is constant over the range of the carbon tax, which would require a very slowly increasing carbon tax that hardly would be sufficient to ensure stabilization of emissions. Also Hoel (1992) discusses the *AUCT* rule, and finds that the fiscal, carbon, and second externality tax components are additive. That does not mean, however, that the carbon tax can be superimposed, as the level of the tax components depends on endogenous variables, such as the fiscal constraint, the carbon constraint and the marginal cost of the second externality. Further empirical research on this is needed.

For Norway, as a gas and oil exporter and an eager proponent for sustainable development, there is no double gain from the EC tax as it is designed from the *AUCT* rule. On the contrary, Norway stands to loose as a petroleum exporter, while the tax is inefficient with respect to carbon abatement. Even though these conclusions are in line with most other studies, we believe that the conclusions should be tested further.

Some specific topics are on the agenda for further research with our model. They include

1. sensitivity tests on exogenous variables, such as growth rates, nuclear power and energy prices, and on calibrated parameters
2. recalibration of the thermal power model such that the fuel share functions reflect cost efficient supply of power
3. excise tax harmonization

Appendix

Table A.1 Real GDP growth forecasts. Average annual growth rates. Per cent

COUNTRY	1990-1995	1995-2000	2000-2010
Germany (West)	3.3	3.1	2.1
Great Britain	1.8	2.6	2.6
France	2.7	3.3	2.6
Italy	2.2	2.4	2.2
Netherlands	2.5	2.4	2.0
Sweden	1.5	2.0	1.6
Finland	1.3	2.4	2.6
Denmark	2.2	2.4	2.0
Norway	3.3	3.1	2.1

Source: Data Resources Institute (DRI), CBS.

Table A.2 Import energy prices. Growth rates in per cent. 1987 prices.
All 9 countries. Per cent

	1990-2000	2000-2010	2010-2030
Coal	0.18	1.69	0.64
Oil	2.14	1.84	1.22
Natural gas	2.14	1.84	1.22

Source: Energy Technology System Analysis Program (ETSAP).

Table A.3 Power production from nuclear and renewable sources. Forecasts. Mtoe

Country	Source	1988	2000	2010
Great Britain	REN	0.6	0.8	0.8
	NUC	5.5	6.9	8.4
France	REN	6.8	7.7	8.5
	NUC	23.7	30.0	34.9
Italy	REN	4.1	5.7	6.6
	NUC	0.0	0.0	0.0
Netherlands	REN	0.0	0.4	0.7
	NUC	0.3	1.7	2.1
Denmark	REN	0.0	0.2	0.3
	NUC	0.0	0.0	0.0
Finland	REN	1.1	1.3	1.4
	NUC	1.7	2.1	2.6
Sweden	REN	6.2	6.6	7.0
	NUC	6.0	5.2	5.2
Norway	REN	9.4	10.4	10.8
	NUC	0.0	0.0	0.0
Germany	REN	2.2	2.7	3.7
(West)	NUC	12.5	16.5	20.1

REN: renewables equals the sum of hydro and other power.
NUC:nuclear

Source: IEA 1988, CBS

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