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Alcamo, J. and Vries, B. de

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Working Paper

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Foreword

Calculations with IIASA's Regional Acidification INformation and Simulation (RAINS) model have shown that the SO_2 and NO_x emission reductions that are presently committed within the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution will not halt the acidification of the environment within Europe. At the same time, there is growing concern that humanity's emissions of greenhouse gases, in particular CO_2, will alter the radiative balance of the earth's atmosphere and cause climate change, possibly leading to social and economic hardship for large segments of the world's population. At the root of both of these major environmental problems lies the combustion of fossil fuels to provide us with energy. It is obvious therefore, that an important measure to combat both regional acidification and climatic change would be to reduce our use of energy. This paper represents an important analysis of the results of a reduction of energy use in Europe and will be of interest to those who are concerned with the above major environmental problem.

Bo R. Döös
Leader,
Environment Program

Roderick W. Shaw
Leader,
Transboundary Air Pollution Project

Acknowledgments

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Abstract

A link is made in this paper between proposed low energy scenarios for different Western European countries and the amount of pollutants that may result from these scenarios. Air pollutant emissions are calculated for the ten countries for which low energy scenarios are available. These scenarios emphasize stringent energy efficiency, maximizing the use of renewable (other than nuclear) energy, and minimizing the use of fossil fuels. Under these low energy scenarios, the average per capita energy use (year 2030) in the ten countries is estimated as 97 GJ/person, which is a decrease of 38% relative to 1980.

Using the energy consumption figures from the low energy scenarios, together with sector- and fuel-specific emission factors from Europe, the resulting emissions of SO_2, NO_X, and CO_2 were computed. These estimates do not take into account any add-on pollution controls over and above what was in place in 1980, or changes in combustion technology; these would result in still lower emissions. Under the low energy scenarios, power plants will continue to be the most important SO_2-producing sector, and transportation the most important NO_X-producing sector. For CO_2, however, no single sector is most important in producing emissions.

The low energy scenarios (year 2030) result in a reduction of 54% for SO_2 emissions, 37% for NO_X emissions, and 41% for CO_2 emissions compared to their 1980 levels. It was concluded that energy efficiency improvements and renewable energy use, if economically and institutionally feasible, will be an effective long term option for simultaneously reducing the gaseous emissions that are major contributors to regional acidification and photochemical air pollution, and potential global warming.

Contents

Low Energy, Low Emissions: SO_2, NO_X and CO_2 in Western Europe

*Joseph Alcamo**
*Bert de Vries***

1 Introduction

It is well known that many key air pollutants in industrial countries come almost entirely from burning fossil fuels. Virtually all of the SO_2 and NO_X emissions in OECD-Europe, for instance, arise from energy combustion – 91% and 93%, respectively (OECD, 1989a). The remainder stems from industrial processes, agriculture, and natural sources (OECD, 1989a). The same holds for anthropogenic emissions of CO_2 in the industrial North, which originate almost exclusively from fossil fuels (Marland, et al, 1989). It is not surprising then that energy conservation has long been regarded as an important strategy for reducing pollutant emissions. Yet until recently it was difficult to quantify the long-term effectiveness of energy conservation in reducing pollutants over large European areas because consistent low energy scenarios were unavailable for these areas. Now, however, sufficiently detailed "low energy" scenarios have been developed for several countries in Western Europe (Figure 1). By "low energy" scenario we mean internally consistent estimates of energy use in different economic sectors of a country which emphasize efficient use of energy and substitution of fossil fuels by renewable energy sources.

The objective of this paper is to estimate the emissions of SO_2, NO_X and CO_2 that result from the low energy scenarios of ten countries in Western Europe. Although it is qualitatively obvious that energy conservation will reduce the emissions of all three pollutants, in this paper we aim to quantify this reduction. We also examine some of the underlying assumptions of the low energy scenarios. We focus on SO_2 because of the public health risk it poses in certain regions and because it is the principal precursor of acidification of Europe's environment. NO_X is examined because it is both an important constituent of acidifying deposition as well as a main ingredient of photochemical air pollution in Europe. CO_2 is important because of its role in anticipated global warming.

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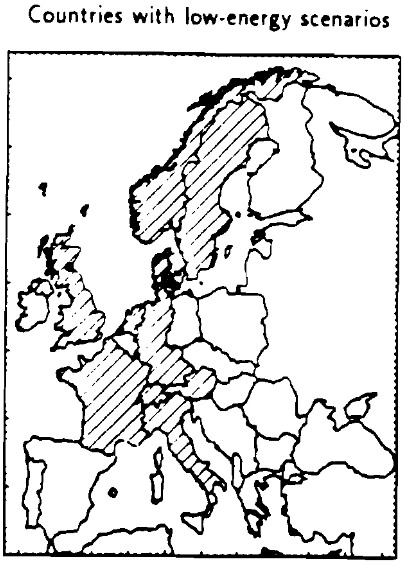

Figure 1: European countries with detailed low energy studies.

2 Method For Calculating Emissions

Anthropogenic emissions of SO_2, NO_X and CO_2 arise during combustion when the nitrogen and oxygen in air reacts with sulfur, nitrogen and carbon contained in fuel. For a particular emission source, the amount of emissions per unit fuel depends on the level of impurities in fuel, the combustion temperature, the amount of air used for combustion, the design of the combustion chamber, and other factors. Since it is infeasible to compile this information for every emission source in every country, a simpler "emission factor" approach is usually taken to compile country-scale emission inventories in Europe.

The amount of pollutant P emitted in sector j by fuel k is given by:

$$P_{jk} = E_{jk} f_{jk} \tag{1}$$

where E_{jk} is the amount of fuel k in energy units used in sector j, and f_{jk} is the appropriate emission factor in units of emissions per unit fuel combusted. We obtain the emission total for country i by summing up the contributions of different fuels and sectors:

$$P_i = \sum_j \sum_k P_{jk} \tag{2}$$

Hence, the calculation of emissions requires an estimate of the fuel combusted per sector and the emission factors for SO_2, NO_X, and CO_2.

For calculations in this paper we divide the energy economy of each country into several fuels and sectors –

Fuels: brown coal, hard coal, derived coal (e.g. briquette, etc.), medium distillate, heavy fuel oil, light fuel oil, and natural gas;

Sectors: fuel conversion (e.g., refineries and coking plants), power plants, domestic combustion, transportation, and industrial combustion.

This breakdown comes from the RAINS model of acidification in Europe (Alcamo, et al, 1990). All emission factors used in our calculations are based on European data. For SO_2 and NO_X, these factors are taken from the RAINS model (Amann, 1990; Springman, 1990).

Emission factors for SO_2 used in RAINS are computed from the sulfur content and heat value of fuels and the sulfur retained in combustion chambers and not emitted to the atmosphere (Amann, 1990). These factors depend on the sector and fuel, and are also country-dependent because the sulfur content of fuels differs substantially from country to country. The emission factors used in RAINS for NO_X take into account the emissions originating from nitrogen in fuel, plus the nitrogen contained in air used in combustion (Lübkert, 1987; Springman, 1990). In reality, these factors strongly depend on the operating conditions of a combustion chamber. Since this information is not available for every source in every country, these factors are assumed to be different for each fuel and sector, but the same throughout Western Europe. The SO_2 and NO_X emission factors used for calculations in this paper are presented in Appendix A.

Emission factors for CO_2 for various fuels are taken from a study of CO_2 emissions in Germany (Western) (Bach, 1989). The authors have applied the same factors (Appendix A) to each country because differences in these factors between Western European countries are probably fairly small. For example, Block et al (1988) estimate CO_2 emission factors for the Netherlands that are 5% lower for natural gas and 10% higher for light fuel than the figures used in this paper (Appendix A). Note that the mass of carbon dioxide emitted per PJ fuel is more than a factor of 100 larger than either SO_2 or NO_X, because of the large fraction of carbon in fossil fuels as compared to sulfur or nitrogen.

The uncertainty of emission estimates are discussed in Section 4.4.

3 Low and Official Energy Scenarios

Before presenting results of the emission calculations we briefly review the key assumptions of the energy data used in these calculations. Low energy scenarios have been constructed by different researchers for twelve Western European countries. (For a list of their reports the reader is referred to de Vries et al, 1989 and Norgard and Jensen, 1989). Data from ten of these twelve countries (shown in Figure 1) were sufficiently detailed for country-scale emission calculations and were compiled, analyzed, and standardized into a common format by de Vries et al (1989). Although not all of Western Europe is covered, the energy used in these ten countries amounted to about 75% of total Western European energy consumption in 1980. Appendix B presents an overview of the key assumptions of each of the country scenarios. Details of the scenarios are given in de Vries et al (1989) and Norgard and Jensen (1989).

The low energy scenarios assume that it is desirable to reduce the use of fossil fuels in order to mitigate the environmental impacts of these fuels and to reduce a country's dependence on imported coal and oil. Most of them (France, West Germany, Italy, Spain, Sweden, Switzerland, United Kingdom) also include a phase-out of nuclear energy as a goal because of safety and environmental reasons, largely inspired by the Chernobyl accident. It is also assumed that it is technically feasible to increase energy efficiency and implement renewable energy sources, and that these options are increasing in cost effectiveness. Consequently, the message of these scenarios is that over the long term Western Europe should increasingly rely on renewable sources including electricity from wind-, wave-, hydro-, and solar-power; heating from active and passive solar power; and fuels and materials from biomass. For four countries (Denmark, West Germany, Netherlands, and Sweden) the potential for combined heat- and power-generation have been assessed in detail, including industrial cogeneration.

Figure 2 presents a key element of the low energy scenarios, i.e. the assumed fuels for generating electricity. Solar and wind power are assumed to contribute over and above currently installed hydroelectric capacity in every country. In several countries (Germany (West), United Kingdom and in the Scandanavian countries) the technical and economic feasibility of solar and wind power has been evaluated. Although the country scenarios are not based on common assumptions about future price and availability of fossil fuels, they almost all come to the same conclusion that coal and oil, supplemented by renewable sources, will dominate the generation of electricity in the near term. [1]

A drastic reduction of energy demand is considered feasible because of the present inefficiency of energy use. Most of the country scenarios highlight the potential for improving energy efficiency in the domestic and transport sectors — the scenarios generally assume that over the next 30 to 50 years energy services such as passenger transport and space heating and cooling will require 50 to 70% less energy per passenger-km or per person than they now do. Most of the scenarios assume that electricity will not be used for space heating. Only a few scenarios assume major changes in infrastructure in the domestic or transport sectors, such as changes in the commuting distances between workplaces and residences. A small number of the low energy scenarios explicitly consider structural changes in the industrial sector, e.g. a shift towards less energy- intensive manufacturing, or an increasing size of the service sector.

Only a few scenarios deal explicitly with the relationship between economic output and energy use. Six scenarios (Denmark, Germany (West), Italy, Sweden, Switzerland, and United Kingdom) are based on the assumption that official growth targets for gross domestic product (GDP), in the range of 1 to 3%/year, can be accomplished with current or lower energy use. The other scenarios are not based on explicit economic assumptions. In comparison to official

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[1] However, we should note that in recent months there has been increasing discussion about minimizing coal use in the future because of coal's relatively large contribution to atmospheric concentrations of "greenhouse" gases compared to other types of fuel .

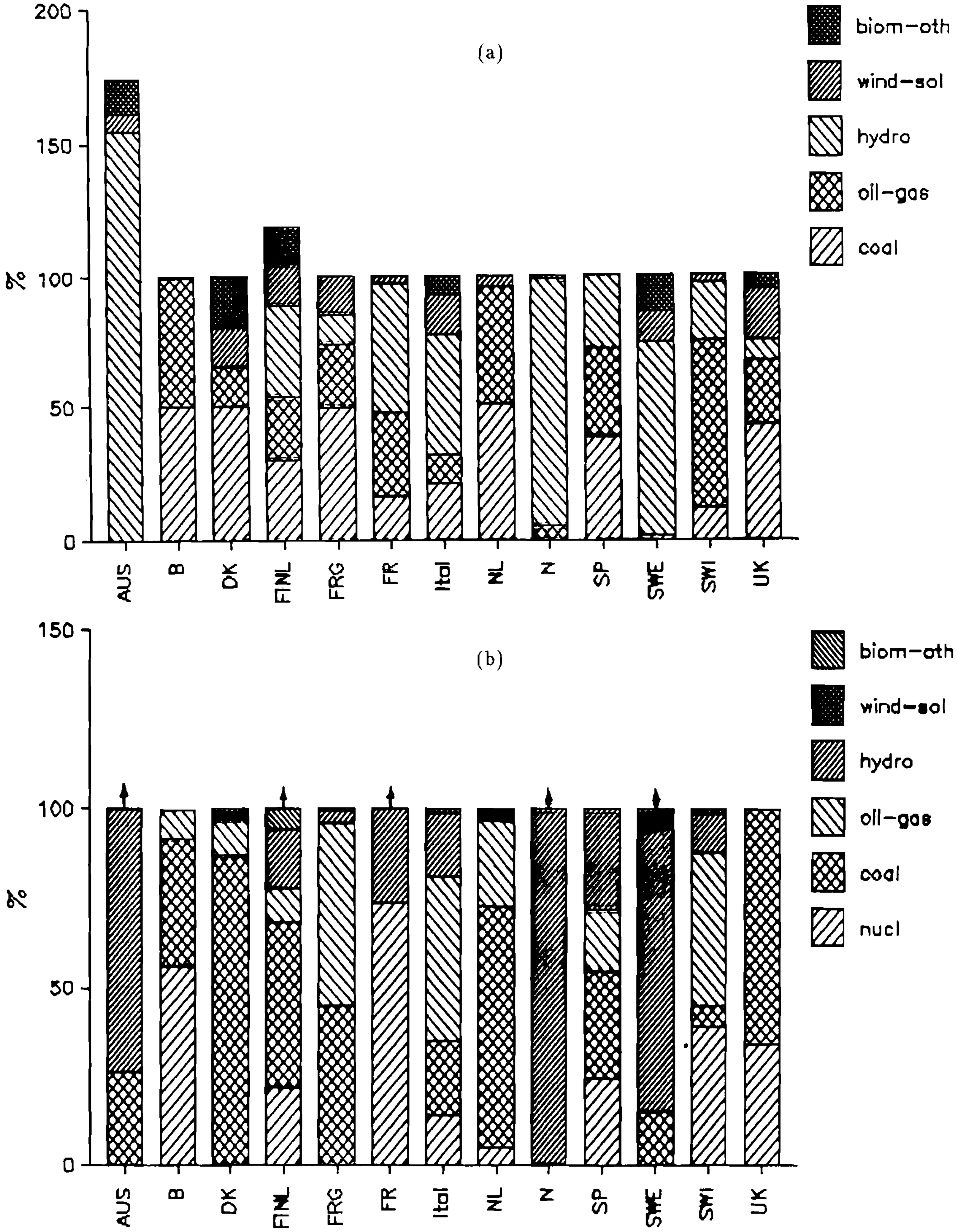


Figure 2: Supply shares of different fuels for electric power generation. (a) Official energy scenarios, year 2000 (IEA, 1986), (b) Low energy scenarios for their final year of implementation (see Appendix B). More than 100% indicates export potential.

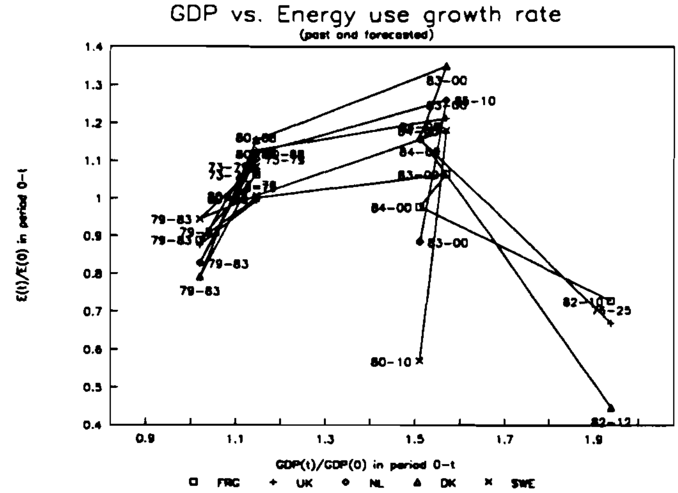


Figure 3: Past and projected changes in the Gross Domestic Product (GDP) versus changes in total energy consumption for five countries. Sources: De Vries et al (1989), IEA (1985), Guilmot (1986), Ministry of Economic Affairs (1990).

Each point shows the ratio of energy consumption in year t (E(t)) versus the energy consumption at some initial year 0 (E(0)). This ratio in energy consumption is plotted against the ratio of the GDP in year t(GDP(t)) versus GDP during the initial year GDP(0). For example, the triangle in the lower left hand side of the figure gives the ratio of energy in Denmark in year 1983 versus 1979, plotted against the ratio of GDP in these two years.

Year 2000 in this figure is indicated by "00", year 2010 by "10", and so on. Therefore, the triangle located in the lower right-hand corner of the figure ("82-12") shows the ratios of energy and GDP for Denmark between the years 2012 and 1982. The lines in the figure connect data from the same country.

The cluster of points on the left-hand side of the figure are results from forecasts from the 70's up to 1980, and indicate a forecasted growth in GDP [GDP(t)/GDP(0)] about the same as growth in energy consumption [E(t)/E(0)]. The cluster of points to the right of the middle are forecasts from 1983 and 1984 and reflect the assumption that energy consumption would not grow as fast as GDP. Forecasts in the lower right-hand part of the figure assume significant growth in GDP with a *decrease* in energy consumption over the same period.

expectations for these countries, the low energy scenarios imply that energy use will decrease as GDP grows, i.e. they will have negative elasticities in the long run (up to the year 2030) (de Vries et al, 1989). Figure 3 illustrates the implied and assumed relationships between changes in GDP versus changes in total energy consumption. Depicted are data from five of the countries which took into account economic growth in their low energy scenarios. During the period 1973–79 the energy growth elasticity was unity, and after the second oil price rise (1979) it drops below one. The forecasts of the International Energy Agency (IEA) for 1983, also shown in this figure, anticipated a continued elasticity below unity for these countries. After the oil price decreases of 1985–86, most governments revised their economic growth and energy use forecasts to reflect a downturn in energy conservation efforts. In comparison, environmentalist groups persisted in their view that economic activities can increase along with a decrease in energy consumption. This is reflected in the data on the lower right-hand side of the figure. Recently, official scenarios from some Scandanavian countries, as well as Germany (West) and the Netherlands have included the same assumption, namely, that economic growth can be accompanied by decreased energy consumption.

To summarize, the low energy scenarios diverge from the official view by emphasizing end-use energy services, the phase-out of nuclear energy, and increased reliance on local renewable sources. Despite their inconsistencies, they provide a valuable contrasting view to "official"

Table 1: Summary of gross energy consumption (PJ/yr) for the 10 Western European countries depicted in Figure 1.

Country	1980	2000 Off. E. Scenarios	2030 Low E. Scenarios
Austria	1111	1366	612
Denmark	807	817	373
France	8124	9084	5543
Ger.(W.)	11431	10752	5615
Italy	5893	7157	5130
Neth	2740	2692	1480
Norway	1009	1311	1054
Sweden	2012	2213	1311
Switz	1032	1352	957
UK	8408	9277	4222
Sum:	42567	46021	26297

energy scenarios. The emissions of these official scenarios are also computed for comparison to the low energy scenarios. Energy data of the official scenarios were submitted by governments to the Economic Commission for Europe (ECE) and Organisation for Economic Cooperation and Development (OECD) (ECE, 1989 and OECD, 1989b).

Table 1 summarizes the energy data for the low and official scenarios. (We remind the reader that the low energy scenario estimates are described in detail in de Vries et al (1989) and Norgard and Jensen (1989).) For the low energy scenarios in the year 2030, total energy consumption for the 10 countries is estimated to be around 26 exajoules, or about 97 gigajoules/person-year. This is 38% lower than year 1980, and 43% lower than the official scenarios for the year 2000.

4 Results of Emission Calculations

4.1 SO_2 Emissions

The calculated SO_2 emissions for different energy scenarios are presented in Table 2. These include estimates for the year 2000 under the official and low energy scenarios for each of ten Western European countries. Also included are the expected emissions in the year 2000 according to the "current reduction plans" of different countries. This scenario is based on the percentage reduction of SO_2 emissions that various countries have pledged relative to their 1980 emissions (Amann, 1990). Results for the low energy scenarios are also given for the year 2030, although estimates are not available for the year 2030 for the other scenarios. The estimated 1980 emissions are also presented for reference. Differences in SO_2 emissions between the official scenarios for year 2000 and low energy scenarios for years 2000 and 2030 result only

Table 2: SO_2 Emissions (as SO_2), country totals and per capita.

Country	Population (Mill.)	1980		2000 Off. E. Scenarios		2000 Current Red.Plans		2000 Low E. Scenarios		2030 Low E. Scenarios	
		Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)
Austria	7.5	349	46.6	350	46.6	105	14.0	350	46.6	127	17.0
Denmark	5.1	449	88.0	403	79.0	224	43.9	154	30.1	58	11.3
France	55.3	3542	64.0	1685	30.5	1774	32.1	2942	53.2	1466	26.5
Ger.(W)	60.4	3198	52.9	2870	47.5	1119	18.5	2481	41.1	1594	26.4
Italy	57.5	3605	62.7	2789	48.5	2526	43.9	2482	43.2	1257	21.9
Nether.	14.7	461	31.4	484	32.9	232	15.8	530	36.0	346	23.5
Norway	4.2	136	32.4	139	33.1	69	16.4	102	24.4	62	14.8
Sweden	7.7	478	62.1	365	47.4	168	21.8	365	47.4	161	20.9
Switz.	5.8	124	21.3	102	17.6	63	10.9	153	26.4	80	13.9
U.K.	52.6	4672	88.8	4137	78.7	3273	62.2	3549	67.5	2553	48.5
Sum or Average	271	17014	62.8	13324	49.2	9553	35.3	13108	48.4	7704	28.4

from differences in energy used in each sector, since no add-on pollution controls over and above what was in place in 1980 are assumed in the low energy scenarios.

Most of the researchers who developed the low energy scenarios assumed that they would not be fully implemented until sometime between the years 2010 and 2030. Hence there is not a large difference between the total SO_2 emissions of the official energy scenarios (13,324 kt/yr) and the low energy scenarios (13,108 kt/yr) in the year 2000 (Table 2.) Both are around one-quarter lower than emissions in 1980. In some countries (France, Sweden, Switzerland) emissions are actually higher in the year 2000 under the low energy scenario because it was assumed that the phase-out of nuclear energy in these countries would lead to an increased dependence on fossil fuels in the near term. However, the situation is different in the year 2030 when the low energy scenarios are fully implemented. SO_2 emissions are then 54% lower than 1980 emissions, and 19% lower than the Current Reduction Plans. It should be emphasized that additional reductions of SO_2 (as well as NO_X and CO_2) can be accomplished under the low energy scenarios by adding pollution control equipment to power plants, heating units, and other emission sources.

Figure 4 gives the source profile of SO_2 emissions, i.e. the breakdown of emissions according to different fuels and sectors for three cases: year 1980, the official energy scenario (year 2000), and the low energy scenario (year 2030). In 1980 the most important SO_2-producing fuels in these countries were heavy fuel oil and hard coal, whereas in years 2000 and 2030 only hard coal predominates. This figure also shows that power plants have been, and will continue to be, the principal sulfur-producing source.

(a)

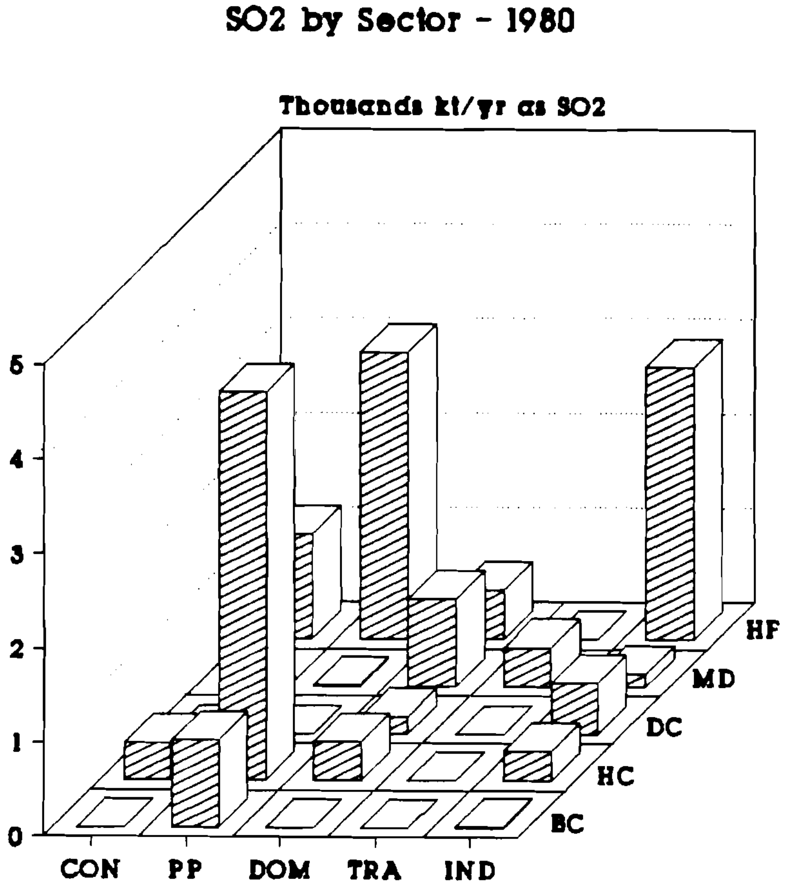
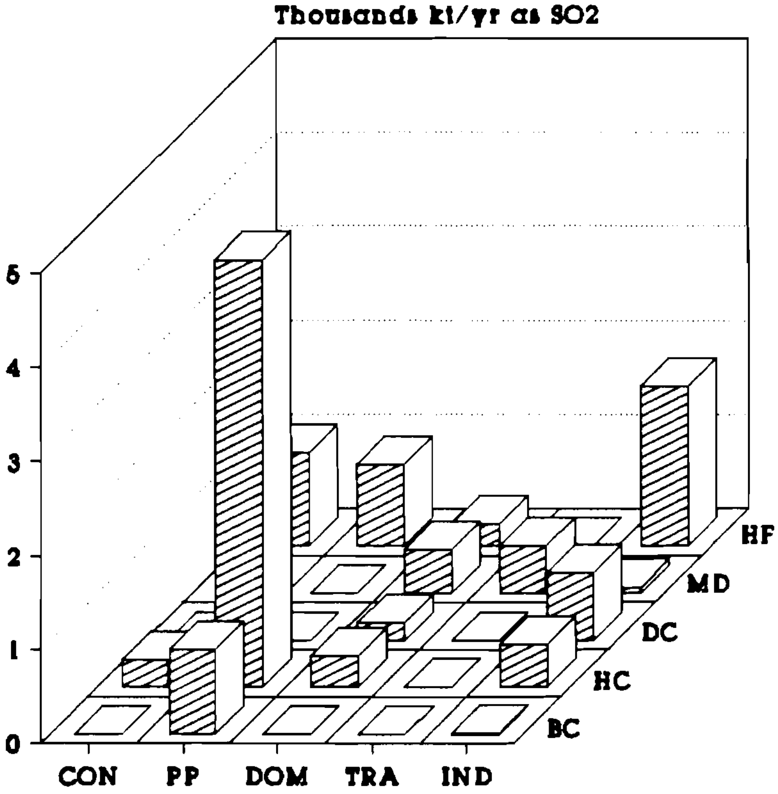


Figure 4: Source profiles for SO_2 for various scenarios. Abbreviations for sectors: CON=Conversion, PP=Power Plants, DOM=Domestic, TRA=Transportation, IND=Industry. Abbreviations for fuels: BC=Brown Coal, HC=Hard Coal, DC=Derived Coal, MD=Medium Distillate, HF=Heavy Fuel Oil.

(b)

SO2 by Sector - 2000 Off. E. Scenario



(c)

SO2 by Sector - 2030 Low Energy Scenario

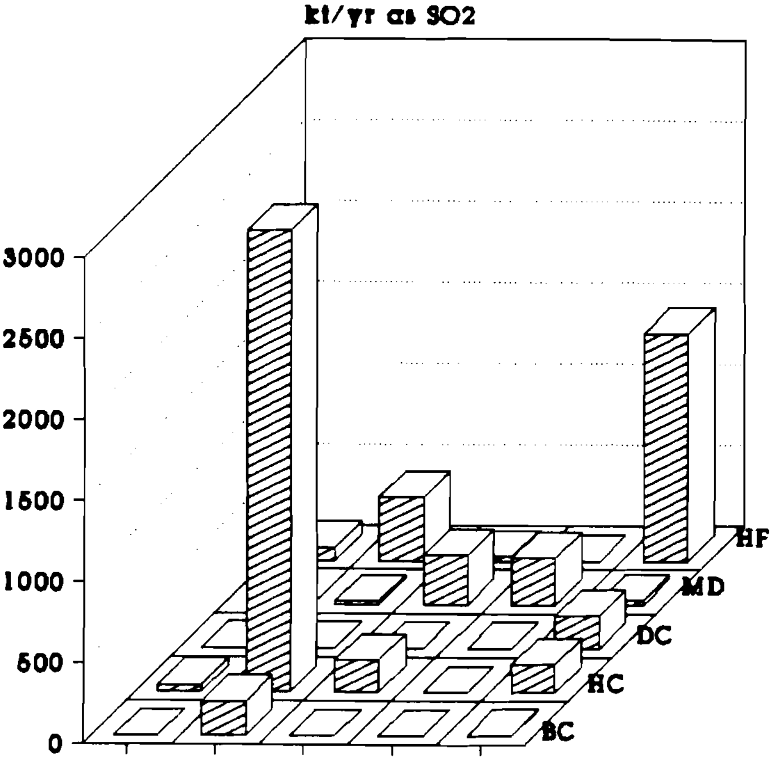


Table 3: NO_X Emissions (as NO_2), country totals and per capita.

Country	Population 1985 (Mill.)	1980		2000 Off. E. Scenarios		2000 Current Red.Plans		2000 Low E. Scenarios		2030 Low E. Scenarios	
		Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)	Total (kt/yr)	Per Cap (kg/pers)
Austria	7.5	233	31.0	269	35.9	149	19.9	269	35.9	62	8.2
Denmark	5.1	255	50.0	270	52.9	190	37.3	124	24.4	81	15.8
France	55.3	2050	37.1	1982	35.8	1360	24.6	2180	39.4	1513	27.4
Ger.(W)	60.4	2892	47.9	2624	43.4	2000	33.1	2057	34.1	1490	24.7
Italy	57.5	1565	27.2	2124	36.9	1125	19.6	1669	29.0	1296	22.5
Nether.	14.7	583	39.7	557	37.9	383	26.1	538	36.6	418	28.4
Norway	4.2	170	40.4	206	49.1	155	36.9	117	27.8	2	0.5
Sweden	7.7	328	42.6	327	42.5	153	19.9	327	42.5	81	10.6
Switz.	5.8	191	32.9	325	56.1	141	24.3	283	48.7	210	36.3
U.K.	52.6	2391	45.5	2530	48.1	2300	43.7	2248	42.7	1396	26.5
Sum or Average	271	10658	39.4	11214	41.4	7956	29.4	9812	36.2	6549	24.2

The average per capita emission of SO_2 in these ten countries was 63 kg/person-year in 1980 and decreases to 29 kg/person-year by year 2030 according to the low energy scenario (Table 2). (We use 1985 population data for all per capita calculations.)

In 1980, per capita emissions were lowest (21 kg/person-year) in Switzerland because hydro- and nuclear-electricity, which does not directly produce sulfur dioxide emissions, is used for a substantial fraction of the country's energy needs. It was highest (89 kg/person-year) in the United Kingdom where sulfur-containing coal is used to satisfy much of its energy demand. The range of per capita emissions is about the same in the year 2000 under the official energy scenario, as in 1980. In year 2030, however, the range between countries is reduced to 10 to 30 kg/person-year.

4.2 NO_x Emissions

In Table 3 we compare NO_X emissions for different scenarios. We again present the emissions expected in the year 2000 according to Current Reduction Plans in different countries (Lübkert, et al, 1990). Only a small difference was calculated between emissions of the low and official energy scenarios for the year 2000 because of the same reasons cited above for SO_2.

For most countries, NO_X emissions under the low energy scenario in the year 2000 exceed the emissions under current reduction plans for the same year. However, the emissions resulting from the low energy scenario in year 2030 are 16% lower than the current reduction plans in 2000 and 37% lower than emissions in the year 1980. NO_X emissions are not reduced as

(a)

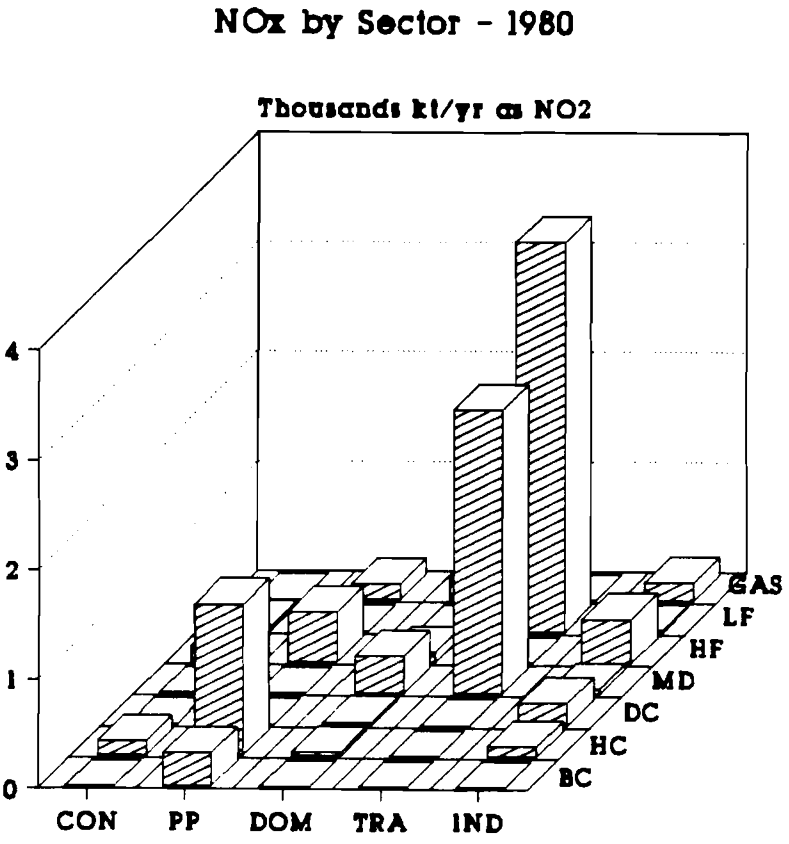
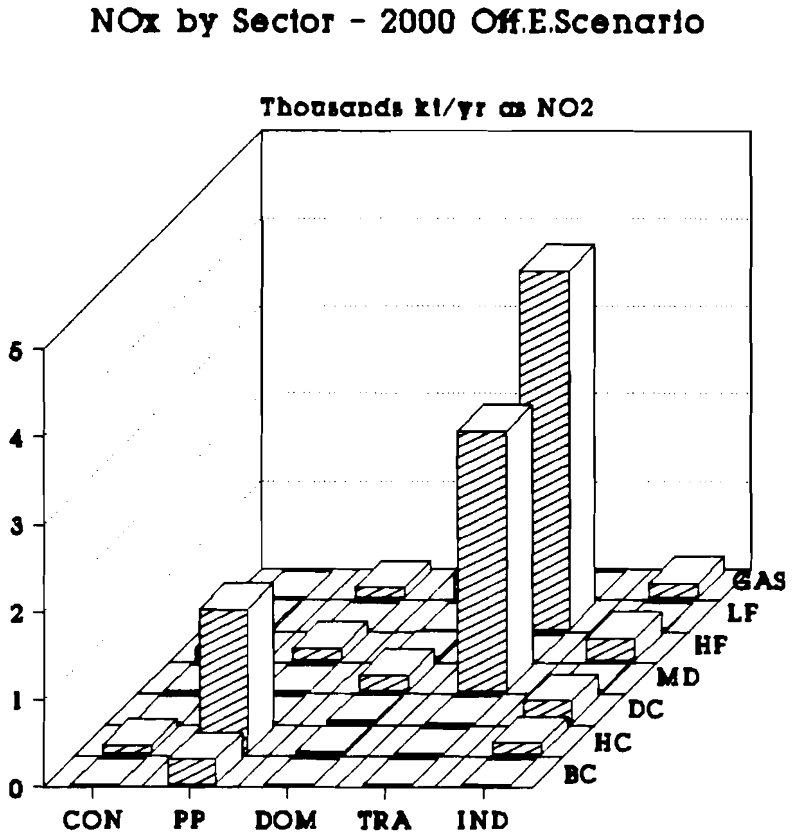


Figure 5: Source profiles for NO_X for various scenarios. Abbreviations for sectors: CON=Conversion, PP=Power Plants, DOM=Domestic, TRA=Transportation, IND=Industry. Abbreviations for fuels: BC=Brown Coal, HC=Hard Coal, DC=Derived Coal, MD=Medium Distillate, HF=Heavy Fuel Oil.

substantially as SO_2 emissions because NO_X emissions in the most important NO_X-producing sector – transportation – decrease only 35% in the low energy scenario between 1980 and the year 2030. Improvements in energy efficiency in this sector will be partly offset by an increase in the amount of traffic in the next century.

Unlike SO_2, the source profile of NO_X is very similar for 1980, 2000 and 2030 (Figure 5). After transportation , which produces 60–65% of total NOx emissions in 1980 and 2000 (Figure 5), the next most important source category is the power plant sector which emitted 20–22% of NO_X emissions in the years 1980 and 2000 and 24% in the low energy scenario, year 2030 (Figure 5). The most important NO_X-producing fuels in the ten Western European countries were medium distillate (mostly diesel) and light fuel oils (mostly gasoline) which together produced nearly two-thirds of NO_X emissions in 1980 and in the low energy scenario, year 2030.

(b)


NOx by Sector - 2000 Off.E.Scenario
Thousands kt/yr as NO2
0
1
2
3
4
5
CON
PP
DOM
TRA
IND
BC
HC
DC
MD
HF
LF
GAS

(c)

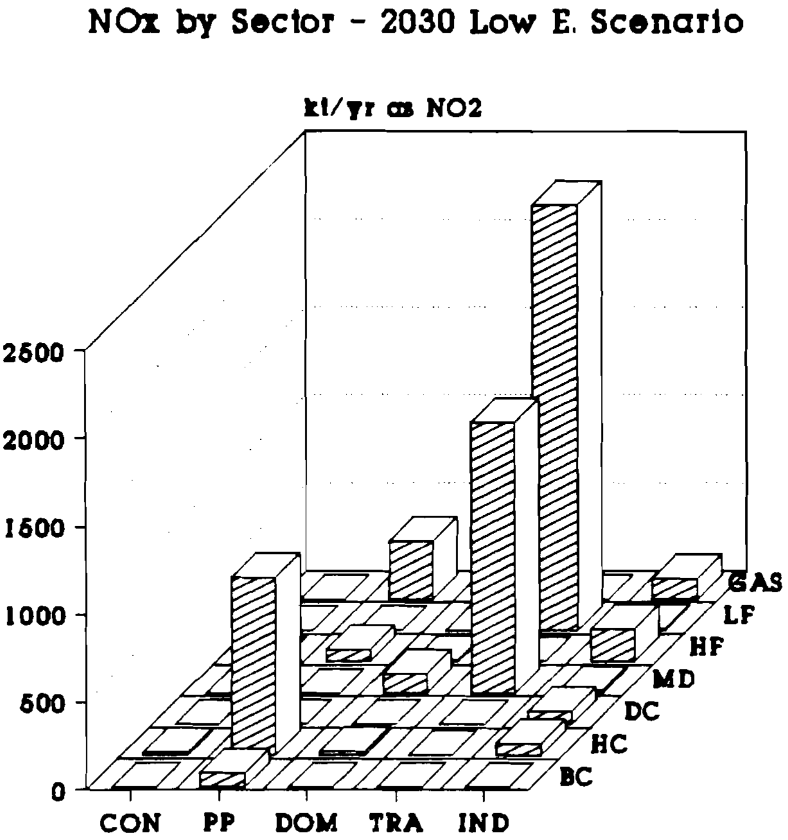

NOx by Sector - 2030 Low E. Scenario
kt/yr as NO2
0
500
1000
1500
2000
2500
CON
PP
DOM
TRA
IND
BC
HC
DC
MD
HF
LF
GAS

Table 4: CO_2 Emissions (as CO_2), country totals and per capita.

Country	Population 1985 (Mill.)	1980		2000 Off. E. Scenarios		2000 Low E. Scenarios		2030 Low E. Scenarios	
		Total (Mt/yr)	Per Cap (t/pers)	Total (Mt/yr)	Per Cap (t/pers)	Total (Mt/yr)	Per Cap (t/pers)	Total (Mt/yr)	Per Cap (t/pers)
Austria	7.5	60	8.0	63	8.4	63	8.4	10	1.3
Denmark	5.1	60	11.8	67	13.1	33	6.4	19	3.7
France	55.3	499	9.0	398	7.2	494	8.9	365	6.6
FRG	60.4	815	13.5	778	12.9	570	9.4	410	6.8
Italy	57.5	375	6.5	476	8.3	413	7.2	313	5.4
Netherlan	14.7	160	10.9	200	13.6	160	10.9	119	8.1
Norway	4.2	31	7.5	34	8.0	29	7.0	0	0.0
Sweden	7.7	82	10.6	65	8.4	65	8.4	24	3.1
Switz	5.8	47	8.1	63	10.9	57	9.8	44	7.6
UK	52.6	606	11.5	646	12.3	512	9.7	319	6.1
Sum or Average	271	2736	10.1	2790	10.3	2395	8.8	1622	6.0

The variation in per capita NO_X emissions between countries (Table 3) was fairly small in the years 1980 and 2000 (31 to 50 kg/person-year), as compared to the variation of SO_2 in either of these years. This is because the main source of NO_X in all countries was transportation, and the same emission factors were used for all countries. The average per capita NO_X emissions decreases from 39 kg/person-year in the year 1980 and 41 in the year 2000 under the official energy scenario, to 25 kg/person-year under the low energy scenario (year 2030). These figures exclude add-on or other controls of NO_X emissions over and above what was in place in 1980.

4.3 CO_2 Emissions

For CO_2 we have computed that total emissions in the ten Western European countries are 41% lower in the year 2030 under the low energy scenario than in 1980 (Table 4). This is approximately the same reduction as for NO_X emissions. In contrast to SO_2 and NO_X, no single sector stood out as the most important contributor to CO_2 emissions (Figure 6). Hence, while SO_2 control strategies can be concentrated on power plants, and NO_X reductions can be focused on transportation sources, CO_2 control strategies must be developed for a number of different source categories now and in the future. Only the fuel conversion sector (refineries and coking plants) is unimportant compared to the other sectors.

In comparing the relative importance of different fuels (Figure 6), only brown and derived coal made relatively small contributions to CO_2 emissions. All other fuel types were significant.

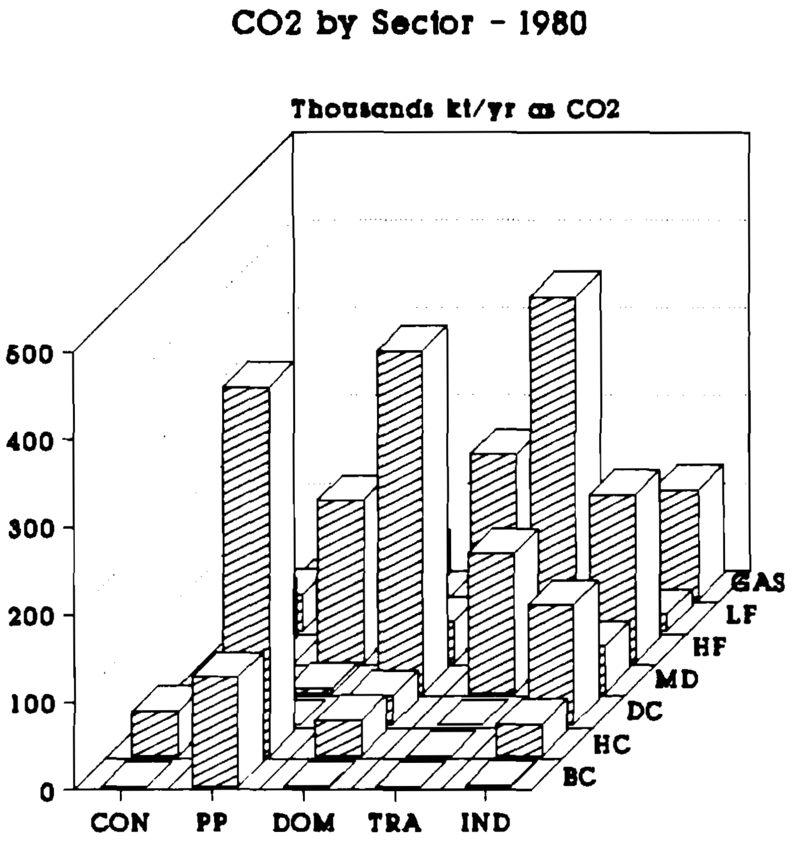
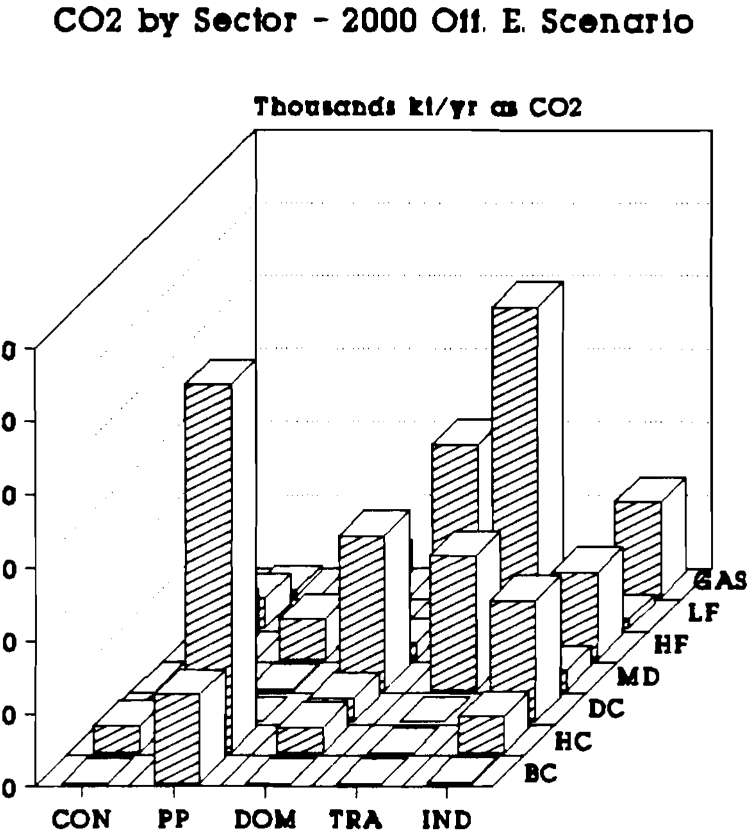


Figure 6: Source profiles for CO_2 for various scenarios. Abbreviations for sectors: CON=Conversion, PP=Power Plants, DOM=Domestic, TRA=Transportation, IND=Industry. Abbreviations for fuels: BC=Brown Coal, HC=Hard Coal, DC=Derived Coal, MD=Medium Distillate, HF=Heavy Fuel.

(b)


CO2 by Sector - 2000 Off. E. Scenario

(c)

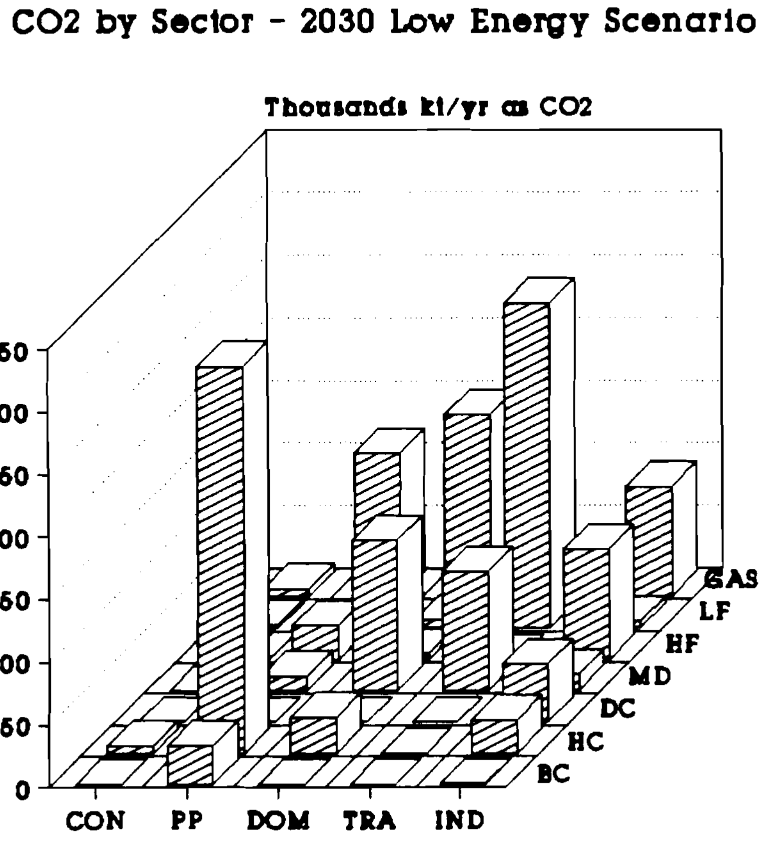

CO2 by Sector - 2030 Low Energy Scenario

Table 5: Per capita CO_2 Emissions in 1980. Source: Rotty, et al (1984), unless otherwise indicated.

Country or Region	Per capita CO_2 emissions (tons CO_2/person-year)
World	4.2
North America	20.5
Oceania (incl. Australia)	9.9
Japan	8.1
Asia (Centrally Planned Economies)	1.5
Middle East	2.4
Latin America	2.4
Africa	1.0
Eastern Europe + USSR	12.5
Western Europe (This Study)	10.1

The range in per capita CO_2 emissions between countries was about 7 to 14 tons/person-year in the year 1980 and year 2000 under the official energy scenario. The average per capita CO_2 emissions for the ten Western European countries in this study was 10.1 tons/person-year in 1980 and 10.3 under the official energy scenario for the year 2000 (Table 4). This is about one-half the per capita emissions in North America, but is in the same range as Japan and countries in Oceania, and a factor of five higher than developing countries (Table 5).

In the year 2030 under the low energy scenario, per capita emissions decrease to an average of 6.1 tons/person-year (Table 4). The range between countries in the year 2030 is large (1 to 8 tons/person-year) because of different assumptions in the low energy scenarios of each country about fuel mix. The Western European countries in the lower end of this range (Austria, Denmark, and Sweden) would have per capita emissions of the same level as currently observed in Latin America or the Middle East (Table 5).

4.4 Uncertainty of Emission Estimates.

The emission factor approach used in this paper to compute emissions has two main sources of uncertainty: the inaccuracy of emission factors and the uncertainty of energy consumption data. As an example of the magnitude of this uncertainty, Eggleston and McInnes (1987a) found that NO_X emissions computed with emission factors were within 40% (two standard deviations) of measured emissions at various road traffic sites in the United Kingdom. For a larger spatial scale, they estimated that the emissions of the United Kingdom computed with emission factors had an uncertainty (two standard deviations) of ±15% for SO_2 and ±45% for NO_X (Eggleston and McInnes, 1987b). Results from the Netherlands are consistent with the British uncertainty estimates. Baars (1990), for example, estimated that emission factors used to compute NO_X traffic emissions in the Netherlands had an uncertainty of about ±10 to ±20% (one standard deviation).

Despite the uncertainty of emission estimates in this paper, they are nevertheless close to other estimates. For instance, the computed SO_2 emissions for 1980 (Table 2) were within ±5% of official estimates for all countries despite somewhat different calculation methods or assumptions. (Official estimates reported in Hordijk, et al 1990, p. 52). The computed sum of emissions for the ten countries was only 1% lower than official estimates.

NO_X emission estimates for 1980 (Table 3) were not as close as SO_2 to official estimates in every country (official estimates also reported in Hordijk, et al 1990, p. 53), although computed emissions for six of the ten countries were within ±10% of official figures. Moreover, the sum of NO_X emissions for the ten countries was within 1% of official estimates.

Calculated CO_2 emissions for 1980 (Table 4) are close to estimates by Rotty, et al (1989), varying from -4% to +15%, depending on the country. The computed sum of CO_2 emissions for the ten countries is slightly larger (5%) than Rotty et al's estimates.

Regarding the computation of future emissions – they have an additional source of uncertainty because emission factors will change according to technological developments and implementation of add-on pollution controls such as catalytic converters and flue gas desulfurization units. Nevertheless, we use the same emission factors for all years, past and future, because we lack sufficient information to change them for all countries and all years. Another reason is that we wish to highlight the reduction of emissions that are obtainable with lower energy use alone without the addition of pollution control devices or the introduction of new combustion technologies.

5 Discussion and Conclusions

The foregoing calculations demonstrate that SO_2, NO_X, and CO_2 emissions can be reduced by substantial amounts (37 to 54%) in Western Europe by improving the efficiency of energy use and by exploiting renewable energy, even without adding pollution control equipment. From an historical perspective (Figures 7, 8 and 9), we see that by the year 2030 the emissions in ten Western European countries could be reduced to their former levels of the 1960s. In the case of SO_2, emissions would decrease far below their magnitude in 1960. This, we reiterate, is without assuming additional pollution controls. Of course, these reductions will not be realized unless the low energy scenarios are technically, economically, and institutionally feasible. In this paper, we have thusfar only briefly touched on these issues.

Regarding technical feasibility, there is mounting evidence that the overall efficiency of energy use in industrial countries can be substantially improved with existing technology. For example,

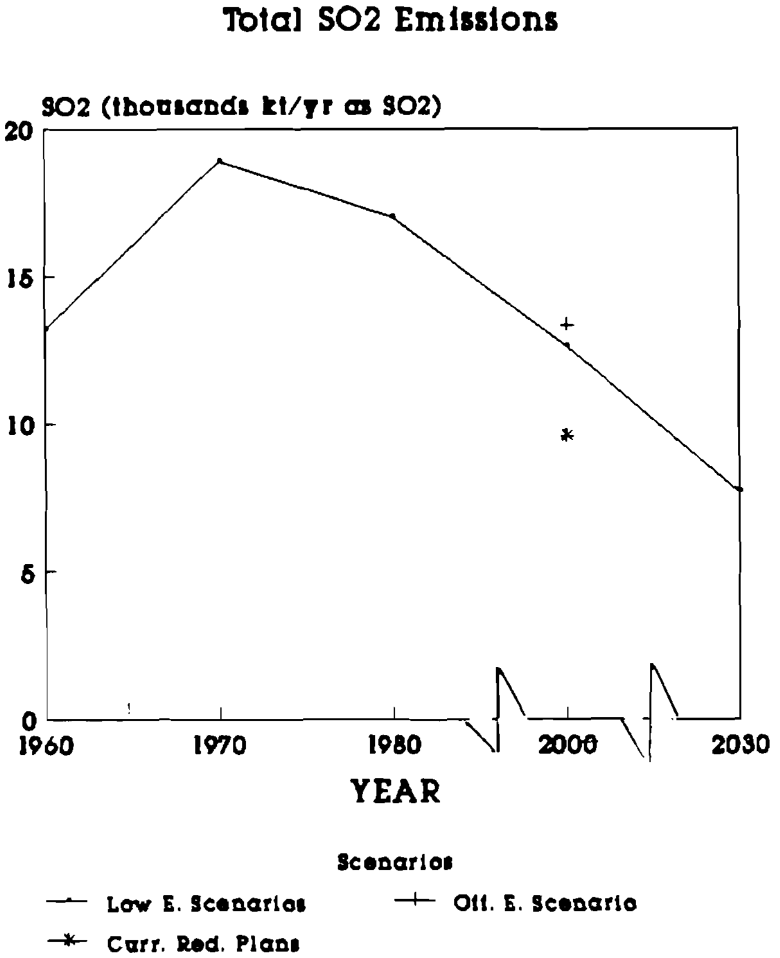


Figure 7: Total SO_2 emissions. Estimates for 1960 to 1980 from RAINS model (Amann, 1990; Alcamo, et al, 1990); for 2000 and 2030, from this paper.

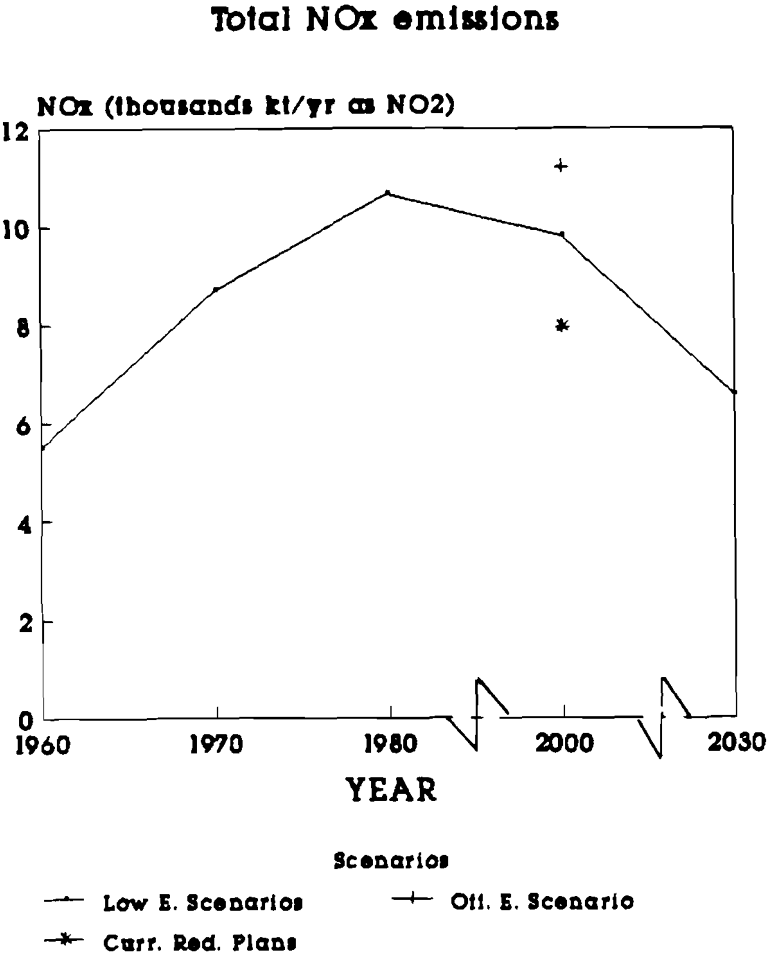


Figure 8: Total NO_X emissions. Estimates for 1960 to 1980 based on emission factors of Springman (1990) as computed in RAINS model (Amann, 1990; Alcamo, et al 1990). Calculations for 2000 and 2030, from this paper.

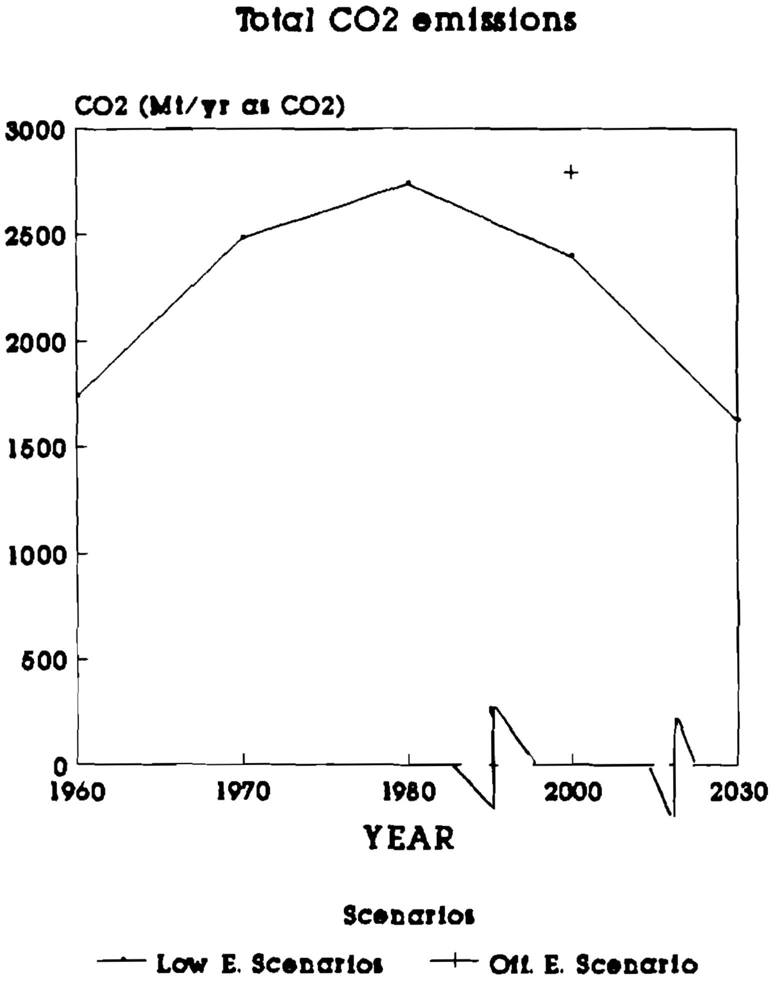


Figure 9: Total CO_2 emissions. Estimates for 1960 to 1980 from Rotty, et al (1984); for 2000 and 2030, from this paper.

Johansson et al (1989) have estimated that up to 50–80% of electricity use in Western Europe can be saved by using currently available technology. In addition they estimated that space heating requirements in northwestern Europe can be reduced by one-third, while maintaining current comfort levels. Automobile performance in km/l fuel can also be doubled with existing technology (Bleviss, 1989).

The economic and institutional feasibility of these low energy scenarios is a more open question. For example, we may see an erosion of public support for energy conservation if these programs begin to compete for capital with social welfare programs. As another example, calculations with a macro-economic model of the European Community (EC) indicate that the costs of a drastic CO_2 emission control program in Europe could be incompatible with the rapid growth of the service-sector projected in recent EC scenarios (Slesser and de Vries, 1990).

Related to the issue of institutional feasibility is the question of how long it would take to implement the low energy scenarios. According to the researchers who developed these scenarios, their low energy goals would not be reached until sometime between 2010 and 2030. Consequently, in this paper we compute that the differences in emissions between the official and low energy scenarios would be rather small in the short run (year 2000) (Tables 2, 3 and 4). Of course the length of time required to phase in the necessary infrastructure is not immutable, and to an extent could be accelerated. Yet there may be greater opportunities for accelerated energy conservation in the coming years in Eastern Europe, where entire national economies are being restructured and where environmental problems are very severe.

For Western Europe, because of this potential lag in implementing energy efficiency improvements, it would not be prudent in the short run to rely on reduced energy use alone to reduce SO_2 and NO_X emissions. For these pollutants, add-on controls are available, cost-effective, and already widely implemented. As Tables 2 and 3 note, many Western European countries have already committed themselves to a 50% or greater reduction in SO_2 emissions by the year 2000, or before. The situation is different for CO_2 where no affordable add-on controls are yet obvious. In this case, the 41% reduction in emissions resulting from low energy scenarios are indeed of significance to Western Europe. Recent government policy statements have recognized the importance of more efficient energy use, as well as shifting their country's fuel mix from coal and oil towards increasing use of gas and nuclear energy, as important strategies for reducing CO_2 emissions. As one example, the Danish government now officially projects a 20% decrease in CO_2 emissions in year 2005 relative to year 1980, as compared to a 12% increase we compute under the official energy scenario (Table 4). Similarly the Dutch government is committed to a 3 to 5% reduction of CO_2 emissions by the year 2000, and at least 10 to 15% by the year 2010.

Apart from these questions of feasibility and timing, our calculations indicate that a low energy strategy would be especially attractive in Western Europe because it would not only substantially, but also simultaneously, reduce SO_2, NO_X, and CO_2. Current international negotiations have thusfar concentrated on individual agreements to reduce SO_2 and NO_X in Europe and CO_2 around the globe. But the calculations in this paper show that these pollutant emissions are closely linked in Europe, and that it is possible to have a common strategy to combat the precursors of regional acidification, large-scale photochemical air pollution, and global warming.

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Appendix A: Emissions Factors for CO_2, NO_X, and SO_2

Fuel: BC=Brown Coal; HC=Hard Coal; DC=Derived Coal; MD=Medium Distillate; HM=Heavy Fuel Oil; LF=Light Fuel Oil; Gas=Natural Gas

Sector: CON=Fuel Conversion; PP=Power Plants; DOM=Domestic Combustion: TRA=Transportation; IND=Industrial Combustion

CO2 Emission Factors (kt CO2/ PJ)

Fuels	Sectors				
	CON	PP	DOM	TRA	IND
BC	111	111	111	111	111
HC	92	92	92	92	92
DC	92	92	92	92	92
MD	80	80	80	80	80
HF	80	80	80	80	80
LF	80	80	80	80	80
GAS	53	53	53	53	53

NOx Emission Factors (t NOx as NO2 / PJ)

Fuels	Sectors				
	CON	PP	DOM	TRA	IND
BC	200	270	70	0	200
HC	230	300	80	150	230
DC	230	0	70	0	140
MD	70	0	70	1300	70
HF	170	200	160	0	170
LF	70	0	0	750	70
GAS	0	150	60	0	70

Sulfur Emission Factors (t SO2/ PJ)
Country: Austria

	CON	PP	DOM	TRA	IND
BC	504	504	504	504	504
HC	649	649	649	649	649
DC	760	760	760	760	760
MD	235	235	235	235	235
HF	1687	1687	482	1446	1446

Sulfur Emission Factors (t SO2/ PJ)
Country: Denmark

	CON	PP	DOM	TRA	IND
BC	758	758	758	758	758
HC	800	800	800	800	800
DC	519	519	519	519	519
MD	188	188	188	188	188
HF	1687	1687	964	964	1205

Sulfur Emission Factors (t SO2/ PJ)
Country: France

	CON	PP	DOM	TRA	IND
BC	3984	3984	3984	3984	3984
HC	619	619	619	619	619
DC	649	649	649	649	649
MD	235	235	235	235	235
HF	1687	1687	675	1687	1687

Sulfur Emission Factors (t SO2/ PJ)
Country: Germany, F.R.

	CON	PP	DOM	TRA	IND
BC	501	752	501	501	501
HC	651	685	651	651	651
DC	389	389	389	389	195
MD	118	118	118	118	118
HF	964	723	482	482	602

Sulfur Emission Factors (t SO2/ PJ)
Country: Italy

	CON	PP	DOM	TRA	IND
BC	1594	1594	1594	1594	1594
HC	584	584	584	584	584
DC	324	324	324	324	259
MD	376	376	376	376	376
HF	1542	1542	1542	1542	1542

Sulfur Emission Factors (t SO2/ PJ)
Country: The Netherlands

	CON	PP	DOM	TRA	IND
BC	372	372	372	372	372
HC	649	649	649	649	649
DC	519	519	519	519	195
MD	141	141	141	235	141
HF	1301	723	723	723	723

Sulfur Emission Factors (t SO2/ PJ)
Country: Norway

	CON	PP	DOM	TRA	IND
BC	559	559	559	559	559
HC	519	519	519	519	519
DC	519	519	519	519	195
MD	141	141	141	141	141
HF	578	578	578	578	578

Sulfur Emission Factors (t SO2/ PJ)
Country: Sweden

	CON	PP	DOM	TRA	IND
BC	372	372	372	372	372
HC	648	648	648	648	648
DC	324	324	324	324	324
MD	141	141	141	141	141
HF	964	482	482	482	964

Sulfur Emission Factors (t SO2/ PJ)
Country: Switzerland

	CON	PP	DOM	TRA	IND
BC	559	559	559	559	559
HC	649	649	649	649	649
DC	514	514	514	514	514
MD	141	141	141	141	141
HF	1157	1157	1157	1157	1157

Sulfur Emission Factors (t SO2/ PJ)
Country: United Kingdom

	CON	PP	DOM	TRA	IND
BC	559	559	559	559	559
HC	1148	1148	1148	1148	1148
DC	577	577	577	577	577
MD	141	141	141	141	141
HF	1012	1205	964	964	1205

Appendix B: Brief Description of Low Energy Scenarios

Country	Target year	Demand analysis	Economic/financial instit. considerations
Austria	2030	++ (HA,HP,T)	o
Belgium	2000	o (E only)	++
Denmark	2000-2012	++++ (IN,E)	+
Finland	2020	++ (E only)	++
France	2010	+	+
FRG	2000-2010	+++ (IN,HA,T)	+
Italy	2020	+	o
Netherlands	2000	+++ (E only)	+++
Norway	2000	+	+
Spain	1992-2017	o (E only)	+
Sweden	2010	++++ (IN,E)	+++
Switzerland	2010	++ (IN,HA,T)	++
UK	2000-2025	+++ (IN,E)	++

	Electric power capacity model	Nuclear phase-out	Cogeneration assessment	Renewable assessment
Austria	-	o	o	+ (H,B,SH)
Belgium	+++	+++	+	o
Denmark	+	o	++	++++ (B,W,S)
Finland	++	+	+++	+++ (H,B,W,S)
France	+	+++	+	+ (H,W,S)
FRG	+	++	+++	+ (W,S)
Italy	o	++	+	
Netherlands	+++	+	+++	+++ (W)
Norway	o	o	o	++ (H,B,S)
Spain	+	+++	+	+ (H,W,S)
Sweden	++	+++	+++	+++ (H,B,W,S)
Switzerland	+	+++	+	+
UK	+	+	+	

Legenda : IN Insulation HA Household Appliances HP Heat Pump E Electricity
H Hydropower W Windpower B Biomass (incl. wood) S Solar energy SH Solar Heat

o not analysed/no details/not known ++++ very well modelled/analysed/documented