Air Pollution Control Strategies

A Comparative Analysis for Poland and the Federal Republic of Germany

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Chapter 1

Introduction

Growing concern in Europe about environmental damage has led to a call to tighten regulations in the area of energy related pollution.

Due to the transboundary transport of pollutants, environmental damage is not limited to the country from which the emissions originate. The damage is distributed throughout Europe burdening other countries. The 'polluter-pays-principle' requires international collaboration in the field of long-range pollutant reduction policies as e.g. for the acidifying substances SO_2 and NO_x. The import and export balances of SO_2 for different countries of Europe indicate that national reduction policies may fail, if neighbouring countries do not pursue the same objective.

International conferences have been organized on this issue with the target to establish an international convention in the area of transboundary pollutants. A general goal was defined by the Economic Commission for Europe to cut SO_2 emissions at least by 30% of the 1980 value in 1993 following the 1982 Stockholm Conference on the Human Environment. The countries which signed a protocol to this UN Convention on Long Range Transboundary Air Pollution became known as the '30% Club'.

Poland is not member of this club but a reduction of SO_2 is an important target. Hence, the protection of the environment has been established as a principal political objective.

In the Federal Republic of Germany laws have already been enforced aiming at the reduction of both pollutants SO_2 and NO_x. Emission control has been applied to all sectors of the economy but the biggest efforts have been made in the power generation and transport sectors. Generally, the best available technology which is economically viable should be applied as a rule, but for real implementation some tighter regulations have been added. The usual instruments for legislation are:

- emission standards
- percentual removal requirements
- fuel quality requirements
- bubble policy
- emission charges or taxes
- fuel taxes
- subsidies for less emittant technologies
- prohibition of using certain technologies or technological processes.

The implementation and enforcement of these instruments do not necessarily result in cost-effective pollution reduction strategies. Furthermore, nationally efficient strategies may not necessarily be equally good in a European context. Different control policies may cause competition distortions due to varying standards and fuel specification restricting the free trade of technologies and fuels. The tightening of regulations may also cause price increases reducing the competitiveness on the world market of energy intensive sectors.

Obviously, control policies cannot directly be transfered to other countries. Policy options, their cost-effectiveness and potentials differ in a broad range in different countries. For this reason, national goals for air pollution control must account for the national pecularities such as:

- energy consumption per capita and dynamics of energy growth
- existing structure of the energy sector
- economic situation, welfare
- social acceptability of supply options
- level of pollution (ambient air concentrations)

Both, goals and the way of achieving them differ from country to country. National energy models being extended to environmental issues have proved to answer a set of questions arising in the context of the energy-environmental questions. This report gives the results of a successful application of the optimization approach to analyse in a comparative way current emission control policies for Poland and the F.R.G. and presents some suggestions for future cost-effective control options for each country.

Chapter 2

The Objectives of the Study

The study presented here has four main objectives, namely:

- to describe and compare the energy and environmental situation in Poland and in the F.R.G.,
- to develop and compare energy-environment models for Poland and for the F.R.G.,
- to demonstrate practical usefullness of the models,
- to elaborate emission control strategies for the next twenty years for Poland and for the F.R.G. and
- to perform a comparative analysis.

The study refers to two countries being very different in many aspects. Different levels of development and a different economic system are the basic causes of differences concerning the ways in which energy is used. As a consequence, serious differences in environmental problems exist. These issues are discussed in chapter 3.

Energy-environment models for both countries are based on the experience gained up-till-now in modelling energy system expansion. Existing energy models, oriented on balancing energy demand with supply have been modified and extended by environmental modules what has made them capable to address environmental issues at a national level.

In case of the F.R.G. the EFOM model has been modified in a way that various emission control options were added to energy production, conversion and utilization technologies. In addition, fuels reflecting different quality standards such as heavy fuel oil with low sulfur content or low grade coal were introduced into the model. Future emission reduced supply options such as renewables (wind, photovoltaics) and 'clean' coal technologies were considered as well.

Investigations for Poland have been based on an extended version of the SPSEK model set. The main extensions of SPSEK can be summarized as:

- changes in the aggregation of energy carriers in order to consider the differences in sulphur and ash content of different grades of fuel,
- calculation of emissions of airborne pollutants from final energy utilization sphere through modifications of final energy demand model PROSK,
- addition of emission control options to energy supply and conversion model DORSEK including retrofitting of existing objects.

The main features of the applied models used within the study are described and compared in chapter 4.

During the study it has been demonstrated that the models can provide a reasonable framework within which environmental protection strategies at a national level can be elaborated. In particular, it has been shown that model analyses can deliver rational arguments in discussions about the ways of achieving environmental goals at a national level. Assumptions for the study as well as a description of environmental scenarios are discussed in chapters 5 and 6.

The models developed during the study were applied to the elaboration of SO_2 and NO_x emission control strategies. Costs of these strategies have been assessed and their effects on emission level, investment funds requirement and the structure of the energy supply system, including fuel exports and imports have been analyzed.

Finally, the results of the analyses for Poland and the F.R.G. have been compared and the main differences and similarities have been identified. This part of the work is summarized in chapters 7 and 8.

The tools developed so far were able to support the analysis of different questions arising in the context of European energy-environmental problems such as:

- What standards should be established for emission reduction?
- How can emission reduction goals be achieved in an effective way? This means:
  - by which technology options?
  - with which efficiency of the energy system?

  - with which technology related side-effects (e.g. new by-products)?

- What will be the impacts of pollution control on the energy supply system?
  - What are the additional investments and costs associated with given control strategies and environmental objectives?
  - What is the effect on the emission level?
  - What is the impact on the energy supply structure and the energy consumption?

To answer these questions the cost and potentials of available emission reduction options must be assessed on a national level. Furthermore, national characteristics of the energy-environmental issue have to be taken into account, such as:

- available domestic energy sources,
- technical structure of the energy system,
- existing demand and supply structure,
- existing legal framework,
- general policy directives concerning other issues of the energy economy (e. g. supply security, long-term contracts, continuity of energy policy).

The approach of energy system modelling provides a useful framework for answering those questions above. But there are also several questions which can not be addressed with the help of this type of models, as e.g.:

- What are the benefits of a given environmental strategy?
- What is the impact on the economy?
- What are the social consequences of a policy?
- Which is the best legal tool to ensure cost-efficiency of measures?

Chapter 3

Present Energy and Environmental Situation

3.1 The Situation in the Federal Republic of Germany

As a result of the rapid increase in forest damages in Central-Europe, the need for the reduction of air pollution from energy conversion and energy-end-use technologies became an important political objective. The acid rain which is mainly caused by SO_2, NO_x, and chemical derivatives thereof, damages buildings, acidifies rivers, lakes and soil and diminishes the harvests. The estimations of those damages are up to several hundred million ECU per year.[1]

Air pollutions are distributed over large distances partly over several thousand kilometers crossing several borders. All European countries are burdened by the transport of air pollutions from other countries. In some countries of the European Community more than 50% of the sulphur deposition are originated by foreign sources. This clarifies the fact that any measures to reduce environmental damages can only be effective in an international context.

The area of the Federal Republic of Germany is 248709 km^2. The population amounts to 61.1 mill people (31.12.1986). This means an average of 246 inhabitants per km^2. With this population density, Germany is third densest country within the European

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[1] Environmental Resources Limited: ACID RAIN - A Review of the Phenomenon in the EEC and Europe, Brussels and Luxembourg, 1983: It is impossible as yet to determine with any precision the average annual damage costs which might be attributable to acid precipitation. However, it seems probable that in total they would be in the range $ 0.5 - 3.5 billion. [16]

Community after Belgium and the Netherlands [1].

The climatic conditions in the Federal Republic of Germany are determined by its location in the temperate zone with frequent changes in the weather. During all times of the year, the winds are mainly coming from westerly directions. The annual precipitation increases from the north to the south from approx. 500 mm to approx. 2000 mm per year. From the northwest to the east and to the southeast there is a steady transition from an oceanic to a more continental climate. Nevertheless, there are no extreme differences in temperature throughout the year [1].

The sulphur dioxide (SO_2) emissions decreased steadily since the early 1970s from 3.7 Mt in 1972 to 2.6 Mt in 1984 due to technological progress in industry, fuel switching in the tertiary and domestic sector and an increasing share of nuclear power for the generation of electricity. At the same time the nitrogen oxides (NO_x) emissions increased from 2.0 Mt in 1970 to 3.0 Mt in 1984. One of the reasons for this increase must be seen in steadily growing energy use for transportation, particularly for road transportation. Technological progress in the development of more efficient engines has led to higher engine temperatures and thus a higher specific NO_x-emission.

For 1980 the SO_2- and NO_x-emissions for the Federal Republic of Germany can be taken from Table 3.1 [2].

Table 3.1: SO_2 and NO_x Emissions in the Federal Republic of Germany in 1980 by sectors

Sector	SO_2-Emission [Mt]	Percentage [%]	NO_x-Emission [Mt]	Percentage [%]
Power and Heating Plants	1.90	59.3	0.86	27.6
Industry	0.87	27.3	0.40	13.1
Tertiary and Domestic Sector	0.33	10.3	0.14	4.5
Transportation	0.10	3.1	1.70	54.8
Total	3.20	100.0	3.10	100.0

Meteorological investigations of transboundary deposition of sulphur dioxide found out that about 44% of the total SO_2-deposition in the Federal Republic of Germany stems from domestic sources [3]. More than a half of the sulphur fall out is imported from neighboring countries. Likewise, the Federal Republic of Germany transports more than half of its total SO_2 emissions into other European countries.

3.1.1 General Environmental Policy

Growing damages in the Black Forest and other mountains in the Federal Republic of Germany lead to a call to rapidly cut down the emissions of sulfur oxides and later on also those of nitrogen oxides. Historically, most attention focused on sulfur dioxide (SO_2) and its wet form sulfuric acid. At that time, the public summarized the problem of newly observed plant and tree damage under the 'acid rain' discussion. Recent investigations suggest that nitrogen oxide (NO_x) emissions may also contribute significantly to plant and tree damage. In particular ozone, of which NO_x is a chemical precursor, can at certain concentrations under summer climate conditions, cause damage to some trees and plants, possible in conjunction with SO_2 and NO_x.

An estimation of the financial consequences of the forest damage is difficult to perform because of the irreplacable ecological importance of the forrest. What can be estimated monetarily without bigger evaluation problems is the value of the timber lost due to environmental impacts. Forest owner associations estimated the present loss in the region of 1 billion DM per year for the Federal Republic of Germany alone. But a direct dose-impact relationship to SO_2 or NO_x can still not be given.

Public awareness and sensitivity of this problem pushed the politicians to fast decisions. For both pollutants, the Bundesimmissionsschutzgesetz (BImSchG) provided a good framework for the introduction of emission standards for new and existing power and heating plants. In the year 1983 the "GFAVO" passed law to reduce significantly the emissions from large fossil fuel burning plants applying emission standards and percentual reduction requirements. The most stringent standards apply to plants over 300 MW_{th} which must be fitted with SO_2 and NO_x equipment until mid 1988, or operated for limited hours and shut down after 1993. Percentual removal requirements force the operator to install secondary SO_2 and NO_x scrubbers. Most of the coal fired units have been retrofitted with limestone/gypsum wet scrubbers and other wet scrubbers and selective catalytic reduction installations (114 GW_{th} [46]). The other measures like spray dry scrubbers, sorbent injection and fluidised bed boilers have been of minor importance (17.7 GW_{th} [46]). In the year 1986 the Technical Guideline for Air Quality Control tightened the emission standards for smaller combustion installations mainly in industry, but its impact on the application of secondary measures was less significant. The main reactions were the adoption of primary measures such as low-NO_x burner, combustion modification or a fuel switch to natural gas which made an inroad in the industrial energy market during the last decade.

For the transport sector the need to come up with a new harmonized European regulation of emission control created big problems. Car producers of different countries feared of loosing market shares if the strict USA standards would have become valid for the EC. Therefore in F.R.G. only cars with a displacement larger than 2.0 l were forced by means of standards to have a controlled catalytic converter, those between 1.4 and 2.0 l have to use at least uncontrolled catalytic converters while for small cars primary measures are sufficient to comply with standards. Recent discussions suggest that this might not be enough to reduce emissions from transport purposes so that the controlled catalytic converter may be obligatory for all gasoline driven cars.

3.1.2 National Emission Standards and Regulations

In the Federal Republic of Germany several different administrative air pollution control regulations have been enforced. In the following the most important regulations are listed for each sector.

- Power and Heating Plants

  In 1983 the Statutory Ordinance on Large-Scale Combustion Installations ("GFAVO") [4], [9], and in 1986 the Technical Guideline for Air Quality Control ("TA Luft") [5], [10], for smaller installations have become effective. These regulations/instructions are based on plant specific emission standards which are summarized (for new installations) in Table 3.2. Already existing plants have to be either converted, retrofitted, or shut down within a specified transition period.

Table 3.2: SO_2- and NO_x-Emission Standards for Stationary Combustion Installations

Thermal Power Input (MW)	Standards [mg/m^3]					
	SO_2			NO_x		
	Coal	Oil	Gas	Coal	Oil	Gas
1-5	2000	Light Oil only	-	500	Light Oil:250 Other :450	-
5-10		1700	-			-
10-50			$35^{3)}$			200
50-100				400	300	
100-300	$2000^{1)}$	$1700^{1)}$				
>300	$400^{2)}$	$400^{2)}$		200	150	100

1)An additional 60% emission reduction efficiency is required
2)An additional 85% emission reduction efficiency is required
3)Emission standard for natural gas

- Industry

The "TA Luft" provides the emission standards for industrial boilers and for most of the applied industrial production processes. Apart from emission standards for particulates, SO_2 and NO_x, the "TA Luft" also includes emission limits for heavy metals and carcinogenic substances. As a more general instruction, the "TA Luft" postulates from the industry to apply the best available control technology according to Paragraph 3 of the "BImSchG"[6].

1. Refineries

   For catalytic crackers the following emission standards are valid:

Pollutant	Standard $[mg/m^3]$
SO_2	1700.0
NO_x	700.0

   Moreover, several product specifications are valid for liquid fuels, which impact (through higher costs) the consumption of the fuels and thus on the environmental situation. One example is the legislation of the maximal sulphur content of gasoil which was set from the previous level of 0.3 to 0.2 weight percentage [7]. This regulation has been set in force on March 1, 1988.

2. Cokeries

   According to "TA Luft", the emission limits are:

Pollutant	Standard $[mg/m^3]$
SO_2	800.0
NO_x	500.0

3. Cement Industry

   While for all processing plants the SO_2-emissions are limited to 400.0 [mg/m^3], the NO_x-standards are different for each type of preheating system:

System	Standard $[mg/m^3]$
Grate Preheater	1500.0
Cyclonic Preheater with heat recovering system	1300.0
Cyclonic Preheater without heat recovering system	1800.0

4. Iron & Steel Industries

SO_2 and NO_x emission standards are valid for sintering plants as well as for rolling mills. In case of the usage of coke oven gas in rolling mills, the SO_2 emissions are limited according to the "TA Luft". The NO_x-standard depends on the temperature of the air preheating system.

Pollutant	Sintering Plant $[mg/m^3]$	Rolling Mill $[mg/m^3]$
SO_2	500	—
NO_x	400	500 - 1300

- Transportation

For all countries of the European Community the ECE-regulation No. 15 in connection with the EEC-regulation 70/220/EEC is valid in its present version (ECE-R-15/04), which has been set in force in the Federal Republic of Germany in 1982. These European regulations set the emission of CO, C_mH_n and NO_x.
Presently, a new updated version of the ECE-R-15 is under discussion. In the Federal Republic of Germany, this regulation has already become effective. It lays down a stepwise reduction of CO, NO_x and VOC emissions depending on the displacement class of the car. The emission limits refer to the EEC 70/220-test.

To reduce emissions as soon as possible, car owners were encouraged by tax reductions to retrofit their cars or to buy new cars with less emissions.

Table 3.3: Emission Limits for Cars According to ECE-R-15/05 (Dec. 3,1987)

Displacement Class [cm^3]	Pollutant	Emission Limit [$g/test$]	Starting Year	
			new cars	new models
≤1400	CO $C_mH_n + NO_x$ NO_x	45 15 6	Oct 1,1991	Oct 1,1990
1400-1999	CO $C_mH_n + NO_x$	30 8	Oct 1,1993	Oct 1,1991
≥2000	CO $C_mH_n + NO_x$ NO_x (at max.)	25 6,5 3,5	Oct 1,1989	Oct 1,1988

- Tertiary and Domestic sector

For the household and tertiary sector, the Statutory Ordinance on Small-Scale Combustion Installations ("Kleinfeuerungsanlagenverordnung")[11], [12] applies nationally. The standards relate to the quality of fuels used as well as operating conditions of the combustion installations. The standards can already be met by burner adjustments. Neither special primary nor secondary measures are required.

3.2 Present Energy and Environmental Situation in Poland

Poland belongs to a group of countries with centrally planned economies. These countries are characterized by relatively high energy intensity to compare with market economies. Comparison of energy consumption per unit GDP for different European countries (after Kumanowski, 1989, [41]) is presented in Table 3.4.

Table 3.4: Energy intensiveness of the European CMEA countries and developed market economies

Country	Gross energy consumption tce/cap	Energy intensity tce/thousand US$ GDP	
		A	B
CMEA average unweighted	5.93	1.04	.
Bulgaria	5.72	1.13	.
CSRS	6.51	0.96	.
GDR	8.04	1.10	.
Hungary	4.23	0.84	2.39
Poland	4.69	1.18	2.45
USSR	6.40	1.04	.
'Market' aver. unweighted	4.67	0.42	0.53
Austria	4.67	0.44	0.54
Denmark	5.38	0.45	0.47
France	4.87	0.43	0.53
FRG	6.39	0.52	0.60
Italy	4.23	0.33	0.48
Spain	2.48	0.33	0.58

A - GDP expressed in US $ according to purchasing power parity

B - GDP expressed in US $ according to official exchange rate

Despite of methodological difficulties in such comparisons, it is evident that Polish economy uses 3-5 times more energy per unit of GDP than Western European countries. The main reasons of it are as follows:

- higher share of branches producing raws in industry;
- low quality of products in manufacturing and consumer goods industries what decreases output value;
- high material intensity of production and excessive transport intensity of the economy;
- heavy dependence on coal in electricity and heat production and, in consequence, lower conversion efficiency;
- extensive use of coal as household fuel what has negative efficiency and environmental impacts. This heavy dependence on coal did not change over the last twenty years;
- high heat losses in residential sector due to bad insulation properties of houses.

A high level of energy consumption relative to GDP is typical of all CMEA economies and this feature is clearly linked to the nature of the incentives, or rather lack of incentives, for efficient use of energy in centrally planned economies.

The structure of final energy demand in Poland in the year 1985 is shown in Table 3.5.

Table 3.5: Final energy demand in Poland in 1985 by fuels and by sectors

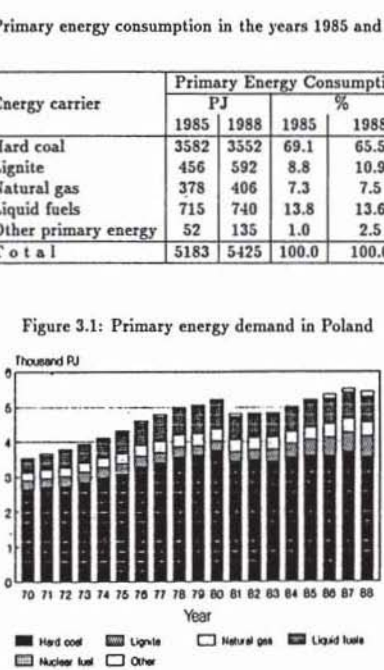
[PJ]							
		of which					
Sector	Total	Solid fuels	Liquid fuels	Gases	Heat	Electricity	Other
Industry	1406	294	88	269	501	177	77
ferr.metals	402	124	26	118	43	31	59
non ferr.met.	52	14	1	8	7	19	3
equipm. goods	158	15	11	21	78	32	0
chemical ind.	332	16	6	84	170	44	11
building mat.	195	109	11	34	25	14	2
other	267	17	32	2	178	37	2
Construction	68	4	28	0	26	10	0
Agriculture	103	21	40	0	32	9	1
Transport	223	56	133	0	9	23	3
Househ.& other	1596	839	178	113	309	128	28
Total	3396	1214	466	384	877	346	109
percentage							
Industry	41.4	20.9	6.3	19.1	35.6	12.6	5.5
ferr. metals	11.8	30.8	6.5	29.3	10.7	7.7	14.7
non ferr.met.	1.5	26.9	1.9	15.4	13.5	36.5	5.8
equipm. goods	4.6	9.5	7.0	13.3	49.4	20.3	0.
chemical ind.	9.8	4.8	1.8	25.3	51.2	13.3	3.3
building mat.	5.7	55.9	5.6	17.4	12.8	7.2	1.0
other	7.9	6.4	12.0	0.7	66.7	13.9	0.7
Construction	2.0	5.9	41.2	0.	38.2	14.7	0.
Agriculture	3.0	20.4	38.8	0.	31.1	8.7	0.1
Transport	6.6	25.1	59.6	0.	4.0	10.3	1.3
Househ.& other	47.0	52.6	11.2	7.1	19.4	8.0	1.8
Total	100.0	35.7	13.7	11.3	25.8	10.2	3.2

In addition to the high energy intensity of the Polish economy, the country is much more dependent upon coal as its primary source of energy than other countries with comparable income levels and industrial structures. In 1985 coal accounted for 78% of Poland's primary energy use. The only countries with higher dependence upon coal were South Africa, North Korea and China. The share of coal in primary energy use was less then 25% in most OECD countries. In general, heavy dependence on coal is a feature of centrally planned economies. Primary energy consumption in Poland (after [37], [38]) is shown in Table 3.6 and in Figure 3.1.

Table 3.6: Primary energy consumption in the years 1985 and 1988 by fuels

Energy carrier	Primary Energy Consumption			
	PJ		%	
	1985	1988	1985	1988
Hard coal	3582	3552	69.1	65.5
Lignite	456	592	8.8	10.9
Natural gas	378	406	7.3	7.5
Liquid fuels	715	740	13.8	13.6
Other primary energy	52	135	1.0	2.5
Total	5183	5425	100.0	100.0

Figure 3.1: Primary energy demand in Poland



The above data show that heavy dependence on coal didn't change over the last 20 years. Additionally, large proportion of hard coal used for electricity and district heat production is of a low quality with calorific value below 20 MJ/kg and ash content 20-30%. Due to deficit of lump size coals sometimes fine coal or even coal sludge is used in boilers with grate firings, what causes high particulate emissions. Thus, environmental impacts of coal utilization are serious.

Estimates of emissions of airborne pollutants in Poland are uncertain, because neither fuel consumption nor fuel quality is known with good enough accuracy. Emission measurements even for big polluters are being done manually because automatic monitoring equipment is in a very short supply in Poland. Statistical data about emissions are collected by the Central Statistical Office (e.g. GUS, [36])). However, they refer only to emissions from about 1400 'environmentally stressful' firms. It is estimated that these firms are responsible for appr. 90% of all industrial emissions in Poland. Emissions from dispersed sources (e.g. small industrial boilers, district heating plants, household firings, vehicles) have been estimated in some scientific studies on the basis of fuel consumption and emission factors. Emissions of SO_2 , NO_x and particulates in 1985 estimated on the basis of emission factors used in this work are shown in Table 3.7.

Table 3.7: Emissions of airborne pollutants in 1985, Mio. t

Sector	SO_2	NO_x	particulates
Fuel-energy industry	2.76	0.60	1.42-1.93
of which:			
- public power plants (PPP)	1.59	0.30	0.48
- PPP with CHP[1]	0.33	0.10	0.38
- industrial power & heating plants	0.69	0.15	0.47-0.90
- heating plants of households/communal sector	0.11	0.03	0.07-0.15
- other	0.04	0.02	0.02
Final energy use	0.92	0.68	0.93
of which:			
- industry (with construct.)	0.20	0.15	0.44
- vehicles	0.09	0.48	0.00
- households and other	0.64	0.05	0.49
TOTAL	3.68	1.28	2.25-2.86

[1] CHP - combined heat and power production

As it has been already pointed out, emission estimates done by various authors differ substantially due to uncertainty in input data. The highest uncertainty refers to particulate emissions from small industrial boilers and household firings. Therefore, some estimates of total particulate emissions are as high as 3.6 million tons, whereas computations performed with the use of energy-environment model (Cofala et al., 1989 [29]) give much lower values, i.e. 2.3-2.8 million tons, only. Discrepancies in estimates of SO_2 and NO_x emissions are lower (less than 10%). Work on increasing accuracy of emission estimates is being continued. For instance, this study uses detailed data about hard coal quality as regards sulphur and ash content. Moreover, in some cases it is possible to use emission factors from measurements instead of literature information. Therefore, it is observed that step-by-step better agreement between various authors is achieved because new data are becoming available.

Table 3.8: Emissions of SO_2, NO_x and particulates in selected European countries

Country	reference Year	Emission					
		Mio. t			kg/capita		
		SO_2	NO_x	Partic.	SO_2	NO_x	Partic.
FRG	1980	3.2	3.1	.	54	51	.
	1987	2.0	2.9	0.6	34	48	10
France	1980	3.2	1.5	0.2	59	27	4
	1987	.	1.7	0.2	.	31	4
Italy	1980	2.7	1.3	.	46	22	.
	1987	2.5	1.6	.	43	27	.
United Kingdom	1980	4.7	1.9	.	83	33	.
	1987	3.7	1.8	.	65	32	.
Spain	1980	3.8	0.8	.	100	22	.
	1987	3.2	.	1.6	84	.	42
Czechoslovakia	1982	3.3	.	.	220	.	.
	1987	2.9	1.1	1.4	193	73	93
GDR	1987	5.0	1.0	.	299	60	.
Poland	1980	3.8	1.3	3.0	107	37	84
	1982	3.6	1.1	2.5	100	31	69
	1987	3.9	1.3	2.5	103	35	66

(.) - no data available

In Table 3.8 (sources [29], [30], [43]), a comparison of SO_2, NO_x and particulate emissions in selected European countries is presented. Poland belongs to a group of countries which are characterized by high emissions both in total volume and in per capita terms. This refers first of all to particulate emissions, which in Poland is 4-5 times higher than in the FRG. Per capita emissions in Poland are even 7-8 times higher than in the FRG. The reasons for it are very well known. The most important ones are: high energy intensity of Polish economy, heavy reliance on coal as primary energy source and as household fuel and relatively low efficiency or lack of dedusting equipment in industry.

Also, per capita SO_2 emissions in Poland are 2-3 times higher than in developed countries with market economies. From the other side relative emissions of neighbouring countries (GDR and Czechoslovakia) are 2-3 times higher than for Poland.

The picture is somewhat different when NO_x emissions are taken into account. Here, Polish emissions are lower than in Western countries, in some cases even in per capita terms. Per capita NO_x emissions in the FRG are by 40% higher than those in Poland. The reason for it is much lower development of motorization in Poland.

Sulphur and nitrogen oxides emitted into the atmosphere are transported over long distances, which results in the fact that their concentrations in a given place depend not only on local emission, but also on emissions from sources which are sometimes hundreds or even thousands kilometers away. Table 3.9 shows transboundary flows of sulphur compounds for Poland in 1984, according to calculations performed by EMEP. Analogous estimates for NO_x have not been published as yet. Poland is a net exporter of SO_2. A difference between exports and imports is 350 thousand tons per year. Main receivers of SO_2 emitted at a Polish territory are USSR (406 thousand tons) and Czechoslovakia (150 thousand tons). From the other side main inflows to Poland are from GDR and Czechoslovakia (308 and 276 thousand tons respectively).

Using data from Tables 3.5 and 3.6 one can estimate that appr. 30% of sulphur compounds deposited in Poland originates from foreign sources. Other estimates (e.g. MOSiZN, 1989, [43] after UN Economic Commission for Europe) assess a share of foreign sources on more than 50% what is mainly due to differences in estimates of SO_2 inflows from the GDR and outflows to the USSR. Nevertheless it has to be kept in mind that environmental quality improvement in Poland and especially in south-western part of the country depends to a large extend on the measures which will be taken abroad, mainly in Czechoslovakia and GDR.

It is worth mention that at present emission standards are not used in Poland as a legislative tool to ensure air quality improvement [1]. Instead, a set of ambient air quality standards is in force. Permissible concentrations of pollutants are in Poland lower than in many other highly developed countries. A comparison of ambient standards for Poland and for the FRG is presented in Table 3.10.

In many industrial regions in Poland concentrations of pollutants in ambient air are excessive when compared with the above standards. For instance, in Katowice/Krakow region air quality condition is significantly deteriorated. In the majority of the cities in the above region annual average concentrations of particulate matter are about 300 mg/m^3. During the heating season, where meteorological conditions and residential emissions contribute to elevated concentrations, average concentrations can exceed 400 to 500 mg/m^3. Maximum

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[1] Emission standards for fuel combustion processes have been introduced after completion of this work (see [51])

Table 3.9: Transboundary flows of sulphur compounds for Poland in 1984 (MOSiZN, 1989, after EMEP/MSC-W no.1/1985 report)

Country	SO_2 transport, thousand tons	
	from Poland	to Poland
Total, of which:	1324	972
Czechoslovakia	150	276
GDR	72	308
FRG	58	64
Sweden	60	4
Hungary	28	80
USSR	406	36

According to UN Economic Commission for Europe the respective flows in 1987 were:
GDR - 620 thousand tons, USSR - 654 thosand tons.

24 hour concentrations range from 750 to 1000 mg/m^3. Concentrations exceeding 400 mg/m^3 on a 24-hour average occur 10 percent of the time for many stations. Observed concentrations of sulphur dioxide in Katowice/Krakow region exceed in some places 75 mg/m^3 on an annual average basis and can reach 200 mg/m^3 during the heating season. Maximum 24-hour average concentrations range from 500 to 700 mg/m^3 at center city locations. For many measuring stations, concentrations exceeding 150 mg/m^3 occur 10 percent of the time. Concentrations of nitrogen oxides are also elevated, i.e. annual averages are in many towns greater than 100 mg/m^3.

Table 3.10: Ambient air quality standards in Poland and in the FRG

	Annual mg/m^3		24 hour mg/m^3	
Pollutant	Poland[1]	FRG	Poland[1]	FRG
TSP[2]	22/11	150	150/60	300
SO_2	64/11	140	350/75	400
NO_x	22/8	80	150/50	300

[1] protected zones/specially protected zones

[2] TSP - total suspended particulates

Chapter 4

Main Features of the Energy-Environment Models

4.1 Federal Republic of Germany: EFOM-ENV Model

4.1.1 General Features

EFOM-12C is a pure energy model and, therefore, not able to deal with the environmental questions and goals outlined above [23]. For this reason, the model has been modified and extended with so-called 'environment modules'. This extended version is called EFOM-ENV. The main characteristics of the original version of the EFOM model are:

- Driven by an exogenous demand for useful or final energy, the optimal supply structure for all kinds of fuels is calculated.
- The modular structure (see figure 4.1) allows for sectorial optimization (e.g. capacity extension planning in the central utility sector). These modules can be subdivided into primary energy extraction, import and preparation sectors, conversion and utilization sectors.
- Energy conversion and transport technologies are modeled by technical and economic data. These are summarized as:
    - input and output fuels
    - efficiency

- existing capacity stock and investment needs for additional capacity
- fixed and variable costs
- technical annual availability and life time
- ancillaries and by-products

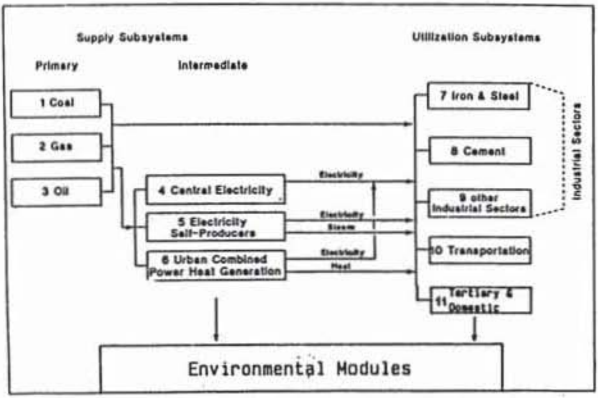

Figure 4.1: Modular Structure of EFOM-ENV

The model must now fulfill additional requirements: Emission reduction technologies must be represented on an adequate aggregation level. These technologies must be modelled in the same way as the corresponding energy conversion technologies. In addition, the model must be able to deal with different environmental policies, for example, emission standards (e.g. 200 mg NO_x/m^3 flue gas), fuel specifications (e.g. 0.3% sulphur content of gasoil) and fuel and technology related emission factors.

These capabilities allow for the investigation of different reduction measures as well as for the evaluation of their effectiveness. The reduction measures, which can be assessed with the EFOM energy-environment model, can be grouped together according to the following characteristics:

- fuel switching and improvement of fuel quality
- emission reduction technologies

- technology substitution (use of technologies with less emissions)
- energy conservation and efficiency improvements

Moreover, these measures can be combined to form numerous mixed strategies in order to achieve pre-defined standards or general emission levels. All specific emission reduction technologies are grouped together in environmental modules and linked to the corresponding energy module. This approach makes it possible to consider pollutants on different aggregation levels. Both sectorial and overall analyses are feasible with EFOM. Another advantage of this concept is the impact analysis of environmental legislation. National bubble policies as well as the impact of more stringent emission standards can be evaluated. In addition, the restructuring of the energy system as a possible consequence of a tightening of environmental policies can be studied.

The original EFOM distinguishes between different subsystems, representing different sectors of the energy system and the economy. This procedure supports a sectorial optimization and analysis as well as a separate testing and updating of the submodels. This approach was also applied to the modelling of emission reduction technologies. Therefore, each energy subsystem was extended by environmental technologies and these were grouped together in environmental modules (called -ENV). These technologies were selected under technical, environmental, economic, and political aspects from a great variety of possible measures [24]. New energy technologies with lower specific emission factors were implemented in the original energetic subsystems. It must be stressed that the new structure was kept as general as possible in order to represent each the characteristics of each country's energy system.

4.1.2 The Structure of the Energy Subsystem

A. Power and Heating Plants
Electricity and district heat production is modelled by three subsystems:

- CENTELEC
  public utilities, power plants larger than 300 MW_{th} (product: electricity)
- SELFELEC
  industrial power plants and coupled production of steam (electricity and steam)
- URB-COMB
  coupled heat power production of public utilities (electricity and district heat)

B. Primary Energy Extraction and Refinement
This sector is represented by six subsystems in the present model version. These are:

- COAL-SS
  coal extraction, briquetting and coking, transport and distribution (steam coal, low grade coal, metallurgical coal, coke, coke oven gas, briquets, lignite, lignite products)
- COAL-NWT
  coal refining processes: gasification and liquefaction (synthetic natural gas, synthesis gas, low btu gas, methanol, gasoil, gasoline)
- GAS-SS
  extraction and import of natural gas, transport and distribution of gaseous fuels (coke oven gas, refinery gas, blast furnace gas, mixing of hydrogen to natural gas grid)
- OIL-SS
  extraction and import of three types of crude oil (light, medium and heavy) and of distillation components, distillation and refining of crude (visbreaker, coker (fluidized, delayed), residue treatment (hydro-cracking, desulfurization), catalytic cracking, reforming, blending of internal refinery fuel, gasoil hydrodesulfurization)
- OILTD-SS
  import and export of oil products, blending, transport and distribution (products: liquified petroleum gas, naphtha, gasoline, gasoil, kerosene, heavy fuel oil high and low sulfur content, bitumen and lubricants, petrol coke, bunker oil)
- HYDROGEN
  production of hydrogen by use of electrolysis (off-peak-electricity, nuclear power),coal gasification (conventional and high temperature reactor), steam reforming, partial oxidation of heavy fueloil, water thermolysis with HTR (products: hydrogen and methanol)

C. Industry

In the present version of the model industry is subdivided into 3 subsectors:

- CEMENT
  production of cement and klinker using the following processes: wet, semi-wet and dry process, grate-belt kiln, parallel flow regenerative kiln, tunnel kiln
- IRON-ST
  iron and steel production using blast-furnace combined with steel works, direct reduction of ore, scrap recycling, rolling mill
- MEDE-IND
  aggregation of the remaining industrial sectors

D. Tertiary and Domestic

This sector is represented by one subsystem containing five categories of demand. These are:

- tertiary / heat and warm water purposes
- single and two family houses / heat and warm water purposes
- multi family houses / heat and warm water purposes
- tertiary / light and power purposes
- households / light and power purposes

E. Transportation

This sector is subdivided into two demand categories:

- passenger transportation: individual and public means of transport
- goods transport: road, rail and ship transport

4.1.3 Environmental Emission Reduction Technologies and Measures

As outlined in other chapters, the inventory of emission reduction technologies and measures is an important prerequisite for the modeling of environmental aspects of the energy system and the cost-effectiveness analysis of different control strategies. This approach requires the identification and separate evaluation of measures and their selection for implementation in the model. In the framework of the 'Energy and Environment' study for the Commission of the European Communities [24], [34] this was performed for the pollutants SO_2 and NO_2, but can also be applied to particulates, volatile organic compounds (VOC), CO_2 and other energy related pollutants.

The control of ambient particulate pollutants was enforced since the 50's of this century in some of the European countries. Therefore, emission control technologies are state-of-the-art. According to different applications, cyclones, fabric filters, poured layer filters, electristatic precipitators, etc are in use. New developments consider the gas cleaning at extreme conditions, e.g. high temperature and pressure, or sticky and moist particles. Satisfactory solutions can be expected within the next years, making possible particulate control for advanced energy conversion processes, such as combined cycle power plants with integrated coal gasification.

The emission reduction technologies for sulphur dioxide and nitrogen oxides can be classified into two groups: primary measures designed to avoid the formation of pollutants and secondary measures for the reduction of already existing air pollutants from fossil fuel based firing installations and industrial production processes.

Primary measures for the partial extraction of sulphur in coal and fuel-oils are state-of-the-art. An intensified preprocessing of run-of-mine coal, resulting in low sulphur coal, has to be seen in the context of an optimal combination of fuel purification and flue gas desulphurization. Fuel oils are supplied in different qualities, e.g. heavy destilates with 1% or 2% sulphur content, gasoils with 0.5%, 0.3% or recently 0.2% sulphur content. The removal of sulphur is achieved by residual desulphurization processes [8].

Sulphur dioxides in the exhaust gas can be removed with different secondary measures which can be classified as dry, semi-wet or wet processes. Dry sorbent processes can be applied by sorbent injection into the boiler or by absorption techniques downstream of the boiler. Dry adsorption or chemisorption processes are an additional technique for the removal of SO_2. Semi-wet processes for flue gas treatment use a suspension of water/sorbent material, resulting in a dry waste product, which is not easily suitable for further applications. Wet flue gas desulphurization processes use, in general, a water/limestone suspension. A removal efficiency of about 95% is obtained. The end-product gypsum can be re-used in a wide range of applications.

Concerning the reduction of NO_x, the following selected primary measures are of exemplary interest: flue gas recirculation, low excess air, reduced air preheating, off-stoichiometric combustion, low-NO_x burners, and in-furnace reduction. A site-specific removal efficiency of up to approx. 60% can be achieved, if several primary measures combined are applied.

Substantial reduction of NO_x emissions requires secondary measures. For smaller installations, especially for oil fired plants, the selective non-catalytic reduction process can be applied. The secondary NO_x removal measure most applied is the selective catalytic reduction process. Ammonia is injected into the flue gas for an accelerated oxidation of NO into NO_2. When in contact with the catalyst, the nitrogen dioxide is reduced to nitrogen and water. The removal efficiency of this technique is about 80%. It is primarily determined by the catalysts activity.

A variety of emission reduction technologies and measures were analyzed in order to identify those that are relevant for the integration into the EFOM-ENV model. Each technology was assessed by its technical and economic characteristics and the commercial availibilty. As a result, a technological minimum cost function is obtained for each type of energy conversion technology.

Finally, 16 different types of emission reduction technologies were selected and implemented into the environmental modules.

The reduction of SO_2 within the intermediate subsystems was carried out by using wet limestone processes or, for small energy conversion units, dry sorbent injection processes, while for NO_x reduction primary measures and/or selective catalytic reduction processes were implemented.

In the environmental module of the Cement subsystem, the model can choose electrostatic precipitators for dust control, and for NO_X removal, pre-calcinators combined with DD-burners (Dual Combustion and Denitrification). SO_2 purification systems are not needed due to the binding of sulphur into the clinker.

The environmental module of the iron and steel subsystem consists of two technologies for dust removal: fabric filter for electric arc furnaces and electrostatic precipitators for all other processes. The SO_2 control of sintering plants was realized by the introduction of wet limestone scrubbing processes. The NO_x reduction technology is modelled by optional primary measures and selective catalytic reduction processes for the removal of NO_x.

Concerning the oil subsystem (refineries), the spray dryer process for SO_2 removal was introduced. For NO_x control, selective catalytic reduction processes are implemented into the model. In addition, a simultaneous process based on activated char-coal was included.

In the tertiary and domestic subsystem, emission control technologies and measures are flue gas washing systems for the desulphurization of flue gases of gasoil and heavy fueloil devices. They are implemented as post processing units to fossil fuel furnaces for heating purposes in multi and single family houses, and commercial structures. Low-NOx burners for gas as well as yellow and blue flame oil burners are included to reduce NO_x emissions.

In the transportation subsystem, emission reduction technologies are the controlled 3-way-catalytic and uncontrolled converter as well as exhaust gas recirculation and primary measures for gasoline cars. For diesel cars and busses, particulate traps are introduced. Emission control measures for trucks, trains, ships and aeroplanes, are not considered.

4.2 Poland: SPSEK-E Set of Models

4.2.1 The Up-Till-Now Approach to Energy System Modelling

The presented here energy - environment model is an extended version of the SPSEK set of models worked out during the last years (Cofala, Ostromecki, 1988 [31]), which enable to investigate development of the energy system in relation with economic growth. The investigations cover a horizon of 25 years. A scheme of the SPSEK set of models is presented in Fig. 1. The SPSEK is composed of four mathematical models and contains some elements of heuristic analysis. The STRUK model describes the interconnections between production output of the economy, capital stock and investments. This model is a dynamic linear optimization model, based on input-output technique. It considers 12 branches (energy industries, energy - intensive industrial and non - industrial sectors), permitting aggregated analyses to be carried out on the effect of structural changes in the economy on energy demand.

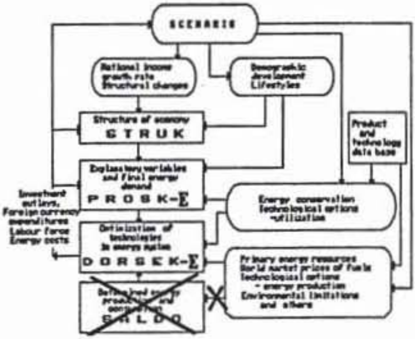

Figure 4.2: Schematic Representation of the SPSEK-E Set of Models

The results obtained from the STRUK model serve in determining the values of about fourty explanatory variables for energy consumption in the country. They characterize the economic activity of the sectors and branches of economy, with a special emphasis put on the energy - intensive products and services, like steel, cement, space heating etc. Each variable generates some final energy demand. This demand is calculated using the model PROSK , which is a simulation model based on engineering data. Detailed description of PROSK can be found in Cofala et al.,1989 [29].

The final energy demand calculated in the PROSK model serves as input information for the dynamic LP model DORSEK (Cofala et al.,1989 [29]). DORSEK ensures optimal choice of technologies in energy production and conversion as well as the optimal level of exports and imports of fuels. It is also possible to introduce into the model essential technological options of fuel utilization but this possibility has not been used as yet due to lack of reliable economic data. The choice of technology is restricted to objects the construction of which is not yet decided. The DORSEK model takes into account 22 types of energy carriers and considers more than 70 technologies. The simulation model SALDO performs the calculation of the balance of energy production and consumption for the existing objects or those under construction at the moment of the calculations.

DORSEK is a dynamic linear model formulated as a linear programming problem. It is adapted to operation over a 20-25 year time horizon. This period is divided into 5-year subperiods. Linearity of the model rests in that both the objective function as well as constraints (equations and inequalities) are linear in respect to decision variables. Dynamics of the model is assured through:

- adopting a common objective function (i.e. discounted cost minimization) for the whole forecasting period;
- balancing production capacities of the considered technologies in each of the subperiods with consideration of production capacities attained during previous subperiods with liquidation of the depreciated or inefficient objects;
- appearance in the model of constraints covering more than one subperiod (e.g. investment expenditures, depletion of resources).

The decision variables in the model include production and production capacities of the energy carriers considered in the model as well as exports and imports of fuels and energy.

The solution of the DORSEK model makes it possible to establish the primary energy balance sheet, and to calculate the investments and foreign exchange supplies, which are necessary for the performance of the system. DORSEK also provides information on the labour force involved in energy production by objects of the considered technology group. Furthermore, DORSEK computes the effects of the technology mix on the environment.

The results of calculations of particular models are then compared to each other. This ensures that the feedbacks are taken into account between individual models and in effect it allows a check for consistency of results.

4.2.2 Extension of Energy Models on Environmental Issues

Up-till-now, the SPSEK set of models had taken into account the problems of environmental impacts of the energy sector in a limited way. Only the conversion technologies in the DORSEK model had their environmental characteristics determining the amount of particulates and sulphur oxide emissions, water consumption and unit production of solid waste and sewage. Besides that, the new power stations had calculation versions with and without flue gas desulphurization.

While such data did enable to assess the level of emissions from objects included in DORSEK, it did not permit calculations of all emissions originating from the national energy system because optimization in DORSEK covered only new energy supply and conversion objects. Majority of energy carriers production is derived from determined (already existing) objects, which are considered in the model SALDO. Lack of data made assessment of pollutant emissions from individual technologies in SALDO impossible. The situation was similar in calculating final energy demand in PROSK, where environmental problems were omitted. Therefore, the assessment of the total impact of the energy system upon the natural environment required additional, post-processing calculations for each of the scenarios, using information from PROSK, DORSEK and SALDO, and also additional data on emission factors.

The need for a complex analysis of the issues of limiting the adverse effect of energy systems on the natural environment has led to the alteration of the existing approach to better include environmental issues into the SPSEK set of models. First of all, the method of aggregating energy carriers had to be changed to account for different sulphur contents in the fuels. This last factor is of paramount importance in assessing the effectiveness and efficiency of abatement technologies. Energy carrier aggregation in the "new", environmental version of SPSEK, i.e. SPSEK-E model set, is shown in the national final report [29]. The new models have 28 types of energy carriers, compared to 22 in the older version.

Extension of final energy demand model

Adaptation of the PROSK model to pollutant emission computations has made it necessary to change the software of the model as well as the structure of the input data. The programs of the PROSK model read - in the initial phase - a list of energy carriers, products and services (explanatory variables) being taken into account. That list has been supplemented by SO_2, NO_x and particulates emission factors. For energy carriers, these factors are expressed in tons per Gigajoule. For the majority of model variables one can assume that emission depends only on the kind of fuel used. In such a case total emissions caused by a given explanatory variable can be calculated on the basis of fuel consumption and emission factors.

However, there are products, for which the emissions differ substantially from the emissions typical for burning fuels in boilers. In case of sulphur oxides this takes place in the combustion processes which either absorb sulphur contained in fuel (e.g. cement) or in which sulphur originates not only from fuel consumption but also from raws (e.g. copper production). Similar differences can appear for nitric oxides. In this case, combustion temperature plays an important role. For such products the so-called process emission factors have been specified. Process emission factors appear for the following products being taken into account in the PROSK-E model:

- agglomerate,
- pig iron,
- raw steel (from open hearth furnaces and oxygen converters),
- copper,
- cement,
- nitric acid,
- nitrogenous fertilizers

Other products, for which process emission factors should have been taken into account are: glass, brick, paper and paper board. In the aggregation applied up-till-now in the PROSK model it was not possible. This problem requires further work.

For all other variables emissions are computed on the basis of fuel consumption. The software of the PROSK model has been extended. New instructions which read values of emission factors have been added as well as procedures which compute the emissions. Finally, two other procedures are used to generate output tables. All these changes have extended the occupation of RAM memory for the executing program PROSK-E.EXE by about 5%. Program execution time has increased by less than 1%. The results regarding SO_2, NO_x and particulates emissions are put on the separate text files. The new version of the model enables also the simulation of fuel switching on emission levels in the sphere of final energy consumption.

Extension of energy supply and conversion model

DORSEK and SALDO required more in-depth technical changes in the modelling procedure. It must be noted that the main possibilities of limiting the adverse effects of the energy system upon the natural environment refer to the existing fuel supply and conversion objects, which were here-to-now treated as predetermined energy sources. Thus, the development of an optimal emission reduction strategy required to shift these into the decision sphere of the model, i.e. to subject these to the optimization procedure. Consequently, the existing technologies were considered by DORSEK, as if including there the SALDO model. This gave the DORSEK-E version of the model.

The DORSEK-E model takes into consideration the environmental protection technologies. Because of the costs differences in applying abatement technologies depending on whether these are used in existing objects (within an up-dating process) or in new objects, characteristics of the technologies differ. The following abatement technology groups are implemented in the model:

1. hard coal cleaning with desulphurization;
2. flue gas desulphurization in hard coal fired power plants:
   - spray dryer method,
   - wet limestone method,
3. flue gas desulphurization in lignite fired power plants:
   - dry method,
   - wet method;
4. flue gas denitrification in power plants (primary measures i.e. combustion modifications, SCR method);

Mentioned under 2. and 4. technologies can also be applied in power plants with combined heat and power production (CHP).

Besides that, the model takes into consideration new technologies of the integrated type, the application of which is being discussed under Polish conditions within the analyzed time horizon. Introduction of these technologies may lead to an abrupt reduction in pollutant emissions. These technologies include:

1. steam-gas combined cycle power plants,
2. power and heating plants with fluidized bed boilers,
3. production of synthesis gas basing on hard coal gasification,
4. production of medium - BTU gas and methanol from hard coal and lignite,
5. oil residuals gasification.

The DORSEK-E model, like its predecessor DORSEK, treats a problem of time dependence of demand for fuel and energy in a simplified way. Each technology has its typical capacity factor. Its value is taken in accordance with the results of more detailed branch investigations of the respective subsystems of the energy system. Thus, for technologies of electricity and heat production the following capacity factors have been assumed:

1. new public power plants (PPP) - 0.74 (t=6500 h/a)
2. existing lignite fired PPP - 0.68 (t=6000 h/a)
3. existing hard coal fired PPP - 0.60 (t=5500 h/a)
4. new PPP with CHP - 0.51 (t=4500 h/a)
5. existing PPP with CHP - 0.46 (t=4000 h/a).

The same capacity factors are assumed for environmental protection technologies, which are combined with energy production technologies.

Formal description of the DORSEK model is given in Cofala et al., 1989 [29]. In the following the main features of the DORSEK-E model are presented. The existing objects are represented in DORSEK-E by variables describing the production of the reference energy carrier in each technology considered. The maximum available energy production from existing objects of a given group (e.g. from hard coal fired power plants) is defined exogenously to the model on the basis of detailed branch investigations performed by other institutions (Chief Design Bureau for Coal Industry (GBSIPG) for coal mines, Power Research Institute for electric utilities etc.). These institutions deliver also data on the investments required to maintain production and to rehabilitate the existing objects.

The DORSEK-E model allows for modelling interfuel substitution in existing objects, e.g. replacement of low quality high sulphur coal by coal of better quality, switch from coal to gas etc. Efficiency and operation costs are dependent on the kind and quality of fuel consumed. The range of substitution is limited additionally by bounds put on the production of existing objects. Energy production from existing objects is also constrained by special constraints which ensure that the production is lower than existing capacities.

Each emission abatement technology is represented in the model by two decision variables, namely

1. activity level (production) in a given subperiod; activity levels of abatement technologies are defined by a quantity of energy carrier produced annually by plants equipped with technology considered,
2. increase in production capacity of the technology in a given subperiod.

The production variables for emission abatement technologies have negative emission factors which are equal to the quantity of pollutant reduced per unit of the energy carrier produced.

Balances of production capacities for abatement technologies are identical with analogous balances for energy production technologies. It is possible to put bounds on abatement technologies in the same way like on other decision variables in the model. Each abatement technology must be properly "connected" to energy production and conversion technology. It is achieved through an additional group of constraints, which ensure that activity level of abatement technology can not be higher than energy carrier production.

The DORSEK-E model is equipped with matrix generator/report writer written in Turbo Pascal 4.0. The model is solved on AT microcomputer equipped with 12808 coprocessor having 2 MB RAM memory. The XMP package is used as LP solver. This package has been extended in order to make it possible to start the computations using previous basic solutions. In the present version the model includes more than 1500 variables and about 1100 constraints. Average computation time is about 10 minutes.

4.3 General Comparison of Modelling Approaches

In general, there are no fundamental methodological differences in which way emission abatement technologies and measures are handled by both modelling approaches. Both approaches are using linear programming techniques to analyse the cost-effectiveness of measures. Therefore, the results of such cost-effectiveness analysis may be compared and their national pecularities can be identified. The systems behaviour of the energy sector is modelled in the same way in DORSEK-E for Poland and in EFOM-ENV for the FRG.

On the other hand, differences exist mainly in the degree of detail of some submodels. While DORSEK-E provides a high disaggregation of fuel quality of coal and a respective modelling of emission abatement technologies differentiated by fuelform, EFOM-ENV yields a detailed representation of different end-use sectors as e.g. households, tertiary and industry including submodels for emission reduction. Moreover, different intermediate sectors are modelled with greater detail according to their greater importance in FRG, as e.g. the refinery submodel and the coal gasification and liquefaction submodel. Furthermore, emphasis in EFOM-ENV was put on renewable energy sources as e.g. hydroelectricity and wind. The greater facilities of the mainframe version of EFOM permit the extension of the model to end-use technologies and useful energy demand. This useful or final energy demand is exogenous to EFOM-ENV and must be supplied by a demand model. On the other hand, the SPSEK-E set of models of which DORSEK-E is a submodel provides a more general framework in which energy related questions may be answered. Main additional features are the macroeconomic model STRUK and the demand model

PROSK-E. The model set is running on a personal computer and therefore is very flexible for implementation and application at different places but limited in model size of the linear programming part.

Chapter 5

Basic Assumptions for the Study

5.1 Federal Republic of Germany

5.1.1 General Economic Indicators

The world GDP is projected to increase at an average annual rate of 3.2% over the period 1985-2010. Although the expected rate is the same as the actual average rate since 1970, it entails the restoration of an upward economic cycle from 1985.

The economic recovery will be based on the combination of three main factors:

- Scenario in [18] provides for a slow, steady increase in the price of imported oil in current dollars: $17 per barrel in 1990, $27 in 1995, $35 in 2000, $45 in 2005 and a projected $60 in 2010. In terms of 1986 purchasing power, allowing for the higher price of manufactured exports, the price per barrel of crude in 2010 is put at about $30 (see Table 5.1).

Table 5.1: Assumptions of Price Variations of Imported Oil

Source: [18]

Price/barrel	1985	1990	1995	2000	2010
Current $	26	17	27	45	60
$ (1986)	26	16	19	20	30

- With the trend for trade and budget deficits to be absorbed, financial markets are expected to be consolidated and capital will be allocated more productively owing to the concomitant fall in real interest rates.
- International trade will be stimulated by the lack of drastic protectionist measures.

Projections of the world economy in 2010 indicate that the United States and Japan will be economically and financially preponderant, that the position of the European Community will be consolidated and that the most recently industrialized countries will continue their dynamic advance (see Table: 5.2).

Table 5.2: Macroeconomic indicators

	GDP in [%/year]		Exports in [%/year]		Imports in [%/year]	
	1970-85	1985-2010	1970-85	1985-2010	1970-85	1985-2010
EEC	2.4	2.6	5.4	4.2	4.5	4.3
World	3.2	3.2	4.6	4.2	4.7	4.1

The GDP of the member countries of the European Community is projected to grow at an average of 2.6% per year from 1985 to 2010.

Although this represents only a modest improvement over the 2.4% growth of the last 15 years, it will help to mitigate imbalances on the labour market without affecting the downward trend of inflation or reversing the current reduction in budget deficits.

As countries bring their macroeconomic policies into line, commercial handicaps within the Community will be reduced, encouraging wider mobilization of capital for productive purposes. As European manufactures again become more competitive on the world market, lasting trade surpluses are expected to accrue, benefiting the Community's capacity to finance investment within the unified internal market.

Growth in the Federal Republic of Germany is expected to continue at a high rate (2.8% from 1985 to 2010), thus consolidating the economic importance of the country in the European Community.

The sector breakdown of GDP will change significantly with the rapid expansion of service activities, whose value added will increase by 3% per year. Manufacturing industry is likely to grow at an average annual rate of 2.68%, with rates as high as 3% in capital goods and 4% in chemicals.

The fall in population which began in the mid-1970s will continue until 2010 at 0,4% per year. The population is decreasing from 61 mill. in 1985 to 60 mill. in 1995 and 56 mill. in 2010. In contrast to this development, the number of households is assumed to increase from 26.6 mill. in 1985 to 28.6 mill for 1995 and 29.3 for 2010.

5.1.2 Energy Prices and Consumption

The energy price projection for the most important energy carriers is given in Figure 5.1.

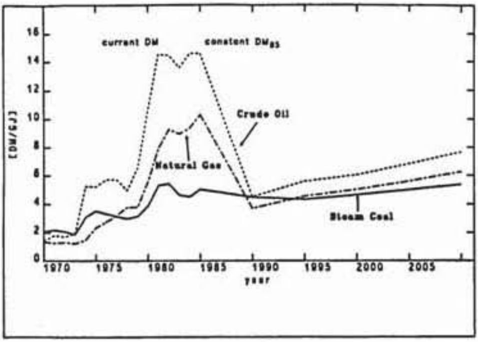

Figure 5.1: Energy Price Projection for Selected Energy Carriers in $[DM_{85}/GJ]$

Final energy consumption in the Federal Republic of Germany as projected for 2010 will be static (excluding raw materials); at the same time, the market shares of the different energy sources will shift in favor of electricity in particular and at the expense of solid fuels.

The energy intensity of economic activity in relation to GDP is likely to fall by about half between 1980 and 2010.

This forecast has a number of structural implications. The separation between socioeconomic development and energy demand will follow from the population decline, industrial restructuring whereby high-energy-consumption production facilities are phased out, the approaching saturation of certain domestic markets (cars, basic electric appliances) and the development of a more efficient technological system. This combination of moderating factors will lie behind the stability of energy consumption associated with the service economy notwithstanding the dynamic pace of economic activity and the fall in domestic energy consumption (averaging 0.5% per year). The industrial and transport sectors are expected to consume more energy (0.3% and 0.2% more per year respectively), although the increase will not be paralleled by their activity levels.

The breakdown of total consumption by energy type indicates a shift in the energy balance in 2010 involving a substantial fall in the share of solid fuels (averaging 2.1% per year) and a relative decline in oil products consumption (0.4% per year) despite a manifest increase in consumption by the industry and transport sectors. Electricity will increase its share with consumption growing by 1.5% per year; district heating, too, will advance by 1.6% per year. Natural gas consumption is expected to increase slowly (by 0.4% per year), mainly in the residential/tertiary sector.

5.1.3 Scenario Assumptions

Those assumptions which reflect the particular FRG energy system and economic situation are summarized in the following :

- For all scenarios, the "Jahrhundertvertrag" was assumed to be extended after the year 1995. The "Jahrhundertvertrag" is a contractual arrangement between the hard coal mining industries and the electric utility companies. With this arrangement, the electric utility companies guarantee a certain minimal consumption of domestic hard coal for the generation of electricity. The amount of coal will increase from 1202 PJ (41 mill tce) in 1986 to 1319 PJ (45 mill tce) in 1990 and 1334 PJ (45.5 mill tce) in 1995.
- Moreover, a further improvement of domestic hard coal quality was forecasted. As a consequence, the extraction share of domestic low grade coal ("Ballastkohle") was reduced from 18% in 1985 to 8% in 1995. This is due to a further improvement of coal preparation methods by the FRG mining industry[13].
- The 'Legal' case considers all those national measures related to the environment which - up to beginning 1987 - already have become effective. These are the "GFAVO" and "TA Luft" and the restrictions of the maximal sulphur content for gasoil and diesel of 0.3%. For the transportation sector, the new regulation of the Economic Commission for Europe (ECE R15), legislating the emission limits for passenger cars was considered. The tax reductions (both for cars and for lead-free

gasoline) established in combination with this regulation were also taken into account. Moreover, a 20% NO_x-reduction was assumed for new trucks and buses from 1.1.1986, as it was agreed by the West German diesel engine manufacturers [15].

- The CEC directive postulates the following reduction developments for existing large-scale combustion plants based on the emissions in 1980 [14]:

	Reduction in 1993	Reduction in 1998	Reduction in 2003
SO_2	40%	60%	70%
NO_x	20%	40%	-

Finally, it should be noted that instead of the 70% SO_2- and NO_x-emission reduction scenarios a 60% reduction case was performed since the simultaneous abatement of 70% of the total SO_2- and NO_x-output did not yield any feasible solution. The absolute emission levels were calculated by multiplying the percentages and the 1980 levels and subtracting the result from the 1980 value. These targets are to be reached from 2000 onwards while half of it is to be reached in the year 1995.

5.1.4 Description of the Environmental Scenarios

The environmental study is conducted in three stages following different objectives:

- identification of the most effective measures for the reduction of SO_2 and NO_x emissions
- cost-effectiveness analysis of emission reduction measures
- investigation of the effects of emission reduction measures and policies already taken on the energy system

In order to achieve these objectives, the following scenarios are investigated:

- 'Doing-Nothing'-Case
- 'Legal'-Case
- 'Cost-Efficient'-Case
  - 30 % reduction of both pollutants combined
  - 50 % reduction of both pollutants combined
  - max. reduction of both pollutants combined
- 'CEC'-Case
- 'Legal-Efficient'-Case
- 'CEC-Efficient'-Case

The energy demand and price projections were kept the same throughout all scenarios.

In the following, the scenarios will be described.

'Doing-Nothing'-Case:
The 'Doing-Nothing'-Case is characterized by the non-realistic fact that *no* environmental measures are taken. It is an ex-post analysis extrapolating the status-quo of the year 1980 by maintaining existing standards and technologies. No reduction measures and policies

have to be considered even if they were implemented in the meantime. The aim of this scenario is to serve as a baseline for the effects of any of the other scenarios.

The demand vectors and the price assumptions for all internationally traded energy carriers were used as they are provided by the Commission of the European Community [19]. This procedure guaranteed consistent assumptions for all countries participating in a study for the Commission of the European Communities (see [21]) relating to energy prices and energy trades among various countries.

'Legal'-Case:

The 'Legal'-Case includes the consideration of all those national measures related to the environment which - up to beginning 1987 - already have passed law, as e.g. in the FRG the 'Verordnung über Großfeuerungsanlagen' (Statutory Ordinance on Large Scale Combustion Installations and the 'TA Luft' (Technical Guideline for Air Quality Control).

'Cost-Efficient'-Case:

The 'Cost-Efficient'-Case does not consider any sectoral emission reduction levels as for the 'Legal'-Case. Therefore, no predefined newly installed capacities or national regulations must be implemented. The objective of this case is twofold:

- assessment of the effectiveness of the environmental measures which have already become effective and
- the identification of additional cost-effective measures.

The 'Cost-Efficient'-Case is performed for three reduction scenarios:

- 30 %
- 50 %
- maximal reduction level

The reduction levels are based on the emissions in 1980. Each of the reduction goals must be reached in the year 2000 whereby half of targets is achieved for the year 1995. Each emission scenario is performed for SO_2- and NO_x-reduction separately and for a combined reduction of both. The maximal reduction case characterizes the scenario in which the maximal level of abatement for both pollutants combined was achieved.

'CEC'-Case

This scenario follows the new European regulation (CEC Council Directive) for the reduction of SO_2- and NO_x -emissions for large scale combustion plants (> 50 MW_{th}). This regulation lays down emission standards for new plants (operation approval after July 1, 1987) depending on size and fuel (see Table 5.3) . Emissions from already existing plants are regulated by global maximal emission levels aggregated nationally over all operational plants. These levels are specified for the years 1993 and 1998.

Although it will be a regulation valid for all countries of the European Community, the level of reduction will be different from country to country.

Table 5.3: SO_2 and NO_x Emission Standards of the CEC Council Directive (Simplified)

Thermal Power Input MW_{th}	Standards [mg/m^3]		
	SO_2		
	Coal	Oil	Gas
< 100	-$^{1)}$	1,700	35$^{2)}$
100-300	2,400-4x	1,700	35$^{2)}$
300-500	2,400-4x	3,650-6.5x	35$^{2)}$
≥500	400	400	35$^{2)}$
	NO_x		
MW_{th}	Coal	Oil	Gas
> 50	650$^{3)}$	450	350

x: Thermal Power Input (MW_{th})

1) Emission standard will be specified in 1990
2) Emission standard for natural gas as a rule
3) Solid fuels with volatile compounds of less than 10%: 1300

Since the model does not consider the time steps 1993 and 1998 the years 1995 and 2000 are chosen for this type of constraint. No restrictions are necessary for the years 1985 and 1990 and no additional national regulation are taken into account.

'Legal-Efficient'- and 'CEC-Efficient'-Case:

The objective of these scenarios is to examine as to whether the exact emission reduction level as achieved by the existing regulations in the 'Legal'- and the 'CEC'-case, respectively, can be obtained at less costs. This analysis required the global SO_2- and NO_x-emissions from the 'Legal'- and the 'CEC'-case as reduction goals which then should be achieved by alternative cost-efficient abatement strategies.

5.2 Poland

5.2.1 Macroeconomic Indicators

Polish economy is characterized by high material inputs intensity to compare with developed countries. Therefore further economy progress is highly dependent on the possibility of decreasing energy and materials intensity of Polish production system. By the end of 1988 three scenarios of economic development for Poland up to the year 2010 have been elaborated with the help of the STRUK model (Cofala, Ostromecki, 1988 [31]). All these scenarios are based on the assumption that population in Poland will grow further from 37,3 mill in 1985 to 39,9 mill in the year 2000 and 41,4 mill inhabitants in 2010. This means an average growth rate of about 0.4%. Various assumptions on the possible decrease of materials and energy intensities and assumptions about repayment of foreign debt by growth rates of net material product (NMP) between 2,0 to 3,5%/a have been investigated.

The "low" scenario assumes growth rates between 2.0 - 2.2%/a by relatively slow (close to statistically observed) decrease of material inputs intensity.

In the "high" scenario, which assumes the growth rates between 3.0 to 3.5%/a, a fast decrease of inputs intensity is achieved as a result of higher depreciation of existing capital stock and higher investment ratio. However, this scenario assumes proportional development of energy intensive industries and in a result changes in production structure are moderate, only. Assumptions of "low" scenario result in stagnation of per capita consumption below the level for the base year (1985). Simultaneously foreign debt is growing in the whole period. The "high" scenario makes it possible to maintain repayment of foreign debt and assures satisfactory level of consumption by the end of the period. However, in the first two subperiods consumption decreases by appr. 7%. Besides, this scenario generates relatively high energy demand. Limitations in energy investments in the last years and decrease in output of coal industry due to change in operating schedule of coal mines [1] make such a demand very difficult to meet.

The third analyzed scenario is called "rationalization" scenario. It assumes slow growth rates at the beginning of planning period (2.2%/a) and a faster rate (3.0%/a) after the year 1995 by simultaneous radical change in production structure. This change depends on liquidating of outdated plants producing energy intensive raws (steel, cement, fertilizers etc.), phasing out of exports of these and promoting imports. Also in manufacturing industries a quick decrease in material and energy intensities is assumed as a result of phasing - in market forces, successful pricing and tax reform etc. This scenario does not ensure repayment of foreign debt. Thus it requires additional supply of foreign exchange or restructurization of Polish debt.

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[1] as aggreed between miners and the Government during the Round Table discussion.

Changes in production structure and relatively slow growth in housing construction cause that this scenario is characterized by low energy demand. In the present economic situation only maintaining energy demand at a low level will allow to avoid huge deficits and subsequent distortions in the economy. Therefore presented in this work emission control strategy is based on the "rationalization" scenario of macroeconomic growth.

Main assumptions and results of the STRUK model for this scenario are presented in Table 5.4. Table 5.5 illustrates changes in branch decomposition of net output in industry for this scenario.

Table 5.4: Main input data and results of the STRUK model "rationalization" case (1985=100).

Category	1990	2000	2010
Assumptions:			
Net material product (NMP)	111	143	191
Export-import balance	215	382	509
Results:			
Per cap. consumption	104	119	160
Capital investments[1]	119	166	180

[1] 1981-85=100

Table 5.5: Structure of net output in industry %, "rationalization" case.

Name of branch	1985	1990	2000	2010
Fuel-energy industry	15.3	13.4	11.8	7.9
Ferrous metallurgy	2.9	2.4	1.6	1.0
Non-ferrous metallurgy	1.8	1.6	1.2	0.8
Equipment goods indust.	31.7	33.5	35.6	35.8
Chemical industry	7.2	7.1	7.1	6.8
Building materials ind.	4.9	4.6	4.2	3.3
Other industries	36.2	37.4	39.2	44.4

Other very important macroeconomic assumptions are the Polish Zloty (zl) exchange rate, the discount rate and the development of world fuel prices. In the presented work it has been assumed that all costs are expressed in 1984 fixed prices. An exception was made for energy carriers due to large price distortions in this segment of the economy. Thus for the purposes of optimization of the energy supply system the world prices of fuels have been assumed. These prices have been converted into domestic currency (zl) using official exchange rate from the year 1984 i.e. 114 zl/US$.

Economists argue that at this exchange rate the Zloty is overvalued and that the so-called shadow exchange rate, which is by 100% higher, would have been more appropriate. It is probably true for consumer goods. For proper decisions about energy system expansion a right proportion between energy and capital goods prices is required. These proportions are closer to international values when official exchange rate is assumed.

In this work a discount rate of 8% has been taken. This rate refers to economic values expressed in fixed prices. It is believed that this rate is consistent with the present level of Poland's economic development. Higher - to compare with FRG - discount rate reflects lower availability of investment resources in Poland.

As regards energy prices scenario, it has been assumed that up to the year 1990 fuel prices will decrease to compare with 1985 prices and then will grow so that by the year 2000 the initial level will be achieved. After that year further growth in energy prices has been assumed. In the assumed scenario growth rates for solid, liquid and gaseous fuel are diversified. For instance, coal prices decrease by 5-15% depending on grade up to 1990 to compare with the base year (1985) and then rise continuously so that in 2010 they are by 20-30% higher than in the base year. In case of oil and gas the initial decrease is deeper (33%). By the year 2010 prices of these fuels reach a level of 120% of the base year prices.

Despite minor differences in fuel price trajectories, this scenario seems to be in a general agreement with the scenario designed for the study of the FRG.

5.2.2 Input Data and other Assumptions

A whole range of new data had to be collected and the existing data required verification. This work was done in cooperation with experts from other research institutions involved in forecasting expansion of individual energy subsystems (coal mining, electric power engineering, etc.), and in development and implementation of new environmental control technologies. The more important assumptions and sources of input data are specified below:

Emission factors for energy conversion and utilization processes:

Data on SO_2 - and NO_x -emission factors for main energy conversion technologies and final energy users were taken from a work done on sulphur and nitrogen oxides emission inventory for Poland (Cofala, Bojarski, 1987 [30]). These data were supplemented by the so-called process emission factors based on domestic information (Balandynowicz et al., 1987 [25], Nowicki et al., 1983 [44]) and foreign sources (Loeblich, 1987 [42]).

Besides SO_2 and NO_x , the model computes also emission of particulates in the national economy. Unit emissions for energy production and conversion technologies are included in standard characterizations of the technologies. Emission factors for existing power plants as well as for other industries have been estimated on the basis of statistical information (CIE, 1986 [28]; GUS, 1986, [36]). Data for households and small boilers in construction, agriculture and transport are based on factors proposed by (Warchalowski et al., 1984 [48]).

Environmental characterizations of energy production and conversion technologies

Technical and economic characteristics of environmental protection technologies have been developed by Polish experts in design of flue gases desulphurization installations. These characteristics (Adamczyk, Janusz, 1988 [40]) take into account both domestic experience from operation of pilot installations, as well as foreign derived data (i.a. Schaerer, Haug, 1986, [45], IIP, IKE, STE, [24] 1987) but used with Polish cost structure. Overview of specific investment cost for emission control technologies is given in the national final report [29].

Data on new technologies having increased efficiency and lower environmental impacts, i.e. technologies which can create integrated energy systems were also verified and supplemented. These data have been developed for manufacturing of electricity and heat by experts from the Power Research Institute (Zembaty, et al., 1988, [50]). These data include gas-steam cycle power plants fueled by natural gas or by gas from coal gasification, as well as plants with fluidized bed boilers (FBB). Characterizations of plants with FBB have been verified using West German data (EUROPLAN, 1984 [33], Bruegel, 1987 [26]). Costs of plants equipped with FBB in relation to conventional plants are shown in the national final report [29].

Possible expansion plans of hard coal industry

Inventory of domestic hard coals from the point of view of their sulphur content was made (GBSiPG, 1988 [35]). Statistical data were analyzed and production of hard coal as well as sulphur content was forecasted for all hard coal mines in Poland until the year 2010. The extent of this research was justified by the leading position of hard coal as the energy source in Poland, contributing over 70% of primary energy. Production of hard coal until 2010 for the base case scenario (after WWK, 1989, [49]) is presented in the national final report [29]. This scenario takes into account capacities of existing mines as well as of new mines being actually under construction. After the year 2000 it is possible to increase production of hard coal in case of additional investments. Characterizations of new coal mines which are considered for construction have been included into the model database.

Base case scenario of coal production assumes six days working week in coal mines. As a result of the Round Table Agreement between miners and the Government working week for coal miners can be shortened from six to five days. In such a case the production of coal would decrease by appr. 17%. After consultations with the Ministry of Industry in the subsequent calculations it was assumed that coal mines will operate 5.5 days per week on average in the period 1990 - 2000. Thus hard coal production will be by 8.5% lower than for the base case. After the year 2000 it should be possible to reorganize coal industry so as to assure coal mines capacity utilization six days per week.

Sulphur content in coal differs considerably, ranging from 0.5% to 2.5%, depending on the mine. The division of Polish coals into grades, as well as their forecasted sulphur content till 2010 (base case scenario) is shown in the national report [29].The base case scenario of coal industry expansion includes only coal cleaning according to existing practices, i.e. without cleaning of steam coal fines. In order to improve quality of steam coals the experts from GBSIPG have proposed an extensive coal fines cleaning program (size 20-0 mm). Coal cleaning reduces not only ash content, but also sulphur content. In case of high sulphur coals (appr. 5% of total coal output) cleaning causes substantial reduction of sulphur content from 1.7-2.7% to 1.1-1.6%. The whole coal cleaning program has been aggregated for the needs of the DORSEK-E model into four technologies. Full application of such technologies would reduce sulphur content in steam coals by one fourth on average to compare with the base-case scenario.

Expansion of nuclear power plants

In this work a very limitted program of nuclear power plants expansion has been assumed. This was justified first of all by the scarcity of investment funds in Poland which will continue over the next ten years. Besides, public opposition against nuclear power in Poland after the Charnobyl accident is very strong. There are also technical difficulties and lack of proper financing of the first nuclear power plant which is now under construction, so that probably this plant will not be commissioned at all. Taking the above into account it has been assumed that development of nuclear power will be limited to 1000 MW_e in the year 2005 and 3000 MW_e in 2010.

5.2.3 Definition of Environmental Scenarios for Poland

Below, four scenarios of environmental pollution control have been formulated, namely:

1. "doing nothing" case,
2. "30% club" case,
3. "legal" case and,
4. "CEC" case.

In the "doing nothing" case it is assumed that no new measures are introduced in order to reduce emissions. No retrofitting of existing plants takes place. All plants built in the future have the same emission factors as in the reference year.[2] The objective of this scenario is to provide the reference case, against which the others can be judged.

The "30%" case means a reduction of SO_2-emissions by 30% in comparison with the emission level in the reference year (1980). It is assumed that this reduction will have a place from the year 2000. This case fulfills the requirements of the European convention to reduce SO_2-emissions by 30% with 7 years of delay.

The "legal" case follows the programs of SO_2 -and NO_x -reduction elaborated by the Ministry of Environmental Protection and Natural Resources (MOSiZN) [43]. These programs assume reduction of SO_2 by 30% up to the year 2000 and by 50% till 2010 to compare with 1980. Analogous targets for NO_x are stabilization of emissions at a present level after the year 1995 and reduction by 50% in 2010. This case fulfills the requirements of the European convention to reduce SO_2 -emissions with 6-7 years of delay. Unfortunately, taking into account emission control options which seem to be realistic in the sphere of final energy utilization (see chapter 4.2) as well as options available in the DORSEK-E model, it is not possible to reduce NO_x emissions so deeply. Therefore, in the "legal" case only 10% reduction of NO_x in years 2000 - 2010 has been assumed. It is worth mention at the moment of completion of the study no clear legal measures existed which could enforce to achieve such targets. Emission standards for fuel combustion processes have been introduced recently ([51]). Thus, it was not possible to analyse their impact on emission levels within this study.

The "CEC" case is based on the Large Combustion Plants Directive adopted by the European Communities (CEC, 1988 [27]). This Directive concerns plants with a thermal rating greater than 50 MW. With some degree of approximation it can be assumed that in case of Poland public power plants (with and without CHP) as well as industrial power

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[2] An exception has been made for power plants because it was assumed that design of new power plants includes already primary NO_x reduction measures.

plants would be affected by this legislation. This Directive establishes emission targets for existing power plants as well as emission standards depending on a size and fuel used for new objects. Although it is a regulation valid for the EC, the level of emission reduction from existing plants is country specific. For majority of the EC countries SO_2 emission target set on existing plants is reduction by 45% up to the year 1993 (to compare with 1980 emissions) and by 60% till 1998. Analogous targets for NO_x are 30% and 40% respectively. In the computations performed for Poland a delay has been assumed to achieve these reduction levels - so as a starting point the year 2000 has been chosen.

Besides these four main scenarios, separate computations have been performed in order to determine the most cost-effective way of reducing emissions of SO_2 and NO_x by fixed amount irrespective of legal requirements. The levels of reduction in relation to the reference year up to 60% with a step 5% were considered. In each case SO_2 - emissions were reduced first, then NO_x , and then both SO_2 and NO_x together.

Chapter 6

Discussion of Results

6.1 Results for the Federal Republic of Germany

6.1.1 Final Energy Consumption

Figure 6.1 displays the final energy consumption for the 'Legal' case in 1985 and 2010.

The general shift to cleaner energy carriers together with the decline of total final energy from 7640 PJ (1985) to 7270 PJ (2010) strengthens the tendency to a further decrease of the overall emissions, especially that of SO_2. Gas, electricity and district heat are likely to gain further market shares. For gas the model evaluated an increase from 21% in 1985 to 23% in 2010. Within the same time span, the market share for electricity increases from 17% to 24%, while district heat elevated its share from 1% to 2%. Main contributors to the decline of final energy are the tertiary and domestic sector (decrease of 510 PJ) and the industrial sector (decrease of 90 PJ). The transportation sector shows a slight increase of 180 PJ for the same time span. This development is accompanied with a further growth of electricity consumption, which will grow annually by about 1.44% up to the year 2000 and later on by 1.35%. Only small market potentials for technologies using renewable energy sources such as heat pumps and solar energy devices in households were evaluated. The main reason for that can be found in the price assumptions for the competing fuels as adopted in this study.

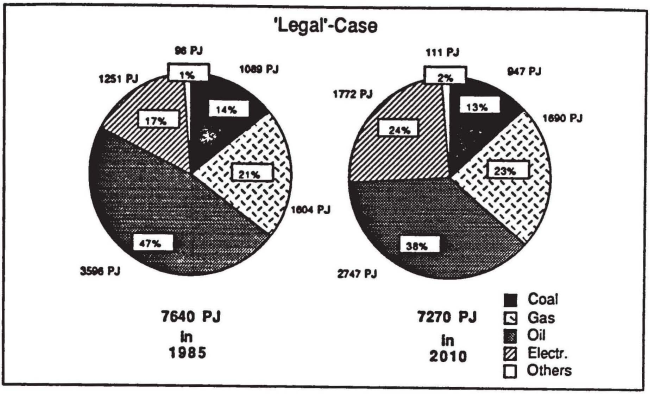

Figure 6.1: Final Energy Development in the 'Legal' Case

6.1.2 Primary Energy Consumption

Figure 6.2 shows the projection of the primary energy consumption for the 'Doing-Nothing', 'Legal' and '60%' reduction case.

Both for the 'Legal' and the 'CEC' case the model evaluated a similar primary energy development over the set period. The primary energy consumption of the 'Legal' case increases by about 540 PJ above the 1985 level up to the year 2010, that means an annual growth rate of about 0.2%. This development shows a continued uncoupling of the primary energy consumption from economic development. The reasons for this can be found in the decline of energy intensive sectors (e.g. iron, steel and non-ferrous metal industry), the more efficient use of energy in different end-use sectors and the decreasing population. The shift of the fuel shares for the primary energy consumption in the 'Legal' case is depicted in table 6.1.

Figure 6.3 illustrates the influence of different environmental strategies, represented in the set of scenarios, on the fuel mix at the primary energy level. Due to the fact that both 'Legal' and 'CEC' case are technology oriented strategies, the impact on fuel mix is small. Nevertheless, it should be mentioned that NO_x-abatement measures for transportation purposes increase the crude oil consumption by 70 PJ in the year 2010. Moreover,

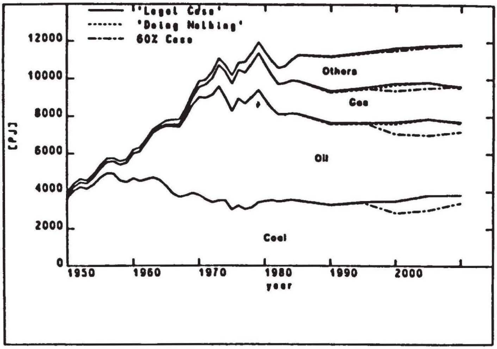

Figure 6.2: Primary Energy Consumption for Selected Scenarios

Table 6.1: Primary Energy Structure for the FRG by Fuel in 1985 and 2010

	Fuel [%]			
Year	Coal	Oil	Gas	Others
1985	30	41	16	13
2010	32	33	16	19

contractual restrictions and dependences (e.g. the "Jahrhundertvertrag" and its assumed prolongation after 1995), limit the possibilities for fuel switching on a larger basis. Only under the 60%-NO_x-reduction constraint, the model chose the fuel switch from imported steam coal to natural gas primarily used in industry for electricity and heat production.

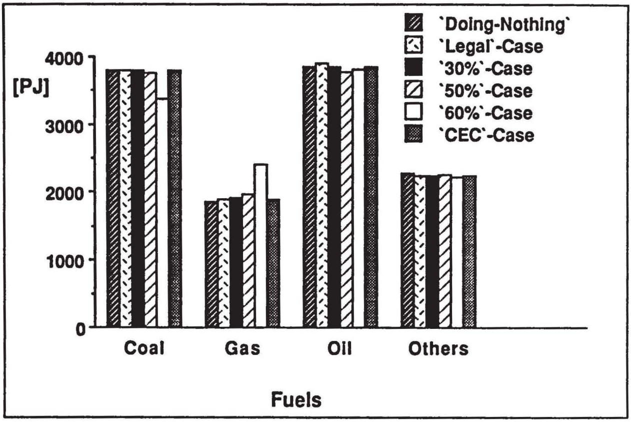

Figure 6.3: Primary Energy Consumption by Energy Carrier and Scenario in 2010

6.1.3 SO_2- and NO_x-Development

The changes in the primary and final energy structure show a significant effect on the development of SO_2-emissions as can be seen in Figure 6.4. In the 'Doing-Nothing' case, the SO_2-emissions are reduced by 37% in 2010 compared with the 1980 level.

The emission projections for the 'Legal' case are based on the introduction of the "GFAVO" and "TA Luft" and the various emission reduction measures for cars as regulated by FRG and European legislation. According to the model results, the SO_2-emissions in the year 2000 will be reduced by about 54% (1.1 Mt), while the projection for the NO_x-emissions indicates a reduction of about 36% (1.0 Mt) with respect to the 'Doing-Nothing' case (see Figure 6.4 and 6.5). The costs associated with all these reduction measures, discounted by 5 % and accumulated over the time period from 1985 to 2010 are in the range of 56 bill. DM_{85}. This yields an average specific reduction cost figure of 2.4 DM_{85} per kg SO_2 and NO_x.

The reduction of SO_2-emissions is mainly achieved in the power plant sector by installing wet limestone scrubbers for fossil fired power plants and advanced "clean" coal technologies after the year 2000. The SO_2-emissions in this sector will decline from 2.0 Mt in

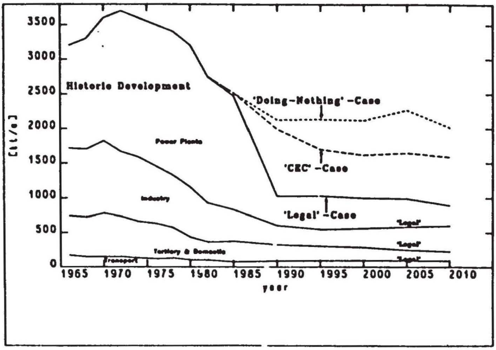

Figure 6.4: Development of SO_2-Emissions

1980 to about 0.3 Mt in 2010. The SO_2-emissions will remain essentially constant in the transportation sector. The model projected a slim reduction of SO_2-emissions for the industrial sector and in the tertiary and domestic sector, due to an increasing consumption of gas for heating and warm water supply purposes.

The overall NO_x-emission projection indicates a decreasing tendency, however, not as significant as for the SO_2- emissions (see Figure 6.5). As far as the power plant sector is concerned the drop from 0.85 Mt in 1980 to 0.27 Mt in 2010 is due to the implementation of selective catalytic reduction installations combined with combustion modification. The increase of electricity produced by nuclear power plants also contributes to the reduction of SO_2- and NO_x-emissions.

In the transportation sector the introduction of low emission cars will be completed by the year 2005. Since diesel driven cars are expected to gain further shares in the expanding market for private cars, coupled with the assumption that the future shares of freight transportation is likely to be shifted from railroad to heavy trucks, a further decrease of NO_x seems to be impossible unless stronger limits for diesel driven cars and trucks are enforced. The regulations that have already become effective will diminish the emissions in the transportation sector from 1.70 Mt in 1980 to about 1.17 Mt in 2010. The overall effects on NO_x-emissions are shown in the Figure 6.5.

With respect to the 'Doing- Nothing' case, the SO_2-emissions in the 'CEC' case can be reduced by about 19% in 2010, while the NO_x-emissions are lowered by 6% only. The

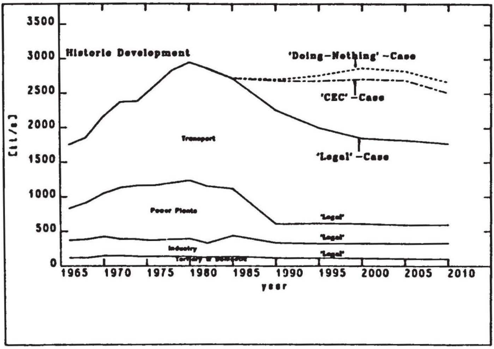

Figure 6.5: Development of NO_x-Emissions

comparison of the 'CEC' case with the 'Legal' case indicates higher levels of emissions for both pollutants throughout the projection horizon. The SO_2-emissions were evaluated to be about 740 [kt/a] (84%) above the figure in the 'Legal' case for the year 2010. For the NO_x- emissions, the model evaluated 750 [kt/a] (43%) more than in the 'Legal' case in 2010. The emission abatement measures associated with the 'Legal' case are roughly 50 bill. DM_{85} more expensive than those for the 'CEC' case, while the costs for the 'CEC' case amount to almost 5.5 bill. DM_{85}. There are two prime reasons for these substantial cost differences between the 'Legal' and 'CEC' cases:

1. There are no measures in the transportation sector in the 'CEC' case.
2. Emission standards only relate to newly built power plants. No retrofit technologies and measures are laid down in the 'CEC'- regulations, but limitations of the overall emissions of large combustion plants. Due to the long lifetime of power plants and existing power plant capacities, the 'CEC'-regulations become more effective after 2010, when additional capacities must be built on a major scale.

6.1.4 CO_2-Emissions Projections

Due to the minor differences in primary energy consumption among different scenarios the projections for CO_2 emissions show quite similar development. In all scenarios no measures aimed at curbing greenhouse gases emissions are implemented. Nevertheless, CO_2-emissions are reduced in the "doing nothing" case from 774 Mio.t/a in 1980 to 704 Mio.t/a in 2010. This refers to a 9% cut due to a larger share of nuclear power and the more efficient use of energy in different end-use sectors and application of low emission fossil power plants. In the 'legal' case, the carbon dioxide emissions are slightly about 8 Mio.t/a higher. This is due to a higher fuel consumption of power plants due to the installation of secondary SO_2- and NO_x-emissions and gasoline driven cars including a catalytic converter. The results presented in the subsequent paragraphs include the assumption that no legislation is introduced to cut significantly the CO_2-emissions. A greenhouse gas oriented energy policy would have a major impact on the development of SO_2 and NO_x since most CO_2 control options also reduce other pollutants. These are:

- fossil fuel substitution
- renewable energy sources
- fuel savings and more efficient use of energy
- nuclear energy
- CO_2-removal and disposal

To date neither it is possible to give any reliable information about the costs and potentials of these counter measures nor it is possible to give complete scientific evidence about the necessary reduction targets to be set in order to allow a safe development of the earth's climate. Nevertheless, most scientists agree that current energy forecasts lead to an unsustainable development, so that political decisions on this issue are required soon.

6.1.5 'Cost-Efficient' Case

The cost curves in Figure 6.6 represent the costs for the reduction of both pollutants (upper curve) as well as those for the reduction of each individually (lower curves). Similar cost characteristics for both the concurrent reduction of SO_2- and NO_x-emissions and that of NO_x alone indicate that the SO_2-emissions can be cut down with very little additional costs as compared to NO_x-emissions reduction only.

Table 6.2 provides an overview of the measures, which were evaluated under a cost-efficient point of view for a simultaneous reduction of both pollutants. These figures give the average annual amount in kt/a reduced by the specified technology for the period 2000 - 2010.

There are two attributing factors for the higher expenses of NO_x-reduction as opposed to that of SO_2. Firstly, only a few secondary measures are necessary to achieve reasonable

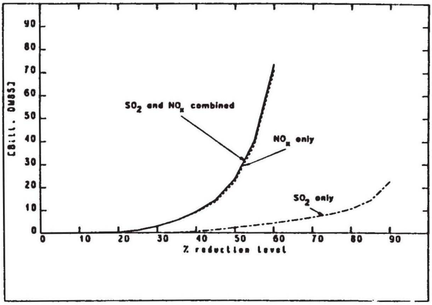

Figure 6.6: Cost Curves for Emission Reduction

Table 6.2: Emission Reductions Achieved by Primary and Secondary Measures, Fuel Switching and Technology Substitution in kt/a

Technology	30 %-Case		50 %-Case		Max-Case (60 %)	
	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x
PRIMARY AND SECONDARY MEASURES						
A: Central Conversion Sector:						
1. Conventional coal power plants	-	380	-	349	-	271
2. Oil and gas fueled power plants	-	31	-	35	-	19
3. New "clean" fossil power plants	-	23	-	25	17	48
B: Industrial Power Plants a. Heating Plants:	-	31	34	42	145	81
C: Industry:						
1 Iron a steel	-	9	-	24	-	24
2 Refinery	-	-	-	15	-	17
3 Others	-	60	-	57	-	54
D: Tertiary and Domestic:	-	-	-	19	-	63
E: Transportation:						
1. Microcat, displ ≤1.4l	-	-	-	201	-	262
2 EGR ≥1.4l	-	47	-	157	-	-
3 Controlled cat ≥1.4l	-	-	-	137	-	516
FUEL SWITCHING AND TECHNOLOGY SUBSTITUTION	37	28	482	173	675	189
TOTAL:	37	611	517	1231	837	1511

Figures refer to the average annual emission reduction in [kt/a] reached by the specified technology for the period 2000 to 2010

Table 6.3: Technology Substitution in the Central Conversion Sector

Technology	30 % case	50 % case	Max case (60 %)
New Technologies			
Combined cycle power plant	±0	-25	+32
Integrated gasification ccpp	+11	+101	+101
Pressurized fluidized bed combustion	±0	+26	+26
Renewables	-	-	-
Existing Technologies			
Dry bottom boiler (steam coal/lignite)	±0	-47	-139
Wet bottom boiler (steam coal)	-12	-61	-75
Nuclear	±0	+30	+51
Hydroelectric	±0	±0	+1
Trivalent coal/oil gas	±0	-1	±0
Oil and gas power plants	+3	-10	-47

These figures refer to the average annual change in energy output compared with the 'Doing-Nothing' case, given in [PJ]

reduction levels for SO_2-emissions (e.g. dry sorbent injection for medium size boilers) and, secondly, the SO_2-emissions declined considerably after 1980 in the 'Doing-Nothing' case. Fuel switching between liquid and gaseous fuels is a measure that reduces emissions to a remarkable degree at very low costs (as e.g. shift from heavy fuel oil with 2%-sulphur to 1%-sulphur). For NO_x, however, there are less potentials for the emission reduction by applying fuel management measures. Thus, effective NO_x reductions techniques require the implementation of primary and secondary measures such as selective catalytic reduction installations.

The 30% case requires primary and secondary measures for all sectors with the exception of tertiary and domestic sectors. The model chooses DeNOx-equipment for conventional coal fired power plants and industrial boilers. For cars with a displacement larger than 1.4 l, the model prefers exhaust gas recirculation to the catalytic converter for cost-effectiveness. However, it must be added, that the exhaust gas recirculation technology does not reduce C_mH_n emissions as does the catalytic converter.

The 50% case requires flue gas treatment for the SO_2-abatement, mainly for multivalent power plants, and additional secondary NO_x-measures in all other sectors. In the power plant sector further reduction of NO_x-emissions can only be achieved by the switching from conventional coal power plants to future 'clean' coal technologies and nuclear power. Uncontrolled catalytic converters for small cars and controlled catalytic converters for cars with a displacement larger than 2.0 l were suggested by the model.

60% NO_x-reduction requires major restructuring within the power generation sector, due to the fact that additional emission reductions in the transportation sector are not feasible with the current model assumptions. The utilization of conventional fossil-fired power plants was reduced drastically in favour of nuclear power and new 'clean' fossil technologies, such as integrated gasification combined cycle power plants. This shift is depicted in Table 6.3. The table gives the average annual change in electricity output of power plants for the period 2000 to 2010 with respect to the 'Doing-Nothing' case.

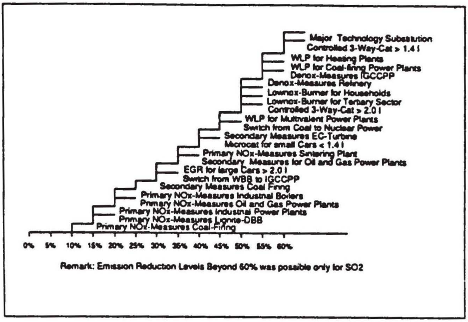

Figure 6.7: Cost-Efficient Strategies

A 70 % reduction of NO_x-emissions did not yield any feasible solution, because reduction measures for diesel powered vehicles and any switches from road transportation to the railway have not been implemented in the model. Figure 6.7 identifies the abatement measures and technologies required for the concurrent reduction of both SO_2- and NO_x-emissions over the entire reduction range. For SO_2 a reduction level of 90% is achieved, even if NO_x-emissions fixed at the 60% reduction level by applying flue gas desulphurization installation for all kind of power plants and industrial boilers.

6.1.6 Cost-Effectiveness Analysis of 'Legal' and 'CEC' Case

Two additional scenarios were performed to allow a detailed cost-efficiency analysis of the legal strategies as implemented in the 'Legal' and 'CEC' scenarios. These two scenarios, called 'Legal-efficient' and 'CEC-efficient', achieve the same reduction level as the 'Legal' and the 'CEC' case respectively, but are free in their choice of strategies to reach these goals.

Although the emission limits are not identical, fuel management and technology substitution characteristics of both the 'Legal-efficient' and the 'CEC-efficient' case are comparable with those of the 30%, 50% and 60% reduction cases. The market shares of future 'clean' coal technologies and nuclear power in the central conversion sector increase under cost-efficient considerations. The reduction of SO_2-emissions is attainable by switching from coal and oil to gas for industrial boilers, refineries and power plants with different fuels. Comparing the 'Legal' and 'Legal-efficient' case, the potential for the fuel switch was evaluated to be in the range of 200 PJ (primary energy). Since reduction measures in the transportation sector are relatively expensive, the contribution of this sector to the overall reduction is limited with regard to cost-effectiveness.

The additional amount reduced by fuel switching and technology substitution in the 'Legal-efficient' case is in the range of 200-300 kt/a for SO_2 and 100-130 kt/a for NO_x.

Figure 6.8 shows the detailed cost figures in sectors. The costs for the 'Legal' case are roughly ten times higher than for the 'CEC' case. The cost-efficient cases show a similar ratio. They require 50% ('Legal-efficient' case) and 43% ('CEC-efficient' case) of the costs of their corresponding legal scenarios.

Figure 6.8 underlines the contribution of primary energy supply sectors to the additional costs for abatement strategies. In the 'Legal' case the share of these fuel costs to the overall costs is about 13%, in the 'Legal-efficient' case 2% and in the 'CEC' case 18%, while for the 'CEC-efficient' case no additional costs in the area of fuel management is accrued. An explanation for this is that the reduction measures for complying with the emission standards generally decrease the efficiency of the conversion technology concerned (e.g. wet limestone process, catalytic converter). This leads to an additional fuel consumption, which results in costs in the corresponding supply sector. On the other hand, in the 'Legal-efficient' cases the possibility to increase the share of nuclear power and new 'clean' coal technologies reduces the fuel consumption. Therefore, the share of fuel costs is lower under cost-effectiveness considerations.

Figure 6.9 provides a general overview of sectorial contributions to the emission target for both the 'Legal' and 'CEC' cases and their corresponding cost-efficient scenarios.

For SO_2-output, the main feature is the switch between the industry and power plant

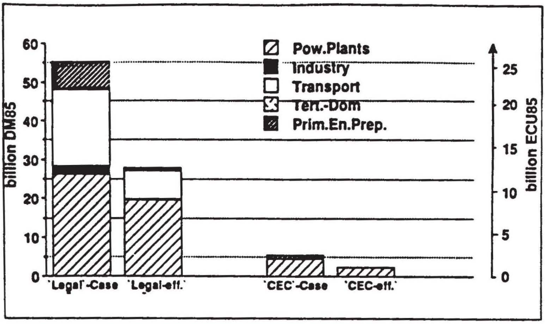

Figure 6.8: Discounted Emission Reduction Costs by Sectors

sector, while for NO_x-emissions, a major shift from the transportation sector to the central utility sector can be observed.

In conclusion, the following points regarding the limitation of the potential cost savings evaluated under cost-effectiveness analysis should be mentioned:

- Institutional and legislative restrictions for the realization of these savings were not considered in the model.
- The percentual largest share of savings could be identified for industry, where a general switch to gas was monitored. Due to the high aggregation of the boiler size distribution, a more detailed analysis in this area would be necessary.
- The GFAVO is justified by the model results. Some minor cost savings appeared to be reasonable with respect to the time schedule for retrofitting of existing power plants.
- A switch of NO_x-measures from the transport sector to any other sector increases the emissions of volatile organic compounds (VOC).

This should be taken into account when comparing 'Legal' and 'Legal-efficient' results.

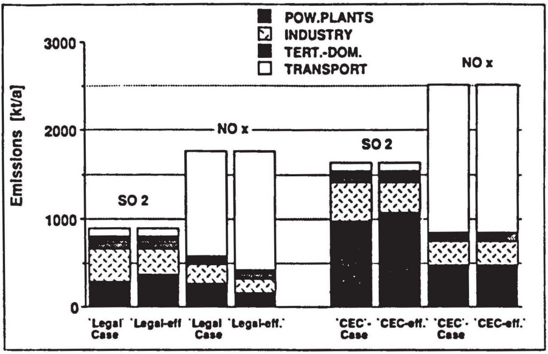

Figure 6.9: Sectorial Contribution of SO_2- and NO_x-Emissions in 2010

6.2 Results for Poland

6.2.1 Final Energy Consumption

Below, the results of computations of final energy demand up to the year 2010 are presented. They refer to the 'rationalization' scenario of economic growth, as described in chapter 5.2. It is worth mention that an aggregation used in the final energy demand model PROSK is consistent with the Polish energy statistics (e.g. CIE, 1988 [28]). Therefore, energy consumption for steam and hot water rising in industrial power and heating plants as well as in heating plants of households/communal sector is treated as energy conversion process and is included in the DORSEK-E model. This explains the relatively high share of heat in final demand. Another peculiarity of final energy consumption in Poland is a high proportion of solid fuels. Hard coal and coke are used in households and in agriculture for cooking/heating. This is a result of autarchic energy policy followed by Poland in the past. This policy was maintained by distorted pricing (low coal prices, artificially high prices of liquid fuels), rationing system, bans on using gas for space heating etc. Present Government declared its willingness to rise energy prices to economic costs (world prices) and to phase-out any limitations in fuel choice. This will result in a switch from coal to gas and also to light fuel oil, specially in little towns [1] and in rural areas. There is a great potential for such a substitution and it is economically viable at world prices. Pace of this substitution is limited only by technical factors (distribution networks, availability of equipment) and fuel availability. In the presented forecast of final energy demand it has been assumed that such a fuel switch will take place to the extent maximally possible taking into account technical limitations (see Hughes, Cofala, 1989 [39]). This forecast has been then used for all environmental scenarios. Final energy demand computed by the above assumptions is presented in Table 6.4.

This demand increases by appr. 30% up to the year 2010 by simultaneous increase in national income by 90%, what is mainly due to an assumption that energy intensity of Polish industry will decrease by nearly 50% as a result of closing down obsolete plants, lower growth rates for energy intensive industries and also rapid increase in value of products due to better quality etc. It is also assumed that unit energy consumption in households sector (e.g. for space heating) will decrease due to successful pricing reform which will promote fuel switching (gas, oil and district heat for coal) as well as enhance energy conservation also in this sector. However, it has to be stressed that at a present stage of economic reform (change from central planning to market forces) all these assumptions are very subjective and cannot be supported by any statistical evidence. Nevertheless, energy conservation targets assumed in this scenario seem to be realistic in the light of experience of other countries.

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[1] in areas where district heat is not available

Table 6.4: Final energy demand till 2010, 'rationalization' scenario of economic growth.

Specification	Unit	1985	1990	2000	2010
Final energy demand	PJ	3396	3589	3853	4433
	Mio. tce	115.9	122.3	131.5	151.3
a) by sectors					
Industry	%	41.4	39.1	34.6	32.9
Construction	%	2.0	1.9	2.4	3.1
Agriculture	%	3.1	2.7	3.1	3.4
Transport	%	6.6	5.9	5.9	6.1
Hauseholds/communal	%	47.0	50.5	53.9	54.4
b) by fuels					
Solid fuels	%	35.8	34.0	25.5	19.9
Liquid fuels	%	13.7	14.4	16.6	18.2
Gaseous fuels	%	11.3	11.5	12.5	13.0
Electricity	%	10.2	11.1	13.1	14.3
Heat (district and local)	%	25.8	25.6	29.3	32.1
Other	%	3.2	3.4	3.0	2.5

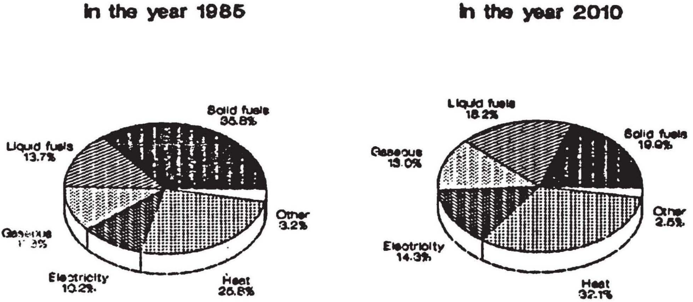

Figure 6.10: Final Energy Consumption by Sectors in Poland

The most important shift in sectorial composition of final energy demand is the increasing share of households/communal sector (from 47% in 1985 to 54% in 2010) by simultaneous decrease of the share of industry. There are also substantial changes in the structure of energy carriers used. The share of solid fuels decreases, whereas the shares of other energy forms (especially of liquid fuels, electricity and district heat) increase. This development is also shown in Figure 6.10.

6.2.2 Primary Energy Consumption

The development of primary energy consumption since the year 1970 and model results for the 'doing nothing' case are shown in Figure 6.11.

Figure 6.11: Primary Energy Consumption in Poland, Historical Data and Projections for 'Doing Nothing' Case

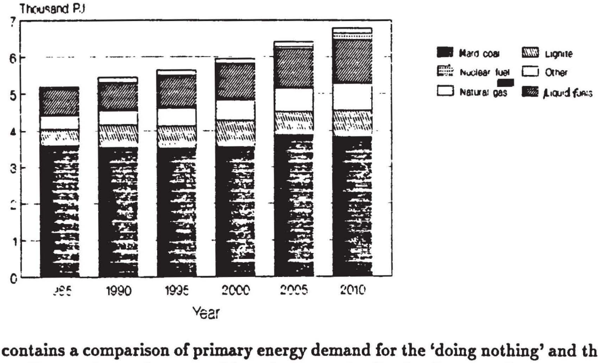

Table 6.5 contains a comparison of primary energy demand for the 'doing nothing' and the 'legal' cases. Energy demand generated by other scenarios lies in - between these extreme cases. Primary energy demand in the 'doing nothing' case increases from 177 Mio. tce in 1985 to 232 Mio. tce in 2010 what means on annual growth rate of about 1.2%. As regards a structure of this demand shares of natural gas and liquid fuels increase by simultaneous decrease in relative role of hard coal. Due to assumptions about very limited expansion of nuclear power plants (maximum 1000 MWe in the year 2005 and 3000 MWe in 2010), nuclear fuels supply only less than 3% of primary energy by the year 2010. Demand for primary energy in other cases is similar (in 2000 - 202 to 203 Mio. tce, in 2010 - 231 to 233 Mio. tce). Also a composition of primary energy carriers does not differ dramatically.

Table 6.5: Primary energy consumption for the ‘doing nothing’ and the ‘legal’ cases.

[PJ]			‘doing nothing’		‘legal’	
Energy carrier	1985	1990	2000	2010	2000	2010
Hard coal	3582	3543	3548	3828	3626	3725
Lignite	456	605	733	719	605	602
Natural gas	378	398	548	740	575	933
Liquid fuels	715	768	988	1175	990	1176
Nuclear fuel	0.0	0.0	0.0	189	0.0	189
Other primary energy	52	136	131	135	131	135
TOTAL in PJ	5183	5450	5948	6786	5927	6760
TOTAL in Mio. tce	176.9	186.0	203.0	231.6	202.3	230.7
%						
Hard coal	69.1	65.0	59.7	56.4	61.2	55.1
Lignite	8.8	11.1	12.3	10.6	10.2	8.9
Natural gas	7.3	7.3	9.2	10.9	9.7	13.8
Liquid fuels	13.8	14.1	16.6	17.3	16.7	17.4
Nuclear fuel	0.0	0.0	0.0	2.8	0.0	2.8
Other primary energy	1.0	2.5	2.2	2.0	2.2	2.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

It is mainly due to a fact that the maximum possible switching from coal to gas in the sphere of final energy utilization is already taken into account in the ‘doing nothing’ case because it seems to be economically viable even without inclusion of environmental factors. Besides, pace of introduction of new advanced combustion gas fired power plants is limited in the model by bounds put on their development up to the year 2000. In this way commercialization and start-up problems of this new technology seem to be taken into account. However, fuel switching plays an important role in achieving environmental goals. For instance, in the ‘legal’ case demand for natural gas in the year 2010 is by 190 PJ higher than in the ‘doing nothing’ case. Simultaneously demand for solid fuels (hard coal and high sulphur lignite) decreases. Gaseous fuels are characterized by higher conversion efficiency. Therefore, in this scenario primary energy demand is by less than 0.5% lower what means that energy losses in emission abatement technologies (flue gas desulphurization, denitrification, coal cleaning etc.) are offset by higher efficiency of gas fired boilers. Impact of analyzed environmental strategies on fuel mix is also illustrated in Figure 6.12.

Production, exports and imports of selected energy carriers up to the year 2010 are presented in [29]. What calls attention is a decrease in hard coal production in the period 1990-2000 due to shorter labour week in coal mines. Of course, this causes at the begin-

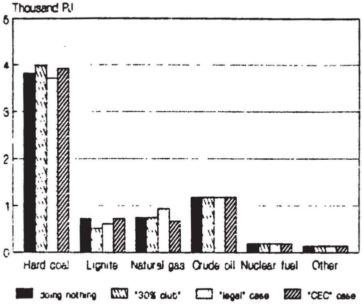

Figure 6.12: Primary Energy Demand in 2010 by Environmental Scenario

ning a rapid decrease in coal exports and then net imports of hard coal. One should note an increase in production of lignite in the 'doing-nothing' case. In the 'legal' case gas option is more attractive. Analyzed in this study economic growth requires 196 TWh of electricity in the year 2000 (230 TWh in 2010) and more than 1200 PJ of heat production (2010 - 1520 PJ). Characteristic is continuous growth of crude oil and natural gas imports. Natural gas imports are higher by 5.7 billion m^3 for the 'legal' case than for the 'doing-nothing' case, due to higher consumption in energy conversion sphere in order to meet environmental constraints.

Economic characterization of analyzed scenarios is presented in Table 6.6. Environmental constraints increase costs of energy system development. For instance, in the 'legal' case discounted costs for the period 1985-2010 are by 3.6% higher than for the 'doing-nothing' case. Main reason for this costs increase is the necessity of investing in pollution abatement equipment or alternatively in 'cleaner' technologies. In the 'legal' case investments in environmental protection technologies are as high as 11.4% of total investments in fuel energy industry. In all scenarios an increase in fuel and energy foreign trade deficit takes place. This deficit increases from appr. 2.7 billion US$ in 1990 to 8.9 billion US$ in 2010 [2]. This is mainly due to a decrease in coal exports by simultaneous increase in oil and gas imports. In the 'legal' case this deficit is by 0.9 billion US$ higher due to increased demand for natural gas.

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[2] For comparison, total Polish exports to 'hard currency' zone were 8.3 billion US$ in 1988.

Table 6.6: Economic characterization of analyzed scenarios.

Specification	Year	Unit	'dn'	'30%'	'legal'	CEC
Objective function		10^{12} zl	14.86	15.06	15.39	15.30
Investment outlays in fuel-energy ind.	1985 - 2010	10^{12} zl	7.35	7.46	8.42	8.20
of which: for SO_2 and NO_x	1985 - 2010	10^{12} zl	-	0.21	0.96	0.55
abatement	1985 - 2010	%	-	2.8	11.4	6.7
Export-import	1990	10^9US$	-2.7	-2.7	-2.7	-2.7
balance in	2000	10^9US$	-5.5	-5.8	-5.9	-5.6
fuel trade[2]	2010	10^9US$	-8.9	-9.5	-9.8	-8.8

[1] Only costs of measures in fuel energy industry included.
Discounted costs of measures in final energy utilization sphere
(SCR for nitric acid plants and car catalytic converters) are 180 billion zl

[2] value of imports/exports expressed in US$ even if in reality
they will be from/to socialist countries

6.2.3 SO_2- and NO_x-Emissions

The evolution of SO_2-and NO_x-emissions over time total and from fuel-energy industry for the scenarios analyzed is presented in Figures 6.13 and 6.14.

More detailed data about sectorial structure of emission can be found in [29]. Emissions of SO_2 increase from appr. 3.8 Mio. t in the year 1980 to 4.1 Mio. t in the year 2010. Emissions of NO_x increase from 1.3 Mio. t to 1.8 Mio. t in 2010. In all emission abatement scenarios SO_2 emissions are reduced drastically. The highest reduction of SO_2 is required in the 'legal' scenario, where 50% decrease by the year 2010 has to take place. This reduction is achieved through various measures (flue gas desulphurization, fuel switching etc.) in energy production and conversion sphere.

As regards NO_x, it has been assumed that in the 'legal' case two reduction measures will be available around the year 2000 in the energy utilization sphere. The first one is SCR installations in nitric acid plants. Total potential for such a reduction is 28 thousand tons/a with average costs 150 zl/kg [3]. The second possibility is the use of catalytic converters for cars. On the assumption that cars equipped with such converters will consume 5% gasoline in the year 2000, 10% in 2005 and 50% in 2010, total potential for reduction of NO_x can be estimated on 7, 29 and 72 thousand tons respectively. Costs of

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[3] under assumption that the costs are the same as for SCR installations in power utility boilers

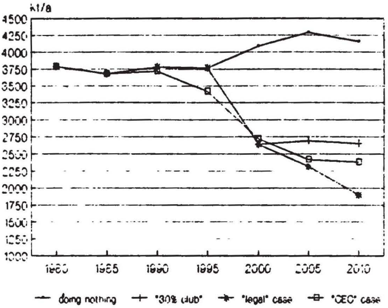

Figure 6.13: Development of SO_2 emissions in Poland

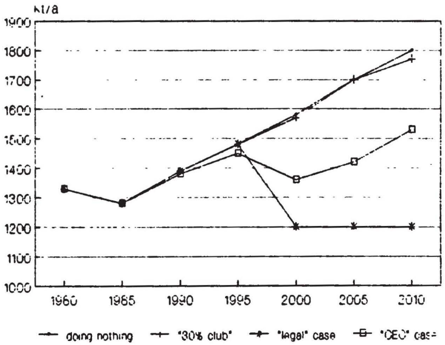

Figure 6.14: Development of NO_x emissions in Poland

such a measure (1920 zl/kg NO_x) [4] have been computed using West German data (IKE, STE, IIP, 1987 [24]). The above measures have been applied in the 'legal' case.

Similarly as in the study for the FRG it has been assumed that technical measures for reduction of NO_x- emissions from diesel engines (trucks, buses etc.) will not be available in the analyzed time horizon [5]. Thus rest of reduction has to take place in energy conversion sphere. Using abatement technologies available in the model, maximum possible reduction of NO_x in the year 2010 is 15%.

Figures 6.15 and 6.16 present the sectorial contribution of various emitter groups to total emission in the base year and in the year 2010. Due to the fact that main emission reduction possibilities exist in energy conversion sphere, by the end of the analyzed period emissions from energy utilization sphere (especially from vehicles and households) predominate.

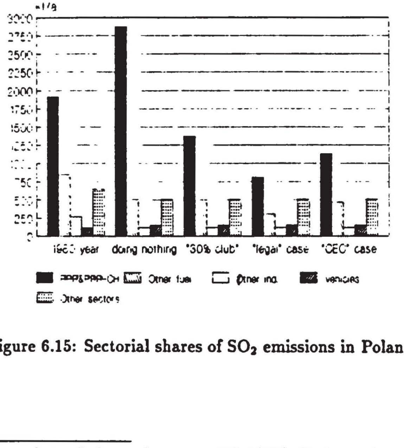

Figure 6.15: Sectorial shares of SO_2 emissions in Poland

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[4] 1500 DM/car converted at a shadow exchange rate 210 zl/US\$. Shadow exchange rate is more appropriate for consumer goods.

[5] However, in the Western Countries new designs of diesel engines are being elaborated. It is claimed that engines with the so-called combustion air cooling system have 20% lower NO_x- emissions. In case of successful setting up production of such engines in Poland just after the year 1995 one can expect reduction of NO_x emission at a national level by 5 and 10% in the years 2005 and 2010, respectively. The above measure can be treated as an effect of the 'trend' technical progress. Thus no additional costs will be attributed to this measure. It is still uncertain whether this measure will be available in Poland in the analyzed time horizon. Thus it has not been taken into account in further calculations.

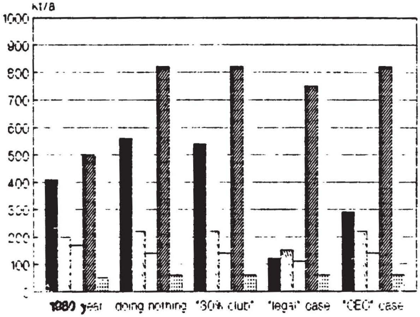

Figure 6.16: Sectorial Shares of NO_x Emissions in Poland

6.2.4 Cost-Efficient Cases

These scenarios aim to achieve an SO_2- and NO_x-reduction at a national level. They are defined by putting overall restrictions in the period 2000 - 2010 on emission levels for SO_2 and NO_x separately and combined. This approach allows to identify cost-effective abatement measures. From the model runs it appears that a 60% reduction of SO_2-emissions to compare with 1980 level is feasible. For NO_x possible reduction is about 15% only, due to much higher growth of emission of this pollutant in the 'doing nothing' case. This is caused mainly by the growth of demand for liquid fuels in the transport sector. Simultaneously, reduction possibilities in this sector are limited to gasoline fueled cars.

The results of this analysis are displayed in Figure 6.17, 6.18 and 6.19, where the so- called step functions for different emission reduction levels (of SO_2, NO_x and SO_2 and NO_x combined) are shown. These figures illustrate which technologies enter the optimal solution when environmental constraints are tightened. Appropriate cost curves are illustrated in Figure 6.20.

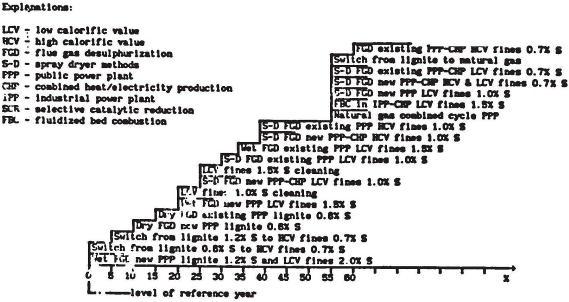

Figure 6.17: Cost-Efficient Strategies for SO_2 reduction in Poland

Reduction of SO_2 only

As it has been already pointed out in the previous chapters SO_2-emissions have presently reached a level of 3.8 Mio. t/a, and for the 'doing nothing' case they will rise to 4.2 Mio. t/a. This evolution is mainly due to the increase in final energy demand (especially for electricity and district heat) what causes the increase in fuel consumption in electricity and heat generation sector. Therefore, it is not surprising that abatement technologies as well as fuel switching are required to achieve in the period 2000 - 2010 the level of SO_2-

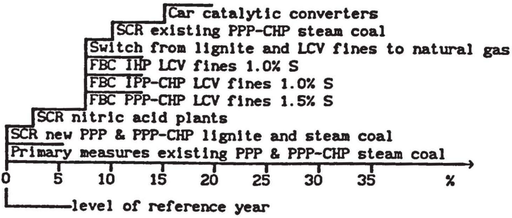

Figure 6.18: Cost-Efficient Strategies for NO_x reduction in Poland

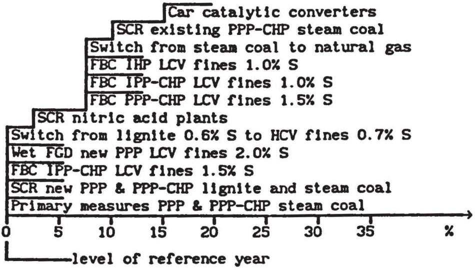

Figure 6.19: Cost-Efficient Strategies for Simultaneous SO_2 and NO_x Abatement

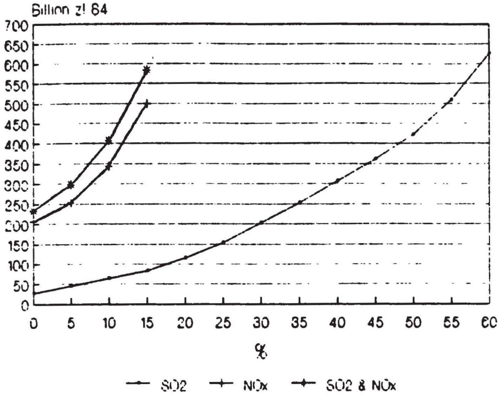

Figure 6.20: Emission Reduction Cost Curves for Poland

emissions from the year 1980 (the reference year). This reduction objective requires the implementation of wet flue gas desulphurization (FGD) equipment in new public power plants (PPP) where high sulphur lignite (1.2% S) and low quality coal (LCV fines, 2.0% S) is fired. Besides, lignite (0.6% S) is replaced in new PPP by high quality coal (HCV fines, 0.7% S).

15% reduction of SO_2 to compare with the reference year implies an application of dry method of FGD in new and existing lignite fired power plants. 40% reduction of SO_2 is achieved through wet and spray dryer (S-D) methods of FGD in new and existing coal fired PPP. Besides, reaching this level of reduction, requires also cleaning of selected coal assortments.

Up to 50% of SO_2-reduction all above measures are applied but on a wider scale. By the 55% reduction of SO_2 integrated natural gas combined cycle plants, as well as fluidized bed boilers in industrial power plants come into solution. Additionally, FGD in new and existing PPP with CHP is required. On this step, the switch from lignite and hard coal to natural gas appears.

The last level of reduction, which is feasible from the point of view of the model, is a 60% reduction to compare with the 1980 level. This is achieved through application of FGD in existing PPP with CHP where HCV coal is fired. Reduction costs rise with the reduction level. For the reference case they are only 28 billion PZL, whereas at 30% reduction they rise to 202 billion PZL. 60% reduction of SO_2 causes costs increase by 625 billion PZL.

It is worth mention that technology of high sulphur coal beneficiation does not enter into optimal solution even with tight SO_2-emission limits. Characterization of this technology used in the model assumes very high coal losses in the process (more than 10%) and high capital costs (four times higher than for other coals). This makes other options, e.g. burning that coal in new power plants with emission control equipment, more economic. This result has to be verified after investment and operating costs become available from pilot plants. Also economic viability of high ash low sulphur coals cleaning requires more in-depth analysis.

Reduction of NO_x only

Relative growth in NO_x-emissions during the next 20 years will be higher than that one for SO_2 . Therefore even to reach emission level from the reference year, abatement measures are required. These are SCR installations for new PPP and primary measures for existing plants. Next steps are: SCR for nitric acid plants, fluidized bed boilers in industrial power and heat plants, switch from lignite and hard coal to natural gas and SCR for existing PPP with CHP. Reduction from 10 to 15% is possible through installation of car catalytic converters.

Total discounted costs of NO_x-emission reduction are much higher than those for SO_2 . Reduction of NO_x-emissions to 1980 level requires 206 billion PZL. 15% reduction increases these costs to 500 billion PZL. Appropriate cost curve is shown in Figure 6.20.

Combined reduction of SO_2 and NO_x

Combined reduction of SO_2 and NO_x is dominated by the need to abate NO_x-emissions. Thus the differences between Figures 6.18 and 6.19 are small. At a level of emissions from the reference year wet FGD for high sulphur coal fired power plants as well as FBC boilers in industrial power plants are applied. To compare with reduction of NO_x only, a switch from lignite to low sulphur coal appears. All other measures are the same.

Discounted emission reduction costs increase from 234 billion zl (for 0% reduction) to 584 billion zl for 15% reduction.

6.2.5 CO_2-Emissions

Over the past century there has been a considerable increase in the rate at which greenhouse gases (carbon dioxide, methane, chlorofluorocarbons, nitrous oxides and ozone) have been emitted to the atmosphere. As a result there has been an increase in the atmospheric concentration of greenhouse gases and there is an evidence that the average world temperature has increased. If this global warming continues several serious consequences will appear.

The objective of this study is, among others, to estimate possible carbon dioxide emissions in Poland between the years 1985 and 2010. The estimation outlined below is a preliminary one and more detailed results will be available in the next year. The estimation has been worked out on the basis of the primary fuel consumption for analyzed scenario and emission coefficients for different types of fossil fuels. Primary energy consumption, for different cases considered, is given in Table 6.5. Emission coefficients which have been applied in the estimation are displayed in Table 6.7.

Table 6.7: CO_2-Emission Coefficients

fuel	t CO_2 / TJ
hard coal	91.44
lignite	110.89
crude oil	78.48
natural gas	51.18
fuelwood, peat	100.10

The results of calculations are presented in Table 6.8. In the period considered (1985 - 2010) CO_2 emissions increase from 460 Mio. t to about 556-574 Mio. t per year depending on analyzed scenario. The highest values (574 Mio. t of CO_2) are for the 'CEC' case and the lowest (556 Mio. t) occur for the 'legal' case. This is mainly due to higher consumption of natural gas in the latter scenario.

The increase in CO_2 -emissions in the analyzed cases is principally a result of growing electricity and heat demand, and subsequent need for additional fossil fired capacity. In result, per capita CO_2 -emissions rise from 3.4 to 3.7 tones of carbon in the period 1985 - 2010. Additional studies are needed to analyze impact of carbon emission limit on energy system expansion. Such a study is planned for the next year.

Table 6.8: CO_2-emissions from fossil fuels for the considered cases in the years 1985 - 2010.

Year	case	CO_2-emissions Mio. t	CO_2-emissions accounted on carbon Mio. t	Per capita CO_2-emissions ton of carbon per inhabitant
1985		461.3	125.8	3.38
1990		480.6	131.1	3.42
2000	A	519.9	141.8	3.54
	B	514.1	140.2	3.50
	C	514.3	140.2	3.50
	D	522.1	142.4	3.55
2010	A	568.9	155.1	3.73
	B	560.7	152.9	3.67
	C	556.3	151.7	3.65
	D	574.1	156.6	3.76
	A	the 'doing nothing' case		
	B	the ' 30% ' case		
	C	the ' legal ' case		
	D	the ' CEC ' case		

6.2.6 Summary and Conclusions

Performed in this work calculations have shown that SO_2- and NO_x- emissions will grow till the year 2010 unless appropriate abatement measures are taken. Even on assumption of intrinsic decrease in energy intensity of Polish economy - as a result of both structural changes and conservation measures - these emissions rise in the 'doing nothing' case from the present level (3.8 Mio. t of SO_2 and 1.4 Mio. t of NO_x) to 4.2 and 1.8 Mio. t respectively. Thus, the following measures are required to achieve environmental targets:

1. Cleaning of selected coal assortments. However, model results show that assessment of economic viability of cleaning of high sulphur coals requires more in-depth review after investment and operating costs become available from the pilot plants.
2. Increased use of natural gas for steam and hot water rising in smaller boilers. It is especially true for new communal heating plants and - in case of very tight SO_2- and NO_x-limits - also for industrial heating plants;
3. Installation of emission control equipment, i.e. flue gases desulphurization and denitrification in all newly built public power and heat plants. For tighter SO_2 and NO_x limits such installations are also needed for existing plants.
4. In the near future application of new advanced combustion technologies, like boilers with fluidized bed combustion (FBC), integrated coal gasification/combined cycle power plants (IGCC) and combined cycle natural gas fired plants becomes economically attractive. FBC, especially for small communal and industrial heating plants, can contribute substantially to air quality improvement in this country. Thus the efforts towards quick commercialization of FBC in Poland should be strengthened.

During the next twenty years emissions of CO_2 from fuel use are likely to increase from the present level of 480 Mio. t to appr. 570 Mio. t around the year 2010. Impact of greenhouse gases emission limit on Polish energy system should be analyzed in a separate study, which is planned for the next year. In future more attention has to be given to the problems of the diminution of particulates emissions in Poland. However, satisfactory solution to the latter problem requires that national level studies be supplemented by more detailed regional assessments.

In order to achieve environmental goals analyzed in this work emission standards have to be enforced in Poland immediatelly. For existing plants more elastic regulation based on mix of standards, fees and fines seems to be appropriate.

Analyzed in this work SO_2- and NO_x-emission control strategies are costly and capital intensive. For instance, in the 'legal' case capital investments into fuel - energy complex are by 1.1 billion zl, i.e. by 15% higher than for the 'doing nothing' case. The '30%' case is by far not so capital intensive because a large proportion of SO_2-emission reduction is achieved through fuel switching. To compare with the 'doing nothing' case, total discounted costs of energy supplies in Poland in the analyzed period increase by 200 billion zl ('30%' case) and by 530 billion zl ('legal' case) i.e. by 1.4% and 3.6% respectively.

At present investment funds are in a short supply even for the 'doing nothing' case of energy system expansion. Control of SO_2-and NO_x-emissions has now become an international issue. Thus meeting of environmental goals in Poland will be possible only with the aid of international financing. Various forms of such an aid are possible, e.g. loans, grants, free technology transfer, debt for nature swap etc.

Presented in this study calculations made with the SPSEK-E model set show its usefulness in investigating development of energy system with environmental constraints. The authors hope, that the results of this study will help in further development of official proposals for environment protection program in Poland (MOSiZN, 1989, [43]). They can also provide more information for foreign or international organizations interested in environmental problems of Poland.

Chapter 7

Comparative Analysis of Results

Countries for which the comparison is being performed are different in many aspects (see Table 7.1). First of all they are at a different level of economic development. At present, per capita GDP in FRG is by 3-6 times higher than in Poland and this difference is likely to continue during the next 20 years. Different are also population projections. In the FRG a decrease in population is expected, whereas in Poland there will be an increase by appr. 10%. Population growth and lower level of satisfaction of basic social needs in Poland is the main cause of growth in energy demand in Poland despite serious efforts towards energy conservation assumed in the study. On the contrary, energy demand in the FRG will remain nearly stable. There are also important differences in present and future structures of primary energy demand in the two countries. In the FRG liquid and gaseous fuels predominate. Also the share of nuclear energy is relatively high and is expected to grow. Poland relies heavily on coal and this reliance will still be very high in the year 2010.

The above tendencies can be retrieved in the emission development of the 'doing nothing' case in each country. Therefore, the percentual reductions to the reference year in both countries are linked to different absolute levels of reduction. This should be kept in mind when comparing results.

Even if the same principal SO_2 reduction technologies are applied, the achieved maximum percentual reductions differ in both countries due to the different starting points, the different structure of the energy system (coal dependence in Poland versus diversified structure (gas, nuclear) in the FRG) and different assumptions concerning the availability of future advanced combustion coal technologies. While in the FRG it is possible to reduce SO_2 by more than 90% in the year 2000, for Poland only 60% reduction in 2010 can be reached with respect to the 1980 level.

Especially, the high share of coal burnt in the small units in households/communal sector

Table 7.1: Comparison of results for the FRG and Poland

		Base year[1]		2010			
Parameter	Unit	FRG	Poland	FRG		Poland	
				A[2]	B[2]	A	B
Population	Mio.	61.6	37.3	56.0	56.0	41.4	41.4
GDP per capita	1000 US$	12.4	1.9[3]	31.2	31.2	3.63[3]	3.63[3]
Primary energy consumption ,of which:	PJ	11314	5183	11803	11877	6786	6760
- solid fuels	%	30.6	77.9	32.2	32.0	71.4	64.0
- natural gas	%	16.5	7.3	15.8	16.4	9.7	13.8
- liquid fuels	%	47.7	13.8	32.6	32.9	17.3	17.4
- nuclear	%	4.1	0.0	18.4	18.2	2.8	2.8
- other	%	1.1	1.0	1.0	0.5	2.0	2.0
Specific energy consumption	GJ/cap	183.7	139.0	210.8	212.1	163.9	163.3
Emissions of:							
- SO_2	Mio. t	3.2	3.79	2.01	0.89	4.16	1.90
- NO_x	Mio. t	3.1	1.33	2.66	1.77	1.80	1.19
- CO_2	Mio. t	774.1	461.0	703.9	711.4	569.0	556.0
Specific emissions of:							
- SO_2	kg/cap	51.9	101.6	35.9	15.9	100.5	45.9
- NO_x	kg/cap	50.3	35.7	47.4	31.6	43.5	28.7
- CO_2	t/cap	12.6	12.4	12.6	12.7	13.7	13.4

[1] FRG: 1980, Poland: 1980 or (when 1980 not available) 1985

[2] A - 'doing nothing' case
B - 'legal' case

[3] Under official exchange rate; 4.0 thousand US$/cap when GDP is converted into US$ according to purchasing power parity of Polish Zloty

and in industry makes it difficult for Poland to reduce emissions of SO_2 below 60% level. For these small units SO_2-scrubbers are too expensive so that the general strategy might be a switch to gas, fuel oil and district/local heat.

Coal cleaning appeared to be a reasonable measure to reduce SO_2-emissions. In the German cases this has been considered as a general progress in the 'doing nothing' case. For Poland, this contributes also to the emission reduction of different cases.

According to the model results the principal SO_2 reduction technology for both countries should be flue gas desulphurization installations. Different methods have been applied for different boiler sizes and fuels. In the FRG, for large units the wet limestone process has been the favorite choice. For smaller units other techniques as spray-dryer and dry sorbent injection have been included. For lignite the dry flue gas desulphurization is an appropiate and efficient measure. For Poland wet limestone method has been chosen for high sulphur coals. In case of low sulphur coals ($< 1\%$ of S) and for smaller units spray dryer method could be used. By low emission reduction targets dry limestone injection method for lignite fired power plants is an appropiate choice. However, as SO_2 emission reduction targets become more ambitious this method has to be replaced by high efficiency scrubbing technology. In general, the model results in both countries have indicated that the higher sulphur content in the fuel, the more efficient application of abatement measure is.

For smaller power and heating plants fluidised bed combustion boilers seem to be promising alternative to flue gas washing systems. This holds especially true if NO_x emissions targets have to be considered.

Qualitative comparison of emissions in the FRG and in Poland for the 'doing nothing' and 'legal' cases is presented in Table 7.1. In the FRG SO_2 emissions decrease for the 'doing nothing' case up to the year 2010 from 3.2 Mio. t in 1980 to 2.0 Mio.t. Analogous numbers for NO_x are 3.1 Mio. t in 1980 and 2.7 Mio.t in 2010. It is worth mention that for the FRG the 'doing - nothing' case is purely theoretical because up-till-now FGD and $DeNO_x$ installations have been applied there on a mass scale. Emissions of SO_2 in the 'legal' case decrease to 0.9 Mio.t in the year 2010 and those of NO_x to 1.8 Mio.t. Thus per capita emissions in the FRG for the 'legal' case are in 2010 very low, i.e. 15 kg SO_2/cap and 32 kg NO_x/cap.

In Poland emissions for the 'doing - nothing' case rise from 3.8 Mio.t of SO_2 in 1980 to 4.2 Mio.t in 2010 and from 1.3 Mio.t of NO_x to 1.8 Mio.t in 2010. Emissions for the 'legal' case decrease in the year 2010 to 1.9 Mio.t of SO_2 and 1.2 Mio.t of NO_x, i.e. to 46 kg SO_2 and 29 kg NO_x per capita. While per capita emissions in Poland are projected to be nearly three times higher for SO_2 in the 'legal' case, those of NO_x will be by 10% higher in the FRG in 2010.

Analized in this work SO_2- and NO_x-emissions control strategies are costly and capital intensive. Comparison of emission reduction costs in the FRG and Poland for 'legal' cases is performed in Table 7.2. Incremental discounted costs are about 28 billion US$ for the FRG and 6.2 billion US$ for Poland. Unit costs are 13.3 US$ per kg of SO_2 and NO_x withheld annually in the period 2000-2010 for the FRG and 2.6 US$/(kg of $SO_2 + NO_x$)/a for Poland. Much higher values for the FRG are justified because in case of the FRG a relatively higher proportion of NO_x has to be removed. This requires measures in the transportation sector which are very costly.

A requirement to reduce emissions has a serious impact on capital intensity of energy supply systems of both countries. For instance, 'legal' case for Poland is by 15 % more capital intensive than the 'doing nothing' case.

Table 7.2: Comparison of emissions reduction costs for 'Legal' cases in the FRG and Poland

Parameter	Unit	FRG	Poland
SO_2 and NO_x withheld [1]	Mio. t/a	2.1	2.4
of which:			
- SO_2	Mio. t/a	1.18	1.9
- NO_x	Mio. t/a	0.92	0.5
Incremental discounted cost[2]	billion US$	28	6.2
Unit cost	US$/kg	13.3	2.6

[1] annual average for the period 2000 - 2010

[2] exchange rates : 2.0 DM/US$, 114 zl_{84}/US$

Chapter 8

Conclusions and Recommendations

Public concern about environmental damages has been rising in both countries, the Republic of Poland and the Federal Republic of Germany during the 80's. However, the political actions in both countries significantly differ. In Poland the social costs connected with energy related air pollution are far from being included in energy prices. Current prices even do not reflect the real costs of energy production due to high subsidies. There are no incentives for energy savings and the consequence is a misallocation of capital, labour force and natural resources in Poland. For this reason, the rise of energy prices will contribute to the improvement of the energy efficiency and hence the environmental situation.

On the other hand, additional investments aiming exclusively at the stabilization of the emission situation seem to be very difficult for Poland due to a shortage of capital, the high foreign debt and a priority of other goals. Therefore, it is very difficult to rapidly improve the situation. But, information from other sources (e.g. Federal Agency of the Environment (Umweltbundesamt) of the FRG) indicates that the prevention of damages is preferable to restauration even in an economic sense. Moreover, expenditures attributable to air pollution as e.g. health care, losses of harvests and timber must be taken into account in a global economic assessment of emission control.

The Federal Republic of Germany has been able to enforce regulations for coping with the SO_2 and NO_x-emissions. This results in a significant cut of both pollutants as it can be found in the 'legal' case. Nevertheless, particularly NO_x-emissions still remain a severe environmental problem. The increase of road traffic density and the lack of effective control techniques for diesel powered trucks require further political and technological efforts. In densely populated areas the concentrations of ozone as a reaction product of NO_x and other substances are still expected to exceed the limits set for smog alarm. Further research is required in this field in order to enhance a rapid progress.

In contrary, for Poland SO_2 emissions appear to bear greater problems than those of NO_x. This is true in particular for highly industrialized areas as e.g. Upper Silesia. Further, long distance transport from German Democratic Republic and Czechoslovakia contributes to the high SO_2 load of south eastern Poland what calls for international collaboration. The general objectives to reduce SO_2 emissions by 30% in 2000 and 50% in 2010 (related to 1980 emissions) require the introduction of administrative and legal tools. The mostly applied emission standards combined with removal requirements (as e.g. in the F.R.G.) suffer from some drawbacks, but their control is relatively easy to handle. On the other hand, a bubble policy combined with emission charges or emission licenses are more efficient and flexible instruments. In case of Poland with its capital scarcity a regional distinction of the applied tool could increase the cost-benefit ratio of such a policy, under the assumption that the damages per unit SO_2 are higher in highly industrialized areas than in low polluted areas. The ambient air concentrations in highly polluted areas would be reduced more significantly. Examples for a similar policy can be found in Italy and Denmark, where a regional distinction for high density and low density areas have been applied. An effect of such policies may be, that high emitting industries move to a location where the standards are less strict. This effect may be avoided by emission licenses issued by a local authority.

The experience on emission control in FRG as well as in other EC countries may be of great importance for Poland to establish regulations which are cost-effective to achieve an optimal allocation of the scarce economic ressources necessary to build up a strong economy. Moreover, the experience gained through operation of abatement installations may contribute to the application of the state-of-the-art of emission control techniques. The adaptation to Polish conditions may also be enhanced by an exchange of such information.

The following areas of cooperation between Poland and the Federal Republic of Germany have been identified:

- coal cleaning methods,
- new clean coal technologies, as e.g. gasification combined cycle power plant, fluidised bed combustion power plants,
- improvement of deduster, SO_2 and NO_x scrubbing techniques,
- use or disposal of by-products of scrubbing techniques.

Generally, the models which have been applied to both countries have been able to analyse in a comprehensive way the cost-effectiveness of abatement technologies. Moreover, the analysis of legal strategies, their economic costs and impacts on emission level and energy supply structure was successful. However, the interactions between energy supply and the economy, the impact of emission reduction measures on energy prices and the price reaction of consumers was out of scope for this study. Furthermore, the sensitivity of cost-effectiveness of measures to changes of the assumptions (robustness of measures) has not been analysed in detail. Therefore, the model provided only a general information on the ranking and cost-effective potential of measures. Nevertheless, the study gave many results concerning the economics of national environmental management focussing on energy related air pollution. For a more comprehensive assessment of energy supply options the models should be extended to other energy related pollutants as e.g. CH_4, CO_2 and others. For an application as decision support instrument for governmental purposes a necessary precondition is a close cooperation between modelling group and decision making institution in order to have a framework which is accepted from decision makers' point of view.

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