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Consequences of an Increased Use of Coal in the Federal Republic of Germany

Summary Version

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K E R N F O R S C H U N G S Z E N T R U M   K A R L S R U H E

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KfK 3521 e

CONSEQUENCES OF AN INCREASED USE OF COAL IN THE FEDERAL REPUBLIC OF GERMANY

- Summary Version -

R. Coenen

1. This study was performed under a contract by the Federal Ministry for Research and Technology.

2. The task was set by the Federal Minister for Research and Technology.

3. The Federal Ministry for Research and Technology has not influenced the results of the study: They are the sole responsibility of the contractor.

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Consequences of an Increased Use of Coal in the Federal Republic of Germany

Abstract

This report contains the summary version of the results of a Technology Assessment Study on the consequences of an increased use of coal in the Federal Republic of Germany which was performed within the framework of a contract by the Federal Ministry for Research and Technology. According to the analyses of this study, oil substitution by hard coal can be attained without additional detrimental impacts on the environment. However, from an economic point of view, only the production of district heat and process heat from coal has favourable economic prospects. The public acceptability of an increased coal utilization should be given if the latest state-of-the-art of environmental technology is implemented and no additional contamination of the environment will be incurred.

Folgen eines verstärkten Kohleeinsatzes in der Bundesrepublik Deutschland

Zusammenfassung

Dieser Bericht enthält als Kurzfassung die Ergebnisse einer im Auftrag des Bundesministeriums für Forschung und Technologie durchgeführten Technikfolgenabschätzung zum verstärkten Kohleeinsatz in der Bundesrepublik Deutschland. Die Studie kommt zu dem Ergebnis, daß die Ölsubstitution durch Steinkohle ohne zusätzliche Umweltbelastungen möglich ist. Aus ökonomischer Sicht ergeben sich allerdings nur für die Verheizung von Kohle zur Fernwärme- und Prozeßwärmeversorgung günstige wirtschaftliche Perspektiven. Die gesellschaftliche Akzeptanz einer verstärkten Kohlenutzung dürfte dann gegeben sein, wenn der verstärkte Steinkohleeinsatz nach dem neuesten Stand der Umwelttechnik erfolgt und keine zusätzlichen Belastungen der Umwelt mit sich bringt.

Preface

This report contains the summary version of the results of a Technology Assessment study on the consequences of an increased use of hard coal for oil substitution in the Federal Republic of Germany which was performed under a contract by the Federal Ministry for Research and Technology. The final report of this study will be published in December 1984 by Springer-Verlag Berlin-Heidelberg-New York-Tokio under the title: "Steinkohle - Technikfolgenabschätzung ihres verstärkten Einsatzes in der Bundesrepublik Deutschland" (editor: R. Coenen). For reasons of space, three parts of the final report could not be included in the book; they are therefore published as separate reports of the Nuclear Research Centre (KfK-reports):

KfK 3525: G. Schufmann, M. Windieck
Risks of accidents and occupational diseases in coal mining in the Federal Republic of Germany, January 1984 (in German)

KfK 3526: D. Brune, H. Stehfest
Analyses of the environmental impacts of wastewater and solid wastes from coal mining and utilization, November 1984 (in German)

KfK 3527: J. Jäger, G. Halbritter, Ch. Kupsch
Potential impacts on the climate from the use of fossil fuels (the "carbon dioxide problem"), December 1984 (in German)

Further reports of the study are published as Supporting Papers also in the form of KfK-reports; two of these are already available -- "Pollutant emissions from coal conversion" (KfK 3523, Jüntgen et al., in German) and "Technical concepts, emission aspects, and middle-term possibilities for deployment of fluidized combustion technologies" (KfK 3524, Bonn, B.; Schilling, H.D., in German).

The following members of the staff of the Department for Applied Systems Analysis were involved in the study:

G. Bechmann, I. von Berg, H. Blume, K.R. Bräutigam, D. Brune, P.M. Fischer, F. Fluck, G. Frederichs, B. Fürniß, F. Gloede-Amft, G. Halbritter, J. Jäger (free-lance), J. Jörissen, H. Katzer, S. Klein-Vielhauer, Ch. Kupsch,

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In addition, the following institutions and experts, whom I would like to thank for their useful cooperation, contributed to the study: ABAS GmbH, Karlsruhe; Bergbau-Forschung GmbH, Essen; Deutsches Institut für Wirtschaftsforschung Berlin; Eproplan GmbH, Ostfildern; Fraunhofer-Institut für Systemtechnik und Innovationsforschung (ISI), Karlsruhe; Gesellschaft für Reaktorsicherheit (GRS), Köln; Institut für Siedlungswasserwirtschaft der Universität Karlsruhe; Rheinisch-Westfälischer Technischer Überwachungsverein e.V., Essen; Zentrum für Umfragen, Methoden und Analysen (ZUMA), Mannheim; Dr. Dlugi and Dr. Güsten from other institutes or departments, respectively, of the Nuclear Research Centre Karlsruhe; Prof. Dr. G. Hoffmann (Staatliche Landwirtschaftliche Untersuchungs- und Forschungsanstalt, Augustenberg); Dipl.-Chemikerin M. Wüstefeld. I also would like to express my gratitude to J. Cofala (Polish Academy of Sciences, Warschau) and B. Dykes (Radian Corporation, North Carolina), who temporarily cooperated as visiting scientists in the study.

R. Coenen (Project director) September 1984

Technology Assessment of an Increased Use of Hard Coal for Oil Substitution in the Federal Republic of Germany

A. Question raised, conception of the study, substitution volume, and coal utilization strategies

Within the framework of a contract by the Federal Minister for Research and Technology, the Department of Applied Systems Analysis (AFAS) of the Nuclear Research Center, Karlsruhe, performed a comprehensive analysis of the technical possibilities, the economic requirements and consequences, the environmental impacts, and the problem of the social acceptability of an increased use of hard coal for oil substitution. The primary goal of the investigation was to determine how an expanded use of hard coal might contribute to reduce the dependence from oil, thus increasing the security of energy supply in the long term, and to analyse the problems and consequences which might be implied by such a policy.

The study was conceived as a (problem-induced) Technology Assessment (TA) study with the following main steps of analysis:

- Analysis of the oil substitution potentials and determination of the substitution volume;
- development of technical alternatives in the form of three coal utilization strategies;
- analysis of the consequences and implementation problems of the coal utilization strategies for the economy, the environment, and the society at large;
- evaluation of the coal utilization strategies in light of their possible consequences and problems of implementation, and formulation of proposals for oil substitution by an increased use of hard coal.

Substitution volume and substitution potentials

The annual oil substitution by hard coal analysed within the framework of this study amounts to 20 million tce+) (586 PJ) of crude oil or 17,6 million tce (516 PJ) of mineral oil products, respectively. This figure is based on considerations concerning a balanced primary energy structure as well as on estimations of the oil substitution potentials remaining for substituting hard coal for oil beyond the "trend" oil savings and oil replacement processes to be expected up to the year 2000. It must be stressed that we are dealing with a substitution of oil by hard coal in addition to the anticipated "trend" oil substitution - in the following called "strategic" oil substitution - which would, a priori, have no chances of realization without political support in light of the economic and energy policy constraints assumed in this study.

In the first two columns of table 1 mineral oil use in 1980 and the projected use of oil to be expected in the reference year 2000 (reference estimate 2000) are given. The table shows that the major remaining potentials for oil substitution are, in the first place, the transport sector and the space heat market of the residential/commercial sector, followed by the process heat market of the industrial sector.

Coal utilization strategies for oil substitution

For substituting 20 million tce of crude oil three alternative coal utilization strategies were developed which differ primarily in respect to the basic types of coal conversion processes considered:

- electricity generation from coal, where mineral oil products are to be replaced by electricity on the basis of hard coal (electricity generation strategy);
- direct use of coal for heating, where mineral oil products are to be replaced by district heat and process heat from coal-fired cogeneration plants and industrial boilers (heat production strategy);
- coal refining, where mineral oil products are to be replaced by products from coal liquefaction and gasification (coal refining strategy).

+) tce = ton of coal equivalent

In each of the strategies, the coal conversion products of the respective conversion type take over the full scope of the oil substitution task of 20 million tce of crude oil. Based on the evaluation of these strategies, a mix of these coal conversion types is also discussed in the final part of the study (see part E of this summary version).

In the electricity generation strategy the substitution takes place primarily in the space heat market, where 65 % of the substitution task defined is accomplished by replacing or supplementing oil heating appliances by electrical heating systems; the remaining 35 % are achieved by substituting electricity for light and heavy fuel oil in the industrial sector. As model technologies -- in the following called "strategy technologies" -- for the conversion sector modern power plants of a capacity of 700 MWe are considered.

In the heat production strategy replacement of fuel oil in the space heat market by district heat from cogeneration on the basis of coal also accounts for about 65 % of the specified substitution volume; the remaining share is achieved by replacing coal-fired boilers for oil-fired boilers for process heat generation in industry. The following model cases for district heat supply are analysed: towns having more than 350 000 inhabitants supplied from coal-fired cogeneration (CHP+)) plants of a capacity of 500 MWe/375 MWth; towns having 150 to 350 000 inhabitants supplied from coal-fired cogeneration plants of a capacity of 120 MWe/200 MWth; towns with 50 to 150 000 inhabitants supplied from coal-fired CHP plants of a capacity of 42 MWe/85 MWth; communities with 20 to 50 000 inhabitants supplied by coal-fired CHP plants of a capacity of 12 MWe/30 MWth (MWth meaning district heating capacity). The two larger plants are designed as "pass-out" steam-turbine type; the two smaller ones as back pressure plants.

In the coal refining strategy two variants are considered: Variant A focuses on oil substitution in transportation; here, 87 % of the specified substitution volume is achieved by replacing liquid fuels derived from coal (gasoline, diesel oil, LPG and methanol) for liquid fuels derived from oil. In Variant B, 62,5 % of the substitution task is accomplished in the heat market by SNG (Substitute Natural Gas) and other products from coal gasification (medium-Btu industrial fuel gas). As conver-

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+) CHP = combined heat and power

Table 1: Oil substitution by the coal utilization strategies (mtce end energy)
- oil use 1980; reference estimate 2000; reduction of oil use and increased use of hard coal for the coal utilization strategies; strategy technologies for oil substitution for end energy use -

	oil use[3] 1980	oil use 2000 (reference estimate)	electricity generation strategy			heat production strategy			refining strategy				
			Δ oil	Δ hard[2] coal	strategy technologies for end energy uses	Δ oil	Δ hard[2] coal	strategy technologies for end energy uses	Δ oil Variants A	Δ oil Variants B	Δ hard[2] coal Variants A	Δ hard[2] coal Variants B	strategy technologies for end energy uses
Residential/ Commercial [1]					bivalent el. heat pumps;+) el. storage+) and direct acting heating systems			house installations for district heat					gas central heating
- space heat	48.2	23.5	-11.6	+18.0		-10.1	+ 4.4		- 2.2	- 6.8	+ 3.6	+10.8	
- hot water/ process heat	8.2	2.9	-	-		- 1.0	+ 0.4		-	-	-	-	
Industry					el. steam boilers, monovalent el. heat pumps; induction ovens; el. glass melting furnaces			coal-fired boilers with and without combined heat and power generation					industrial boilers for medium BTU gas
- space heat	4.8	3.0	- 1.0	+ 0.8		-	-		-	-	-	-	
- process heat	19.0	11.0	- 5.0	+ 6.7		- 6.5	+ 6.9		-	- 4.2	-	+ 5.9	
Transport													methanol-, diesel oil-, gasoline- and LPG-motor vehicles
- (liquid fuels)	59.4	51.0	-	-		-	-		-15.4	- 6.6	+25.4	+10.9	
T o t a l	139.6	91.4	-17.6	+25.5		-17.6	+11.7		-17.6	-17.6	+29.0	+27.6	

1) Excluding fuels for vehicles in agriculture and military services which are included in the "transport sector"
2) In mtce primary energy
3) Excluding nonenergy consumption

+) (night-time; night-time/day-time storage) sion technologies in this strategy, direct coal liquefaction, fixed-bed coal gasification as well as gasification of pulverized coal - the latter technology including different variants - are considered.

In table 1, the quantitative structure of the strategies and the strategy technologies to be implemented for final energy use are given in greater detail.

The amount of hard coal necessary for substituting 20 mtce of crude oil or 17,6 mtce of mineral oil products differs from strategy to strategy on account of the different energy efficiencies of the respective substitution processes (hard coal input per tce of oil substitution). In the heat production strategy, only about 12 mtce of hard coal are required as a result of the large share of district heating on the basis of combined heat and power generation. The electricity generation strategy and the refining strategy are less advantageous energetically; for these strategies 25,5 mtce or 29 mtce (Variant A), respectively, and 27,6 mtce (Variant B) of hard coal are needed to substitute 20 mtce of crude oil.

B. Analyses of the economic conditions and consequences of an increased use of coal (analyses of the economic consequences)

The main emphasis of the economic analyses is on the comparison of the useful energy costs between the coal technologies which are to substitute, according to the respective strategy, for mineral oil products (strategy technologies) and the mineral oil technologies to be replaced. In addition, overall economic indicators are determined for comparisons between the strategies (total substitution costs, investment costs, and manpower requirements). Moreover, problems of implementing the strategy technologies are discussed, such as, e.g., legal and institutional problems, competition with other energy carriers, such as natural gas, and demands on infrastructure.

The analyses of the economic consequences are based on an energy price scenario as base case which can be characterized by annual price increase rates for mineral oil products of 2 %, for imported coal of 2 %, and for domestic hard coal of 1 %. For the strategy-specific use of hard coal the ratio between domestic hard coal and imported coal is assumed to be 1:2. These assumptions - which are described in greater detail in Part B of the final report of the study - are, however, also submitted to sensitivity analyses, the results of which are briefly discussed under 4) of this section of the summary version. The comparisons of the useful energy costs are based on two reference periods of 20 years each: 1982 - 2001 and 1992 - 2011.

1. Cost analyses for the electricity generation strategy

The following strategy technologies are considered for substituting oil in the domestic sector within the framework of the electricity generation strategy:

- electric storage heating system using "off-peak" electricity during night-time;
- electric heat pumps in bivalent operation with a supplementary oil heating system;
- electric storage heating using "off-peak" electricity during night-time as well as during day-time;
- an electric heating system where the space heat requirements of a household are in part supplied by a night-time storage heating system and in part by direct-acting electro-heating (combination of direct-acting and storage heating systems).

The comparisons with the respective mineral oil based technologies (oil central heating) yield the following results: Assuming a real annual price increase rate for mineral oil of 2 % for the reference period 1992-2011, all strategy technologies considered show cost advantages compared to the oil technologies, with the only exception of the bivalent heat pump which has advantages only in the case of a two-family house, but not in a one--family house. With about 10 % the electric night-time storage heating system offers the greatest cost advantages compared to the oil case, if no additional power plant capacity is required. The relatively small cost advantages of the combined electric heating system, the electric night-time/day-time storage heating system, and the bivalent heat pumps in a two-family house are obtained only, if in each case only a part of the fixed costs of the power plants is attributed to the respective heating system. Such a distribution of the fixed costs of the power plant is justified because the strategy is conceived in such a way that the electric heating systems supplement each other as far as the demand on power plant capacity is concerned. If a real price increase rate for oil products of only 1 % per year is assumed, only the electric night-time storage heating system still has cost advantages, which are, however, only minor. The same applies the reference period 1982-2001 is considered.

From the technical point of view, in industry almost every oil-based heating technology could be substituted by electric heating processes on account of the technological flexibility of electricity as final energy carrier. At present, however, the cost advantages of the fuel costs alone of oil-based technologies are such that the cost advantages of the electric heating processes in terms of investment costs and other operating costs are of no account. If only economic aspects are considered, the substitution of oil by electric heat will therefore be limited primarily to those areas, in which qualitative advantages of electric heat regarding applicability etc. predominate compared with the rather simple process of steam generation, the main area of oil use in industry. Examples of this are: dielectric processes for drying and heating, induction ovens, electric heat pump. However, these areas do not account for the bulk of process heat generation from oil.

The above is confirmed by the cost comparisons carried out: If simple oil-fired and electric boilers are compared, the oil technology offers clear advantages; but for heat pumps operated on a monovalent basis which can, however, be utilized for substitution only in the low temperature range, advantages compared to oil-fired boilers are shown for large plants with high operating times. Induction ovens and electric glass melting furnaces also have cost advantages over the corresponding oil-based technologies; however, as the operating times clearly lie in the base-load period of electricity generation, the cost advantages would be even greater if supplied by base-load power plants (nuclear energy, lignite).

With view to the conditions for realizing the strategy it cannot be expected that the processes for substituting electricity for oil considered here will, on a larger scale, take off "by themselves", even though the strategy technologies offer cost advantages over the oil technologies in some cases in the residential sector as well as in industry. In the residential sector, for example, the cost advantages are so small that from the point of view of economic efficiency the later switch from oil to resistance heating systems is not very attractive. This does, of course, not apply to bivalent heat pumps as supplements to existing oil heating systems, the economics of which are, however, difficult to assess in light of the uncertainties of oil price developments.

As far as tariffs are concerned, possibly special agreements for electric heat might be necessary for realizing the strategy, which would be controversial under energy policy and anti-trust legislation considerations.

2. Cost analyses for the heat production strategy

The analyses of the costs of useful energy for oil substitution by district heat on the basis of coal in the space heat market of the residential/commercial sector show a strong dependence of the costs on the size of the coal-fired power plant where the district heat is generated. Assuming beginning of operation in 1992 and a 20-year period of consideration, the costs of coupling out district heat from large "pass-out" steam-turbine plants are 30 % lower than when coupled out from the smallest back pressure plant considered (12 MWe/30 MWth). Correspondingly, comparisons of the useful heat costs for oil central heating in multi-dwelling houses with district heat yield greater cost advantages for the large supply areas with big plants: Assuming real increase rates for fuel oil of 2 % annually, the big plants have a 33 % cost advantage over oil heating, for the smallest plant only 6 % are calculated. In the case of only 1 % price increase per year for fuel oil the smallest coal-fired cogeneration plant would be less advantageous than oil heating, while the bigger plants would still offer cost advantages. The same applies if calculated for the earlier period from 1982 - 2001 and a 2 % annual price increase rate for fuel oil.

Assuming implementation of flue gas desulphurization, which is not required for plants of this size according to the new Regulation concerning the emissions from large boilers (known as "Großfeuerungsanlagenverordnung" - GFAVO), additional costs for district heat on the level of end energy use of about 10 % would be incurred. In the case of fluidized bed combustion, which is rather low in emissions, the additional costs are somewhat lower. The economic prospects for the smallest plant would be even worth.

These differences in the costs of district heat generation are mainly attributable to cost degression effects for personnel and operating costs as well as to different exergetic efficiencies of the cogeneration plants, according to which the small plants are allotted lower "credits for cogenerated electricity" than big plants. The differences in the costs of distributing the district heat in the model district heat networks of the different scales analysed here are clearly less significant than the cost differences of generating the district heat in plants of the different sizes considered. This is mainly due to the fact that the conditions for district heat to penetrate into new supply areas in big towns are not much more favourable than in medium-sized towns, because, in the Federal Republic of Germany, the densely populated areas of large towns are often already supplied with district heat.

Despite the rather favourable 20-year-balance of the useful heat costs of district heat from coal-fired power plants compared to oil heating, the introduction of district heat on a large scale will raise problems even from an economic point of view because the high initial costs of implementing district heat resulting from low operating times of the CHP plants and low utilization of the distribution network in the first years of operation will entail considerable financial problems during the initial phase of implementation.

Moreover, under realization aspects it has to be kept in mind that it is not oil, but natural gas which is presently the main competitor of district heat. Over a 20-year period of consideration the calculations show cost advantages for district heat supply from big and medium-sized coal-fired power plants compared to natural gas. For smaller communities which would be supplied from smaller plants, the economic perspectives are at present somewhat more favourable for natural gas; on account of the large share of energy costs in the overall costs in the case of natural gas the relation shifts in favour of district heat if similar real price increases are assumed for natural gas as for fuel oil and coal.

Apart from these economic problems it should be pointed out that the realization of the heat production strategy would entail a partial decentralisation of the electricity generation structure which would not be in harmony with the present prospective siting plans of the states ("Länder") and the power plant construction programmes of the electric utilities. If the communes intend to build their own cogeneration plants, the economic efficiency is heavily dependent on the conditions obtained for reserve capacity and supply of additional electricity as well as on the payment for excess electricity. In the calculations of the study, the "credits for cogenerated electricity" are determined according to the costs which would have accrued had the electricity been produced in new power plants operated on hard coal of the size of 700 MWe, because, according to the assumptions about future energy demand, the capacities for generation of medium-load electricity would have to be expanded in any case up to the year 2000. In how far such "credits" will actually be granted in a concrete supply case depends on the respective electricity production and demand structure of the supply area considered.

A critical review of present energy and related legislation suggests that, on the one hand, the electric utility sector cannot be expected to consent to an extension of district heat supply in the scope discussed within the framework of this study, and that, on the other hand, current law does not contain sufficient provisions for implementing such a district heating strategy if the electric utility sector is not willing to cooperate.

In <u>industry</u>, coal-fired boilers are to substitute for steam generators operated on oil. Considered are boilers with a steam output of 2, 8, 15 and 60 MWth, the smaller plants (2 and 8 MWth) are compared with boilers burning light oil, the larger facilities with boilers burning heavy oil. Assuming oil price increase rates of 2 % annually, conventional coal-fired plants (without flue gas desulphurization) have cost advantages between 15 and 45 % considering the period 1992 - 2011; in some cases cost advantages are also calculated for boilers with fluidized-bed combustion, especially for plants with good operating times. The economic perspectives become somewhat less favourable if lower oil price increase rates are assumed or the earlier period from 1982 - 2001 is considered; this applies above all to fluidized-bed combustion.

The propensity to invest is often also determined by the question whether additional investments for coal-fired boilers compared to boilers burning oil will amortize sufficiently quickly. For 1982, corresponding calculations show amortization periods of about 5 years or below for smaller conventional coal firings (in the case of a 2 MWth plant, however, only in the event of good operating times) as well as for big plants (60 MWth); in the other cases, especially for fluidized-bed combustion, they are in excess of 5 years so that the firms should be hesitant to invest.

Apart from the too long amortization periods in some cases, this part of the strategy might be difficult to realize because the switch from oil to coal may in many cases be impaired by the additional space needed for the boiler, the treatment of the coal and ash, and the bunker, and because the replacement might entail difficult and time-consuming licensing procedures.

3. Cost analyses for the coal refining strategy

In both variants of the refining strategy liquid and gaseous coal refining products are to replace mineral oil products -- though in different quantities.

Liquid coal refining products

The cost analyses for the generation, distribution and utilization of liquid coal refining products for substituting gasoline in the transport sector yield the following results assuming operation of the plants to begin in 1992 and a 20-year period of consideration:

- To achieve parity of costs for the products from direct coal liquefaction (gasoline, diesel oil, and LPG) the prices for gasoline from refinery would have to rise by more than 80 % between 1982 and 2000.

Assuming annual price increase rates for gasoline of 2 % the plants starting operation in 1992 would have to be subsidized over their entire lifetime (20 years).

- If gasoline is to be substituted by methanol derived from hard coal (in pulverized coal gasification plants) the cost comparisons are somewhat more favourable. However, even in this case price increase rates of 2 % do not suffice to achieve cost advantages for methanol derived from hard coal, assuming operation of the plants to begin in 1992 and a life-time of 20 years.

In order to substitute methanol for gasoline in the amounts discussed here (about 5 million methanol motor vehicles) a large number not only of domestic petrol stations but also stations in the other European countries would have to be equipped accordingly. Presupposition would be joint decisions in the field of transport policy on the European level. To achieve this in time should, apart from the poor economic efficiency, be one of the main problems of enabling the potential contribution of methanol to the substitution of oil in the scope discussed to become a reality.

Gaseous coal refining products

Compared with light fuel oil, the perspectives for SNG generated in fixed-bed gasification plants for heating in multi-dwelling houses are rather favourable assuming operation of the plants to begin in 1992. When the costs of distributing the gas and the procurement and maintenance costs of the heating facility are taken into account, costs of useful heat are obtained which, assuming real annual oil price increases of 2 %, differ only slightly from the useful heat costs of an oil central heating. Compared with natural gas, however, considerable disadvantages emerge which illustrate the problems to be reckoned with should this strategy be implemented. For plants starting operation in 1992, the costs of generating the gas exceed the import prices of natural gas in 1982 by 100 %.

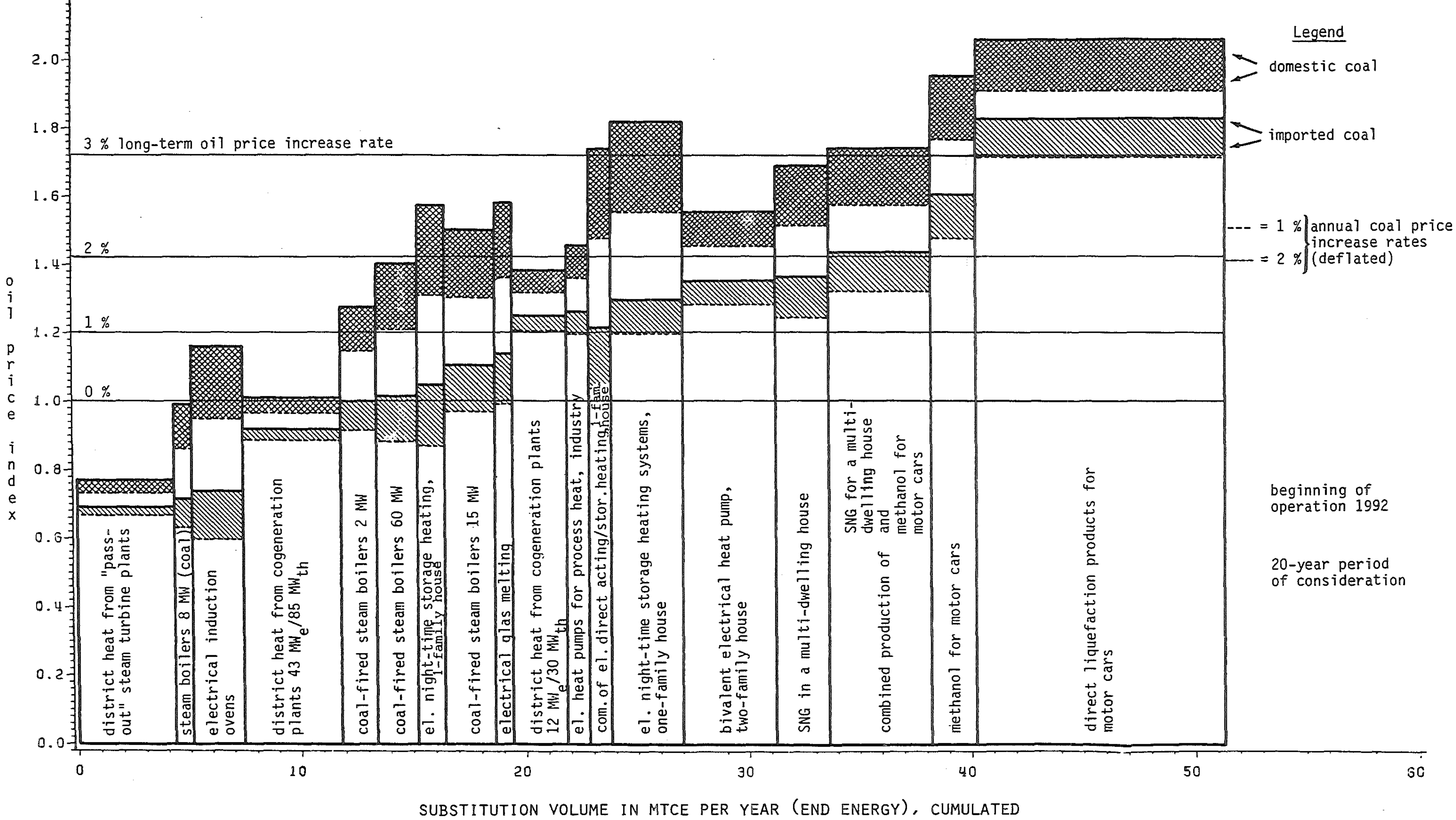
Medium Btu industrial fuel gas can be generated from coal with less technical effort and better efficiencies than SNG. However, for gasification plants with a throughput of 1 million tons of coal annually even the costs of generating medium-Btu industrial fuel gas exceed those of steam generation in steam boilers operated on heavy fuel whether assuming 1 % or 2 % real oil price increases, so that boilers fed with industrial fuel gas cannot compete with heavy oil-fired boilers. The costs of generating industrial fuel gas are, however, lower than comparable prices for light fuel oil. In this case, the comparison of the costs for industrial fuel gas and oil steam boilers is heavily dependent on the density of the distribution network required and on the exceptionally high initial costs of distributing the industrial fuel gas. In order to achieve competivity with light oil-fired steam generators assuming a 2 % annual oil price increase rate, very optimistic assumptions concerning the distribution costs have to be made. Even then, industrial fuel gas still has economic disadvantages compared with steam generation in conventional coal-fired boilers as analysed in the heat production strategy.

4. Sensivity analyses

In figure 1, the strategy technologies of all three strategies are compared with each other; furthermore, the sensitivities with respect to the development of the prices of oil and coal as well as the ratio of domestic coal to imported coal use are contrasted. For each of the different strategy technologies the factor (oil price index) is given by which in 2000 the prices for mineral oil products (leaving the refinery) would have to exceed those of 1982 in order to achieve parity of costs of useful energy between coal and mineral oil technologies. The oil price indices corresponding to long-term real annual oil price increase rates of 0 %, 1 %, 2 %, and 3 % are drawn as parallel lines to the abscissa.

In this figure, the strategy technologies are ranked according to increasing oil price indices assuming price growth rates for domestic coal of 1 %/a, for imported coal of 2 %/a, and a ratio of use of 1:2 (base case). The width of the beam indicates the substitution volume of the respective technology. The upper and lower hatched areas within the beams apply to domestic coal and imported coal, respectively, for annual price increase rates between 1 and 2 %. The base case is situated in between the hatched areas.

Figure 1: OIL PRICE INDICES FOR THE STRATEGY TECHNOLOGIES



The ranking in the base case shows a clear advantage for the strategy technologies of the heat production strategy; the strategy technologies of the electricity generation strategy occupy -- apart from a few relatively favourable and a few very unfavourable technologies (the latter are not included in the figure; e.g. electric steam boilers) with, in each case, minor substitution contributions -- a position in the middle while the refining technologies come last. This constellation proves to be rather stable with regard to coal price developments and the ratio of domestic coal use to imported coal use; the advantages of the heat production strategy become more pronounced if higher growth rates for coal prices are assumed and/or a larger share of domestic coal.

Furthermore the figure shows that, assuming moderate annual oil price increases (real 0 to 1 %), only district heat from larger cogeneration plants, process heat from coal-fired boilers, and some strategy technologies of the electricity generation strategy with, however, only small substitution contributions, have cost advantages compared to the respective oil technologies; large and medium-sized cogeneration plants and steam boilers of 8 MW and 2 MW and electric induction furnaces still have advantages also if only domestic coal is used. Assuming long-term real oil price increase rates of up to 2 % all strategy technologies of the heat production strategy have cost advantages even if only domestic coal is used; in this case, the strategy technologies of the electricity generation strategy have cost advantages only if larger fractions of imported coal are used.

In addition, the sensitivity analyses suggest the following general trends:

- Variations in coal prices and different assumptions about the ratio of domestic coal use to imported coal have relatively little bearing on the costs of district heat from coal-fired cogeneration plants.

- The relative position of the strategy technologies with good energy efficiencies -- district heat from coal-fired cogeneration plants, heat pumps -- improves if higher oil prices or larger proportions of domestic coal are assumed.

- The economically favourable position of oil substitution in the heat market compared to substitution in the transport sector is not affected by variations in coal prices and the ratio of domestic coal use to imported coal.

5. Indicators for an overall economic assessment of the coal utilization strategies

For an overall economic assessment of the coal utilization strategies three indicators were determined: investment costs, labour requirements, and total substitution costs.

The investment costs for implementing the strategies to the full extent of 20 mtce of crude oil substitution range between 40 billion DM and 100 billion DM; the electricity generation strategy marks the upper border of this margin, the heat production strategy the lower border. The distribution of the total investments for the strategies on a 20-year period for full implementation of the strategy yields for all strategies considered annual investment amounts which should be no burden for the capital market.

The manpower requirements, of which only a rough estimation could be presented within the framework of this study, range between 40 000 and 80 000 man-years annually, taking account of the labour requirements for operation of the strategies, mining of one third of the coal needed according to the ratio of domestic coal use to imported coal of 1:2, as well as the labour requirements due to investments (plant installation, production of the required investment goods). The manpower requirements of the heat production strategy lie at the lower border, those of the refining strategy/Variant A at the upper border of this margin. From the point of view of the labor market as a whole, the differences between the strategies of, at the most, 40 000 man-years annually are quite remarkable, but whether these differences between the strategies would become effective on the labour market to their full extent depends on various preconditions which cannot be described in detail here. Of greater importance, therefore, is the regional concentration of the manpower requirements, which is especially high for the coal refining strategy and can, under regional labor market aspects, be an important item for assessing the strategies.

As far as the total substitution costs (difference of the annual costs between coal and oil-based technologies, summed up over the substitution contributions of all strategy technologies of a strategy) are concerned a clear ranking of the strategies emerges which could already be expected on account of the cost comparisons: heat production strategy - electricity generation strategy - refining strategy Variant B - refining strategy Variant A. For the period of consideration from 1992 to 2011, the range extends from a substitution gain of 3.8 billion DM annually (assuming full implementation of the strategy) in the case of the heat production strategy to a substitution loss (higher costs than in the oil case) of about 3.4 billion DM in the case of the refining strategy Variant A. But it has to be pointed out that this indicator should be interpreted in the sense of minimum additional costs or maximum savings (in the case of a substitution gain) -- which means that this indicator draws a favourable picture of the coal technologies -- because the calculations for the coal technologies were based only on minimum interest rates on the capital spent, margins for risks or reserves, which are usually included in business calculations, are not taken into account. In this sense, calculated additional substitution costs (substitution losses) represent the minimum subsidy requirements; if interventionistic measures are to be avoided additional financial incentives beyond these minimum subvention requirements would have to be offered. A final remark concerns the fact that the subsidy requirements would have to be determined in terms of the additional costs in relation to the most favourable offer on the market; on the energy markets considered here, however, other energy carriers (e.g., natural gas) are sometimes more advantageous than the oil products on which the comparison is based so that in these cases higher subsidies would be required.

6. Overall economic assessment of the coal utilization strategies

From an overall economic perspective the heat production strategy would be given the most favourable position because judged from the evaluation aspect which the authors of this study consider to be the most important one - the substitution costs - this strategy shows a substitution gain, i.e., lower costs compared to the oil case. However, this favourable picture needs to be put in perspective because despite this overall economic substitution gain considerable government subsidies will be required during the long implementation phase of district heat supply. In the long run, however, these could be repaid, at least in part, from future gains. The electricity generation strategy occupies an intermediate position. Compared to the oil case, additional costs are calculated. But the economic prospects of this strategy improve if the substitution volume is somewhat reduced because by some of the strategy technologies with only minor contributions to substitution very high substitution costs are incurred (e.g., electric steam boilers, monovalent heat pumps for space heating in industry). The two variants of the refining strategy have unfavourable economic prospects; contributions to the substitution goal beyond what is needed for large-scale commercial demonstration of this technology could be justified from an economic point of view only under regional labour market aspects.

The economically most favourable strategy, the heat production strategy, will, however, probably have to cope with the severest implementation problems. This applies primarily to district heat which, first, would have to compete with natural gas, second, would imply changes in the prospective planning and in the structure of the electric utility sector, third, would have to reckon with considerable financial problems. The conditions for realizing the gasification variant of the refining strategy are also rather unfavourable as long as sufficient amounts of natural gas are available. In this respect, the electricity generation strategy has the relatively most favourable conditions. Assuming economic profitability of this strategy, only heat pumps, which are to contribute a large share to the substitution goal, would raise problems. It is doubtful whether the individual households will be prepared and in a position to finance the rather high investments. The conditions for realizing the liquefaction variant of the refining strategy are also rather favourable as far as contributions of hydrogenation products are concerned, because, in the foreseeable future, only these products offer a chance of substituting mineral oil products in the transport sector. But it has the highest substitution costs of all the strategies considered.

C. Analyses of the environmental impacts of an increased coal utilization

The environmental impact analyses are concentrated on the question whether an increased use of hard coal will lead to an additional degradation of the environment due to emissions of atmospheric pollutants, wastewater as well as solid waste. The risk of accidents from an increased coal use is also estimated.

1. Environmental impacts from emissions of atmospheric pollutants

Investigated are - with differing degrees of intensity - sulphur dioxide (SO_2), nitrogen oxide (NO_x), flue dust and selected suspended particulates, polycyclic aromatic carbonhydrates (PAH) and carbon dioxide (CO_2). Apart from comparisond between the strategies, the impact analyses are focused on contrasting the emissions and concentration levels, respectively, in the reference year 1980 and in 2000, and on estimating the impact of the new Regulation on emission standards for large boilers (known as Großfeuerungsanlagenverordnung (GFAVO)) which came into effect in 1983. In order to be able to interpret the changes in the environment associated with an increased use of hard coal in light of the development of overall pollution levels, the emissions of SO_2, NO_x, and dust are analysed not only for coal conversion and utilization plants, but also for other energy facilities having a major share in releasing these compounds.

Sulphur dioxide

Development of emissions

In table 2, column 2, the emissions of sulphur dioxide (SO_2) are given for the different cases considered. The most striking result is the considerable reduction in sulphur dioxide emissions in 2000 (reference estimate) compared to the situation in 1980 (cf. rows 1 and 2). If fossil fuel use is reduced by only 10 % compared to 1980, as assumed in the re-

Table 2: Primary energy use of fossile energy carriers; emissions of SO_2, NO_x and dust from energy use in the sectors "power plants and district heating plants", "industry", "residential/commercial", "transport", "refineries and coal refining facilities" in the Federal Republic of Germany [1]

	(1) primary energy use of fossil energy carriers (mtce)		(2) SO_2 emissions (1000 tons)			(3) NO_x emissions (1000 tons)			(4) dust emissions (1000 tons)		
				from			from			from	
	total	hard coal	total	hard coal and hard coal products	mineral oil and mineral oil products	total	hard coal and hard coal products	mineral oil and mineral oil products	total	hard coal and hard coal products	mineral oil and mineral oil products
(1) reference year 1980	366	77	3200	1190	1200	3280	760	1870	310	140	110
(2) reference estimate 2000	325	90	1130	440	470	2470 (1720)	700 (220)	1290 (1280)	150	50	70
(3) electricity generation strategy 2000	330	115	1110	530	360	2640 (1740)	910 (270)	1250 (1240)	160	70	70
(4) heat production strategy 2000	317	102	1280 [6]	710	350	2510 (1780)	790 (320)	1250 (1230)	170	70	70
(5) refining strategy 2000 (A)	334	119	1140	480	450	2390 (1620)	960 (450)	960 (940)	160	70	70
(5) refining strategy 2000 (B)	333	118	1100	490	390	2410 (1650)	840 (340)	1100 (1090)	150	60	70
(6) reference year 1980 according GFAVO [3]	366	77	1440	380	860	2820 (2240)	480 (150)	1830 (1820)	180	50	100

1) Excluding emissions from industrial processes

2) Values in brackets: Assuming implementation of abatement measures for NO_x according to the state-of-technology as stipulated in the Resolution passed by the Environment Ministers' Conference (EMC) on April 5, 1984

3) Assuming implementation of GFAVO for energy use in 1980 (values in brackets for NO_x: implementation of the EMC-Resolution of April 5, 1984 for energy use in 1980)

4) As concerns the NO_x emissions from the use of mineral oil and mineral oil products, the planned legal measures for emission reduction in road transport, which accounts for almost 90 % of total NO_x-emissions from mineral oil use, are not taken into account; their inclusion would have resulted in further considerable reductions in NO_x-emissions from the use of oil for the reference estimate 2000 and the coal utilization strategies

5) Due to roundings, there are no differences between cases 2 to 5; however, the values for the strategies are up to 10 % more favourable than for the reference estimate

6) If fluidized-bed combustion is used for boilers of an overall thermal capacity $\leq$ 300 MWth, the value would be 1090 thousand tons of SO_2

ference estimate, SO_2 emissions diminish to slightly less than one third of the emissions in 1980, i.e., from roughly 3.2 to about 1.1 mt. This is mainly the result of the implementation of the new Regulation on large boilers (GFAVO) as demonstrated by a comparison with row 6, where the emissions are listed which would have resulted had the GFAVO already been in effect in 1980. The thus determined "emission reduction potential" of the GFAVO amounts to about 1.75 mt per year. The additional reduction in the case of the reference estimate 2000 is the result of a lower overall utilization of fossil energy carriers compared to 1980, and to structural shifts in end energy use (shifts towards grid-dependent end energy carriers - gas, district heat, electricity).

SO_2 emissions from the use of hard coal alone also diminish considerably though, compared to 1980, according to the assumptions made the use of hard coal increases markedly for the reference estimate and the strategies. The comparison of the results of the reference estimate, on the one hand, and of the strategies, on the other hand, shows that, on the whole, the additional "strategic" use of coal for oil replacement is not accompanied by any, or only minor, additional emissions because the emissions from the increased coal use are compensated by a decrease in emissions due to reduced mineral oil use. The rather unfavourable position of the heat production strategy would improve if the small cogeneration plants and industrial boilers using coal which are to be implemented according to the strategy and for which no, or only limited, desulphurization is stipulated in the GFAVO, would be equipped with fluidized-bed combustion. SO_2 emissions would then be of nearly the same order as in the case of the gasification variant of the refining strategy (Variant B) for which the most favourable values are obtained.

Development of SO_2 air concentration levels in conglomeration areas of the Federal Republic of Germany

The question whether the increased use of hard coal might imply health hazards from SO_2 for persons living in regions of the Federal Republic of Germany which are already heavily polluted (primarily conglomeration areas) is addressed via an analysis of two representative types of "model conglomeration regions"; one of these types represents the conditions of the Ruhr region (Type A), the second (Type B) those of the conglomeration areas situated at a distance from mining districts and having an industrial structure characterised by low proportions of energy conversion industries and heavy industry.

In the conglomeration areas, the same development of emissions -- comparing the years 1980 and 2000 -- is found as for the overall emissions of SO_2; in the conglomeration areas along the Ruhr river the effect of the GFAVO will be especially strong because of the great number of large coal-fired power plants situated here. The differences in emissions between the reference estimate 2000 and the coal-use strategies are rather small. Again, the heat production strategy occupies the least favourable position unless fluidized-bed combustion is implemented.

As could be expected, a decrease in air concentration levels is found for the conglomeration areas in the year 2000. For the "Model Region Ruhr" as well as for the "Model Region Type B" long-term SO_2 concentration levels are calculated which are significantly lower than the average annual limit value (IW 1) of 140 µg SO_2/m^3 stipulated in the so-called "TA Luft" (Technische Anleitung zur Reinhaltung der Luft), a regulation concerning limit values for emission and air concentration levels of various pollutants. This holds true even if the concentrations calculated for the half-year heating period are compared with the limit values referring to the full year. If the upper threshold value of 60 µg SO_2/m^3 air recommended by the World Health Organisation (WHO) is taken as reference scale, however, considerable proportions of the population are exposed to higher values. This applies especially to the "Model Region Ruhr" considering the heating period and the year 1980 but higher values (during the heating period) are also obtained for the reference estimate 2000 and the coal utilization strategies (between 5 and 43 % for the reference estimate and the strategies); it should, however, be borne in mind that the values recommended by WHO apply to annual mean values of SO_2 concentrations. Only the version of the heat production strategy incorporating the implementation of fluidized-bed combustion for smaller plants yields also for the "Model Region Ruhr" during the winter heating period a very low value for that part of the population which is exposed to SO_2 concentration levels above the WHO threshold value.

Based on existing epidemiological and experimental investigations, the majority of experts does - so far - not expect that concentrations as discussed above will have detrimental health effects on man. But according to a more recent, not yet concluded epidemiological study carried out in the Netherlands, impairments of certain lung functions from concentrations of SO_2 and dust even clearly below the annual limit values of the TA Luft cannot be ruled out. The deterioration of the investigated lung functions alone cannot, however, be interpreted as impairment of health in the sense of an illness.

The reduction of SO_2 emissions in the "Model Region Ruhr" to about one third of the volume of 1980 results in a reduction of the air concentration levels to only about 60 % in this conglomeration area (during the heating period). This is mainly due to the fact that in the Ruhr region emissions are released mainly from big power plants having high stacks already today and therefore have only a limited effect on local ground level concentrations. In general, ground level concentrations in the model conglomeration regions are primarily determined by emissions released from low heights. Main contributor to atmospheric concentrations are therefore the emissions of the residential/commercial sector, though, in the case of the "Model Region Type B", they only account for about 10 %, and, in the case of the "Model Region Ruhr", even for only about 5 % of overall emissions.

Assuming equal emission volumes, considerably higher air concentration levels were found for the "Model Region Type B" with dispersion conditions prevailing in the southern part of Germany, compared to the same model region with dispersion conditions which are predominant in the northern part of Germany. These differences are attributable to the more unfavourable dispersion conditions prevailing in southern Germany which are characterised by low wind speeds and more frequent occurance of so-called stable weather conditions, which enhance the effect of the emissions released from low heights for local ground level concentrations.

Air concentration levels and deposition of sulphur compounds due to long-range transport

The analyses of long-range transport of sulphur compounds are aimed at determining the atmospheric concentrations and deposition of sulphur in the chemical forms of sulphur dioxide ($S\text{-}SO_2$) and sulphate ($S\text{-}SO_4^{--}$). As model for the long-range transport, transformation, and deposition of sulphur emissions the MESOS model, which was developed at Imperial College London, was applied and extended within the framework of this study. The results of these analyses are an important basis for assessing the possible impacts an increased use of hard coal might have on ecological systems, e.g. forests. However, considering the present state of model development and the available data base, the results of the analyses are rather suited for comparative statements (e.g., the impact of the electricity generation strategy compared to the effects of the reference estimate) and not so much for projections of the absolute level of sulphur depositions. Furthermore, it should be emphasized that the statements apply primarily to long-range (> 100 km) transport; the influence of emissions in the vicinity of the source is only roughly estimated.

According to the MESOS calculations, domestic emission sources have, on the whole, a somewhat lower share in total sulphur depositions over the area of the Federal Republic of Germany than in former investigations (47 % compared to 50 - 54 %). These differences are probably the result of the differentiation of emissions according to stack heights in this study.

An "analysis of origin" of sulphur depositions in forest regions with high damage of the Federal Republic of Germany shows a dominant influence of foreign sources. Thus in 1980, for example, 75 % of the sulphur input in the Oberpfälzer Wald, an area near the CSSR border, was caused by foreign sources and only 25 % were of domestic origin according to these calculations; emissions from the CSSR provided the largest proportion with about 36 %. Corresponding results were obtained for areas of the Black Forest.

The expected reduction in SO_2 emissions in 2000 compared to 1980, due mainly to the implementation of the GFAVO, will, if no comparable abatement measures are taken in the neighbouring countries, not have a corresponding effect on depositions within the Federal Republic of Germany. In this case, SO_2 concentrations as well as total sulphur deposition - averaged over the area of the Federal Republic of Germany - will diminish only by 30 % compared to 1980, while domestic emissions are reduced by more than 60 %. The influence foreign measures for emission control would have on depositions in the Federal Republic of Germany is demonstrated by the following estimation: Assuming full implementation of the regulations of the GFAVO concerning the limitation of sulphur emissions from the use of fossil fuels in large boilers in the Federal Republic of Germany in 1980, and no attendant reduction of SO_2 emissions from foreign sources, ground level SO_2 concentrations and total sulphur depositions would, on the average, have been lower by about 25 % than was the case in 1980 (while sulphur emissions would have been reduced by more than 50 %). The simultaneous reduction of emissions in the neighbouring countries to the west by 30 % would have effected a 30 % decrease; a corresponding reduction in all neighbouring countries, i.e., including the GDR and the CSSR with, at present, very high emissions, would even have produced a 40 % reduction.

A considerable difference in air concentration levels between 1980, on the one hand, and the reference estimate 2000 and the coal utilization strategies, on the other hand, emerges when the shares of those areas of the Federal Republic of Germany are compared, where the <u>IUFRO limit value</u> (IUFRO = International Union of Forest Research Organisations) for SO_2 concentrations (25 $\mu g\ SO_2/m^3$) is exceeded. While for 1980, this share was calculated to amount to 20 %, the value for all the other cases considered is less than 5 %. However, when evaluating these results it should be borne in mind that also short-term peak concentrations which might occur under certain meteorological constellations also in areas located at a great distance from emission sources, are held responsible for forest damage. Such episode analyses are not performed within the framework of this study.

As concerns <u>forest damage</u>, it should be noted that, according to present knowledge, it is caused by a complex constellation of factors, among which air pollution is, however, thought to play the major role. SO_2 and NO_x are assumed to be the main pollutants which have -- primarily in the form of acids and photo-oxidants created during transport in the atmosphere -- a detrimental effect on plants. Natural stress factors (climate and weather, noxious organisms) and forest management measures are considered to play only a minor, at most intensifying, role.

Nitrogen oxides

The importance of nitrogen oxides results from their potential impacts on human health and on ecosystems. As concerns the effects on ecosystems, two aspects have to be differentiated: the contributions of NO_x as acid former, on the one hand, and as reactive partner for the formation of oxidants which are also held responsible for damages to ecosystems, on the other hand.

The analyses of nitrogen oxides could not be performed on the same quantitative level as for SO_2, because knowledge about dispersion, chemical transformation and deposition of nitrogen oxides and of the secondary compounds does not yet suffice for making definitive statements about air concentration patterns in dependence from changes in emissions.

According to present knowledge, the by far largest part of nitrogen oxides is released as nitrogen monoxide (NO) which oxidizes in the atmosphere into nitrogen dioxide (NO_2). In the course of the ensuing reactions, secondary pollutants, such as ozone or peroxyacethylnitrate (PAN) are formed - especially in the atmosphere of conglomeration areas - which are considered to be indicators of photosmog. NO_x can be removed from the atmosphere by dry deposition. Through reactions of NO_2 with OH-radicals nitric acid is formed which reaches the ground or the biosphere, respectively, via dry and wet deposition.

Even the estimation of total NO_x emissions is linked with greater insecurities than for sulphur dioxide. While SO_2 emissions are largely determined by the sulphur content of the fuel, nitrogen oxides are generated mainly during the combustion process by reactions between the nitrogen and the oxygen of the combustion air. They are thus dependent on combustion conditions, especially combustion temperatures; high temperatures are favourable for the formation of nitrogen oxides. In addition, the nitrogen bound to the fuel is transformed into nitrogen oxide.

As shown in table 2, in 1980 NO_x emissions amounted to about 3.3 mt and will diminished to about 75 % of this volume in 2000. But this value considerably underestimates the anticipated decrease for two reasons: First, the planned legal measures for emission reduction in the transport sector, the main source for NO_x emissions, have not been accounted for. Second, the calculations of the emissions from large boilers are based on the limit values of the GFAVO of June 1983 which have to be considered as obsolete in light of a recent resolution passed by the Environment Ministers' Conference (EMC) on April 5, 1984. By fixing significantly lower limit values also for old plants, the EMC has newly defined the state-of-the-art of technology which, according to GFAVO, is relevant for NO_x retention. If these limit values are implemented (cf. values in brackets in column 3, table 2), NO_x emissions will amount to about 1.7 mt in 2000. This corresponds to a reduction to about half the emission volume of 1980. The "emission reduction potential" of the EMC resolution is roughly 1 mt (cf. value in brackets, row 6, table 2).

Thus, together with the planned measures for emission retention in the transport sector, also for NO_x at least similar emission reductions as for SO_2 should be attainable by 2000.

The differences between the reference estimate and the coal utilization strategies in terms of NO_x emissions are slight. The relatively unfavourable position of the electricity generation strategy vanishes if the limit values of the recent EMC resolution are taken as the basis for the calculations. The most favourable values are obtained for both variants of the refining strategy.

For the reasons mentioned above, quantitative analyses of atmospheric concentrations were not performed. At clean air stations, concentrations between 3 and 14 $\mu g\ NO_2/m^3$ have been measured. In polluted areas, average annual values of atmospheric NO_x concentrations between 30 and 70 µg/m^3 have been obtained, i.e., concentrations which are only slightly below the long-term value of 80 µg NO_2/m^3 stipulated in "TA Luft". The majority of experts is of the opinion that such concentrations will have no detrimental effects on human health.

A characteristic feature of the deposition values for nitrogen is that, in the vicinity of the source, a far greater amount is deposited by dry deposition than by wet deposition. In clean air regions, wet deposition of nitrate is at least of the same importance as total dry deposition of NO_2 and nitrate. A rough estimation of total deposition in the Federal Republic of Germany yields some 260 000 to 700 000 t of nitrogen annually in the form of nitrate compounds and NO_2.

Dust and suspended particulate matter (SPM)

Comprehensive analyses about flue dust are complicated due to the heterogenity of this substance, which is released from a great number of natural and anthropogenic emission sources and therefore occurs in quite different forms with different chemical and physical structures.

Suspended particulates (trace elements) contained in dust emissions from the combustion of fossil fuels are of special importance. Some of these compounds are known to have toxic effects on man as well as on plants. Present knowledge about suspended particulates is, however, much poorer than about sulphur, so that more detailed quantitative analyses similar to those performed for sulphur had to be abandoned.

According to the estimates performed in this study (cf. table 2, column 4), dust emissions from the use of fossil fuels amounted to roughly 0.3 mt in 1980. This value corresponds to roughly 40 % of total anthropogenic (and measured) dust emissions. Compared to 1980, a reduction in dust emissions of more than 50 % is obtained for the reference estimate 2000, which is mainly the result of the implementation of the GFAVO. Between reference estimate and coal utilization strategies there are, however, hardly any differences in dust emissions.

The considerable reduction in total dust emissions as a consequence of the more stringent regulations of the GFAVO have an impact also on the emission volume of suspended particulates. But it would be wrong to assume that the emissions of suspended particulates diminish in proportion to total dust emissions because the reductions in total dust emissions have an only underproportional effect on emissions of fine dust, which are assumed to be the main carrier of suspended particulates.

On the whole, in conglomeration areas pollution from trace elements is -- at least with regard to the compounds considered in this study: arsenic, cadmium, mercury, and lead -- by no means without problem. This applies to atmospheric concentrations as well as to concentrations in soil, because the measured values - with the exception of atmospheric mercury concentrations - are in the order of limit values or recommended threshold values or "tolerable" values, respectively. A strategy for reducing these values must commence with the main sources and enforce emission reductions at those places. According to the estimations of this study, energy conversion plants utilizing hard coal are, in general, not of major importance.

Significant contributions of the emissions of suspended particulates from the use of hard coal to atmospheric concentrations are found only for arsenic. Estimations of long-term concentrations of the trace elements considered here for conglomeration areas or the entire area of the Federal Republic of Germany show that the contribution from hard coal utilization in energy conversion plants is only very small. This also applies to arsenic.

When evaluating these results it should be considered that large fractions of a number of trace elements, such as mercury, are released in gaseous form. For some elements, e.g. cadmium, there is still uncertainty about the percentage released in gaseous form; in these cases, corresponding measurement programmes are required to improve our knowledge. Rough estimations for mercury - including the fraction released in gaseous form - do not yield critical levels for atmospheric concentrations either.

At present, detrimental health effects from emissions of heavy metals constitute less a "widespread" problem but are rather a problem of locally high emissions and corresponding concentrations in the vicinity of, for example, smelters and metal working plants.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH), e.g., benzo(a)pyrene (BaP), are at the focus of the discussion about carcinogens in emissions from coal combustion. The carcinogenic effects of a number of these compounds has been proven in different experiments with various animal species.

Only very small amounts of PAH are released from big coal-fired power plants and district heating plants. PAH emissions from coal use in the "residential/commercial" sector and "coke oven plants" are considerably higher.

A rough estimation of the emissions of BaP for the reference estimate 2000 gives the following results: Slightly higher BaP emissions are obtained in the sector "power plants and district heating plants" due to the increased use of hard coal in this sector in 2000. In the "residential/commercial sector" and "coke ovens" BaP emissions will diminish drastically as a result of the considerable reduction of hard coal use in these areas in 2000. But the latter two sectors will continue to be by far greater sources of PAH emissions than power plants and district heating facilities.

The differences in PAH emissions between the reference estimate 2000 and the coal utilization strategies should be of no great significance.

Carbon dioxide

In a number of studies published recently, the increasing emissions of carbon dioxide from fossil fuel use are considered to be the cause for potential future global and regional temperature rises. A doubling of the CO_2 concentration to the value of 600 ppm is thought to be the critical threshold; it is estimated that this concentration will be associated with a rise of mean global temperatures between 1.5 and 4.5 K. In this study, the validity of the models used for calculating the point in time when a doubling of the CO_2 concentration might occur, and the expected rise in temperatures are critically investigated.

At present, statements about the development of atmospheric CO_2 concentrations from the use of fossil energy carriers as well as statements concerning the impact of rising CO_2 concentrations on the climate are fraught with great uncertainties. Analyses about the consequences of climatic changes on agriculture and forestry, on the overall economy, and on general living conditions, and interpretations of the results of such analyses have to take account of these basic uncertainties. As changes in the climate can, however, have considerable long-term effects, research on the carbon cycle as well as on climate models should be intensified.

2. Environmental impacts of wastewater emissions

The environmental impact analyses of wastewater emissions from coal mining and utilization suggest that coal use as assumed in the reference estimate and the coal utilization strategies will not entail general "problems of water supply"; but it cannot be excluded that, at individual selected sites for power plants, the supply of the necessary amounts of water might be difficult.

The disposal of pit waters from coal mining will raise problems. Their high salt content of 200 g/l adds heavily to the salinity of the Rhine river. In other rivers, they prevent the possibility of using the water as a source for drinking water or for other purposes, or they impair the living conditions of fish populations and other aquatic forms of life, respectively. So far, limit values for discharging saline wastewater have not been stipulated.

Wastewater from coal preparation facilities and coal-fired power plants can be treated rather easily so that they need not be hazardous for surface and groundwater. But even here contamination of the receiving stream may occur if the wastewater - especially in the case of flue gas desulphurization plants - contains large amounts of salt. It should therefore be considered whether priority should generally be given to those treatment and purification processes which might reduce salinity, even if higher costs are involved.

Despite their sometimes very high content in organic substances which are detrimental to health or toxic, wastewater from coal refining plants can be treated satisfactorily. The usable substances contained in these effluents (such as, e.g., phenol and ammonia) can be recovered economically. But the purification effort should go beyond the present state-of-technology (full biological purification) and incorporate also a physico-chemical purification stage to eliminate substances which are difficult to decompose.

3. Environmental impacts of solid wastes

Compared to today, the amounts of solid wastes from the utilization of hard coal will increase for the reference estimate 2000; for the strategies even larger amounts must be expected.

As concerns the disposal of the solid wastes, the idea of their utilization is currently being given greatest attention. However, the possibilities of utilizing the different wastes vary greatly. Utilization of mining wastes, which have, in the past, also been used in road and dam construction, will stagnate or diminish, respectively. Measures for treating the mining waste so that it can be utilized as construction material might open up new markets. Part of these mining wastes, which are rich in hydrocarbons, could, in the more distant future, also be used to generate energy in fluidized-bed furnaces. The possibilities for utilizing the residuals from water preparation and purification are still being tested. More than 65 % of the bottom ashes from power plants and refining facilities are presently utilized (e.g., for road construction); they should raise no difficulties also in the future.

As concerns fly ash, the recommendation of the Deutsche Ausschuß für Stahlbeton (German expert commission on reinforced concrete), according to which the minimum cement content in concrete is raised from 240 kg/m^3 to 300 kg/m^3, will entail considerable difficulties. Only if new utilization possibilities, e.g., its use as fly ash concrete or filling material, are found, there are good chances of maintaining the present level of utilization (about 75 %). The additional amounts which are produced according to the assumptions underlying the reference estimate and the strategies (on the average a doubling compared to 1980) will considerably aggravate the utilization problem. The major part will probably have to be disposed of in dumps.

The uses of gypsum from flue-gas desulphurization plants are manifold. So far, no difficulties are expected for the amounts obtained according to the reference estimate and the heat production and refining strategies. As concerns the significantly higher amounts of gypsum in the case of the electricity generation strategy, however, difficulties cannot be excluded.

The different residuals can be disposed of in dumps, provided that the official regulations for constructing and operating such sites are observed. But the area requirements will - especially on the local level - be increasingly difficult to meet so that highest priority should be given to utilizing these residuals.

4. Risks of accidents from mining, transportation, preparation and conversion of hard coal

The decline in the number of accidents underground per 1 mt of hard coal mined, recorded in the hard coal mining industry of the Federal Republic of Germany in the past, should continue in the future with a slightly diminishing tendency. The estimations performed within the framework of this study demonstrate that even if coal production is raised to 100 mtce - which would imply a very large share of domestic coal for supplying the additional amounts of hard coal required according to the strategies - the number of accidents will not be as high as those registered in 1981.

The risks of accidents from transport, preparation and conversion of hard coal are of minor significance only when compared to the environmental hazards due to emissions. Relevant differences between the coal utilization strategies and the corresponding oil case in terms of accidents are not to be expected. As concerns coal preparation and conversion, risks of accidents for the population at large can almost be excluded; the risk for the manpower employed does not exceed that observed in similar industrial plants.

5. Summary of the results of the environmental impact analyses

From the point of view of environmental impacts the substitution of 20 mtce of crude oil by hard coal is not associated with relevant additional impairments; emissions of atmospheric pollutants from the additional coal utilization is counteracted by emission reductions from oil use of about the same scale. The amounts of wastewater and solid wastes are largely correlated with coal input so that in this respect the heat production strategy offers advantages; the larger amounts of wastewater and residuals resulting from the other strategies appear, however, to be manageable as far as their impact on the environment is concerned, even though problems on a local scale (supply of the necessary amounts of water, salinity of the receiving stream with high background concentrations, area requirements for waste disposal) cannot be excluded. Under environmental aspects the question which coal-based technologies substitute for oil is hardly of any importance on a global level. Though the heat production strategy would have advantages if all hard coal-burning facilities of a capacity below 300 MWth, which are to be implemented within the framework of this strategy, would be equipped with fluidized-bed combustion, the differences compared to the other strategies would, considering the substitution volume discussed here, not be relevant.

Compared to the present situation, the environmental impacts due to atmospheric pollutants from the use of hard coal will be reduced considerably as a result of the implementation of the new Regulation on large boilers (GFAVO). This applies above all to sulphur dioxide. Despite a considerable increase in the use of hard coal (13 to 42 mtce according to strategy) SO_2 emissions diminish by about 40 to 60 % of present SO_2 emissions from hard coal utilization. In light of the rapidly proceeding forest decline, to which, it is hardly doubted any more, SO_2 also contributes, the emission reduction potential of the GFAVO of 1750 kt/a (related to the present use of fossil energy carriers) should be realized as quickly as possible. The situation concerning sulphur air concentration levels and deposition will also have improved considerably in 2000, though not in proportion to the development of emissions, if measures for their reduction are not initiated in the neighbouring countries of the Federal Republic of Germany.

NO_x emissions from hard coal utilization will also decline considerably and attain only 30 to 60 % of the present level by 2000, if the more stringent limit values incorporated in the recent resolution of the Environment Ministers' Conference of April 1984 compared to the GFAVO of June 1983 are taken into account. Emissions of other polluting substances - such as heavy metals, polycyclic aromatic hydrocarbons, radioactive substances - from hard coal utilization in large boilers have no relevant impact on overall concentration levels of these pollutants in the Federal Republic of Germany.

D. Analyses of the social implications of an increased coal utilization

The main question of these analyses was to determine whether an increased utilization of coal might encounter similar protest and resistance as nuclear energy.

Two representative population surveys were carried out in December 1980 and in May 1982. In September 1983, these surveys were supplemented by a brief survey about public response to the recent development of the "forest decline" ("Waldsterben"). Parallel to these surveys, articles dealing with coal issues published in three daily newspapers and 2 weekly periodica were analysed.

First, it can be stated that coal utilization is judged positively by the majority of the population. If one differentiates according to types of coal utilization, it is shown that heat production from coal is viewed more favourably by the population than coal-based electricity generation. Coal gasification and/or liquefaction has little bearing on the opinion formation about coal, but it is - as far as it is known - evaluated positively in the majority of cases.

On the whole, two diverging attitudes emerge: A "traditional" attitude which is oriented along the topics which were basically generated in the course of the crisis of the coal industry persisting since the end of the fifties: employment aspects, profitability, subsidies, dependence of energy supply from abroad, etc.; and a "new" attitude characterized by the themes of the conflict about nuclear energy and the discussion about environmental hazards which has been going on intensively since the seventies: environmental compatibility, risks, etc.

Both attitudes on coal, the "traditional" as well as the "new", incorporate positions in favour of, as well as critical of, coal use. Characteristic of the "new" attitude towards coal utilization is the fact that the judgements about coal and nuclear energy run parallel: Either both are judged favourably, or both are rejected - though the attitude towards nuclear energy is more pronounced. What we are faced with here is the fundamental opposition between an attitude which is generally in favour of industrialism, on the one hand, and an attitude basically critical towards industrialism, on the other hand.

In the survey of 1982, the overall sample was divided as follows into the four groups characterized below:

1. Unconditionally positive attitude towards coal linked with a decidedly positive attitude towards nuclear energy: 13.8 % of the interviewed

2. Unconditionally positive attitude towards coal linked with a moderately positive attitude towards nuclear energy: 23.5 %

3. Unconditional rejection of coal linked with a rather positive attitude towards nuclear energy: 14.6 %

4. Conditional to unconditional rejection of coal linked with a corresponding rejection of nuclear energy: 6.9 %.

The contrast between positions 2 and 3 corresponds to the controversy among those parts of the population having a "traditional" attitude towards coal; the opposition between positions 1 and 4 characterises the controversy pervading the "new" opinion formation on coal utilization. The attitude groups "in between", which are not represented here, have a rather balanced and not very decisive opinion on coal.

In light of its representation in the attitudes of the population at large, the position of a critical attitude towards coal based on a critical view of industrial development as a whole (position 4) is clearly underrepresented in press reporting. The articles in the press are primarily dominated by energy economics and technical aspects, which are connected more with the "traditional" attitude towards coal utilization.

The data also reveal that the impulses for a critical attitude towards coal based on a general criticism of industrialism do not primarily emanate from editors' offices; rather, they are fed by a general potential for conflict of the society at large which emerged in the course of the nuclear energy controversy and has, to a certain extent, set up its own political and scientific infrastructure.

As concerns the question of a potential conflict about an increased coal utilization, the "traditional" and the "new coal critics" within the population are therefore of special interest. In accordance with their negative attitude towards increased coal use an above average proportion of both groups expects similar protests in connection with the construction of coal-fired power plants as in the case of nuclear power plants (in each case just under 40 % compared to just under 30 % in the overall sample). There are, however, significant differences in the preparedness for conflict of both groups: In the 1982 survey, questions were included concerning the general attitude towards certain forms of unconventional political behaviour and participation in such actions; it emerged

- that an above average percentage of the "new coal critics" were in favour of such actions,
- that they were more decidedly in favour of,

- and had made more extensive use of such unconventional forms of political behaviour than the sample as a whole.

In contrast, the "traditional coal critics" range on each of these items below the average of the overall sample.

Thus it can be concluded that it is mainly the "new coal critics" who could become the focal point for similar protests against increased coal use as in the case of nuclear energy, or who might join such protest actions, respectively.

A different question is, what are the chances that a fraction of the population of only about 7 % can - even if protests should arise - trigger a political and social conflict. When dealing with this question, two factors, among others, have to be considered which will, without doubt, influence the conflict potential of the "new coal critics": their above average educational level which enhances their capacity to argue and articulate their criticism and ideas, and their lower average age compared to the population at large which suggests a mobility and liberty specific of this generation, and which can be interpreted as a favourable disposition to participate in unconventional forms of political protest. In addition, the results of the surveys indicate that the movement critical of industrialism has in fact assumed opinion leader functions in conflicts as the one discussed here.

The results of the supplementary population survey and the media analysis carried out in 1983 indicate, however, that in spite of the heavily intensified discussion about the problems of "acid rain and forest decline" no general change in attitude unfavourable for coal has occured. But a heightened public response to the coal criticism would be a major precondition for the identified conflict potential to become effective. Though in the meantime a number of expectations in, and demands on environmental policy concerning the retention of hazardous substances associated with coal utilization have been formulated and are widely shared, they are presently hardly influencing the attitudes about coal utilization expressed by the media and the population at large. However, the current largely conflict-free positive attitude towards coal as an energy policy option will, in light of the general social constraints and the conflict potential of the "new coal criticism", persist only

- if the expectations in environmental policy are met by those responsible in industry and politics, i.e., if the latest state-of-the-art of retention technology is implemented in the extent and within the time frame required;
- if the reductions in emissions and pollutant concentrations to be expected as a consequence of more stringent environmental regulations are not thwarted by an increased use of coal. According to the environmental analyses of this study, however, this is not to be feared.

E. Summary evaluation of the coal utilization strategies and recommendations for an increased use of hard coal for oil substitution

Under economic, ecological and social aspects the coal utilization strategies are assessed as follows:

The high substitution costs which would require massive subsidies are prohibitive of larger contributions of the coal refining strategy, i.e., of coal gasification and liquefaction products, as substitutes for oil. From the point of view of environmental impacts there would be no objections because no relevant additional pollution compared to the oil case should occur. The problem of public acceptance of large-scale coal refining is dificult to assess as there is not yet much public awareness of this technology.

As concerns substitution costs, the electricity generation strategy could be more favourable if the substitution volume would be somewhat reduced, as the economic prospects of some of the technologies considered for substituting mineral oil by electricity generated from coal are extremely negative. One of the major advantages of this strategy would be the possibility of reducing, via coal-derived electricity, the dependence from oil for space heat supply in areas with low population densities. Under environmental aspects this strategy can - on the whole - also be advocated, though certain additional negative impacts compared to the oil case might be incurred due to increased amounts of solid wastes which are difficult to utilize. However, should hard coal be increasingly used in big power plants for generating electricity for space heat supply problems of public acceptance cannot be ruled out because this coal utilization option is a very controversial issue among the population at large.

The heat production strategy offers the most favourable economic prospects; it even does not lose its top position among the strategies in terms of economic advantages if fluidized-bed combustion is to be implemented in smaller plants. Under environmental aspects the heat production strategy would be the most favourable should fluidized-bed combustion be installed. At the same time, the use of coal for heating in decentralized units is the coal utilization option most favoured by the population at large. Under economic, ecological and social aspects the heat production strategy would therefore be the most favourable to be realized to the full substitution volume considered in this study. Nevertheless, this would entail considerable problems which suggest a reduction of the substitution volume also in the case of the heat production strategy. The extension of district heat in the scope projected in this strategy would, on the one hand, require higher subsidization of district heat (financial support during the long implementation phase) than today, and, on the other hand, imply energy policy measures for preventing a further rapid expansion of natural gas - due to a better economic starting position - in areas appropriate for district heat supply. Measures for preventing a too strong expansion of natural gas would have to be discussed against the background whether, from the point of view of long-term security of energy supply, it is reasonable to leave the largest part of the space heat market in densely populated areas to natural gas. The results of this study would suggest the following policy: to implement district heat in larger and medium-sized towns where district heat will have long-term economic advantages compared to natural gas, and to feed the natural gas into smaller towns or areas having a more unfavourable housing structure, respectively, i.e., areas where gas would remain competitive against district heat from coal also in the long-term. In addition, such a policy might also mitigate the problems associated, from the point of view of the electric utility sector, with a rapid expansion of district heat from co-generation.

The summary evaluation indicates that for each of the strategies a reduction of the substitution volume appears expedient, therefore a mix of the strategy technologies of the different strategies should be considered. For chosing the strategy technologies to be incorporated into such a strategy mix, the authors of this study have given priority to the evaluation aspects: substitution costs, emissions of SO_2 and NO_x, and the energy efficiency, which is correlated with various positive environmental effects (lower emissions of other substances, lower amounts of wastewater and solid waste, sparing use of resources). Under the assumption that an increased use of hard coal for oil substitution, supported by energy policy measures, is considered as desirable, the following ranking of strategy technologies for a strategy mix is suggested:

- district heat from coal-fired power plants in towns with more than 50 000 inhabitants;
- process heat from steam boilers burning coal, district heat in communities with less than 50 000 inhabitants generated in small coal-fired cogeneration plants (each preferably equipped with fluidized-bed combustion);
- selected electric heating systems (possibly supplied with electricity generated in coal-fired cogeneration plants) and monovalent electric heat pumps.

This strategy mix would, despite their favourable environmental prospects, include no major substitution contributions of the coal gasification and liquefaction technologies. But the necessity of large-scale demonstration in order to optimize these technologies in terms of economic and ecological implications, as well as regional labour market considerations would suggest the construction of a limited number of coal refining facilities on an commercial scale.