COMMISSION OF THE EUROPEAN COMMUNITIES

environment and quality of life

An evaluation of economical consequences resulting from the application of directive proposal Com (75) 681

'The use of low sulphur fuel oils with the aim of decreasing sulphurous emissions'

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'The use of low sulphur fuel oils with the aim of decreasing sulphurous emissions'

Study carried out by
R. J. ELLIS
Lange Voort 16, Oegstgeest
The Netherlands

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SUMMARY

1. Based on data provided by the EEC Commission an assessment has been made of the location and size of protected zones as defined by the EEC draft fuel oil sulphur directive. The required quantities of low sulphur fuel have been identified per country and the additional quantities of low sulphur crude oil required have been calculated. Finally an indication of the resulting costs has been made.

2. A study of this kind made on a country basis has many difficult and interwoven facets and the results can only be of a first order of magnitude. The report has been prepared to allow individual countries to carry out their own studies, which no doubt will lead to an even better appreciation of the situation.

3. The energy forecasts used are single line and not scenaric. The results especially for 1985 are therefore strictly linked to the energy forecasts used. A qualitative indication of the effect of changes in assumptions e.g. lower energy growth, nuclear delay, is given on pages 18 and 19.

Summary of Results

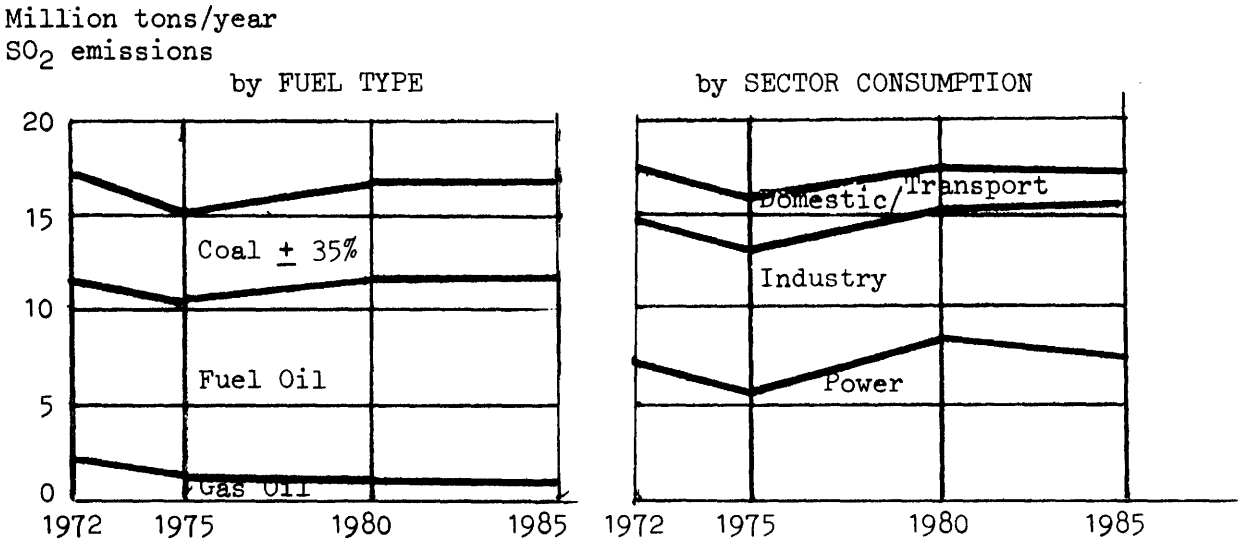
SO_2 Emission Situation

4. Assuming that the growth in energy consumption particularly post 1980 is in nuclear and natural gas, total SO_2 emission in the Community without additional fuel oil legislation is more or less constant over the period 1972 to 1985 with a dip between 1972 and 1980. Individual countries show variations of which the largest is exhibited by the Netherlands.

5. SO_2 emissions from coal represent some 35% of the total. In Germany and UK this proportion is in the range of 50-60%.

6. SO_2 emissions from the domestic/transport sector are halved over the period 1972-1985 mainly because of the gas oil directive.

7. The following graphs illustrate these points:



Low Sulphur Fuel Oil/Crude Oil Requirements

8. For the period 1980/1985, 24 zones have been identified, which would require low sulphur fuel oil to be used according to the draft fuel oil sulphur directive. The reduction from 40 zones originally identified in 1972 is mainly due to the introduction of the gas oil sulphur directive.

9. The 24 protected zones required by the fuel oil directive will need in 1980, about 20 million tons of additional low (2%) sulphur fuel (10% of total inland fuel oil) and in 1985 about 22 million tons (11%) of additional low (1%) sulphur fuel oil.

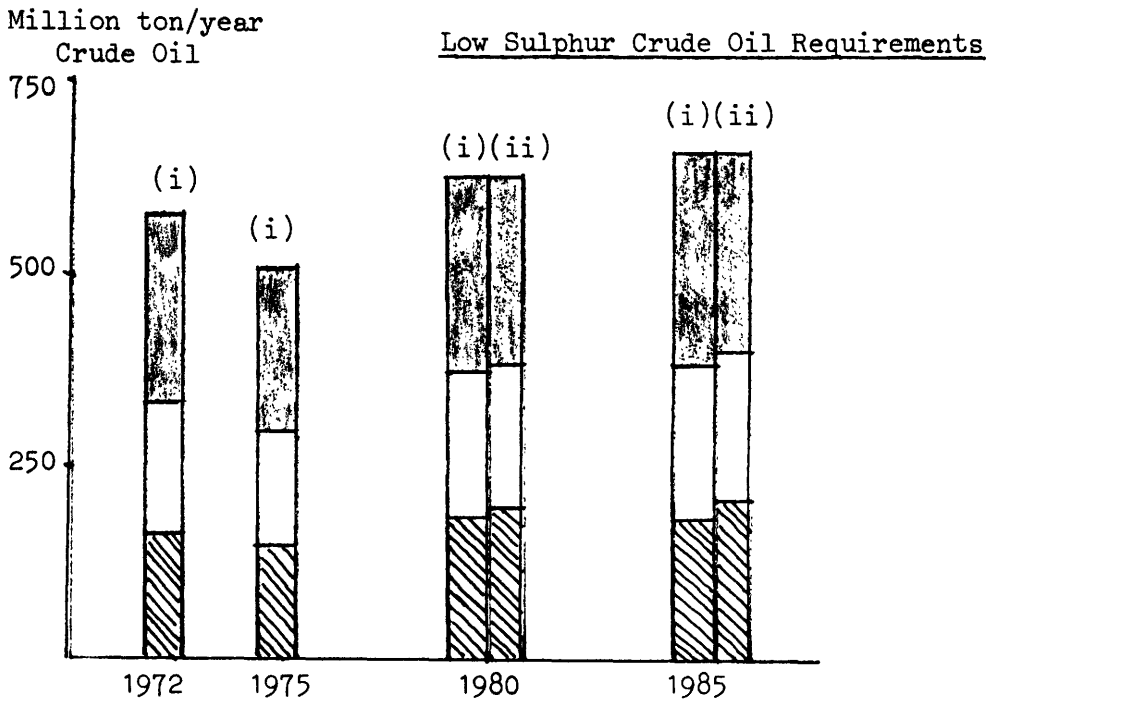
10. The situation is shown in more detail in the following table:

Year	Inland fuel oil demand (million tons oil equiv/year)	Low sulphur fuel oil required in the protected zones (million tons oil equiv/year)	
		2% sulphur	1% sulphur
1972	197	-	-
1975	165	-	-
1980	196	20	-
1985	195	-	22

11. The proportion of low sulphur (2%m or 1%m) varies from country to country and these aspects are discussed in more detail in paragraphs 51 and 57-64 of the report.

12. About half of the protected zones would not require 1% sulphur fuel oil in 1985 since with 2% sulphur fuel oil (already introduced in 1978) these zones have an acceptable SO_2 ground-level concentration.

13. Some additional 12 million tons of low sulphur crude oil in 1980 and some 30 million tons in 1985 would be required to meet the additional low sulphur fuel oil requirement. This should be viewed against a total low sulphur crude oil requirement without fuel oil legislation of some 180 million tons in 1980/85. This is illustrated in the following graph:



14. On the basis of today's open literature estimates for North Sea crude the total low sulphur crude requirement of 200-220 million tons/year could just be met by the British/Norwegian North Sea sector assuming it all to be available to the EEC.

15. It is assumed therefore that residue desulphurization will not be required for the first stage of the proposed directive i.e. 2% sulphur fuel oil in the protected zones.

16. Unless there are unexpected low sulphur crude oil supply difficulties post 1983, residue desulphurization will not be required for the second stage of the directive i.e. 1% sulphur fuel oil in the protected zones.

Cost Aspects

17. A number of cost aspects have been examined viz.:

a) Cost range of low-sulphur crude oil to the refiner on the assumption that the crude is priced on the basis of residue desulphurization costs.

b) Cost of the impact of introducing additional low sulphur crude oil into refineries.

c) Cost of storage and transport of additional low sulphur fuel oil grades.

d) Cost of storage of stand-by low sulphur fuel oil for large users.

e) Cost of SO_2 measuring networks.

The cost estimates indicate a first order of magnitude only, because local circumstances can have a significiant effect.

18. The cost of the additional low sulphur fuel oil for the EEC as a whole is shown in the following table:

	1980	1985
	$ x 10^6/year	$ x 10^6/year
Money of the day	0-170	0-565
1976 money	0-120	0-275

This represents some 0.2-0.4 per cent of the Community's total crude oil bill in 1976.

19. A differential cost of low sulphur fuel oil (2% in 1980, 1% in 1985) over fuel oil of average sulphur in the market (about 2.5% m) would result from the above costs:

	1980	1985
	$/ton fuel oil	$/ton fuel oil
Money of the day	0-7	0-22.5
1976 money	0-5	0-11

This could be compared to a market price for fuel oil in 1976 in the range of $65-75/ton.

20. In the unlikely case of low sulphur crude supply difficulties whereby physical residue desulphurizationwould be required instead of producing the additional quantities of low sulphur fuel oil from low sulphur crude, the maximum of the cost range would be incurred. This would assume a 20 year full operation of the units.

21. The cost of additional storage for low sulphur fuel oil grades in refineries/depots could be in the range of

	1980		1985	
	10^6/year	$/ton low S fuel	10^6/year*	$/ton low S fuel*
Money of the day	0-17	0-0.7	0-28	0-1.1
1976 money	0-12	0-0.5	0-14	0-0.5

---

* These costs will not be incurred if tanks are built in 1980

22. No reliable method has been found for estimating the extra transport cost on an average basis.

23. The cost of tankage for stand-by low sulphur fuel oil in power stations is estimated to be in the range of \$0-3 x 10^6 money of the day (1980) (\$0-2 x 10^6 in 1976 money). In view of the EEC's compulsory storage requirements, the costs are likely to be at the lower end of the range.

24. Insufficient information has been located on the cost of SO_2 measuring networks to enable a community cost to be estimated. Some cost data is given in paragraphs 92-94. A further study of this aspect seems to be warranted.

25. The overall accuracy of the study is difficult to determine. The main area of uncertainty lies in the estimation of the protected zones. It is felt that the calculated low sulphur fuel oil requirements on a country basis could have an error of $\pm$ 100%, however it is unlikely that such a margin of error would apply to the community as a whole. A realistic range of the calculated community low sulphur fuel oil requirement of about 10% on inland fuel (refer para. 9) would be 5-15% which would have a consequent effect on costs.

26. Calculations or actual measurements by countries would no doubt lead to a better appreciation of the situation.

INTRODUCTION

27. The purpose of this study is to evaluate where possible in terms of cost the consequences of implementing the draft proposed fuel oil sulphur directive COM (75) 681 Final in the nine member countries of the EEC.

28. The proposed directive consists in essence of the following concepts:

a) Establishment of protected zones defined as areas where the SO_2 ground level concentration exceeds certain levels which depend upon the associated concentration of suspended particles.

b) That from 1/6/78, the sulphur content of fuel oil burnt in the protected zones shall not exceed 2.0% m and from 1/6/83 shall not exceed 1.0% m. There are exceptions e.g. for installations having flue gas desulphurization or tall stacks.

c) The draft directive does not apply to solids fuels.

d) The draft directive covers a number of other aspects such as the influence of large combustion installations in and outside the protected zones, stand-by quantities of low sulphur fuel oil, possibilities to review the stipulations.

29. In order to conduct such an evaluation it has been necessary to carry out the following steps for each country:

A. Establish for the years 1972, 1975, 1980 and 1985, the primary energy consumption in terms of gas, oil, coal and electricity. Within this framework to establish the sulphur containing energy consumption in the three end-use sectors, power generation, industry and domestic/transport. Establish in each sector the split between solid fuel, residual fuel and gas oil.

   All of the information required to derive the above was forwarded by the Commission in the Summer of 1976.

B. Establish for the years 1972, 1975, 1980 and 1985 the refinery input/output. The output has been split out in terms of inland fuel oil, residual bunker fuel and bitumen. The refinery conversion capacity has been established for 1972, 1975 and 1980 (no data was available for 1985). The crude oil intake for 1972, split out into low sulphur, medium sulphur and high sulphur type has been established. All of the information required to derive the above was also forwarded by the Commission in the Summer of 1976.

C. Establish the identity and size of the protected zones on the basis of 1972 conditions, and predict their development for the years 1975, 1980 and 1985 in terms of consumption sectors and sulphur emitting energy use. The location of the zones was indicated by the Commission. The establishment of their size and composition proved to be the most difficult and time-consuming part of the study and it was necessary to develop some form of methodology which is described in paragraphs 36 - 43.

D. From C calculate the quantity of low sulphur residual fuel oil (2% in 1980, 1% in 1985)* that would be needed according to the proposed directive. Calculate, by use of CONCAWE report No. 9/75 the Sulphur Grid Method (1) the amount of low sulphur crude oil required to produce the required low sulphur fuel oil grades.

E. Where applicable and possible, estimate costs and energy consumption involved for the provision of the low sulphur fuel.

30. The above steps A to E represent in a simplified form the framwork of the study. In the following sections these steps are described in more detail together with the results.

ENERGY FORECASTS

31. Any study dealing with SO_2 pollution must take into account the development of energy types which produce SO_2 in significant quantities on combustion. For the purpose of this exercise these types have been taken as solid fuel, residuel fuel oil and gas oil burnt in the inland market. The underlying pattern of development in primary energy forms is included because it is useful in explaining large changes in the pattern of sulphur emitting energy (E_S). For example, a sharp increase in the use of residual fuel can be explained when the availability of natural gas falls off. The data is shown in Appendix 1 Tables 1-9.

32. When it is required to consider SO_2 concentrations at ground level, it is also important to know at what height the SO_2 is emitted. For this purpose three types have been defined, viz.:

a) Powerstations (stack height 150 metres)
b) Industry including oil refineries (stack height 75 metres)
c) Domestic and Transport (stack height 15 metres).

33. For each country and each year required for the study, the following energy picture has been constructed:

	Power Station	Industry	Domestic/Transport
Coal	X	X	X
Fuel oil	X	X	X
Gas oil	X	X	X

34. This data is reported in Appendix 2 Tables 1-16. Also included in Appendix 2 are the SO_2 emissions per sector. For this calculation a knowledge of the sulphur contents of the individual fuels is required. This data is generally available for solid fuels, but for liquid fuels the sulphur content is dependent upon the crude oil mix, the processing facilities and the sulphur sink capacity of products such as bitumen and residual bunker fuels. An estimate of the situation for 1972 has been obtained from literature and via the Sulphur Grid Method (1) (Concawe report No. 9/75).

34 bis The sulphur contents of the fuels used is reported in Appendix 3. It is interesting to note that the % SO_2 emission from coal is in most cases significantly lower than that from the residual fuel oil being used.

* These study years have been chosen because of the available data although the draft directive is in terms of 1978 and 1983.

SULPHUR GRID METHOD CALCULATIONS

35. The information required for these calculations has been supplied by the Commission and details are shown in Appendix 4 Tables 1-9. An important problem is that some member countries have a significant net import of oil products (Denmark, Germany, Ireland) and others significant net exports (the Netherlands). Also most countries are already producing low sulphur grades either for application reasons (production of steel/glass) or to meet local environmental regulations. The Sulphur Grid calculations have been based on actual refinery operation in each country and it has been assumed that imports and exports of fuel oil have the same sulphur content as calculated for the refinery production of inland fuel, which is the average of all the different sulphur grades.

THE CALCULATION OF THE PROTECTED ZONES

36. Because of the lack of detailed information about the E_s pattern within the areas indicated by the Commission as possible protected zones it was decided to use as a basis the essentially statistical method as developed by Mr. H.J. Löblich for a study commissioned by the German Federal Minister for the Interior entitled Calculations on the Influence of Sulphur Reduction Measures on the Regional SO_2 Immission (2). Essentially this method consists of the following steps:

a. Calculate for a given area the E_s in terms of coal, fuel oil and gas oil consumed in the sectors, Power generation, Industry, Domestic/ Transport.

b. Calculate the sulphur emission per sector and express it is in terms of tons SO_2 per km^2 per day.

c. With the aid of calculations from a model town containing power generation, industry and domestic emitting sources with assumed chimney heights, so-called immission appraisal factors were calculated. These give the relative contribution of SO_2 emission to SO_2 immission for each sector.

d. The product of SO_2 density and immission appraisal factor gives an immission coefficient which can be correlated with SO_2 ground-level concentration. Since SO_2 ground-level concentration is dependent not only on the sulphur containing energy within the area but also from adjacent areas, the method also allows for this effect to be included.

37. From a study of the calculations it is possible to derive the following relationship:

$$IKZ = \frac{10^4}{A \times 365} = \left[IBF_{V/H} \, (S_{V/H} . E_{V/H}) + IBF_I \, (S_I E_I) + IBF_K \, (S_K E_K) \right]$$

where

IKZ = immission coefficient
A = area of zone in km2
IBF = immission appraisal factor
S = SO_2 kg SO_2/toe
E = energy 10^6 toe consumed in the zone
V/H = domestic/transport sector
I = industrial sector
K = power generation sector.

38. From an examination of this relationship it can be concluded that:

a) "A" can be estimated from an approximate knowledge of the position of the SO_2 measuring stations.

b) "IBFs" are known for a given "A".

c) $S_{V/H}$, $S_I S_K$ can be estimated/calculated. It is assumed that the proportion of coal, fuel oil and gas oil in each zone sector is the same as in the country sectors.

d) $E_{V/H}$. The E_s per inhabitant is reported as a country average in EEC statistics. It is assumed that it is also valid within the zone under consideration.

e) E_K can be calculated knowing the position of power stations their efficiency and their operating factor. Since many of the power stations use gas together with sulphur containing energy it is assumed that the country-wide proportion of gas in the total power station fuel is also valid for the power stations in the zone.

f) IKZ. This is known for a given SO_2 ground-level concentration, assuming the relationship found in Germany is valid in other countries. In some cases this assumption will not be true but only comparison with actually measured ground-level concentrations will lead to a better relationship. Considerable information is available in the Commission's report "Air Sulphur Dioxide Concentrations in the European Community - Report of April 1971 - March 1972" EUR5417e 1976 (3).

g) The only unknown left is E_I and the equation can therefore be solved.

39. The energy sector picture per zone is completed by assuming the same plit between coal, fuel oil and gas oil as in the whole country. No attempt has been made to assess the effect of combustion sources outside the zone. This is possible in principle for power stations but was considered too time-consuming for this study. As a result the method as applied will represent energy sources outside the zone as industrial sources inside the zone.

40. Having established the energy picture for the protected zones in 1972 it is assumed that the E_s consumption per fuel type and per sector will change in the same way as established for the country as a whole for the years 1975, 1980 and 1985. The Löblich equation is applied again to calculate the resulting SO_2 ground-level concentration per year in each zone.

41. Only those zones which in 1980 and 1985 are calculated to have an SO_2 ground-level concentration of 80 µ g/m3 or more are used to estimate the required quantities of low sulphur fuel (2% in 1980, 1% in 1985). These results are shown in Appendix 5 Tables 1-9.

42. The assumptions used for calculating the protected zones are shown in Appendix 6.
The locations of the individual protected zones are shown in Appendix 7.

43. A typical calculation of a protected zone is given in Appendix 8. This together with the information in Appendix 6 will enable countries to check the data and where necessary to carry out calculations of their own.

DISCUSSION OF RESULTS

44. A study of the results shows that each country has a different sulphur situation because of differing energy patterns and differing sulphur contents of the fuels being consumed. The following discussion gives mainly a community picture but where appropriate also the individual country positions.

45. An important aspect to be taken into account is that the energy forecasts are single-line and not scenaric. The conclusions especially for 1985 are therefore strictly linked to the energy forecasts used.

TOTAL SO_2 EMISSIONS (all sulphur emitting inland fuels) (10^6 tons SO_2)

46.

	No Fuel Oil Legislation			
	1972	1975	1980	1985
Belgium/Luxembourg	0.97	0.84	0.96	0.87
Denmark	0.49	0.38	0.45	0.56
France	2.80	2.41	3.08	2.26
Germany	4.41	4.01	3.88	3.80
Ireland	0.25	0.25	0.23	0.27
Italy	2.91	2.90	3.83	3.58
Netherlands	0.56	0.40	0.72	1.25
United Kingdom	5.10	4.58	4.51	4.97
EEC	17.49	15.77	17.66	17.56

More details can be found in Appendix 2 Tables 1-16.

47. For the Community as a whole without fuel oil legislation there is more or less a constant SO_2 emission picture with a dip between 1972 and 1980 due to the drop in S emitting energy consumption. The somewhat surprising result for 1985 is obtained because the increase in energy consumption is assumed to come mainly from gas and nuclear power.

48. Most of the member countries show a similar trend to that above, with the 1985 position being better than 1972 in some cases reflecting a quicker/larger move to low S emitting energy. The Netherlands are strikingly different showing a sharp increase in SO_2 emissions from a low position (0.56×10^6T SO_2 in 1972 to 1.25×10^6T SO_2 in 1985). Here the increase in energy consumption has been assumed in terms of residual fuel oil.

49. SO_2 emissions from coal represent some 35% of the total SO_2 emissions. In Germany and UK this proportion is in the range of 50-60%. (Refer appendix 2 tables 7/8, 15/16 and 17).

50. SO_2 emissions in the transport/domestic sector are halved over the period 1972-1985 from 3.2 to 1.7×10^6 tons mainly because of the gas oil directive. (Refer paragraph 54 for effect on SO_2 ground-level concentration.)

PROTECTED ZONES

51. According to information provided by the Commission some forty areas could be identified in 1972 as possible protected zones. The calculations have indicated that in 1980/1985, twenty-four of these zones would have an SO_2 ground-level concentration yearly average above 80 μ g/m3. The quantities of residual fuel oil defined as low sulphur by the directive are:

	Population in Protected Zones	Low Sulphur Fuel Oil							
		1980				1985			
	% of Total Population	(a) 10^6TOE	%(c)	(b) 10^6TOE	%(c)	(a) 10^6TOE	%(c)	(b) 10^6TOE	%(c)
Belgium/ Luxemburg	13	1.7	16	2.0	19.5	1.7	21	1.8	23
Denmark	28	-	-	0.3	4	1.3	14	1.7	17
France	17(3*)	2.4	6	3.7	9	1.2	4	1.4	5
Germany	-	-	-	0.8	2.5	-	-	0.8	2.5
Ireland	20	0.04	2	0.1	5.5	0.04	1.5	0.1	4.5
Italy	9	7.7	13	10.1	17	8.4	15	10.2	18.5
Netherlands	14	1.9	17	2.4	21	3.2	14.5	4.2	19
United Kingdom	16	2.8	8	4.3	12.5	3.2	8	4.9	12.5
EEC	11(8*)	16.54	8.5	23.7	12	19.04	9.5	25.1	13

(a) 100% fuel oil in domestic/transport/industrial sector in the protected zones. In addition 10% of fuel oil burnt in the power station sector of the protected zones has been included to cover the possibility that for 10% of time meteorological conditions would require the use of low sulphur fuel oil.

(b) As (a) but 10% of the fuel oil burnt in country-wide power stations to allow for the extreme case that this would be the contribution of power stations outside the protected zones to SO_2 ground-level concentrations inside the zones.

(c) % low sulphur fuel (2% in 1980, 1% in 1985) on total inland fuel oil.

52. The locations of the individual zones are shown in Appendix 7 Tables 1-3.

53. For the total Community some 16-24 million tons of low sulphur fuel (2%S) will be required in 1980 and some 19-25 million tons (1%S) in 1985. These quantities represent some 9-13% of the total inland fuel oil demand.

54. There is no doubt that the gas oil sulphur directive has a significant beneficial effect on the development of SO_2 ground-level concentration. The calculation indicates a reduction of 30-50 μ g/m3 SO_2 in the protected zones. This is the main reason why the forty areas identified in 1972 as possible protected zones has reduced to 24 in 1980/85. In Germany alone this is equivalent to some 6 million tons of low sulphur fuel oil.

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* in 1985

55. Scrutiny of the protected zones indicates that in about a half of the cases low sulphur fuel at 2% sulphur brings the SO_2 ground-level concentration down to around 80 μ g/m3 even in 1985 which means that in these cases the second stage of reducing sulphur content to 1% would not be required. The following table gives an indication of the position in 1985:

	SO_2 μ g/m3 1985 (Annual average)	
	No fuel oil legislation*	Fuel oil max. 2%S*
Belgium/Luxemburg		
Antwerp	90	75
Brugge	120	95
Charleroi	80	65
Ghent	117	95
Kortrijk	117	90
Liege	100	80
Denmark		
Copenhagen	90	75
France		
Marseille	130	95
Rouen	85	60
Ireland		
Dublin	85	85
Italy		
Milan	>170	>130
Turin	>170	>150
Genoa	>170	>130
Bologna	>170	>130
Padua	>170	>130
Reggio Emilia	>170	>130
Venice	160	95
Netherlands		
The Hague	145	120
Rotterdam	170	145
United Kingdom		
London	85	70
Barnsley	110	80
Leeds	115	80
Manchester	80	55
Sheffield	90	65

56. The Italian situation is difficult to assess for reasons already mentioned, but it is unlikely that 2% sulphur fuel oil will be sufficient in the protected zones. In the Netherlands a sulphur content between 1 and 2% will be required in the protected zones, to bring the SO_2 concentration down to 80 μ g/m3.

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* Gas oil sulphur legislation is assumed to be in effect.

Individual Country Situations

57. In terms of quantity Italy will require the largest amount of low sulphur fuel oil. The eight protected zones identified have very high SO_2 ground-level concentrations and the methodology indicates a high concentration of residual fuel being used in the industrial sectors. The effect of this strongly outweighs the positive effect of the gas oil directive. It should be noted however that a number of the areas are located in unfavourable situations (low lying valleys) and it is likely that the calculation has given undue emphasis to industrial emissions. This is certainly an example where further study locally will be beneficial.

58. The effect in the Netherlands is less than might have been expected from the large increase predicted for total SO_2 emissions. The explanation is that most of the increased emissions have occurred in the power station sector and are deemed to have a small effect on SO_2 ground-level concentration because of the use of tall chimneys.

59. The calculation for Denmark has given problems. Copenhagen is the only area qualifying as a possible protected zone. The main source of SO_2 is from the domestic/tranport sector, because of the large amount of residual fuel being consumed in the domestic sector. It can be queried whether this will be the situation in 1980/1985. Be this as it may the 14-17% low sulphur fuel requirement indicated for 1985 (appendix 5-2) is largely in the domestic sector.

60. The calculation indicates that no protected zones are required for Germany. This may appear to be contrary to the Löblich report (2) but the primary and S-emitting energies used in this study are 15% lower than used by Löblich in 1974. Further it is known that there will remain some small areas within the Ruhr area which exceed the 80 μ g/m3. This again emphasizes the need for countries to carry out studies of their own on a detailed basis supplemented by measuring campaigns in the critical regions. It must also be noted that the inland fuel oil sulphur content is assumed to be 1.8% over the whole period which is tantamount to stating that up to 1983 the whole of Germany is supplied by low sulphur fuel oil and is therefore a protected zone. In 1980 the quantity of low S fuel is 31 million tons which is by far the largest country requirement and which is reflected in the fact that Germany has the highest proportion of low sulphur crude in its crude oil packet (Refer paragraph 67).

61. In France there is a sharp decrease in the size of protected zones between 1980 and 1985-low sulphur fuel requirements are approximately halved. Although there is assumed to be a large drop in use of S-emitting energy in the power station sector (refer Appendix 2 Table 6), lower S-emitting energy consumption in the other sectors are the main reasons for the improved situation.

62. In 1985 Belgium/Luxemburg shows the highest percentage requirement of low sulphur fuel (22%). This is mainly due to a concentration of industry burning a significant amount of S-emitting energy including 65% of the total amount of coal consumed in the country. Refer appendix 5-1.

63. Although in the UK 56% of the total S-emitting energy is in terms of coal, in 1985, 70% of this coal is burnt in power stations. On the other hand 38% of the sulphur emitting energy in the domestic sector is still assumed to be coal in 1985 which must have a bad influence on SO_2 ground-level concentrations.

64. In Ireland only Dublin qualifies as a protected zone. The sulphur content of the energy is relatively high (refer Appendix 3) and some 60% of the domestic/transport sulphur emitting energy is solid fuel.

EFFECT OF VARIATIONS OF THE BASIC ASSUMPTIONS

65. It has already been mentioned that the total SO_2 emissions and SO_2 ground-level concentration pictures are strictly limited to the one-line energy forecasts and energy sulphur contents assumed for this study. Since forecasting is difficult in a changing world it is of interest to have some indication of the effects of changes in assumptions on the SO_2 picture. These effects are illustrated in the following matrix:

Effect of Variables on SO_2 Picture

Variable	Assumed Energy Effect	Effect on SO_2 picture in					
		Power Sector		Industry Sector		Domestic/ Transport Sector	
		TE	GLC	TE	GLC	TE	GLC
Lower energy growth	Less fuel oil	↘ p	↘ -	↘ p	↘ --	↘ p	↘ ---
Nuclear delay	More fuel oil in power sector	↗ p	↗ +	nil	nil	nil	nil
Less gas	More fuel oil	↗ p	↗ +	↗ p	↗ ++	↗ p	↗ +++
Lower sulphur content	Nil	↘ p	↘ -	↘ p	↘ --	↘ p	↘ ---

Symbols:

↗p	Proportional increase
↘p	Proportional decrease
↗+	Small increase
↘-	Small decrease
↗++	Intermediate increase
↘--	Intermediate decrease
↗+++	Large increase
↘---	Large decrease
TE	Total SO_2 emission
GLC	SO_2 ground-level concentration.

Conclusions

66. a. Changes in total SO_2 emission in the domestic/transport sector have the largest effect on SO_2 ground-level concentration therefore

1) energy forms having the highest sulphur content should be transferred to the power (or industrial) sector.

2) sulphur emitting energy consumption should be reduced in the domestic/transport section.

b. Nuclear delay only affects the power sector and the effect on SO_2 ground-level concentration is low.

c. Lower growth in energy consumption can compensate for nuclear delay or less gas.

LOW SULPHUR CRUDE OIL REQUIREMENTS

67. In 1972 the actual crude oil intake to the Community's refineries was as follows:

	Low sulphur (10^6 TOE)	Medium sulphur (10^6 TOE)	High sulphur (10^6 TOE)
Belgium/Luxemburg	5.7	10.7	19.90
Denmark	1.5	4.35	3.85
France	36.3	30.35	53.15
Germany	52.5	39.25	19.65
Ireland	Nil	0.85	1.85
Italy	29.2	37.4	55.1
Netherlands	17.0	21.8	31.1
United Kingdom	27.2	28.4	50.2
EEC	169.4	173.1	234.8
%	(30)	(30)	(40)

68. Based on the sulphur content assumed for the inland fuel oil bunker fuel and bitumen and the processing configuration, the Concawe Sulphur Grid Calculations (1) gives the following picture for 1972 at the same high sulphur crude/medium sulphur crude ratios as above:

	Low sulphur (10^6 TOE)	Medium sulphur (10^6 TOE)	High sulphur (10^6 TOE)
Belgium/Luxemburg	8.0	10.0	18.0
Denmark	2.75	4.0	3.45
France	36.0	30.0	54.0
Germany	38.0	49.0	24.5
Ireland	0.05	0.85	1.8
Italy	30.0	36.0	54.0
Netherlands	17.5	22.0	30.5
United Kingdom	29.5	27.5	49.0
EEC	161.8	179.35	235.25

69. The totals derived via the sulphur grid are within 5% of the actuals and can be considered acceptable. The most serious discrepancy is Germany, the sulphur grid method giving only 38 million tons of low S crude against an actual of 52.5 million tons. A plausible explanation could be that the average sulphur content of inland fuel oil in Germany in 1972 was 1.5% and not 1.8% as assumed.

70. The additional amounts of low sulphur crude oil required to produce the additional quantities of low sulphur fuel oil in 1980 and 1985 have been calculated with the following results:

	Additional Low Sulphur Crude 10^6 TOE			
	1980		1985	
	(a)	(b)	(a)	(b)
Belgium/Luxemburg	1.2	1.5	2.0	2.4
Denmark	Nil	0.1	1.8	2.2
France	2.5	3.9	1.8	2.8
Germany	Nil	Nil	Nil	1.0
Ireland	<0.1	<0.1	<0.1	<0.1
Italy	3.8	5.6	10.9	13.8
Netherlands	1.0	1.3	3.0	4.1
United Kingdom	1.0	2.4	4.6	7.1
EEC	9.5	14.8	24.1	33.4

(a) 100% fuel oil in domestic/transport/industrial sector + 10% fuel oil in power station sector in the protected zones. For more details refer to paragraph 51 (a) (b).

(b) As (a) but 10% of fuel oil in the country-wide power station sector.

71. The above calculation assumes that the individual country's heavy/medium sulphur crude ratio is the same in 1980/1985 as the actual in 1972. Obviously a lowering in sulphur content could also be obtained by processing more medium sulphur crude at the expense of high sulphur crude. The total amounts of crude oil assumed to be processed in 1980/1985 are shown in Appendix 9. The total low sulphur crude oil requirement is assumed to be 190/195 million tons in 1980 and 210/220 million tons in 1985.

AVAILABILITY OF LOW SULPHUR CRUDE OIL

72. No data has been provided by the Commission for low sulphur crude oil availability to the EEC in 1980/1985. Availability of North Sea crude oil depending upon today's literature source will be of the following order in the period 1980/1985:

	10^6 TOE/year
British Sector	100-150
Norwegian Sector	50-100
Total	150-250

73. If the British sector availability would be processed entirely in the EEC countries and assuming low sulphur crude oil imports of the same order as 1972 there would be ample low sulphur crude to meet the proposed sulphur regulations. On the basis of no low sulphur crude oil imports from third countries, some 90% of the upper forecast for the British and Norwegian sectors would be required.

COST ASPECTS

74. The following cost items can be identified resulting from the introduction of the fuel oil sulphur directive. Measures which have already been implemented by some countries to reduce SO_2 emissions are not included in this approach since strictly speaking they are independent of the proposed fuel oil directive.

a) Cost of additional low sulphur crude oil

b) Cost of residual (and possibly distillate) desulphurization facilities.

c) Cost of the impact of introducing 1 and 2 into refineries (a discussion on this subject can be found in Concawe report No. 5/76 "The Impact of Sulphur Limitations on Refinery Facilities" (4).

d) Cost of refinery/depot storage and transport of additional low sulphur grades.

e) Cost of storage of stand-by low sulphur fuel oil for large users, e.g. power stations, who are using high stacks.

f) Cost of SO_2 measuring networks.

75. The following sections attempt a quantification of these costs but it must be emphasized that they are only meant to identify the order of magnitude.

Cost of low sulphur crude oil

76. The following considerations are relevant:

a) Low sulphur crude imported from outside the EEC is more expensive than higher sulphur crude. The premium will depend upon supply and demand and upon OPEC pricing policy.

b) The price of crude oils is not only determined by its sulphur content but also by its distillate content.

c) Low sulphur crude oil produced within the EEC e.g. North Sea, although having relatively high production costs, will be used whether or not there is sulphur legislation, but it could be exported and that could mean that sulphur legislation could restrict such exports thereby resulting in a loss of proceeds.

77. The following simple approach to costs has been applied:

i) Assume that direct desulphurization cost of residual fuel oil will be used by sellers of low sulphur crude to set its price compared with that of high sulphur crude - the so-called "sulphur premium". In practice this sulphur premium will be between zero and maximum.

ii) Assume that the additional low sulphur crude required to meet low sulphur fuel oil demand in the protected zones determines the range of cost of the sulphur directive and that this cost is a function of the "sulphur premium".

78. An example of how the sulphur premium can be determined is given in Appendix 10.

79. For the purposes of this study the following range of sulphur premia have been used:

Sulphur Premia

(High/medium vs. low sulphur crude)

	1980	1985
	$/ton crude	$/ton crude
Money of the day	0-11.6	0-17.5
1976 money	0- 8.1	0- 8.1

80. The cost of additional low sulphur crude oil per country is given in the following table:

	1980		1985	
	Money of the day		Money of the day	
	(a) ($x10^6$)	(b) ($x10^6$)	(a) ($x10^6$)	(b) ($x10^6$)
Belgium/Luxemburg	0- 14	0- 17.5	0- 35	0- 41
Denmark	Nil	0- 1	0- 31.5	0- 38
France	0- 29	0- 45	0- 32	0- 48
Germany (c)	Nil(c)	Nil(c)	Nil(c)	Nil(c)
Ireland	<0.5	<0.5	<0.5	<0.5
Italy	0- 44	0- 65	0-191	0-241
Netherlands	0- 11	0- 15	0- 53	0- 72
United Kingdom	0- 12	0- 28	0- 80.5	0-124
EEC	0-110	0-171.5	0-423	0-564
(1976 money)	(0- 76)	(0-120)	(0-205)	(0-275)

(a) 100% fuel oil in domestic/transport/industrial sector + 10% fuel oil in power station sector in the protected zones. For more details refer to paragraph 51 (a) (b).

(b) As (a) but 10% of fuel oil in the country-wide power station sector

(c) As mentioned earlier Germany has already in the base case 47% low sulphur crude oil.

81 These costs would give a differential cost of low sulphur fuel oil (2% in 1980, 1% in 1985) over fuel oil of average sulphur in the market (about 2.5%) in the following ranges:

	1980	1985
	$/ton fuel	$/ton fuel
Money of the day	0-7	0-22.5
1976 money	0-5	0-11

This can be compared with a fuel oil price in 1976 in the range of $65-75/ton.

Cost of Desulphurization Facilities (Point 2)

82. It is assumed in this exercise that no additional desulphurization facilities would be required and that low sulphur fuel demand is covered by low sulphur crude oil. If in the unlikely case of a difficult low sulphur crude supply situation, residue desulphurization would be physically required, the maximum costs quoted above would be incurred. This would also assume a 20 year full operation of the units.

Impact on Refineries (Point 3)

83. In view of the relatively small additional quantities of low sulphur crude oil, with the possible exception of Italy, the impact on the refineries is expected to be small, with a consequential small cost effect.

Cost of Storage and Transport (Point 4)

84. It is considered not possible to assess on an average basis the additional storage and transport costs of the extra low sulphur fuel oil grades from the refinery to the customer. A detailed study of each refinery and/or groups of refineries and their supply envelops would be required. The essential elements for a cost assessment are:

(a) Additional refinery/depot tankage.

(b) Increased transport costs. This is only applicable when the supply pattern is changed e.g. when low sulphur fuel oil must be supplied from refinery B instead of refinery A which supplied the high sulphur grade being replaced.

85. With respect to point (a) although in total the same volume of oil is involved new tankage could be required for segregation of the low sulphur grades. In the extreme but unlikely case new tankage would be required for the total volume of low sulphur fuel oil. The cost of this can be assessed as follows for the Community as a whole:

		1980	1985***
Additional low S fuel oil	10^6T/year	17-24	19-25
	1000 t/day	47-66	52-70
Assume 20 days storage	10^6T	0.94-1.32	1.04-1.40
(maximum for economic optimum stock-keeping)			
Cost of new tanks (10 000 tons)	$/ton	66* (45)**	100*
Capital expenditure	$ 10^6	62-87* (43-61)**	104-140*
At capital charge 20%	10^6/year	12-17* (8-12)**	21-28*
	$/ton low S fuel	0.7* (0.5)**	1.1*

This should represent the maximum cost, which in practice will be lower since it is unlikely that so much segregation tankage would be required.

86. With respect to point (b) no realistic method has been found to give an average cost indication. However additional transport costs are unlikely to be large since this would result in an uneconomic supply situation.

Cost of Stand-by Tankage (Point 5)

87. The cost of storage of stand-by low sulphur fuel oil within the protected zones for those installations having high stacks can be calculated for power stations assuming they would be required to burn low sulphur fuel for 2% respectively 5% respectively 10% of the year because of meteorological episodes.

88. The method of calculation is identical to that for the refinery

		1980			1985		
Fuel in power station sector of protected zone	10^6 t/a	8			6		
Fuel oil involved in meteorological episodes	%	10	5	2	10	5	2
	10^6 t/a	0.8	0.4	0.16	0.6	0.3	0.12
	1000 t/d	2.2	1.1	0.44	1.6	0.8	0.32
20 days storage [2]	1000 t/a	44	22	9	32	16	6
Cost of tankage							
Money of the day	$10^6$$	2.9	1.5	0.6	3.2 [1]	1.6 [1]	0.6 [1]
1976 money	$10^6$$	2	1	0.4	1.6 [1]	0.8 [1]	0.3 [1]

89. The above costs will be lower since power stations are required to hold 30 days strategic stocks of fuel according to Council directive 75/339/EEC of 10th May, 1975 (OJL 153 p. 35 of 13/6/75).

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* Money of the day
** 1976 money
*** Costs will not be incurred in 1985 if tanks built in 1980

1) Costs not incurred if tankage built in 1980
2) Assumed to be maximum for economic optimum stock-keeping. In practice can be lower depending upon circumstances.

90. The costs of stand-by low sulphur fuel oil at refineries is considered to be low also because of the existing need to keep strategic stocks and the flexibility normally available to refineries.

91. It has not been possible to locate other large users of fuel oil within the protected zones which would require to keep stand-by low sulphur fuel. No method has been found to assess the quantity of stand-by low sulphur fuel oil required by large installations outside the protected zones.

Cost of SO_2 measuring networks (Point 6)

92. It has proved very difficult to obtain meaningful data. A network in the Rotterdam area set up in 1968 with 31 on-line and 16 off-line measuring points cost some $300 000 (1968 money) and the operating costs are some $70 000/year (today's money). The scope of this network is larger than would be required for the directive.

93. A network set up in Feyzin, France during 1973 cost some $200 000 (1973 money) and the operating costs are some $40 000/year (1976 money). About 12 measuring points are involved.

94. This is insufficient information for estimating costs on an EEC basis since there appears to be neither information available on the size and scope required for such a network, nor on the extent to which measuring stations already exist in the likely protected areas. A further study on these aspects seems to be warranted.

ACKNOWLEDGMENT

95. The main bulk of the data used in this study was provided by the Commission. In addition it was necessary to obtain non-confidential information by consultation with a variety of persons and organizations among whom were Stichting Concawe; Mr. H.J. Löblich; the CEGC United Kingdom; Dienst Centrale Milieu Beheer Rijnmond, the Netherlands.

LITERATURE

96. 1. Sulphur Grid Method Concawe report No. 9/75.

2. Calculations on the Influence of Sulphur Reduction Measures on the Regional SO_2 Immission by Mr. H.J. Löblich commissioned by the German Federal Minister for the Interior December 1974.

3. Air SO_2 Concentrations in the European Community - Report for April 1971 - March 1972 by the Commission of the European Communities EUR 5417e 1976.

4. The Impact of Sulphur Limitations on Refinery Facilities by R.J. Ellis. Concawe report No. 5/76.

5. A Study of the Costs of Residue and Gas Oil Desulphurization for the Commission of the European Communities. Concawe report No. 13/72 December 1972.

6. Supplement to (4) Concawe November 1974.

Appendix 1-1

ENERGY FORECASTS

Country : Belgium/Luxemburg

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	0.6	2.4	4.8	11.8
Natural gas	6.2	8.4	12.9	20.4
Coal	14.0	9.8	14.3	13.3
Oil	28.0	25.0	31.0	37.0
Total	48.8	45.6	63.0	82.5
Sulphur containing Energy (E_s)				
Coal	9.5	9.0	12.5	13.7
Fuel oil	10.9	8.8	10.3	7.9
Gas oil	9.4	9.0	9.8	10.7
Total	29.8	26.8	32.6	32.3
$\frac{100\ E_s}{E_p}$	60	59	52	39

(a) Nuclear, hydro and geo thermal

Appendix 1-2

ENERGY FORECASTS

Country : Denmark

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	-	-	-	-
Natural gas	-	-	-	-
Coal	1.40	2.30	3.60	4.50
Oil	19.00	15.30	17.92	20.80
Total	20.40	17.60	21.52	25.30
Sulphur containing Energy (E_s)				
Coal	1.36	2.23	3.60	4.47
Fuel oil	8.33	6.24	7.95	9.70
Gas oil	6.35	5.39	5.90	6.40
Total	16.04	13.86	17.45	20.57
$\frac{100\ E_s}{E_p}$	79	79	81	82

(a) Nuclear, hydro and geo thermal

Appendix 1-3

ENERGY FORECASTS

Country : France

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	12.7	17.9	31.0	72.0
Natural gas	11.7	15.6	24.5	34.0
Coal	29.0	25.7	28.0	23.3
Oil	110.0	103.9	128.2	120.4
Total	163.4	163.1	211.7	249.7
Sulphur containing Energy (E_s)				
Coal	23.10	21.80	26.90	21.7
Fuel oil	36.38	29.60	41.10	28.6
Gas oil	41.18	38.00	44.90	39.4
Total	100.66	89.40	112.90	89.7
$\frac{100\ E_s}{E_p}$	62	55	53	36

(a) Nuclear, hydro and geo thermal

Appendix 1-4

ENERGY FORECASTS

Country : Germany

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	7.7	11.2	31.0	57.0
Natural gas	22.0	35.0	51.0	68.0
Coal	82.0	71.4	75.0	75.0
Oil	137.0	125.8	143.5	150.9
Total	248.7	243.4	300.5	350.9
Sulphur containing Energy (E_s)				
Coal	67.4	63.4	64.4	61.6
Fuel oil	37.0	30.6	31.4	31.8
Gas oil	59.0	56.0	62.0	65.0
Total	163.4	150.0	157.8	158.4
$\frac{100\ E_s}{E_p}$	66	62	52	45

(a) Nuclear, hydro and geo thermal

Appendix 1-5

ENERGY FORECASTS

Country : Ireland

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	0.20	0.10	-	-
Natural gas	-	-	1.00	1.00
Coal	1.90	1.90	2.00	2.00
Oil	5.00	5.04	5.25	6.34
Total	7.10	7.04	8.25	9.34
Sulphur containing Energy (E_s)				
Coal	1.9	1.85	1.94	2.01
Fuel oil	2.4	2.40	2.12	2.62
Gas oil	0.8	1.00	1.20	1.50
Total	5.1	5.25	5.26	6.13
$\frac{100\ E_s}{E_p}$	72	75	64	66

(a) Nuclear, hydro and geo thermal

Appendix 1-6

ENERGY FORECASTS

Country : Italy

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	10.5	11.2	14	41
Natural gas	12.8	19.5	33	41
Coal	8.0	10.4	13	13
Oil	89.0	88.2	110	115
Total	120.3	129.3	170	210
Sulphur containing Energy (E_s)				
Coal	4.7	6.2	12.6	12.2
Fuel oil	46.0	44.8	59.0	54.6
Gas oil	16.6	18.5	21.0	23.4
Total	67.3	69.5	92.6	90.2
$\frac{100\ E_s}{E_p}$	56	54	54	43

(a) Nuclear, hydro and geo thermal

Appendix 1-7

ENERGY FORECASTS

Country : The Netherlands

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	Nil	0.8	1.0	3.0
Natural gas	26.3	31.3	38.0	31.5
Coal	3.2	2.3	5.0	6.5
Oil	29.0	23.6	33.2	45.4
Total	58.5	58.0	77.2	86.4
Sulphur containing Energy (E_s)				
Coal	2.2	2.3	5.0	6.3
Fuel oil	8.7	5.6	11.4	21.8
Gas oil	7.3	6.0	6.8	7.2
Total	18.2	13.9	23.2	35.3
$\frac{100\ E_s}{E_p}$	31	24	30	41

(a) Nuclear, hydro and geo thermal

Appendix 1-8

ENERGY FORECASTS

Country : U.K.

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	8.7	8.5	15.0	18.0
Natural gas	23.6	32.0	47.0	48.0
Coal	75.0	70.0	74.0	77.0
Oil	107.0	88.0	86.5	103.5
Total	214.3	198.5	222.5	246.5
Sulphur containing Energy (E_s)				
Coal	67.8	65.0	69.0	73.0
Fuel oil	47.7	37.0	34.0	39.0
Gas oil	20.3	18.4	15.5	18.0
Total	135.8	120.4	118.5	130.0
$\frac{100\ E_s}{E_p}$	64	61	53	53

(a) Nuclear, hydro and geo thermal

Appendix 1-9

ENERGY FORECASTS

Country : EEC

Units : 10^6 TOE

	1972	1975	1980	1985
Primary Energy (E_p)				
Electricity (a)	40.4	52.1	96.8	202.8
Natural gas	102.6	141.8	207.4	243.9
Coal	214.5	193.8	214.9	214.6
Oil	524.0	474.8	555.6	599.3
Total	881.5	862.5	1,074.7	1,260.6
Sulphur containing Energy (E_s)				
Coal	177.96	171.78	195.94	194.98
Fuel oil	197.41	165.04	197.27	196.02
Gas oil	160.93	152.29	167.10	171.60
Total	536.30	489.11	560.31	562.60
$\frac{100\ E_s}{E_p}$	61	57	52	45

(a) Nuclear, hydro and geo thermal

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Belgium/Luxemburg

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	1.50	40.5	5.40	146.0	2.60	70.0	9.50	256.5	32	26
Fuel oil	4.90	270.0	5.16	283.0	0.83	45.5	10.89	598.5	37	62
Gas oil	-	-	1.17	14.0	8.24	99.0	9.41	113.0	31	12
Total	6.40	310.5	11.73	443.0	11.67	214.5	29.80	968.0	100	100
Year: 1975										
Coal	1.50	40.5	5.80	156.0	1.70	46.0	9.00	242.5	33.5	29
Fuel oil	3.60	198.0	4.44	244.0	0.76	42.0	8.80	484.0	33	58
Gas oil	-	-	1.40	17.0	7.60	91.5	9.00	108.5	33.5	13
Total	5.10	238.5	11.64	417.0	10.06	179.5	26.80	835.0	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Belgium/Luxemburg

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	2.7	73.0	8.2	220.0	1.6	43.0	12.5	336.0	38.5	35
Fuel oil	5.3	291.0	5.0	275.0	-	-	10.3	566.0	31.5	59
Gas oil	-	-	1.7	10.0	8.1	48.5	9.8	58.5	30	6
Total	8.0	364.0	14.9	505.0	9.7	91.5	32.6	960.5	100	100
Year: 1985										
Coal	3.2	86.0	9.0	243.0	1.5	40.5	13.7	369.5	42.5	42.5
Fuel oil	2.5	137.0	5.4	297.0	-	-	7.9	434.0	24.5	50
Gas oil	-	-	2.0	12.0	8.7	52.0	10.7	64.0	33	7.5
Total	5.7	223.0	16.4	552.0	10.2	92.5	32.3	867.5	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Denmark

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	1.10	22	0.10	2	0.16	3.0	1.36	27	8.5	5.5
Fuel oil	3.90	226	2.43	121	2.00	50.0	8.33	397	52	81.5
Gas oil	-	-	0.78	8	5.57	55.5	6.35	63.5	39.5	13
Total	5.00	248	3.31	131	7.73	108.5	16.04	487.5	100	100
Year: 1975										
Coal	1.40	28	0.49	10	0.34	7.0	2.23	45	16	12
Fuel oil	2.60	151	1.54	77	2.10	52.5	6.24	280.5	45	74
Gas oil	-	-	0.47	4.5	4.92	49.0	5.39	53.5	39	14
Total	4.00	179	2.50	91.5	7.36	108.5	13.86	379.0	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Denmark

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	2.63	52.5	0.60	12.0	0.37	7.5	3.60	72.0	20.5	16
Fuel oil	2.64	153	2.20	110.0	3.11	78.0	7.95	341.0	46	76
Gas oil	-	-	0.26	1.5	5.64	34.0	5.90	35.5	33.5	8
Total	5.27	205.5	3.06	123.5	9.12	119.5	17.45	448.5	100	100
Year: 1985										
Coal	3.35	67.0	0.73	14.5	0.39	8.0	4.47	89.5	21.5	16
Fuel oil	3.36	195	3.04	152.0	3.30	83.0	9.70	430	47.5	77
Gas oil	-	-	-	-	6.4	38.5	6.40	38.5	31	7
Total	6.71	262	3.77	166.5	10.09	129.5	20.57	558	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : France

Year: 1972	Power		Industry		Domestic/ Transport		Total			
	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	7.70	154	9.2	184	6.20	124	23.10	462	23	16
Fuel oil	12.40	694	21.75	1,090	2.23	56	36.80	1,840	26	66
Gas oil	-	-	10.57	126	30.61	369	41.18	495	41	18
Total	20.10	848	41.52	1,400.	39.04	549	100.66	2,797	100	100
Year: 1975										
Coal	9.70	194	8.60	172	3.50	70	21.8	436	24.5	18
Fuel oil	12.70	710	14.90	835	2.00	50	29.60	1,595	33	66
Gas oil	-	-	10.40	104	27.60	276	38.0	380	42.5	16
Total	22.40	904	33.90	1,111	33.10	396	89.4	2,411	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : France

Year: 1980	Power		Industry		Domestic/ Transport		Total			
	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	10.8	216	13.0	260	3.1	62	26.9	538	24	17.5
Fuel oil	14.2	795	26.0	1,450	0.9	23	41.1	2,268	36	74
Gas oil	-	-	6.2	37	38.7	232	44.9	269	40	8.5
Total	25.0	1,011	45.2	1,747	42.7	317	112.9	3,075	100	100
Year: 1985										
Coal	5.5	110	14.0	280	2.2	44	21.7	434	24	19
Fuel oil	2.4	134	25.7	1,440	0.5	13	28.6	1,587	32	70
Gas oil	-	-	1.4	8	38.0	227	39.4	235	44	11
Total	7.9	244	41.1	1,728	40.7	284	89.7	2,256	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Germany

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	43.5	1,610	14.9	550	9.0	334	67.4	2,494	41.5	56.3
Fuel oil	9.5	342	26.0	935	1.5	54	37.0	1,331	22.5	30
Gas oil	-	-	7.0	70	52.0	520	59.0	590	36	13.5
Total	53.0	1,952	47.9	1,555	62.5	908	163.4	4,415	100	100
Year: 1975										
Coal	37.3	1,380	17.9	660	8.2	304	63.4	2,344	42.5	58.5
Fuel oil	6.6	238	23.0	830	1.0	36	30.6	1,104	20	27.5
Gas oil	-	-	5.8	58	50.2	502	56.0	560	37.5	14
Total	43.9	1,618	46.7	1,548	59.4	842	150.0	4,008	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Germany

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	46.2	1,700	12.6	465	5.6	207	64.4	2,372	41	61
Fuel oil	7.7	277	22.7	820	1.0	3.6	31.4	1,133	20	29
Gas oil	-	-	5.6	34	56.4	338	62.0	372	39	10
Total	53.9	1,977	40.9	1,319	63.0	581	157.8	3,877	100	100
Year: 1985										
Coal	46.2	1,700	11.9	440	3.5	130	61.6	2,270	39	60
Fuel oil	7.7	277	23.1	830	1.0	36	31.8	1,143	20	30
Gas oil	-	-	4.9	29	60.1	360	65.0	389	41	10
Total	53.9	1,977	39.9	1,299	64.6	526	158.4	3,802	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Ireland

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	0.5	17.5	0.2	7.0	1.2	42.0	1.9	66.5	37.5	27
Fuel oil	1.1	77.0	1.2	84.0	0.1	3.0	2.4	164.0	47	67
Gas oil	-	-	0.2	4.0	0.6	12.0	0.8	16.0	15.5	6
Total	1.6	94.5	1.6	95.0	1.9	57.0	5.1	246.5	100	100
Year: 1975										
Coal	0.47	16.5	0.03	1.0	1.35	47.5	1.85	65.0	35.5	26
Fuel oil	1.21	85.0	1.05	73	0.14	4.5	2.40	162.5	45.5	66
Gas oil	-	-	0.15	3.0	0.85	17.0	1.00	20.0	19	8
Total	1.68	101.5	1.23	77.0	2.34	69.0	5.25	247.5	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Ireland

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	0.70	24.5	0.12	4.0	1.12	39.0	1.94	67.5	37	29.5
Fuel oil	1.20	84.0	0.92	65.0	-	-	2.12	149.0	40	65.5
Gas oil	-	-	0.47	4.5	0.73	7.5	1.20	12.0	23	5
Total	1.90	108.5	1.51	73.5	1.85	46.5	5.26	228.5	100	100
Year: 1985										
Coal	0.71	25.0	0.12	4.0	1.18	41.5	2.01	70.5	33	26
Fuel oil	1.20	84.0	1.42	100.0	-	-	2.62	184.0	42.5	68.5
Gas oil	-	-	0.70	7.0	0.80	8.0	1.50	15.0	24.5	5.5
Total	1.91	109.0	2.24	111.0	1.98	49.5	6.13	269.5	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Italy

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	0.8	19	3.4	82	0.5	12	4.7	113	7	4
Fuel oil	16.2	970	22.4	1,340	7.4	222	46.0	2,532	68.5	87
Gas oil	0.2	3	0.2	3	16.2	260	16.6	266	24.5	9
Total	17.2	992	26.0	1,425	24.1	494	67.3	2,911	100	100
Year: 1975										
Coal	0.5	12	4.4	106	1.3	31	6.2	149	9	5
Fuel oil	17.9	1,070	21.9	1,310	5.0	150	44.8	2,530	64.5	87
Gas oil	0.2	2	0.8	10	17.5	210	18.5	222	26.5	8
Total	18.6	1,084	27.1	1,426	23.8	391	69.5	2,901	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : Italy

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	4.9	118	6.5	156	1.2	29	12.6	303	13.5	8
Fuel oil	27.3	1,640	27.2	1,630	4.5	135	59.0	3,405	63.5	89
Gas oil	0.3	2	0.8	5	19.9	119	21.0	126	23	3
Total	32.5	1,760	34.5	1,791	25.6	283	92.6	3,834	100	100
Year: 1985										
Coal	5.0	120	6.2	148	1.0	24	12.2	292	13.5	8
Fuel oil	20.1	1,200	30.5	1,830	4.0	120	54.6	3,150	60.5	88
Gas oil	0.2	1	0.5	3	22.7	135	23.4	139	26	4
Total	25.3	1,321	37.2	1,981	27.7	279	90.2	3,581	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : The Netherlands

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	0.6	14.5	1.2	29.0	0.4	9.5	2.2	53.0	12	9.5
Fuel oil	2.5	120.0	5.2	250.0	1.0	48.0	8.7	418.0	48	75
Gas oil	-	-	0.4	5.0	6.9	83.0	7.3	88.0	40	15.5
Total	3.1	134.5	6.8	284.0	8.3	140.5	18.2	559.0	100	100
Year: 1975										
Coal	0.5	12.0	1.7	40.5	0.1	2.5	2.3	55.0	16.5	14
Fuel oil	0.8	38.5	4.8	230.0	-	-	5.6	268.5	40	67.5
Gas oil	-	-	0.3	3.5	5.7	69.0	6.0	72.5	43.5	18.5
Total	1.3	50.5	6.8	274.0	5.8	71.5	13.9	396.0	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : The Netherlands

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	2.6	62.5	2.4	57.5	-	-	5.0	120.0	21.5	16.5
Fuel oil	5.4	258.0	6.0	288.0	-	-	11.4	546.0	49	76
Gas oil	-	-	0.5	4.0	6.3	50.0	6.8	54.0	29.5	7.5
Total	8.0	320.5	8.9	349.5	6.3	50.0	23.2	720.0	100	100
Year: 1985										
Coal	3.3	79.0	3.0	72.0	-	-	6.3	151.0	18	12
Fuel oil	12.1	580.0	9.7	465.0	-	-	21.8	1,045.0	62	84
Gas oil	-	-	0.95	7.5	6.15	50.0	7.2	57.5	20	4
Total	15.4	659.0	13.65	544.5	6.25	50.0	35.3	1,253.5	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : U.K.

	Power		Industry		Domestic/ Transport		Total			
Year: 1972	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	38.0	1,330	13.6	475	16.2	568	67.8	2,373	50	46.5
Fuel oil	19.4	1,070	24.5	1,350	3.8	106	47.7	2,526	35	49.5
Gas oil	1.6	16	5.8	58	12.9	129	20.3	203	15	4
Total	59.0	2,416	43.9	1,883	32.9	803	135.8	5,102	100	100
Year: 1975										
Coal	40.0	1,400	13.0	455	12.0	420	65.0	2,275	54	50
Fuel oil	12.0	710	23.0	1,350	2.0	56	37.0	2,116	31	46
Gas oil	1.0	10	5.3	53	12.1	121	18.4	184	15	4
Total	53.0	2,120	41.3	1,858	26.1	597	120.4	4,575	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country : U.K.

	Power		Industry		Domestic/ Transport		Total			
Year: 1980	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	10^6 TOE	1000 T SO_2	% TOE	% SO_2
Coal	44.0	1,540	15.0	525	10.0	350	69.0	2,415	58	53.5
Fuel oil	15.8	930	18.2	1,070	-	-	34.0	2,000	28.5	44.5
Gas oil	1.2	7	3.8	22	10.5	62	15.5	91	13.5	2
Total	61.0	2,477	37.0	1,617	20.5	412	118.5	4,506	100	100
Year: 1985										
Coal	51.0	1,790	14.0	490	8.0	280	73.0	2,560	56	52
Fuel oil	17.5	1,030	21.5	1,270	-	-	39.0	2,300	30	46
Gas oil	1.5	9	3.5	21	13.0	78	18.0	108	14	2
Total	70.0	2,829	39.0	1,781	21.0	358	130.0	4,968	100	100

ENERGY/SO_2 EMISSION DISTRIBUTION

Country: EEC

	1972		1975		1980		1985	
	10^6 TOE	%	10^6 TOE	%	10^6 TOE	%	10^6 TOE	%
Coal	178	33	172	35	196	35	195	35
Fuel oil	198	37	165	34	197	35	196	35
Gas oil	161	30	152	31	167	30	172	30
Total	537	100	489	100	560	100	563	100
	1000 T SO_2	%	1000 T SO_2	%	1000 T SO_2	%	1000 T SO_2	%
Coal	5,845	33	5,611	36	6,224	35	6,237	35
Fuel oil	9,806	56	8,541	54	10,408	59	10,273	59
Gas oil	1,835	11	1,602	10	1,018	6	1,047	6
Total	17,486	100	15,754	100	17,650	100	17,557	100

Appendix 3

SULPHUR CONTENT OF FUELS (b)

1 9 7 2

Country	Coal	Fuel Oil	Gas Oil
	%MOE (a)	%MOE (a)	%MOE(a)
Belgium/Luxemburg	1.35	2.75	0.6
Denmark	1.0	2.9/2.5/1.25	0.5
France	1.0	2.8/2.5/1.25	0.6
Germany	1.85	1.8	0.5
Ireland	1.75	3.5/1.5	1.0
Italy	1.2	3.0/1.5	0.8
Netherlands	1.2	2.4	0.6
United Kingdom	1.75	2.75	0.5

(a) % mass oil equivalent. To obtain % mass of SO_2 emission the data should be multiplied by a factor of 2.

(b) In the case of coal the data refers to the sulphur that would be released on combustion since some of the sulphur is retained in the ash.

Appendix 4-1

Sulphur Grid Calculation

Country : Belgium/Luxemburg

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	37.	32.5	41.5			4.9		
Cat. cracking (C_c) (% on crude)	8.7	10.2	6.8			5.7 (a)		
Thermal cracking (C_v) (% on crude)	nil	nil	nil			nil (a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	6.7	6.7	6.8			6.8		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	15.0	16.3	15.4			15.0		
$B = B_i + B_u$	21.7	23.0	22.2			21.8		
Sulphur content of B, % m	3.95	3.94	3.95			3.95		
Sulphur content of high S fuel, % m	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	12.1	14.8	-	10.4	11.4
Required S content of inland fuel*, % m	2.75	2.75	2.75	2.66	2.64	2.75	2.56	2.54
F_C	1.06	1.07	1.045	1.045	1.045	1.04	1.04	1.04
F_B	1.08	1.09	1.08	1.09	1.09	1.08	1.11	1.11
$F = \frac{F_B}{F_C}$	1.02	1.02	1.035	1.04	1.04	1.04	1.07	1.07
Low sulphur residue (L), % m	23	23	21.5	24.4	25.1	21.3	25.4	26.1
Medium sulphur residue (M), % m	27	27	27.5	26.6	26.5	27.7	26.1	25.9
High sulphur residue (H), % m	50	50	51	49	48.4	51.0	48.5	48
$\frac{H}{M}$ ratio	1.85	---	-----	-----	-----	---	---	---

* Inland fuel also includes exports where applicable

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-2

Sulphur Grid Calculation

Country : Denmark

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	10.2	8.2	10			12		
Cat. cracking (C_c) (% on crude)	4.9	6.1	5.0			4.2(a)		
Thermal cracking (C_v) (% on crude)	15.6	19.5	16			13.3(a)		
Bitumen (B_i) (% on inland fuel*+ bitumen + bunkers)	4.35	6.9	6.8			7.1		
Bunkers (B_u) (% on inland fuel*+ bitumen + bunkers)	11.20	11.5	10.0			9.3		
$B = B_i + B_u$	15.55	18.4	16.8			16.4		
Sulphur content of B, % m	3.92	4.06	4.09			4.13		
Sulphur content of high S fuel, % m	2.4	2.25	2.15	2.15	2.15	2.2	2.2	2.2
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	nil	10	-	35	43
Required S content of inland fuel*, % m	2.4	2.25	2.15	2.15	2.13	2.2	1.78	1.68
F_C	1.065	1.09	1.067	1.067	1.067	1.054	1.054	1.054
F_B	1.10	1.16	1.15	1.15	1.15	1.15	1.19	1.21
$F = \frac{F_B}{F_C}$.	1.035	1.065	1.08	1.08	1.08	1.09	1.13	1.15
Low sulphur residue (L), % m	27.7	30.8	33.8	33.8	34.6	30.8	45.8	48.9
Medium sulphur residue (M), % m	38.5	36.8	35.2	35.2	34.8	36.8	28.8	27.2
High sulphur residue (H), % m	33.8	32.4	31	31	30.6	32.4	25.4	23.9
$\frac{H}{M}$ ratio	0.9	----	----	----	----	----	----	----

* Inland fuel also includes exports where applicable

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-3

Sulphur Grid Calculation

Country: France

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	120	112	139			131		
Cat.cracking (C_c) (% on crude)	7.5	8.5	9.0			9.6 (a)		
Thermal cracking (C_v) (% on crude)	1.6	1.7	2.8			3.0 (a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	7.3	7.9	8.1			11.2		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	9.0	9.6	9.6			11.8		
$B = B_i + B_u$	16.3	17.5	17.7			23.0		
Sulphur content of B, % m	4.17	4.2	4.2			4.27		
Sulphur content of high S fuel, % m	2.5	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	5.9	9.0	-	3.7	4.4
Required S content of inland fuel*, % m	2.5	2.75	2.75	2.71	2.68	2.75	2.69	2.64
F_C	1.048	1.055	1.063	1.063	1.063	1.067	1.067	1.067
F_B	1.09	1.08	1.08	1.08	1.08	1.11	1.12	1.12
$F = \frac{F_B}{F_C}$	1.04	1.02	1.016	1.016	1.016	1.04	1.05	1.05
Low sulphur residue (L), % m	30	22.5	22.8	24.6	25.6	20.7	22.1	22.8
Medium sulphur residue (M), % m	26	28	28.2	27.4	26.9	28.8	28.4	28.2
High sulphur residue (H), % m	44	49.5	49	48	47.5	50.5	49.5	49
$\frac{H}{M}$ ratio	1.75	-----	-----	-----	-----	-----	-----	-----

* Inland fuel also includes exports where applicable.

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-4

Sulphur Grid Calculation

Country: Germany

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	112	96	114			120		
Cat.cracking (C_c) (% on crude)	6.2	7.2	8.9			8.4(a)		
Thermal cracking (C_v) (% on crude)	7.2	8.4	7.1			6.7(a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	11.5	11.9	11.7			12.3		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	7.4	6.8	6.4			6.7		
$B = B_i + B_u$	18.9	18.7	18.1			19.0		
Sulphur content of B, % m	4.4	4.5	4.45			4.5		
Sulphur content of high S fuel, % m	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Sulphur content of low S fuel, % m	-	-	-	1.8	1.8	-	1.8	1.0
Low S fuel (% on inland fuel*)		-	-	nil	2.35	-	nil	2.35
Required S content of inland fuel*, % m	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.785
F_C	1.05	1.06	1.08	1.08	1.08	1.07	1.07	1.07
F_B	1.27	1.27	1.26	1.26	1.26	1.28	1.28	1.28
$F = \frac{F_B}{F_C}$	1,21	1.20	1.17	1.17	1.17	1.195	1.195	1.195
Low sulphur residue (L), % m	34.2	35.0	37.2	37.2	37.2	35.4	35.4	36.2
Medium sulphur residue (M), % m	43.8	43.3	41.8	41.8	41.8	43.0	43.0	42.5
High sulphur residue (H), % m	22.0	21.7	21.0	21.0	21.0	21.6	21.6	21.3
$\frac{H}{M}$ ratio	0.5	-----	-----	-----	-----	-----	-----	-----

* Inland fuel also includes exports where applicable.

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-5

Sulphur Grid Calculation

Country: Ireland

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	2.75	2.5	2.6			2.6		
Cat.cracking (C_c) (% on crude)	nil	nil	nil			nil (a)		
Thermal cracking (C_v) (% on crude)	nil	nil	nil			nil (a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	nil	nil	nil			nil		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	3.6	2.3	2.7			2.9		
$B = B_i + B_u$	3.6	2.3	2.7			2.9		
Sulphur content of B, % m	3.5	3.5	3.5			3.5		
Sulphur content of high S fuel, % m	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	3.5	9.3	-	3.4	9.3
Required S content of inland fuel*, % m	3.4	3.4	3.4	3.35	3.26	3.4	3.32	3.16
F_C	1	1	1	1	1	1	1	1
F_B	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005
$F = \frac{F_B}{F_C}$	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005
Low sulphur residue (L), % m	0.4	0.4	0.4	0.5	0.9	0.4	0.6	1.2
Medium sulphur residue (M), % m	31.4	31.4	31.4	31.4	31.2	31.4	31.4	31.2
High sulphur residue (H), % m	68.2	68.2	68.2	68.1	67.9	68.2	68	67.6
$\frac{H}{M}$ ratio	2.2	-----	-----	-----	-----	-----	-----	-----

* Inland fuel also includes exports where applicable.

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-6

Sulphur Grid Calculation

Country: Italy

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	121	100	131			133		
Cat.cracking (C_c) (% on crude)	10.4	12.6	9.6*			9.5(a)		
Thermal cracking (C_v) (% on crude)	2.5	3.0	2.3			2.3(a)		
Bitumen (B_i) (% on inland fuel*+ bitumen + bunkers)	3.5	3.4	2.85			3.2		
Bunkers (B_u) (% on inland fuel*+ bitumen + bunkers)	10.8	11.8	13.0			15.6		
$B = B_i + B_u$	14.3	15.2	15.85			18.8		
Sulphur content of B, % m	3.85	3.85	3.80			3.76		
Sulphur content of high S fuel, % m	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	15.1	2.0	-	18.5	22.6
Required S content of inland fuel*, % m	2.75	2.75	2.75	2.64	2.60	2.75	2.42	2.36
F_C	1.07	1.1	1.065	1.065	1.065	1.065	1.065	1.065
F_B	1.05	1.05	1.04	1.05	1.05	1.05	1.09	1.09
$F = \frac{F_B}{F_C}$	0.98	0.955	0.975	0.985	0.985	0.985	1.025	1.025
Low sulphur residue (L), % m	24.7	26.5	25.4	28.3	29.7	24.4	32.6	34.8
Medium sulphur residue (M), % m	30.6	29.8	30.2	29.1	28.5	30.6	27.3	26.4
High sulphur residue (H), % m	44.7	43.7	44.4	42.6	41.8	45	40.1	38.8
$\frac{H}{M}$ ratio	1.45	----	----	----	----	----	----	----

* Inland fuel also includes exports where applicable.

(a) No information available. Capacity assumed the same as in 1980.

Appendix 4-7

Sulphur Grid Calculation

Country: The Netherlands

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	70	68	87			95		
Cat.cracking (C_c) (% on crude)	5.6	5.7	4.5			4.1(a)		
Thermal cracking (C_v) (% on crude)	0.7	0.7	3.3			3.1(a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	3.2	3.3	3.25			3.2		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	31.5	27.5	25.2			25.6		
$B = B_i + B_u$	34.7	30.8	28.45			28.8		
Sulphur content of B, % m	3.63	3.67	3.69			3.68		
Sulphur content of high S fuel, % m	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	6.3	7.8	-	9.5	12.6
Required S content of inland fuel*, % m	2.4	2.4	2.4	2.38	2.37	2.4	2.26	2.23
F_C	1.04	1.04	1.035	1.035	1.035	1.03	1.03	1.03
F_B	1.16	1.14	1.13	1.13	1.13	1.13	1.16	1.16
$F = \frac{F_B}{F_C}$	1.115	1.095	1.09	1.09	1.09	1.095	1.125	1.125
Low sulphur residue (L), % m	25.2	27.0	27.3	28.4	28.8	27	30.2	31.3
Medium sulphur residue (M), % m	30.8	30.1	30.0	29.5	29.4	30.1	28.8	28.3
High sulphur residue (H), % m	44.0	42.9	42.7	42.1	41.8	42.9	41.0	40.4
$\frac{H}{M}$ ratio	1.4	-----	-----	-----	-----	-----	-----	-----

* Inland fuel also includes exports where applicable.

a) No information available. Capacity assumed the same as in 1980.

Appendix 4-8

Sulphur Grid Calculation

Country: United Kingdom

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	107	91	100			118		
Cat.cracking (C_c) (% on crude)	10.1	11.8	11.6			9.8(a)		
Thermal cracking (C_v) (% on crude)	1.4	1.6	4.0			3.4(a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	4.0	4.2	4.6			4.7		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	9.0	6.6	4.9			6.2		
$B = B_i + B_u$	13.0	10.8	9.5			10.9		
Sulphur content of B, % m	4.17	4.10	4.25			4.15		
Sulphur content of high S fuel, % m	2.65	2.85	2.85	2.85	2.85	2.85	2.85	2.85
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	7.5	11.5	-	7.4	11.2
Required S content of inland fuel*, % m	2.65	2.85	2.85	2.79	2.75	2.85	2.71	2.64
F_C	1.07	1.085	1.095	1.095	1.095	1.07	1.07	1.07
F_B	1.06	1.04	1.04	1.05	1.05	1.04	1.05	1.05
$F = \frac{F_B}{F_C}$	0.99	0.96	0.95	0.96	0.96	0.97	0.98	0.98
Low sulphur residue (L), % m	29.2	25.2	26.0	27.0	28.4	24.2	28.1	30.2
Medium sulphur residue (M), % m	25.4	26.9	26.6	26.3	25.8	27.3	25.9	25.1
High sulphur residue (H), % m	45.4	47.9	47.4	46.7	45.8	45.8	46.0	44.7
$\frac{H}{M}$ ratio	1.8	----	----	----	----	----	----	----

* Inland fuel also includes exports where applicable.

(a) No information available. Capacity assumed the same as in 1980

Appendix 4-9

Sulphur Grid Calculation

Country: EEC

	1972	1975	1980			1985		
Crude oil processed, 10^6 t/a	577	510	625			660		
Cat.cracking (C_c) (% on crude)	8.1	9.2	8.6			8.1 (a)		
Thermal cracking (C_v) (% on crude)	3.0	3.4	3.9			3.7 (a)		
Bitumen (B_i) (% on inland fuel* + bitumen + bunkers)	5.8	6.1	5.8			6.5		
Bunkers (B_u) (% on inland fuel* + bitumen + bunkers)	12.0	12.2	12.1			13.4		
$B = B_i + B_u$	17.8	18.3	17.9			19.9		
Sulphur content of B, % m	3.98	3.99	3.98			3.98		
Sulphur content of high S fuel, % m	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Sulphur content of low S fuel, % m	-	-	-	2.0	2.0	-	1.0	1.0
Low S fuel (% on inland fuel*)	-	-	-	7.8	11	-	9.1	12
Required S content of inland fuel*, % m	2.5	2.5	2.5	2.46	2.44	2.5	2.36	2.32
F_C	1.055	1.063	1.063	1.063	1.063	1.058	1.058	1.058
F_B	1.09	1.09	1.09	1.09	1.09	1.10	1.11	1.11
$F = \frac{F_B}{F_C}$	1.03	1.025	1.025	1.025	1.025	1.04	1.05	1.05
Low sulphur residue (L), % m	28.6	29.0	29.0	30.4	31.2	27.5	31.9	33.3
Medium sulphur residue (M), % m	31.3	30.1	30.1	29.5	29.2	30.8	28.9	28.3
High sulphur residue (H), % m	41.1	40.9	40.9	40.1	39.6	41.7	39.2	38.4
$\frac{H}{M}$ ratio	1.3	---	---	---	---	---	---	---

* Inland fuel also includes exports where applicable.

a) No information available. Capacity assumed the same as in 1980

Appendix 5-1

Country: Belgium/Luxemburg		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	0.54	1.61	0.41	2.56		
	Fuel oil	1.81	1.52	0.12	3.45	(a)1.82	16.6
	Gas oil	-	0.35	1.28	1.63	(b)2.13	19.5
	Total	2.35	3.48	1.81	7.64		
1975	Coal	0.54	1.72	0.28	2.54		
	Fuel oil	1.32	1.31	0.11	2.74	(a)1.55	17.6
	Gas oil	-	0.42	1.19	1.61	(b)1.78	20.2
	Total	1.86	3.45	1.58	6.89		
1980	Coal	0.98	2.43	0.26	3.67		
	Fuel oil	1.94	1.47	-	3.41	(a)1.66	16.1
	Gas oil	-	0.51	1.27	1.78	(b)2.00	19.4
	Total	2.92	4.41	1.53	8.86		
1985	Coal	1.16	2.68	0.23	4.07		
	Fuel oil	0.90	1.59	-	2.49	(a)1.68	21.3
	Gas oil	-	0.60	1.35	1.95	(b)1.84	23.3
	Total	2.06	4.87	1.58	8.51		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-2

Country: Denmark		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	-	-	-	-	a) Nil	Nil
	Fuel oil	-	-	-	-		
	Gas oil	-	-	-	-	b) Nil	Nil
	Total	-	-	-	-		
1975	Coal	-	-	-	-	a) Nil	Nil
	Fuel oil	-	-	-	-		
	Gas oil	-	-	-	-	b) Nil	Nil
	Total	-	-	-	-		
1980	Coal	-	-	-	-	a) Nil	Nil
	Fuel oil	-	-	-	-		
	Gas oil	-	-	-	-	b) 0.3	4
	Total	-	-	-	-		
1985	Coal	0.12	0.07	0.12	0.31		
	Fuel oil	0.12	0.35	0.98	1.45	a)1.34	13.8
	Gas oil	-	-	1.89	1.89	b)1.67	17.2
	Total	0.24	0.42	2.99	3.65		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-3

Country: France		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	0.69	0.86	1.25	2.80		
	Fuel oil	1.19	2.00	0.42	3.52	a)2.53	7.0
	Gas oil	-	0.96	6.16	7.12		
	Total	1.79	3.82	7.83	13.44	b)3.66	10.1
1975	Coal	0.87	0.50	0.53	1.90		
	Fuel oil	1.13	0.87	0.29	2.29	a)1.27	4.3
	Gas oil	-	0.61	4.23	4.84		
	Total	2.00	1.98	5.05	9.03	b)2.43	8.2
1980	Coal	0.97	1.08	0.55	2.60		
	Fuel oil	1.26	2.15	0.15	3.56	a)2.43	5.9
	Gas oil	-	0.50	6.90	7.40	b)3.72	9.0
	Total	2.23	3.73	7.60	13.56		
1985	Coal	-	0.64	0.07	0.71		
	Fuel oil	-	1.17	0.01	1.18	a)1.18	4.1
	Gas oil	-	0.06	1.09	1.15	b)1.42	5.0
	Total	-	1.87	1.17	3.04		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-4

Country: Germany		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	9.31	3.85	1.36	14.52		
	Fuel oil	2.05	6.68	0.24	8.97	a)7.12	19.2
	Gas oil	-	1.78	7.84	9.62		
	Total	11.36	12.31	9.44	33.11	b)7.87	21.2
1975	Coal	7.99	4.62	1.23	13.84		
	Fuel oil	1.41	5.92	0.16	7.49	a)6.22	20.2
	Gas oil	-	1.47	7.55	9.02		
	Total	9.40	12.01	8.94	30.35	b)6.74	22.0
1980	Coal	-	-	-	-		
	Fuel oil	-	-	-	-	a) Nil	NIl
	Gas oil	-	-	-	-		
	Total	-	-	-	-	b)0.77	2.5
1985	Coal	-	-	-	-	a) Nil	Nil
	Fuel oil	-	-	-	-		
	Gas oil	-	-	-	-		
	Total	-	-	-	-	b)0.77	2.5

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-5

Country: Ireland		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	0.18	-	0.27	0.45		
	Fuel oil	0.41	-	0.025	0.435	a)0.065	2.7
	Gas oil	-	-	0.13	0.13		
	Total	0.59	-	0.425	1.015	b)0.135	5.7
1975	Coal	0.17	-	0.30	0.47		
	Fuel oil	0.45	-	0.035	0.485	a)0.08	3.3
	Gas oil	-	-	0.18	0.18		
	Total	0.62	-	0.515	1.135	b)0.155	6.5
1980	Coal	0.25	-	0.25	0.50		
	Fuel oil	0.45	-	-	0.45	a)0.045	2.1
	Gas oil	-	-	0.16	0.16		
	Total	0.70	-	0.41	1.11	b)0.12	5.7
1985	Coal	0.26	-	0.27	0.53		
	Fuel oil	0.45	-	-	0.45	a)0.045	1.7
	Gas oil	-	-	0.17	0.17	b)0.12	4.6
	Total	0.71	-	0.44	1.15		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-6

Country: Italy		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	0.07	0.86	0,09	1.02	a)7.11	15.5
	Fuel oil	1.72	5.65	1.29	8.66		
	Gas oil	0.01	0.05	2.83	2.89	b)8.56	18.6
	Total	1.80	6.56	4.21	12.57		
1975	Coal	0.04	1.12	0.16	1.32	a)6.3	14.1
	Fuel oil	1.91	5.55	0.56	8.02		
	Gas oil	0.01	0.20	1.96	2.17	b)7.9	17.6
	Total	1.96	6.87	2.68	11.51		
1980	Coal	0.42	1.65	0.14	2.21	a)7.67	12.9
	Fuel oil	2.86	6.87	0.51	10.24		
	Gas oil	0.01	0.20	2.24	2.45	b)10.11	17.1
	Total	3.29	8.72	2.89	14.90		
1985	Coal	0.43	1.56	0.12	2.11	a)8.35	15.3
	Fuel oil	2.13	7.70	0.44	10.27		
	Gas oil	0.01	0.10	2.56	2.67	b)10.15	18.6
	Total	2.57	9.36	3.12	15.05		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-7

Country: The Netherlands		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	0.08	0.38	0.05	0.51		
	Fuel oil	0.325	1.62	0.12	2.065	a)1.77	20.3
	Gas oil	0.055	0.11	0.94	1.105	b)1.99	23.0
	Total	0.46	2.11	1.11	3.68		
1975	Coal	-	-	-	-		
	Fuel oil	-	-	-	-	Nil	Nil
	Gas oil	-	-	-	-		
	Total	-	-	-	-		
1980	Coal	0.35	0.76	-	1.11		
	Fuel oil	0.71	1.86	-	2.58	a)1.94	17
	Gas oil	-	0.14	0.87	1.01	b)2.41	21.2
	Total	1.06	2.77	0.87	4.70		
1985	Coal	0.43	0.95	-	1.38		
	Fuel oil	1.57	3.00	-	4.57	a)3.16	14.5
	Gas oil	-	0.25	0.84	1.09	b)4.21	19.3
	Total	2.00	4.20	0.84	7.04		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-8

Country: United Kingdom		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal	11.02	2.29	3.79	17.10	(a)5.20	10.9
	Fuel oil	2.03	4.11	0.89	7.03		
	Gas oil	0.08	0.99	3.04	4.11	(b)6.94	14.5
	Total	13.13	7.39	7.72	28.24		
1975	Coal	7.82	1.98	2.14	11.94	(a)3.96	10.7
	Fuel oil	0.63	3.53	0.37	4.53		
	Gas oil	0.06	0.81	2.21	3.08	(b)5.1	13.8
	Total	8.51	6.32	4.72	19.55		
1980	Coal	7.90	2.19	1.73	11.82	(a)2.80	8.3
	Fuel oil	0.82	2.72	-	3.54		
	Gas oil	0.07	0.57	1.85	2.49	(b)4.30	12.6
	Total	8.79	5.48	3.58	17.85		
1985	Coal	9.51	2.07	1.39	12.97	(a)3.20	8.2
	Fuel oil	0.91	3.11	-	4.02		
	Gas oil	0.08	0.52	2.26	2.86	(b)4.86	12.5
	Total	10.50	5.70	3.65	19.85		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 5-9

Country: EEC		Protected Zones 10^6 TOE					
		Power	Industry	Domestic/ Transport	Total	Low S fuel oil	% low S fuel oil on inland consumption
1972	Coal				38.96		
	Fuel oil				34.12	a)25.61	12.9
	Gas oil				26.61	b)31.28	15.8
	Total				99.69		
1975	Coal				32.01		
	Fuel oil				25.55	a)19.38	11.8
	Gas oil				20.90	b)24.10	14.6
	Total				78.46		
1980	Coal				21.91		
	Fuel oil				23.78	a)16.54	8.5
	Gas oil				15.29	b)23.7	12
	Total				60.98		
1985	Coal				22.08	a)19.04	9.5
	Fuel oil				24.43		
	Gas oil				11.78	b)25.1	13.0
	Total				58.29		

a) Defined as 100% from Industry and Domestic/Transport sectors and 10% of Power sector, in the protected zones.

b) Defined as 100% from Industry and Domestic/Transport sectors and 10% of total fuel oil consumed in country wide power stations.

Appendix 6-1

	Area (km2)	Inhabitants (10^6)	E_s in domestic/transport sector per inhabitant (toe)	Power Stations Hours/year	Power Stations 100 MW = toe/hour
Belgium	33 100	9.98	1.17	5200	24.5
Brussels	166	1.1			
Antwerp	190	0.67			
Brugge	35	0.052			
Charleroi	93	0.22			
Ghent	38	0.15			
Kortrijk	22	0.045			
Liege	170	0.40			
Denmark	43 100	4.89	1.66	3300	21
Copenhagen	520	1.38			
France	551 000	50.32	0.75	4700	22
Paris	760	6.88			
Lille	22	0.177			
Lyon	116	1.17			
Marseille	280	1.07			
Rouen	75	0.389			
Germany	248 000	60.8	1.04	4900	23.4
Berlin	480	2.08			
Ruhr	2 000	4.00			
Hamburg	753	1.78			
Frankfurt	195	0.66			
Mannheim-Ludwigsh.	459	0.51			
Ireland	70 300	2.92	0.75	4000	26.4
Dublin	108	0.57			
Italy	301 000	54.12	0.525	4500	22
Rome	350	2.86			
Bologna	141	0.49			
Genoa	236	0.81			
Milan	182	1.74			
Padua	93	0.24			
Reggio Emilia	51	0.13			
Turin	130	1.20			
Venice-Mestre	146	0.37			

Appendix 6-2

	Area (km2)	Inhabitants (10^6)	E_S in domestic/transport sector per inhabitant (toe)	Power Stations Hours/year	Power Stations 100 MW = toe/hour
Netherlands	36 600	12.87	0.64	4100	23
Amsterdam	171	0.76			
The Hague	210	0.71			
Rotterdam	428	1.03			
UK	244 000	55.64	0.63	3600	26.3
London	1 580	7.45			
Belfast	63	0.36			
Birmingham	209	1.02			
Barnsley	35	0.075			
Glasgow	157	0.897			
Leeds	164	0.496			
Liverpool	113	0.61			
Manchester	110	0.54			
Newcastle o.T.	50	0.29			
Sheffield	184	0.52			
Teeside	177	0.396			

Appendix 7-1

Location of Protected Zones

SO_2 ground-level concentration (g/m3, annual average)

	1972	1975	1980	1985
Belgium/Luxemburg				
Brussels	136	120	50	50
Antwerp	140	120	87	90
Brugge	113	95	115	120
Charleroi	100	80	75	80
Ghent	140	120	98	117
Kortrijk	111	100	100	117
Liege	124	100	90	100
Denmark				
Copenhagen	70	65	76	90
France				
Paris	140	95	95	70
Lille	120	75	80	70
Lyon	100	65	65	65
Marseille	140	90	140	130
Rouen	100	65	85	85
Germany				
Berlin	125	117	78	70
Ruhr area	100*	90	75	75
Frankfurt	110	105	70	65
Hamburg	90	85	65	60
Mannheim-Ludwigshafen	100	90	75	70
Ireland				
Dublin	76	140	80	85

* Actually measured value according to Landesanstalt Für Immissions Und Bodennutzungschutz, Nordrhein Westfalen, 102 µ g/m^3 as arithmetic annual average over the whole Ruhr area: this compares with a value of 93.5 µ g/m^3 as median annual average over the same area.

Appendix 7-2

SO_2 ground-level concentration (g/m3, annual average)

	1972	1975	1980	1985
Italy				
Rome	100	65	40	40
Milan	>170	>170	>170	>170
Turin	>170	>170	>170	>170
Genoa	>170	>170	>170	>170
Bologna	>170	>170	>170	>170
Padua	>170	>170	>170	>170
Reggio Emilia	>170	>170	>170	>170
Venice	120	115	130	160
The Netherlands				
Amsterdam	60	30	35	55
The Hague	100	65	80	145
Rotterdam	100	70	105	170
UK				
Greater London	135	110	85	85
Birmingham	95	65	40	40
Barnsley	135	130	95	110
Leeds	165	130	100	115
Liverpool	90	65	40	30
Manchester	135	110	80	80
Newcastle	115	85	60	55
Sheffield	135	115	85	90
Glasgow	90	65	40	35
Belfast	85	60	30	30

Appendix 8-1

A Typical Calculation of a Protected Zone

The following calculation was carried out for the Ruhr area of Germany. The basic relationship derived from the Löblich study is:

$$IKZ = \frac{10^4}{A \times 365}\left[IBF_{V/H}\,(S\ V/_H\ E_{V/H}) + IBF_I\,(S_I E_I) + IBF_K(S_K E_K)\right]$$

where IKZ = Immission coefficient

A = Area of zone in km^2

IBF = Immission appraisal factor

S = SO_2 kg SO_2/TOE

E = Energy 10^6TOE consumed in the zone

V/H = Transport/domestic sector

I = Industrial sector

K = Power generation sector

For 1972 all the quantities are known or can be calculated except E_I, which is therefore resultant.

IKZ. In 1972 the annual average SO_2 concentration in the Ruhr area was assumed to be 100 ug/m^3. According to the empirical relationship derived by Löblich this is equivalent to an IKZ of 26 (ref. Appendix 8-5).

A The Ruhr is assumed to have an area of 2000 km^2.

$IBF_{V/H}$ The Löblich study gives factors for IBF depending upon the area of the zone being considered (ref. Appendix 8-6)

For an area of 200 km^2 $IBF_{V/H}$ = 7.52

$S_{V/H}$ This is the sulphur content of the sulphur emitting energy in the transport/domestic sector in the protected zone.
For this exercise it is assumed equal to that of the country-wide energy mix in the transport/domestic sector. From Appendix 8-7 this is 14.5 kg SO_2/TOE.

$E_{V/H}$ For this exercise it is assumed that $E_{V/H}$ is related to the population of the protected zone and that this relationship is the same as that for the average of the country.
Population of the Ruhr area is assumed to be 4 million. According to the European Energy Statistics 1975, the following consumptions per head were applicable for 1972.

	Transport TOE	Domestic TOE	Total TOE
Mogas	0.5	-	0.50
Gas oil	0.14	-	0.14
Gas oil/Fuel oil	-	0.74	0.74
Coal	-	0.15	0.15
			1.53

Since mogas is considered to be non-S emitting in this study the energy consumption per head $E_{V/H}$ is assumed to be 1.03 TOE.

IBF_I For an area of 2000 km^2 is 5 (Appendix 8- 6)

S_I Calculated as 32.5 kg SO_2/TOE (Appendix 8- 7)

E_I Unknown

IBF_K For an area of 2000 km^2 is 2 (Appendix 8- 6)

S_K Calculated as 36.7 kg SO_2/TOE (Appendix 8- 7)

E_K Calculated from the power station capacity in the protected zone, its efficiency and operating factor.

Capacity = 6400 MW in Ruhr area

Efficiency = 100 MW = 23.3 TOE/hour

Operational factor = 4900 hours/year

$$E_K^1 = \frac{4900 \times 23.3 \times 6400}{100 \times 10^6} = 7.3 \text{ million ton O.E.}$$

10% of the intake to power stations is gas, therefore $E_K = 6.6$

Solving the basic equation

$$26 = \frac{10^4}{2000 \times 365}\left[7.52 \times 14.5 \times 1.03 \times 4 + 5 \times 32.5 \times E_I + 2 \times 36.7 \times 6.6\right]$$

$$\frac{26 \times 2000 \times 365}{10^4} = \left[450 + 162E_1 + 485\right]$$

$$1\,900 = 935 + 162E_1$$

$$E_I = \frac{965}{162} = 6$$

The total sulphur emitting energy consumption of the Ruhr area in 1972 is therefore

	10^6 TOE
$E_{V/H}$	4.1
E_I	6.0
E_K	6.6
Total	16.7

Appendix 8-3

It is assumed that the split between coal, fuel oil and gas oil in each sector of the protected zone is the same as for the whole country which gives therefore the following result:

10^6 TOE	Coal	F.O.	G.O.	Total
$E_{V/H}$	0.60	0.10	3.40	4.1
E_I	1.87	3.26	0.87	6.0
E_K	5.40	1.20	-	6.6
	7.87	4.56	4.27	16.7

For the years 1975, 1980 and 1985 it is assumed that the energy consumption per type per sector grows at the same rate as in the whole country. The following is obtained:

		Coal	F.O.	G.O.	Total
	$E_{V/H}$	0.55	0.07	3.37	3.99
	E_I	2.25	2.89	0.72	5.86
1975	E_K	4.63	0.83	Nil	5.46
	Total	7.43	3.79	4.09	15.31
	$E_{V/H}$	0.37	0.07	3.78	4.22
1980	E_I	1.58	2.85	0.70	5.13
	E_K	5.70	0.97	Nil	6.67
	Total	7.65	3.89	4.48	16.02
	$E_{V/H}$	0.23	0.07	4.05	4.35
1985	E_I	1.50	2.89	0.61	5.00
	E_K	5.72	0.97	Nil	6.69
	Total	7.45	3.93	4.66	16.04

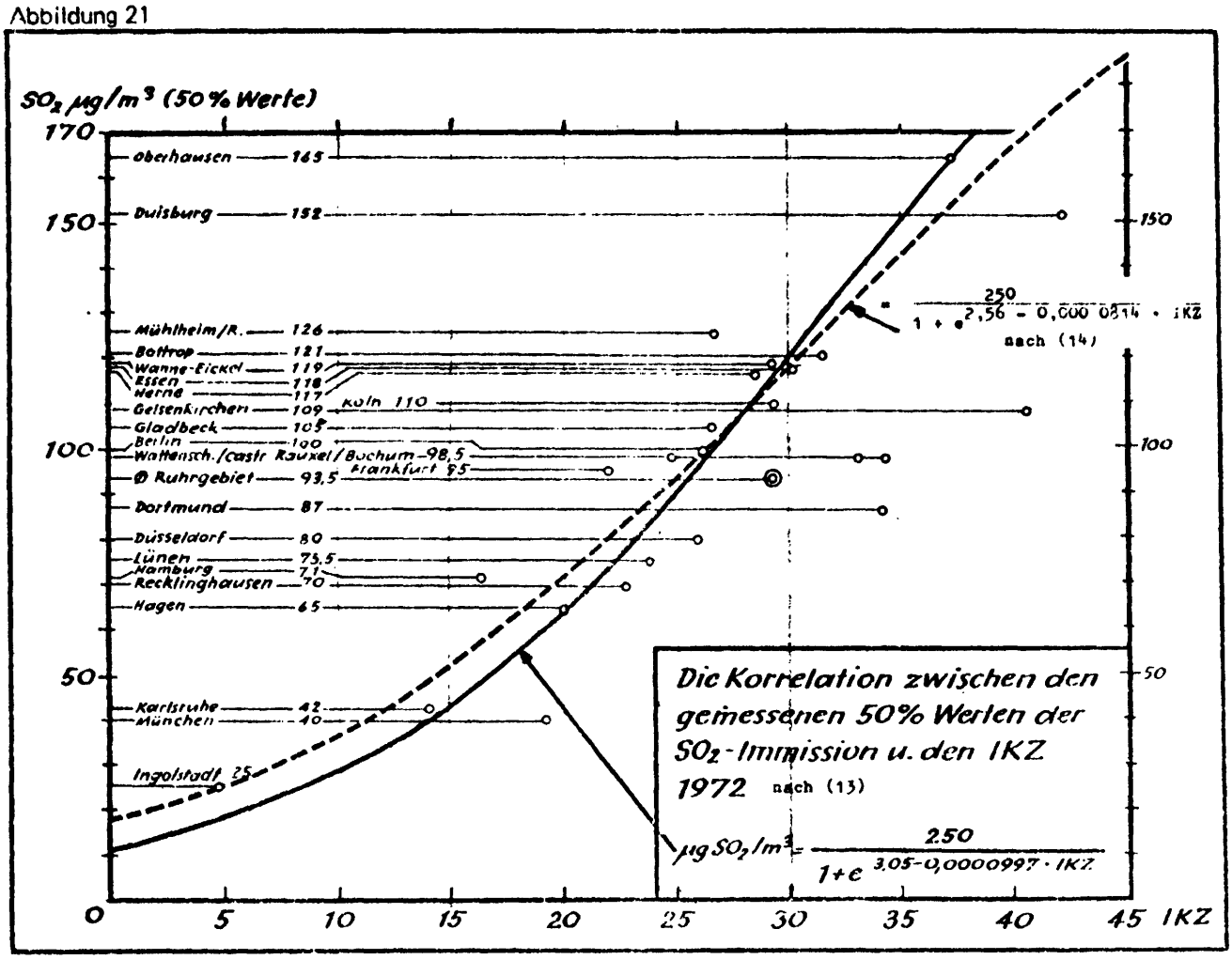
Using the $E_{V/H}$, E_I and E_K derived, in the basic relationship, the SO_2 ground-level concentration for each year can be calculated. The sulphur

content of gas oil was reduced to 0.3%m in 1980 and 1985 to reflect the EEC gas oil sulphur directive. The sulphur contents of the remaining fuels were unchanged. The following results were obtained:

	SO_2 ug/m^3 (annual average)
1972	100 (assumed)
1975	90
1980	75
1985	75

A similar chain of calculations was made for the other identified protected zones.

Abbildung 21



IBFe

Immissionsbewertungsfaktoren (IBF)

für die Berechnung der Eigenbelastung

in Abhängigkeit von der Kreisgröße

Windgeschwindigkeit 3 m/sec.

km^2	HH	Ind	KW	Groß-KW	KW - Entwicklung:					
					1972	1980	1985	1990	1995	2000
30	6.30	1.25								
40	6.70	1.46								
50	7.00	1.60								
60	7.35	1.80								
70	7.66	1.96								
80	7.90	2.10								
90	8.15	2.20								
100	8.40	2.30								
120	8.80	2.50								
140	9.05	2.80								
160	9.30	3.00	0.09	0.09						0.09
180	9.60	3.28	0.11	0.11						0.11
200	9.84	3.60	0.17	0.17						0.17
220	10.10	3.90	0.20	0.20						0.20
240	10.35	4.20	0.25	0.25						0.25
260	10.60	4.50	0.30	0.30						0.30
280	10.90	4.80	0.34	0.34						0.34
300	10.85	4.95	0.36	0.36						0.36
350	10.65	4.99	0.45	0.41	0.45	0.44	0.43	0.43	0.42	0.41
400	10.40	5.00	0.50	0.43	0.50	0.49	0.47	0.46	0.44	0.43
450	10.20	5.02	0.60	0.49	0.60	0.58	0.56	0.53	0.51	0.49
500	10.00	5.06	0.65	0.50	0.65	0.62	0.59	0.56	0.53	0.50
550	9.76	5.10	0.70	0.55	0.70	0.67	0.64	0.61	0.58	0.55
600	9.50	5.13	0.80	0.60	0.80	0.76	0.72	0.68	0.64	0.60
650	9.30	5.17	0.85	0.62	0.85	0.80	0.76	0.71	0.67	0.62
700	9.18	5.17	0.90	0.67	0.90	0.85	0.81	0.76	0.72	0.67
800	9.00	5.19	1.05	0.72	1.05	0.98	0.92	0.85	0.79	0.72
900	8.80	5.21	1.20	0.80	1.20	1.12	1.04	0.96	0.88	0.80
1.000	8.60	5.25	1.34	0.84	1.34	1.24	1.14	1.04	0.94	0.84
1.150	8.35	5.25	1.57	0.91	1.57	1.44	1.31	1.17	1.04	0.91
1.300	8.20	5.23	1.75	0.95	1.75	1.59	1.43	1.27	1.11	0.95
1.450	8.01	5.20	1.96	1.00	1.96	1.77	1.58	1.38	1.19	1.00
1.500	7.96	5.17	1.98	1.00	1.98	1.78	1.59	1.39	1.20	1.00
2.000	7.52	5.00	2.00	1.05	2.00	1.81	1.62	1.43	1.24	1.05
2.500	7.10	4.80	2.09	1.12	2.09	1.90	1.70	1.51	1.31	1.12
3.000	6.65	4.62	2.12	1.20	2.12	1.94	1.75	1.57	1.38	1.20
3.500	6.30	4.50	2.17	1.26	2.17	1.99	1.81	1.62	1.44	1.26
4.500	5.90	4.26	2.16	1.28	2.16	1.98	1.81	1.63	1.46	1.28
4.941	5.31	3.92	2.15	1.30	2.15	1.98	1.81	1.64	1.47	1.30

IBFf

Immissionsbewertungsfaktoren (IBF)

für die Berechnung der Fremdbelastung

in Abhängigkeit von der Entfernung

Windgeschwindigkeit 3 m/sec.

km	HH	Ind	KW	Groß-KW	KW - Entwicklung					
					1972	1980	1985	1990	1995	2000
3	4.10	1.30	0	0						0
4	4.95	1.75	0.04	0.04						0.04
5	5.85	2.25	0.07	0.07						0.07
6	6.80	2.80	0.10	0.10						0.10
7	6.35	3.15	0.28	0.20	0.28	0.26	0.25	0.23	0.22	0.20
8	5.80	3.45	0.44	0.32	0.44	0.42	0.39	0.37	0.34	0.32
9	5.25	3.85	0.60	0.44	0.60	0.57	0.54	0.50	0.47	0.44
10	4.85	3.90	0.75	0.50	0.75	0.70	0.65	0.60	0.55	0.50
12	4.38	3.65	1.00	0.60	1.00	0.92	0.84	0.76	0.68	0.60
14	3.86	3.35	1.25	0.70	1.25	1.14	1.03	0.92	0.81	0.70
16	3.36	3.05	1.50	0.80	1.50	1.36	1.22	1.08	0.94	0.80
18	2.88	2.75	1.78	0.90	1.78	1.61	1.44	1.25	1.08	0.90
20	2.45	2.45	1.95	1.00	1.95	1.76	1.57	1.38	1.19	1.00
22	2.16	2.16	1.85	1.00	1.85	1.68	1.51	1.34	1.17	1.00
24	2.07	2.07	1.76	0.95	1.76	1.60	1.44	1.27	1.11	0.95
26	1.98	1.98	1.70	0.94	1.70	1.55	1.40	1.24	1.09	0.94
28	1.90	1.90	1.65	0.93	1.65	1.51	1.36	1.22	1.07	0.93
30	1.80	1.80	1.62	0.88	1.62	1.48	1.33	1.18	1.03	0.88
35	1.56	1.56	1.40	0.82	1.40	1.28	1.17	1.05	0.94	0.82
40	1.35	1.35	1.23	0.75	1.23	1.13	1.04	0.94	0.85	0.75
45	1.12	1.12	1.05	0.70	1.05	0.98	0.91	0.84	0.77	0.70
50	0.90	0.90	0.90	0.60	0.90	0.84	0.78	0.72	0.66	0.60

Country-wide Energy/Sulphur mixture per end-use sector and per fuel type

Germany

	1972		1975		1980		1985	
Power	10^6 TOE/Year	SO_2 Kg/TOE	10^6 TOE	SO_2 Kg/TOE	10^6 TOE	SO_2 Kg/TOE	10^6 TOE	SO_2 Kg/TOE
Coal	43.5	37	37.3	37	46.2	37	46.2	37
Fuel oil	9.5	36	6.6	36	7.7	36	7.7	36
Gas oil	-	10	-	10	-	6	-	6
	53.0	36.7	43.9	36.7	53.9	36.7	53.9	36.7
Industries including Refineries								
Coal	14.9	37	17.9	37	12.6	37	11.9	37
Fuel oil	26.0	36	23.0	36	22.7	36	23.1	36
Gas oil	7.0	10	5.8	10	5.6	6	4.9	6
	47.9	32.5	46.7	33.2	40.9	32.2	39.9	32.5
Domestic/Transport								
Coal	9.0	37	8.2	37	5.6	37	3.5	37
Fuel oil	1.5	36	1.0	36	1.0	36	1.0	36
Gas oil	52.0	10	50.2	10	56.4	6	60.1	6
	62.5	14.5	59.4	14.3	63.0	9.3	64.6	8.2

Crude Oil Processed 1972-75-80-85

	1972	1975	1980			1985		
	NO EEC S. LIMIT IN FUEL OIL 10^6TOE	NO EEC S. LIMIT IN FUEL OIL 10^6TOE	NO EEC S. LIMIT IN FUEL OIL 10^6TOE	PROTECTED (a) 10^6TOE	PROTECTED (b) 10^6TOE	NO EEC S. LIMIT IN FUEL OIL 10^6TOE	PROTECTED (a) 10^6TOE	PROTECTED (b) 10^6TOE
Belgium/Luxemburg								
Low sulphur crude (LSC)	5.7	7.5	8.9	10.1	10.4	10.4	12.5	12.8
Medium sulphur crude(MSC)	10.7	8.8	11.4	11.1	11.0	13.6	12.8	12.7
High sulphur crude (HSC)	19.9	16.2	21.2	20.3	20.1	25.0	23.7	23.5
Denmark								
LSC	1.5	2.5	3.4	3.4	3.5	3.7	5.5	5.9
MSC	4.35	3.0	3.5	3.5	3.5	4.4	3.5	3.3
HSC	3.85	2.7	3.1	3.1	3.0	3.9	3.0	2.8
France								
LSC	36.3	25.2	31.7	34.2	35.6	27.1	29	29.9
MSC	30.35	31.4	39.2	38.1	37.4	37.7	37.2	36.9
HSC	53.15	55.4	68.1	66.7	66.0	66.2	64.8	64.2
Germany								
LSC	52.5	33.5	42.5	42.5	42.5	42.5	42.5	43.5
MSC	39.25	41.5	47.7	47.7	47.7	51.6	51.6	51.0
HSC	19.65	21.0	23.8	23.8	23.8	25.9	25.9	25.5
Ireland								
LSC	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
MSC	0.85	0.79	0.83	0.83	0.83	0.83	0.83	0.83
HSC	1.65	1.71	1.77	1.77	1.77	1.77	1.77	1.76

Crude Oil Processed 1972-75-80-85

	1972	1975	1980			1985		
	NO EEC S LIMIT IN FUEL OIL 10^6TOE	NO EEC S LIMIT IN FUEL OIL 10^6TOE	NO EEC S LIMIT IN FUEL OIL 10^6TOE	PROTECTED (a) 10^6TOE	PROTECTED (b) 10^6TOE	NO EEC S LIMIT IN FUEL OIL 10^6TOE	PROTECTED (a) 10^6TOE	PROTECTED (b) 10^6TOE
Italy								
LSC	29.2	26.5	33.2	37	38.9	32.5	43.3	46.3
MSC	37.4	29.8	39.5	38.1	37.3	40.7	36.3	35.1
HSC	55.1	43.7	58.3	55.9	54.8	59.8	53.4	51.6
The Netherlands								
LSC	17.0	18.4	23.7	24.7	25.1	25.6	28.7	29.7
MSC	21.8	20.5	26.1	25.7	25.6	28.6	27.4	26.9
HSC	31.1	29.1	37.2	36.6	36.3	40.8	38.9	38.4
United Kingdom								
LSC	27.2	22.9	26.0	27.0	28.4	28.6	33.2	35.7
MSC	28.4	24.5	26.6	26.3	25.8	32.2	30.6	29.6
HSC	502	43.6	47.4	46.7	45.8	57.2	54.2	52.7
EEC								
LSC	169.4	148	181	190	195	182	211	220
MSC	173.1	153	188	184	182	203	191	187
HSC	234.8	209	256	251	248	275	258	253

The Estimation of Sulphur Premium

The sulphur premium is the price difference between low sulphur and higher sulphur crude oil. It is assumed that the maximum sulphur premium is directly related to the cost of physically desulphurizing the residue of the higher sulphur crude since this would be the alternative source of low sulphur residue if sufficient low sulphur crude is not available.

Direct residue desulphurization costs are reported by Concawe (5, 6). The following have been used for this study:

	1980	1985
Cost $/ton residue intake		
Money of the day	26 (a)	39 (b)
1976 money	18 (c)	18 (c)

(a) Based on escalation at 9%/year from 1972 base and a crude oil cost of $140/ton in 1980.

(b) Based on escalation at 9%/year from 1972 base and a crude oil cost of $220/ton in 1985.

(c) Based on escalation at 9%/year from 1972 base and a crude oil cost of $100/ton in 1976.

Individual countries can of course use other inflation factors if they see fit.

The desulphurization is assumed to remove 85% of sulphur from a 50:50 mixture of 2.5/4.0% sulphur residue i.e. 2.75% S.

The cost of 1% sulphur removal is therefore

	1980	1985
Cost of 1% S/ton feedstock	$/t	$/t
Money of the day	9.5	14
1976 money	6.5	6.5

These costs must be translated into crude oil differentials between low sulphur and higher sulphur crude. The ratio of high sulphur crude to medium sulphur crude in the EEC is 1.3 which means that the mixed residue has a sulphur content of 3.35%. The sulphur content of low sulphur residue is assumed to be 0.6% on average. Therefore to desulphurize one ton of residue from 3.35% S to 0.6% S i.e. reduction of 2.75% S would cost

		1980	1985
Money of the day	$/t residue	26	39
1976 money	$/t residue	18	18

Assuming that there is a yield of 47% residue on crude these costs translate per ton crude oil:

		1980	1985
Money of the day	$/ton crude*	11.6	17.5
1976 money	$/ton crude*	8.1	8.1

* These are differentials between low sulphur and medium/high sulphur crude oil.

In practice the sulphur premium applied to low sulphur crude will be between zero and the maximum differential as calculated above.

European Communities — Commission

EUR 6011 — An evaluation of economical consequences resulting from the application of directive proposal Com (75) 681 — 'The use of low sulphur fuel oils with the aim of decreasing sulphurous emissions'

R. J. ELLIS, Lange Voort 16, Oegstgeest, The Netherlands, Environment and Consumer Protection Service

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Based on data provided by the EEC Commission an assessment has been made of the location and size of protected zones as defined by the EEC draft fuel oil sulphur directive. The required quantities of low sulphur fuel have been identified per country and the additional quantities of low sulphur crude oil required have been calculated. Finally an indication of the resulting costs has been made. The energy forecasts used are single line and not scenaric. The results especially for 1985 are therefore strictly linked to the energy forecasts used. A qualitative indication of the effect of changes in assumptions e.g. lower energy growth, nuclear delay, is given on pages 18 and 19.

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