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# RECENT AND FUTURE DEVELOPMENT OF EMISSIONS OF NITROGEN OXIDES IN EUROPE

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**Abstract**—An emission inventory for all of Europe shows that between 1980 and 1985 $NO_x$ emissions almost stabilized as a consequence of structural changes in the energy consumption. This paper analyzes potential future emissions of nitrogen oxides for the hypothetical case of no control measures being applied and the effects of the reduction commitments made in the 'Sofia Protocol' and the 'Declaration on a 30% cut' of $NO_x$ emissions in Europe. Finally, the costs for implementing the committed emission reductions are assessed.

*Key word index*: Emission inventories, nitrogen oxides emissions, emission forecasts.

## 1. INTRODUCTION

Atmospheric emissions of nitrogen oxides contribute both to the acidification of natural ecosystems and to the formation of tropospheric ozone. Therefore, the need for reduction of nitrogen emissions is currently internationally accepted and agreed upon in the UN–ECE 'Protocol on the Control of Emissions of Nitrogen Oxides', signed in November 1988 in Sofia*.

One important prerequisite for international agreements on emission reductions is the availability of reliable, internationally consistent emission inventories and forecasts. Based on international statistics this paper analyzes the development of $NO_x$ emissions in Europe between 1980 and 1985 and assesses the impacts of the currently planned energy policies up to the year 2000. Furthermore, the impacts of the Sofia Protocol on $NO_x$ emissions are analyzed. In order to draw a consistent picture for all of Europe, both Western and Eastern European countries are considered.

The analysis is based on databases on energy consumption, emission forecasts and abatement potentials and costs provided by the Regional Acidification Information and Simulation (RAINS) model. The RAINS model, which was developed at the International Institute for Applied Systems Analysis (IIASA) (Alcamo *et al.*, 1987), combines information on causes and effects of acidification processes in the environment on a regional scale for Europe.

## 2. HISTORICAL AND FUTURE ENERGY CONSUMPTION

Nitrogen oxides are formed during the combustion of fuel to produce energy and also occur as a by-product of some industrial processes. Several analyses indicate that the share of emissions generated by industrial production processes is less than 10 per cent of most European countries total $NO_x$ emissions (Springmann, 1990; Pacyna *et al.*, 1989; OECD 1989). Therefore, this survey focuses on the more important source of energy combustion.

In order to base the emission inventory on internationally consistent data, UN–ECE energy statistics were used to compile information on fuel consumption for the years 1980 and 1985 (UN–ECE, 1989a). To attain reasonable accuracy of the emission estimates it was necessary to differentiate the highly aggregated fuel categories into more specific fuel classifications. This could be achieved by the incorporation of additional national and international statistics (e.g. OECD/IEA, 1989). Due to special emission properties, a further breakdown was necessary to differentiate between boiler types for solid fuel combustion (dry bottom vs wet bottom type), for gasoline car engines between two-stroke engines and four-stroke engines and for diesel vehicles between passenger cars and heavy duty trucks (Springmann, 1990).

Major efforts were also required to estimate the correct figures for fuel consumption for mobile sources in Eastern European countries. Since most of the commercial goods transported in centrally planned economies is considered as an industrial activity, its fuel consumption is consequently attributed to the industrial sector. However, $NO_x$ emissions for fuel oil vary up to a factor of 10 depending on whether it is used as fuel for automotive purposes or burned in conventional boilers. Usually the 'domestic' fuel use comprises the residential and the service sector as well as agricultural and military energy consumption. In the last two categories, most of the liquid fuel consumption is used for mobile sources (mainly off-road vehicles, e.g. tractors, harvesters). Whereas in Western Europe these last two categories typically

* Protocol to the 1979 Convention on Long-range Transboundary Air Pollution concerning the Control of Emissions of Nitrogen Oxides or their Transboundary Fluxes.

add up to less than 10 per cent of total oil use in the 'domestic' sector, the vehicular use reaches up to 70 per cent of the 'domestic' oil combustion due to the lower importance of oil for heat generation in Eastern Europe.

There is a variety of forecasts and scenarios for future energy consumption available in Europe with considerable differences among them, not the least depending on the year they were generated. However, for estimating future levels of $NO_x$ emissions a base case must be selected upon which all calculations can be performed. Since none of the existing forecasts are generally accepted, this analysis uses, as a pragmatic approach, the projections of individual governments for their national development of energy use. Although these projections represent policy targets it is recognized that there is no guarantee for national and international consistency, either on the underlying assumptions (e.g. economic growth, development of the oil price, etc.), or on their feasibility (e.g. availability of fuel types). Such forecasts were collected and published by several international organizations (e.g. OECD/IEA, 1989; UN–ECE, 1989a).

## 3. THE EMISSIONS OF NITROGEN OXIDES

Although the formation mechanisms for nitrogen oxides depend on a variety of fuel and site specific conditions, the RAINS model makes an attempt to estimate and verify national emission figures in an internationally consistent way. As was demonstrated by the OECD–MAP emission inventory (Lübkert and Tilly, 1989), emission factors used by individual countries show a wide range of variation, even for the same emission source category, that is not always explainable by technical and structural reasons. Therefore, in this study, one common set of average emission factors has been identified representing typical values from reliable measurements, that enables the reconstruction of officially published emission data within reasonable ranges (Table 1). Using this set of factors, the computed country total emission figures deviate from official information for most countries by not more than 10–15 per cent.

In order to demonstrate regional differences in historical and future developments of $NO_x$ emissions, this paper aggregates European countries into three regions.

Countries in Western and Northern Europe with relatively high levels of economic development: Austria, Belgium, Denmark, Finland, France, F.R.G., Ireland, Luxembourg, The Netherlands, Norway, Sweden, Switzerland and U.K.

Centrally planned economies in Eastern Europe, excluding the U.S.S.R., Bulgaria, C.S.S.R., G.D.R., Hungary, Poland and Romania.

Southern European countries, which are aiming for considerable economic growth with low elasticity of energy consumption: Albania, Greece, Portugal, Spain, Turkey and Yugoslavia. For geographical reasons, Italy is also included into this category, although its economic development is more similar to countries within the first group.

Although the RAINS model also covers the European territory of the U.S.S.R., the corresponding analysis is not presented in this paper because the major disagreement between the data computed by the RAINS model and the official Soviet emission data have not yet been resolved.

### 3.1. *Western and Northern Europe*

In contrast to previous periods, the total energy consumption in Western and Northern Europe almost stabilized (+1.5%) between 1980 and 1985 with a decline of fossil fuel use by 8 per cent. As Table 2 shows, this reduction was mainly caused by a rapid (26 per cent) decline of liquid fuels for heating purposes. This trend is forecast to continue for the future, but with a further growth of total primary energy demand of 14 per cent by the year 2000. In this context, the fuel use for transport is not expected to grow more than proportionally to primary energy demand.

Table 1. $NO_x$ emissions factors (in g $NO_2$/GJ fuel use)

| Fuel | Conversion | Power plants | Sector Domestic | Transport | Industry |
|---|---|---|---|---|---|
| Brown coal | 200 | 270 | 70 | 0 | 200 |
| Hard coal | 230 | * | 80 | 0 | 230 |
| Coke, briquettes | 230 | 0 | 70 | 0 | 230 |
| Middle distillates | 70 | 0 | 70 | † | 70 |
| Heavy fuel oil | 170 | 200 | 160 | 0 | 170 |
| Gasoline | 70 | 0 | 0 | ‡ | 70 |
| Natural gas | 0 | 150 | 60 | 0 | 70 |
| Other solids | 130 | 0 | 60 | 0 | 130 |

* Hard coal, dry bottom boiler, 300. Hard coal, wet bottom boiler, 420.
† Diesel, passenger cars and light duty trucks, 350. Diesel, heavy duty trucks, 1300.
‡ Gasoline, four-stroke engines, 750. Gasoline, two-stroke engines, 160.
Source: Springmann (1990).

Table 2. Development of energy consumption and $NO_x$ emissions in Western and Northern Europe

| | Energy consumption (PJ) | | |
|---|---|---|---|
| | 1980 | 1985 | 2000 |
| Solids | 9734 | 9400 | 10,435 |
| Heating oil | 12,969 | 9514 | 8629 |
| Transport | 6259 | 6735 | 8072 |
| Natural gas | 6423 | 6925 | 8264 |
| Nuclear | 1929 | 5140 | 7709 |
| Other | 2632 | 2829 | 3100 |
| Total | 39,946 | 40,543 | 46,209 |
| | $NO_x$ emissions (kt $NO_2$) | | |
| Power plants | 2281 | 1906 | 1996 |
| Industry + domestic | 2148 | 1909 | 1902 |
| Gasoline | 3263 | 3408 | 4064 |
| Diesel | 2020 | 2320 | 2816 |
| Total | 9712 | 9543 | 10,778 |

The decline in fuel oil consumption between 1980 and 1985 also had positive effects on $NO_x$ emissions. However, part of these reductions were compensated for by the growth in emissions from the transport sector, where the emissions from gasoline increased by 4 per cent and from diesel use by 15 per cent. Therefore, the overall decline of $NO_x$ emissions over this 5-year period amounts to only 3.5 per cent.

If no measures were taken in the future for controlling $NO_x$ emissions, the projected change in energy infrastructure would again increase $NO_x$ emissions by 13 per cent, mainly as a consequence of the forecasted growth of fuel use for vehicular purposes.

### 3.2. *Eastern Europe*

During recent years Eastern European countries have showed an inhomogeneous development in energy consumption. While some countries (e.g. the G.D.R., C.S.S.R., etc.) recognized the low efficiency of their energy infrastructures and made improvements in efficiency a major goal of their energy policies, others continued to follow the undisrupted growth path as observed over the last decades. In total, primary energy consumption between 1980 and 1985 increased by 2.5 per cent, mainly due to an expanded use of nuclear power. Due to the severe dependency on imported oil, major efforts were undertaken to reduce oil consumption. In contrast to Western European countries, this substitution was not only limited to oil use for heating purposes, but was also achieved by shifting freight transport from road to railway. Consumption of natural gas and nuclear power increased steadily.

In view of the dramatic political and economic changes occurring in these countries at present, any forecast on future energy consumption must be considered to be extremely uncertain. Although in Western Europe these changes are sometimes seen as the start of a major economic upswing, some experts in Eastern countries foresee a prolongation and possible intensification of the current economic difficulties for at least the next decade.

The energy projections used in this analysis date back to the mid-eighties and represent the view of the future developments at this time. Since more recent information is not available, these forecasts were taken as a basis for the analysis of future $NO_x$ emissions. According to these data, total primary energy consumption is expected to grow by an additional 15 per cent up to the year 2000 (Table 3) with a particularly large increase in energy demand for transportation (+34 per cent). However, the planned expansion of nuclear power and the simultaneous decline of $NO_x$ emissions from the power generation sector compensate for this increase in transport emis-

Table 3. Development of energy consumption and $NO_x$ emissions in Eastern Europe (excl. U.S.S.R.)

| | Energy consumption (PJ) | | |
|---|---|---|---|
| | 1980 | 1985 | 2000 |
| Solids | 9705 | 10,397 | 11,101 |
| Heating oil | 2470 | 2055 | 1632 |
| Transport | 1650 | 1565 | 2094 |
| Natural gas | 2792 | 2829 | 3101 |
| Nuclear | 153 | 290 | 1700 |
| Other | 214 | 276 | 512 |
| Total | 16,984 | 17,412 | 20,140 |
| | $NO_x$ emissions (kt $NO_2$) | | |
| Power plants | 2125 | 2290 | 1602 |
| Industry + domestic | 969 | 923 | 1117 |
| Gasoline | 435 | 414 | 554 |
| Diesel | 1034 | 878 | 1175 |
| Total | 4563 | 4505 | 4448 |

Table 4. Development of energy consumption and $NO_x$ emissions in Southern Europe

| | Energy consumption (PJ) | | |
|---|---|---|---|
| | 1980 | 1985 | 2000 |
| Solids | 1635 | 2706 | 5457 |
| Heating oil | 4967 | 4120 | 5154 |
| Transport | 2393 | 2649 | 4074 |
| Natural gas | 1043 | 1275 | 2754 |
| Nuclear | 68 | 328 | 2494 |
| Other | 1309 | 1118 | 2000 |
| Total | 11,415 | 12,196 | 20,933 |
| | $NO_x$ emissions (kt $NO_2$) | | |
| Power plants | 652 | 775 | 1124 |
| Industry + domestic | 837 | 804 | 1025 |
| Gasoline | 1009 | 1040 | 1576 |
| Diesel | 1079 | 1283 | 2052 |
| Total | 3577 | 3902 | 5777 |

sions, resulting in a slight decline of the overall $NO_x$ emissions in Eastern Europe by −1.4%.

At present gasoline cars with two-stroke engines represent a large fraction of the whole fleet in some Eastern European countries (between 15 and 60 per cent). Although these cars are generally considered to be heavy polluters, this does not hold for their $NO_x$ emissions. Measurements of exhaust gases report only 10–20 per cent of the $NO_x$ concentrations observed for typical four-stroke engines (Larssen, 1989). However, the production of two-stroke engines was stopped in 1989. Consequently, a phase-out of this car type is anticipated, with a simultaneous increase in $NO_x$ emissions if they are replaced by four-stroke engines. Although the resulting increase in unit emissions is considerable, only limited effects on total emissions can be expected up to the year 2000. Given the long average lifetime of cars in Eastern Europe (typically about 25 years), the effect on total $NO_x$ emissions in this region for the year 2000 would be an increase of 1.4 per cent, compared to a case with unchanged fleet structure. The increase is already incorporated into the values in the last paragraph.

### 3.3. *Southern Europe*

In contrast to other European regions, Southern Europe experienced a continued increase in energy consumption, although starting from a comparable low level of economic development. Between 1980 and 1985, total primary energy consumption increased by 6.8 per cent; major growth rates were observed for solid fuels (+65 per cent), natural gas (+22 per cent) and oil for transportation purposes (+11 per cent), whereas oil use for heat generation declined by 17 per cent. The changed structure and higher level of energy consumption in 1985 resulted in an increase of $NO_x$ emissions by 9 per cent. Despite the considerable development of the transportation sector, $NO_x$ emissions from gasoline cars showed the lowest growth rate of 3 per cent, whereas emissions from diesel use increased by 19 per cent.

Compared with the development between 1980 and 1985, future projections of energy consumption seem rather ambitious. According to official sources, annual growth rates are forecast to be double historical values, resulting in a further overall increase of 55 per cent in total primary energy consumption by the year 2000. $NO_x$ emissions would then be 48 per cent higher than in 1985 if no control measures are taken. Still it should be kept in mind that this sharp increase would only bring the per capita emissions in Southern Europe up to the average values presently observed in Central and Western European countries.

## 4. REDUCTION PLANS FOR NITROGEN OXIDES

The last section outlined the theoretical future development of $NO_x$ emissions up to the year 2000 if no control measures were to be applied. However, in reality some countries have already announced plans for reducing $NO_x$ emissions. Table 5 lists the currently committed reduction rates for all European countries, as agreed in the Sofia Protocol on $NO_x$ reduction and in the 'Declaration on the 30 Per Cent Reduction of Nitrogen Oxides Emissions' (UN–ECE, 1989b).

In the Sofia Protocol, 1987 is defined as the default base year, to which emission reductions will be related. However, countries may also individually specify any other year between 1980 and 1987 upon signature. The 'Declaration', signed by 11 countries, leaves the base year selection to the individual signatories.

In order to assess the effects of these commitments and for reasons for simplicity, the emissions of 1985 were taken as base case to which the reductions rates are related. In Western and Northern Europe, most countries signed the 30 per cent declaration; however, because several countries did not join this group, the overall reduction in this region will actually amount to only 22 per cent compared to 1985. In Eastern Europe all countries with the exception of Romania signed the Sofia Protocol with a commitment not to increase their emissions above the 1985 level. If one takes the official energy projections of Romania seriously (although probably they are outdated by the recent events in this country) the Romanian projection would increase the overall $NO_x$ emissions of this region by 4.6 per cent over the level of 1985. In Southern Europe only Italy, Greece and Spain have made commitments. The growth paths of the remaining countries, however, more than compensate for these reductions, so that overall emissions will increase by 5.7 per cent. Over all of Europe (excluding the U.S.S.R. territory), $NO_x$ emissions will decline until 1995 by almost 10 per cent due to the currently committed reductions. If no additional countries join the group of signatories, an increase after the year 1995 must be expected.

### 4.1. *Potential for* $NO_x$ *control*

The RAINS model contains a submodule to assess the potential and costs for alternative $NO_x$ abatement options. This evaluation is based on internationally reported performance and cost data of control devices

Table 5. Currently committed reduction rates on $NO_x$ emissions

| 30% Reduction | No increase | No commitments |
|---|---|---|
| Austria | Bulgaria | Albania |
| Belgium | C.S.S.R. | Ireland |
| Denmark | G.D.R. | Portugal |
| Finland | Greece | Romania |
| France | Hungary | Turkey |
| F.R.G. | Luxembourg | Yugoslavia |
| Italy | Poland | |
| Netherlands | Spain | |
| Norway | U.K. | |
| Sweden | U.S.S.R. | |
| Switzerland | | |

that are extrapolated by the model and take into account country specific conditions of application (Amann, 1989). In particular, for stationary sources combustion modification (e.g. low-$NO_x$ burners) and SCR technology are considered as control options both for retrofit applications and for new plants. Emissions from diesel engines can be reduced to two different levels (relating to U.S. emission standards 1988 and 1991), whereas for gasoline cars a 50 per cent reduction level (e.g. as required by the 'Luxembourg agreement') and the introduction of controlled three-way catalysts are included.

Based on the energy projections (not taking into account fuel substitution and energy conservation as a means for emission reductions) the potential for $NO_x$ abatement for alternative control options can be explored. Table 6 analyzes this potential for the year 1995, when both the Sofia Protocol and the Declaration should be fully implemented, for the following abatement measures.

*SCR for new power plants.* All new power stations (built after 1985) will be equipped with low-$NO_x$ burners and SCR technology, resulting in a 90 per cent emission reduction compared to the unabated case.

*Low-$NO_x$ burners for existing plants.* All old plants still in operation in 1995 will be retrofitted with low-$NO_x$ burners, achieving a 50 per cent $NO_x$ reduction.

*SCR for old plants.* As a further step all old plants will be additionally equipped with SCR units, reducing the emissions in total by 90 per cent compared to the unabated case.

*Three-way catalyst.* Gasoline cars will be equipped with controlled three-way catalysts, reducing the emission rates by 90 per cent. For this analysis it is assumed that only new cars will adhere to this requirement, resulting in a 50 per cent market penetration in 1995.

*U.S. norm 1991 for heavy duty trucks.* In analogy to gasoline cars, a 50 per cent market penetration of the U.S. Standard 1991 for heavy duty trucks (requiring a 40 per cent emission reduction over the ECE-R.49 regulation) is also assumed for this analysis.

A comparison of the committed reductions and the potential provided by control technologies in Table 6 shows that for Western and Northern Europe the committed reductions involve almost 80 per cent of the technically feasible reduction potential. If by 1995 no efficient measures were taken for diesel engines in heavy duty trucks, almost all other control options (including the retrofit of a major portion of the existing powerplant stock with SCR units) will be necessary to implement the current reduction plans. For the rest of Europe (Eastern and Southern Europe) no major efforts are necessary to implement the currently committed reduction rates, mainly due to the modest control targets set by these countries. Again it must be emphasized that this analysis is based on the assumption that the official energy projections will become true and no structural changes in the energy systems (fuel substitution, energy conservation) will take place.

### 4.2. *Costs for $NO_x$ control*

As mentioned above, the RAINS model provides cost estimates for emission control strategies based on internationally reported technology cost data and country specific factors. With this information it would be possible to assess the national abatement costs implied by the committed reduction plans. However, since both the protocol and the declaration specify only overall reduction rates of country total emissions, no specification is available on how countries will actually implement these committed reductions. If cost efficiency is selected as a criterion, a ranking of control options can be established and the minimum costs for achieving any reduction level can be computed.

Based on the energy consumption pattern of the official energy projections, the annual costs implied by the current reduction plans for $NO_x$ can be estimated to be some 4.5 billion DM per year for the whole of Europe, which is roughly one-third of the costs necessary to implement the committed $SO_2$ emission reductions. However, major differences among countries occur. As already indicated earlier, currently major reductions efforts are mainly being planned by

Table 6. Potential for emission reduction for different control options in 1995

| | Western and Northern Europe | Eastern Europe (excl. U.S.S.R.) | Southern Europe |
|---|---|---|---|
| Control option | $NO_x$ removal potential (kt $NO_2$) | | |
| SCR, new plants | 154 | 251 | 233 |
| Low-$NO_x$, old plants | 882 | 475 | 352 |
| SCR, old plants | 705 | 380 | 282 |
| Three-way catalyst | 1700 | 387 | 625 |
| U.S. norm 1991 | 513 | 428 | 327 |
| Total | 3954 | 1921 | 1819 |
| Necessary reductions to achieve commitments in 1995 | 3104 | 207 | 215 |

Western and Northern European countries, resulting in correspondingly high costs. This fact is illustrated by Fig. 1, which shows the required expenditure for implementation of the $NO_x$ reductions on a per capita basis.

According to this analysis, the planned reductions would be most expensive for the 30 per cent cuts committed by Finland and Norway with some 30 DM/person/year. For Finland these high costs are mainly caused by the projected very large increase of unabated $NO_x$ emissions as a consequence of the Finnish policy to increase coal consumption within the next decade (see e.g. Savolainen and Tähtinen, 1989). Not surprisingly, major efforts will therefore be necessary to simultaneously bring the $NO_x$ emissions down to a level of 30 per cent lower than 1985.

Due to the unique situation in Norway, where virtually no thermal power plants are necessary to supply the electricity demand, only a minor potential for the control of emissions from stationary sources exists. Therefore, in order to realize the 30 per cent cut of Norwegian $NO_x$ emissions, control measures have to focus on mobile sources, in which the control of mobile diesel engines (both in trucks and ships) is also indispensable.

Figure 1 also underlines, that for the Eastern European signatories the Sofia Protocol (no further increase of $NO_x$ emissions) implies no costs to them, since this standstill is to be achieved solely by the projected changes in energy infrastructures. It is important to mention that these energy forecasts, however, originate from a time when $NO_x$ emissions were of no concern. Therefore these structural changes were definitely not motivated by $NO_x$ control reasons.

## 5. EFFECTS OF A PHASE-OUT OF NUCLEAR POWER ON $NO_x$ EMISSIONS

As indicated earlier, emission forecasts are sensitive to the structure of energy consumption. Therefore, fuel substitution is one important means of $NO_x$ reduction that has not yet been explored in this paper. Since all the side effects of substitution strategies (necessary changes to infrastructure, impacts on the energy market, effects to trade balances, etc.) cannot be assessed with a simple model operating on an European scale, a scenario is instead analyzed in which fossil fuel use is increased to replace nuclear power plants.

Although more sophisticated assumptions could be made, for reasons of simplicity this paper explores the worst case in which all nuclear power stations in Europe would be replaced by hard coal plants in the year 2000 (without changing electricity demand). If these new coal power stations were built without any flue gas denitrification, total $NO_x$ emissions in Europe would be 18 per cent higher than current projections (Table 7). However, it seems reasonable to assume that for new stations control equipment (e.g. according to 'Best Available Technology' of today) will be required. The technical skills for constructing, for example SCR units, should not create unresolvable problems for countries that are able to construct and operate nuclear power plants. If denitrification were installed, the additional emissions of $NO_x$ in Europe caused by a nuclear phase-out would amount only to 1.8 per cent.

## 6. CONCLUSIONS

Between 1980 and 1985 the trend of increasing $NO_x$ emissions observed during the last decades in Europe was clearly interrupted as total $NO_x$ emissions in Europe stabilized; the slight decrease in Western and Northern Europe (mainly caused by the substitution of heavy fuel oil by other fuels) and the standstill in Eastern European countries was compensated for by growing energy consumption in Southern Europe.

Relying on official forecasts of energy consumption it can be estimated that, up to the year 2000, $NO_x$ emissions will increase only slightly in Northern and Western Europe, even if no control measures were taken. In Eastern Europe, due to the planned expansion of nuclear power, $NO_x$ emissions are expected to stabilize, while in Southern Europe, continued economic growth with a simultaneous growth in energy consumption will increase $NO_x$ emissions considerably.

Table 7. Additional $NO_x$ emissions caused by a phase-out of nuclear power in the year 2000

| | Western and Northern Europe | Eastern Europe (excl. U.S.S.R.) | Southern Europe | Total Europe |
|---|---|---|---|---|
| Nuclear power use | 7709 PJ | 1700 PJ | 495 PJ | 9904 PJ |
| $NO_x$ emissions in 2000 according to Current Reduction Plans | 7544 kt | 4569 kt | 4280 kt | 16393 kt |
| Increment by substitution of nuclear power (no control) | 2312 kt (30%) | 509 kt (11%) | 150 kt (3%) | 2971 kt (18%) |
| Increment by substitution of nuclear power (SCR) | 231 kt (3%) | 51 kt (1.1%) | 15 kt (0.3%) | 297 kt (1.8%) |

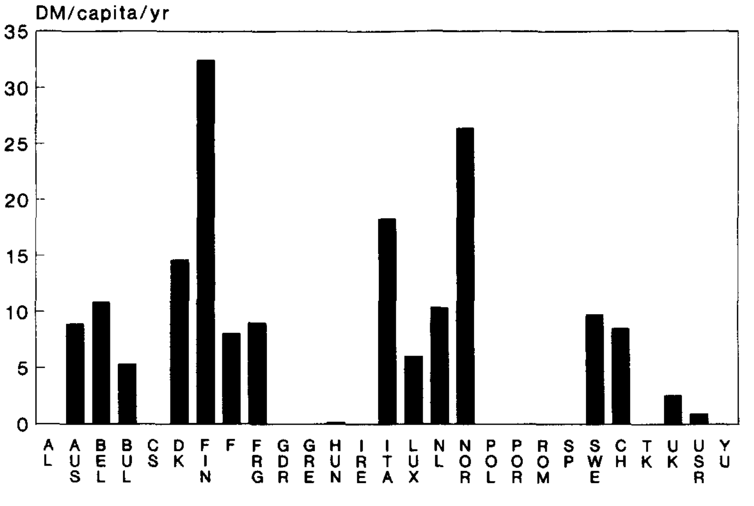


Fig. 1. $NO_x$ abatement cost per capita for current reduction plans.

Currently, reductions of $NO_x$ emissions have mainly been committed by Western and Northern European countries; this would result in a 22 per cent decline in this region compared to 1985. If energy consumption develops as projected, these reductions will only be achievable if virtually all currently available technical control measures for stationary and mobile sources are fully applied. This includes, in particular, denitrification for all existing power stations. Eastern European countries strive for a further standstill of their $NO_x$ emissions, which should be achieved as a result of the projected structural changes in energy consumption. The current commitments (the Sofia Protocol and the 30 per cent Declaration) will decline total European $NO_x$ emissions by 10 per cent up to the year 1995, since reductions are partly compensated for by a considerable increase in Southern Europe.

As a rough estimate, the control costs necessary to implement the current commitments for all of Europe would amount to 4.5 billion DM $year^{-1}$, which is about one third of the costs for committed sulfur reductions. The distribution of these costs is however rather inhomogeneous due to the different levels of reduction committed and the structure of the energy systems.

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