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NO_X/SO_X EMISSIONS AND CARBON ABATEMENT

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NO_x/SO_x Emissions and Carbon Abatement

This paper provides evidence on the reductions of NOx/SOx emissions induced by the adoption of carbon abatement policies. It describes the methodology to compute emissions of these pollutants and the way they were introduced in the OECD GREEN model. This required a compromise between the “top-down” structure of the model and the very detailed information that, in principle, is required to compute NOx/SOx emissions. The simulation results suggest that, on average, the reductions relative to Baseline levels of NOx/SOx emissions may be in the same order of magnitude or are higher than the abatement imposed on carbon emissions.

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Cette étude analyse les effets de réduction des émissions de NO_x/SO_x dus à la mise en place de politiques visant à réduire les émissions de carbone. Elle décrit la méthodologie pour calculer des émissions de ces polluants et la façon selon laquelle ils ont été introduits dans le modèle GREEN de l’OCDE. Cela résulte d’un compromis entre la structure assez agrégée du modèle et l’information très détaillée nécessaire au calcul des émissions de NO_x/SO_x. Les résultats des simulations suggèrent, qu’en moyenne, les réductions des émissions de NO_x/SO_x par rapport au scénario de référence peuvent être dans le même ordre de magnitude ou supérieures à la réduction imposée sur les émissions de carbone.

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NO_x/SO_x EMISSIONS AND CARBON ABATEMENT

by

Christophe Complainville and Joaquim O. Martins[1]

I. Introduction

The OECD Secretariat has developed a multi-country, multi-sector, dynamic applied general equilibrium (AGE) model called GREEN to quantify the economy-wide and global costs of policies to curb emissions of carbon dioxide (CO_2)[2]. The possibility of extending GREEN via the introduction a module to calculate NO_x/SO_x emissions was envisaged in order to give an indication of potential secondary benefits of carbon abatement associated with emission reduction in those gases[3]. When compared with the CO_2 case, the computation of NO_x/SO_x emissions raises many additional difficulties. Namely, emission factors have to be specific to fuels, sectors and regions[4]. Moreover, country specific regulations and abatement technologies and their changes through time must also be taken into account. This implies that NO_x/SO_x emission coefficients cannot be assumed to remain constant.

The sectoral breakdown of GREEN does not allow for a comprehensive treatment of NO_x/SO_x emissions. In addition, within the framework of GREEN, technological progress is exogenous. Thus, changes in NO_x/SO_x emissions can only be modeled as an indirect impact of policies to curb CO_2 emissions through substitution among fossil fuels, introduction of back-stop energies or energy conservation effects[5].

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[1] OECD, Development Centre and Economics Department. The authors want to thank for useful comments Peter Sturm, Jon Nicolaisen, Jane Corfee-Morlot and the participants of the ECE Workshop on Emission Projection, Roskilde, Danemark. The opinions expressed in this paper are our own and cannot be held to represent the views of the OECD or its Member governments.

[2] See Burniaux, Nicoletti and Martins (1992*a*) for a detailed discussion of the specification, parameterisation and calibration of GREEN.

[3] This link was put forward by Alfsen, Brendemoen and Glomsrod (1992) in a case study for Norway.

[4] The CO_2 emission factors (in Tons of carbon per TeraJoule) are constant and only depend on the type of fuel used.

[5] An accurate assessment of the secondary effects of CO_2 abatement should also take into account the atmospheric chemistry interactions among gases (see Liu, 1994).

The paper begins with a discussion of the different approaches to compute national NO_x/SO_x emission inventories. Next, are described the estimation method of the emission factors for the aggregate sectors of GREEN and the assumptions driving their changes through time and across regions. Finally, some simulation results are presented which illustrate the potential for reducing NO_x/SO_x emissions as a result of international agreements to curb CO_2 emissions.

II. Methods to compute NO_x/SO_x emission factors

This section recalls briefly the measurement problems and the approaches usually followed to compute emission factors for each type of energy demand (see UN, 1991).

A. NO_x emissions

NO_x ($NO+NO_2$) emissions are produced by two primary mechanisms during combustion: i) the "fuel NO_x" related to the nitrogen content of the fuel and combustion conditions; and, ii) the "thermal NO_x", the chemical formation of NO from N_2 and O_2, which occurs at temperatures exceeding 1400°C [6].

Generally, NO_x inventories are highly disaggregated because emissions are related to technology, environmental regulations, as well as combustion conditions and fuel characteristics. All these elements require detailed data on energy use. Usually, the disaggregation distinguishes between two major categories: i) *stationary* combustion sources; and, ii) *mobile* sources. The key factors determining NO_x emissions for each category are given in Table 1.

Table 1. **Factors determining NO_x Emissions**

Stationary sources	*Mobile sources*
• Fossil fuel type and quality	• Fuel used
- *Nitrogen contents*	- *Gasoline, diesel, LPG, etc.*
• Technology type	• Transport class
- *Firing configuration*	- *Cars, trucks, airplane, etc.*
- *Size of the boiler*	• Emissions controls
- *Maintenance*	• Other factors
- *Operation (load factor)*	- *Fleet age*
• Pollution control technology	- *Operating characteristics*
	- *Maintenance procedures*

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[6] For further information about nitrogen chemistry in connection with fuel use, see CEC (1992).

There are two main inventories of NO_x emissions (see UN, 1991). The OECD data base[7] has a fairly high level of disaggregation of economic activities according to the type of the emission generation process. Similarly, the EEC CORINAIR project proposed the "SNAP (Selected Nomenclature for Air Pollution) 90 CORINAIR Nomenclature", using three different levels of sub-categories and individual activities. The OECD and CORINAIR methodologies are typically "bottom-up" approaches. Both are based on estimates of the emission factors for individual emission sources which are then added to compute total emissions for a given country or region. OECD(1991b) proposes two basic formulas to compute consistent national emissions inventories which are given in Table 2.

Table 2. **Formulas to Compute Total NO_x Emissions**

Stationary sources	*Mobile sources*
Emissions = $\sum \Phi_{ijk} \cdot C_{ijk}$ where: Φ : Emission Factor (in g/GJ) C : Energy consumption (GJ) i : Fuel-type j : Sector or activity k : Technology-type	Emissions = $\sum \Phi_{ijk} \cdot C_{ijk}$ where: Φ : emission factor (g/GJ or g/km) C : energy consumption or distance covered (g/GJ or g/km) i : transport-type (road, air, etc.) j : Fuel-type (gasoline, diesel, etc.) k : Vehicle type

Source: OECD (1991*b*).

For stationary sources it is difficult to establish *in situ* measurements, therefore *national* emission factors are currently used. When national emission factors are not available or imprecise, default emission factors are applied. Typically, default emission factors are "expert guesses" and need to be updated according with the evolution of technologies and air pollution control regulations. Table 3 gives the range of variation of NO_x emission factors for stationary sources according to the fuel type and activity. In this Table, NO_x emission factors are measured in *grams of NO_2 per energy input* , but other conventions could be adopted.

Table 3. **Range of NO_x emission factor for stationary sources (in g/GJ)**

Type of fuel	*Coal*	*Oil*	*Gas*
Electric utilities	156 - 558	112 - 200	50 - 170
Industry	130 - 540	85 - 180	50 - 98
Residential/Commercial	75 - 290	50 - 200	40 - 140

Source: IEA (1991).

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[7] See OECD (1991*a*).

The wide range of variation for the NO_x emission factors explains why usually the computation of emissions is carried out at a very detailed level.

There are significant emission reductions that can be achieved by using existing abatement technologies. For example, low-NO_x burners can reduce emissions by 30-50 per cent. A selective catalytic reduction controlling the post-combustion process could also reduce emissions by roughly 80 to 90 per cent (see IEA, 1988). Depending on the installation of these devices, the corresponding emission factors can display large differences.

Mobile sources represent at the world level more than 33 per cent of total man-made NO_x emissions. There are large measurement problems associated with these sources[8]. For example, the installation of catalyst control reduces NO_x emissions by a factor of roughly one-third. In the Unites States, the range of NO_x emission factors for the road transport can vary from 0.14g/MJ to 1.01 g/MJ. Consequently, a comprehensive assessment of car types is required to produce accurate statistics.

B. SO_x emissions

Aside the impacts of abatement technologies, SO_x emissions are rather easy to compute from fossil-fuel consumption. The major measurement problem is related to the fuel sulfur retained in the ash. The methodology followed by the CEE-CORINAIR project to compute SO_x emissions is based on emission factors calculated from the sulfur content of different fuels and the capacity of ashes to capture sulphur-compounds. SO_x emission factors for each fuel can be computed from the following formula:

$$\Phi = (1-r)\cdot\frac{S}{H}$$

where:

Φ = fuel emission factor.
S = sulphur content of the fuel.
H = thermal content of the fuel.
r = mass fraction of sulfur retained in the ash.

The fraction of sulphur retained in the ash (r) is variable. For hard coal it is currently assumed that 5 per cent of sulphur is retained in the bottom ash. In the case of brown coal, values between 34 and 45 per cent have been proposed (see CEC, 1992). For liquids and gaseous fuels r is assumed to be zero. The sulphur content (S) and the thermal content (H) are the most important factors determining emission coefficients for each fossil fuel. Some examples of SO_x emission factors for power plants are given in Table 4. Depending on the type of fuel the emission factors can vary from a high of 1930g per GigaJoule in the case of brown coal to 1g per GigaJoule for the gas powered plants.

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[8] See CEC (1991).

Table 4. **SO_x Emission factors for power plants**[1]

Energy source	*Sulphur content (in % of fuel weight)*	*Thermal content (in MJ/kg)*	*SO_x emission factor - (in g/GJ)*
High-sulphur coal	3	28	1930
Low-sulphur coal	1	28	645
Residual fuel oil	3	43	1395
Distillate fuel oil	0.3	45	135
Natural Gas	0.002	51	1

1. Assuming that 10 per cent of sulphur is retained in the bottom ash.

Source: IEA (1992*a*).

Emission control technologies can be very efficient in reducing the amount of SO_x emitted per unit of fuel. The scrubbing potential of various technologies for the electricity generation is given in Table 5. The most efficient technique can reduce emissions by 90 per cent.

Table 5. **SO_x emission control technologies for power plants**

Technology	*SO_2 reduction (in %)*
Pre-combustion	
Physical coal cleaning	10-30
Combustion control	
Furnace absorbent injection (in experimentation)	60-75
Post-combustion	
Fluid gas desulphurisation	70-90

Source: IEA (1992*a*).

Finally, through the generation process itself, new combustion technologies can achieve a high potential of SO_x emission reductions. These advanced technologies improve plant efficiency and are compatible with tight emission standards. In some cases they can provide an interesting option because emission control systems are often rather costly. Some examples of new combustion processes are given in Table 6. The most performant technique -- the integrated gasification combined cycle generation -- can achieve 40 per cent combustion efficiency[9] with almost no emissions of sulphur-dioxide.

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[9] The present average generation efficiency is around 33 per cent.

Table 6. **Net combustion and abatement efficiency of advanced generation technologies**

Technology	*Net combustion efficiency*	*SO_2 reduction*
Atmospheric fluidised bed combustion	*34%*	*70 - 95%*
Pressurized fluidised bed combustion	38 - 40%	90 - 98%
Integrated gasification combined cycle	35 - 40%	99%

Source: IEA (1988).

III. Implementation of a NO_x/SO_x module in the GREEN model

As discussed above, for a given country and point in time, the estimation of total NO_x/SO_x emissions usually results from the aggregation of detailed emission sources. In a "top-down" model like GREEN, it is not possible to implement such a comprehensive treatment of NO_x/SO_x emissions. The data on emission factors available at a very detailed level need to be adapted to the structure of GREEN.

A. An illustrative calculation of NO_x/SO_x emissions

Energy demand in GREEN has an input-output structure. Energy consumption is split into eight types of energies (coal, crude oil, natural gas, refined oil, electricity and three back-stops) across eight sectors of intermediate consumption and four final demand goods. Since NO_x/SO_x emissions depend on specific sectoral uses, in principle, each case of the input-output matrix would require a distinct emission coefficient Φ_{ij} -- emission factor of fuel *i* consumed by sector *j*. Given differences in technology and regulations, these coefficients can also vary across regions and through time.

NO_x emissions are mainly concentrated in power generation plants and transportation (respectively, 30 and 41 per cent of NO_x emissions in the United States). Accordingly, these sectors need to have specific emission factors. In other sectors, the coefficients can only differentiated by type of fuel. For SO_x, emissions are mainly related to the electricity generation sector (65 per cent of emissions in the United States).

Among the back-stop fuels assumed to come on stream in the future[10], the carbon-based synthetic oil produces NO_x/SO_x emissions. To simplify, it was assumed that this backstop fuel will have the same emission factor as crude oil.

Given these assumptions, an illustration of a simplified table of emissions factors for the United States is given in Table 7. The estimates are based on detailed information from OECD and IEA sources. Note that there are no backstop fuels in 1985. Except for the main emitting sectors (in bold in the table) the coefficients are cross-sector average emission factors. They were calibrated in order to reproduce the observed levels of NO_x/SO_x emissions in 1985. Consequently, no particular interpretation should be drawn from these estimates. The emission factors in 1985 for the other regions of the GREEN model are shown in Table A1 of the Annex.

Table 7. **Emission factors for the United States in 1985 (in g per GigaJoules)**

(a) NO_x

	Intermediate demand								*Final demand*			
Sector number	Agr	Coal	Oil	Gas	Ref. Oil	Elec	EIS	Other	Food	Fuel & Power	Trans-port	Other
Coal Mining	300	300	300	300	300	**450**	300	300	300	300	300	300
Crude Oil	.	.	.	.	**200**	.	.	.	.	.	.	.
Natural Gas	70	70	70	70	70	**190**	70	70	70	70	70	70
Refined Oil	160	160	160	160	160	**200**	160	160	160	160	**490**	160

(b) SO_x

	Intermediate demand								*Final demand*			
Sector number	Agr	Coal	Oil	Gas	Ref. Oil	Elec	EIS	Other	Food	Fuel & Power	Trans-port	Other
Coal Mining	350	350	350	350	350	**950**	350	350	350	350	350	350
Crude Oil	.	.	.	.	**650**	.	.	.	.	.	.	.
Natural Gas	100	100	100	100	100	**370**	100	100	100	100	100	100
Refined Oil Products	250	250	250	250	250	**550**	250	250	250	250	**50**	250

Source: Authors' calculations based on OECD and IEA sources.
Legend: Agr: Agriculture; Elec: Electricity; EIS: Energy-intensive sectors; Oth: Other Goods & Services.

Emissions are computed by applying these emission factors to the energy demands expressed in physical units[11]. The result of this calculation is given in Table 8. Total emissions of NO_2 and

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[10] See Burniaux, Nicoletti and Martins (1992) for a description of the assumptions regarding back-stop energies embodied in the GREEN model.

[11] The energy demands by sector and fuel were derived from the IEA, *Energy Balances*, 1987 and 1989.

SO_2 are respectively 19.6 and 21.1 million tons for the United States in 1985[12]. By construction, these estimates are consistent with the OECD (1991*a*) source.

Table 8. **Emissions of NO_x and SO_x for the United States in 1985**

NO_2 (in 10^3 tonnes)	Oil Refineries	Electricity generation	Transportation	Other sectors	Total by type of energy	*(in per cent)*
Coal Mining	.	5884	.	1455	**7338**	*37.3*
Crude Oil	345	.	.	.	**345**	*1.8*
Natural Gas	.	670	.	987	**1657**	*8.4*
Refined Oil Products	.	209	8931	1173	**10313**	*52.5*
Total by sector	**345**	**6762**	**8931**	**3615**	**19653**	
(in per cent)	*1.8*	*34.4*	*45.4*	*18.4*		

SO_2 (in 10^3 tonnes)	Oil Refineries	Electricity generation	Transportation	Other sectors	Total by type of energy	*(in per cent)*
Coal Mining	.	12421	.	1697	**14118**	*66.4*
Crude Oil	1120	.	.	.	**1120**	*5.3*
Natural Gas	.	1304	.	1411	**2715**	*12.8*
Refined Oil Products	.	575	911	1832	**3319**	*15.6*
Total by sector	**1120**	**14300**	**911**	**4940**	**21272**	
(in per cent)	*5.3*	*67.2*	*4.3*	*23.2*		

Source: Authors' calculations.

B. Time variability of the emission factors

There are at least two reasons why the emission factor of a given sector and country may not remain constant through time. First, country specific regulations (e.g. emission standards) evolve through time. Second, all countries do not share the same level of technical progress but it is likely that in future decades both technology and environmental regulations will become more similar across countries leading to a convergence of emission factors.

Figure 1 illustrates different time paths for a given emission factor. The coefficient is characterised by a lower bound (Min). Three types of regions are drawn in the Figure. Region (a) is the leading country. Region (b) follows a rapid catch-up process. In region (c) the emission coefficient decreases approximately in an homothetic way relative to region (a) but without full convergence. The concavity of the curves captures possible decreasing returns in the emission factor improvement through time.

Figure 1. **Different time-paths of an emission factor**

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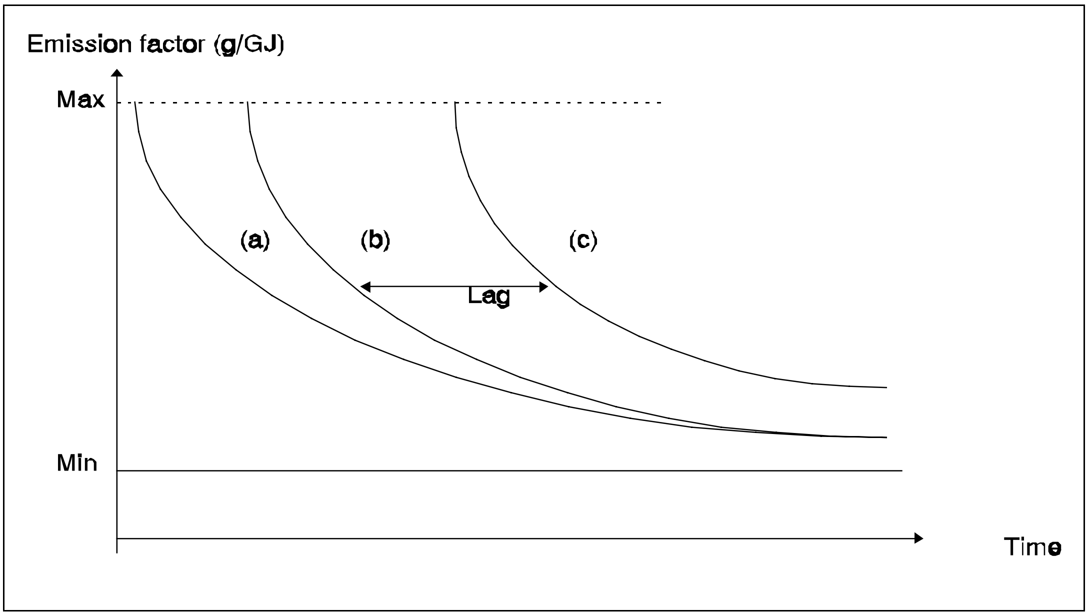
[12] NO_x/SO_x emissions are usually expressed in NO_2/SO_2 equivalents.



More precisely, it was assumed that, after a certain date, emission factors follow a decreasing trend ruled by an exponential decay:

$$\phi_t = (\phi_{1985} - \phi_{Min}) \cdot e^{-\alpha t} + \phi_{Min}$$

where:

Φ_{1985} is the emission factor in the benchmark year,
Φ_{Min} is the long-run lower bound for the emission factor,
α the rate of autonomous improvement in emission factors.

The autonomous improvement α was calibrated in such a way that, *ceteris paribus*, NO_x and SO_x emissions are reduced by 20 per cent by 2000 relative to their 1985 levels[13]. This implies an approximate value of 0.03 for the α coefficient. It is worth noting that this value is not unplausible when compared with the significant emission reductions observed in almost all countries signatories of the European Convention on Long-range Transbordary Air-Pollution.

For OECD countries the autonomous improvement starts in 1990. For non-OECD countries, the decrease in emission factors takes place with a lag of 10 years relative to the OECD group, i.e. by 2000. The lower bounds Φ_{Min} were derived from the emission factors of the most advanced technologies presently available (see details in Table A2 in the Annex).

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[13] This is the actual NO_x/SO_x abatement target for some OECD countries (see UN, 1987).

This set of assumptions is speculative. Its purpose is to define a reference scenario for NO_x and SO_x emissions. The policy experiments discussed in the next section will then be compared to this baseline emission path.

IV. Policy experiments

A. NO_x/SO_x emissions in the Baseline scenario

In the so-called Business-as-Usual (BaU) scenario there is no policy action to reduce CO_2 emissions. In particular, the energy subsidies observed in the base year are maintained throughout the entire period[14]. The regional breakdown of NO_x and SO_x emissions in the BaU scenario is given in Figure 2. At the world level, both NO_x and SO_x emissions would increase between 1985 and 2050, by respectively 30 and 40 per cent. This moderate increase is a direct result of the autonomous improvement in the emission factors. A striking fact is the large share of China in global emissions. For SO_x emissions, its share would grow from 15 in 1985 to 43 per cent of world emissions by 2050. The combination of a rapid GDP growth and the intensive use of coal explains this pattern.

The energy subsidies observed in 1985 are unlikely to be remain sustainable over the long-run. Actually, many countries, in which large distortions existed, have already taken the direction of reforming energy markets. Another picture emerges when energy subsidies are assumed to be removed in all regions[15]. This scenario is labelled "Baseline" in that it differs from the previous BaU and will serve as the reference for comparison.

In the Baseline scenario by 2050 world emissions of NO_x and SO_x decline relative to 1985 (Figure 3). The peak in the curves for non-OECD countries results from the assumption that the autonomous improvement in emission factors in these regions only takes place after 2000. Emissions in China are significantly lowered by the removal of energy subsidies which increase the relative price of coal and induce a strong substitution towards cleaner fuels. An opposite change is observed in the former Soviet Union. The effect of removing subsidies in this region is to decrease the relative price of coal. Indeed, energy subsidies in the former Soviet Union were mainly concentrated in oil and gas.

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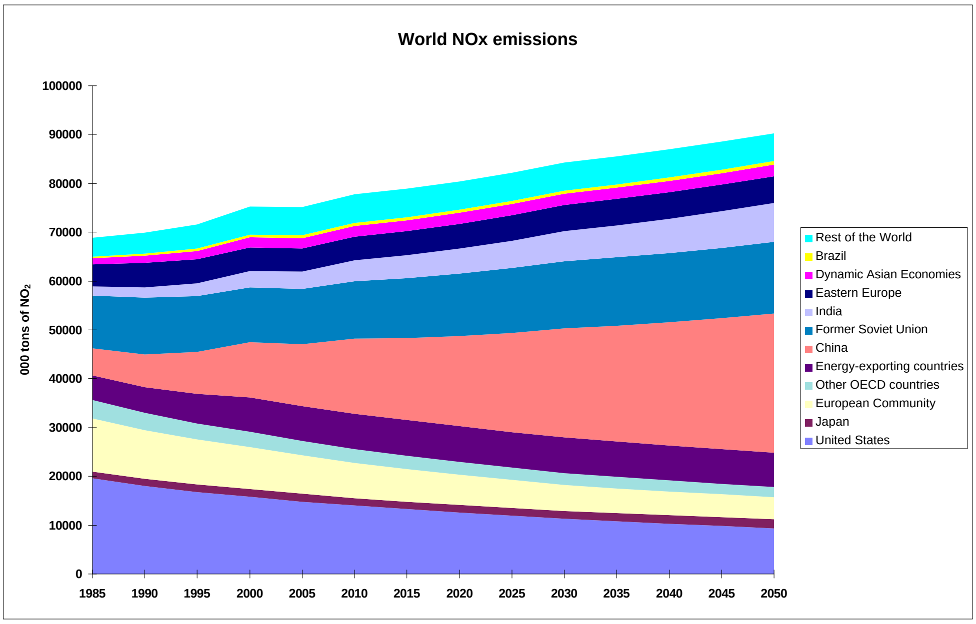
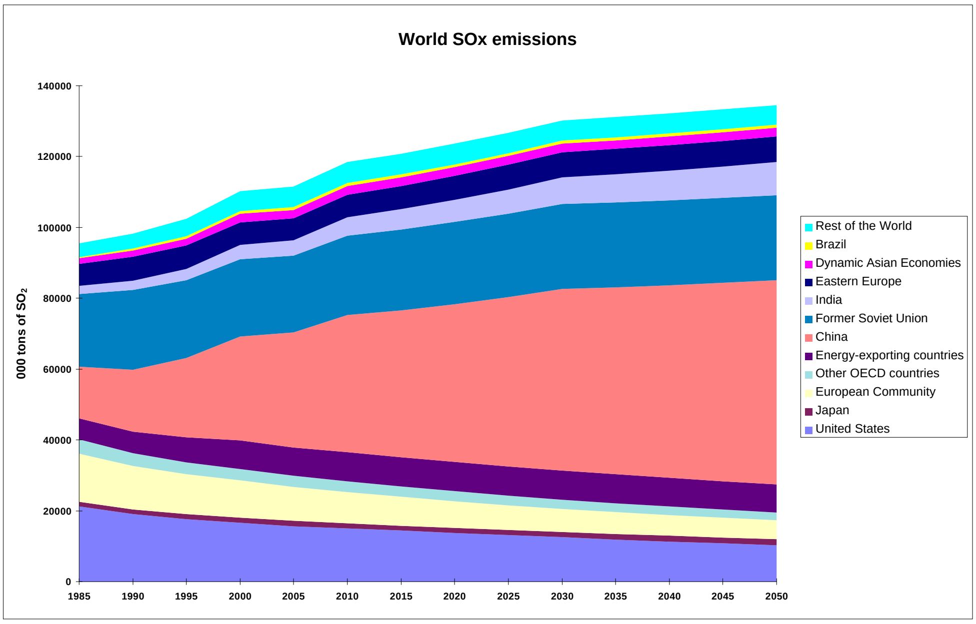
14. See Burniaux, Martin and Martins (1992*b*) for a discussion of the computation of energy subsidies in GREEN.

15. Subsidies in crude oil are phased out by the year 2000. Subsidies on coal and natural gas are phased out by 2010. All fuel taxes rates existing in 1985 are assumed to remain constant throughout the period.

Figure 2. BaU scenario (with no-removal of energy subsidies).





An alternative baseline scenario is given in Figure 4. In this simulation, the emission factors are held constant, i.e. there is no autonomous improvement. Not surprisingly, this has a dramatic effect on global emissions. By 2050, they are now between two to three times higher than in the previous scenario. However, the latter projections do not seem very plausible. Contrary to the case of carbon emissions, there are available technological options that can increase energy efficiency and reduce pollution. Those should be progressively implemented leading to a decrease of NO_x and SO_x emission factors in all countries.

B. Potential for NO_x/SO_x mitigation through carbon emission abatement

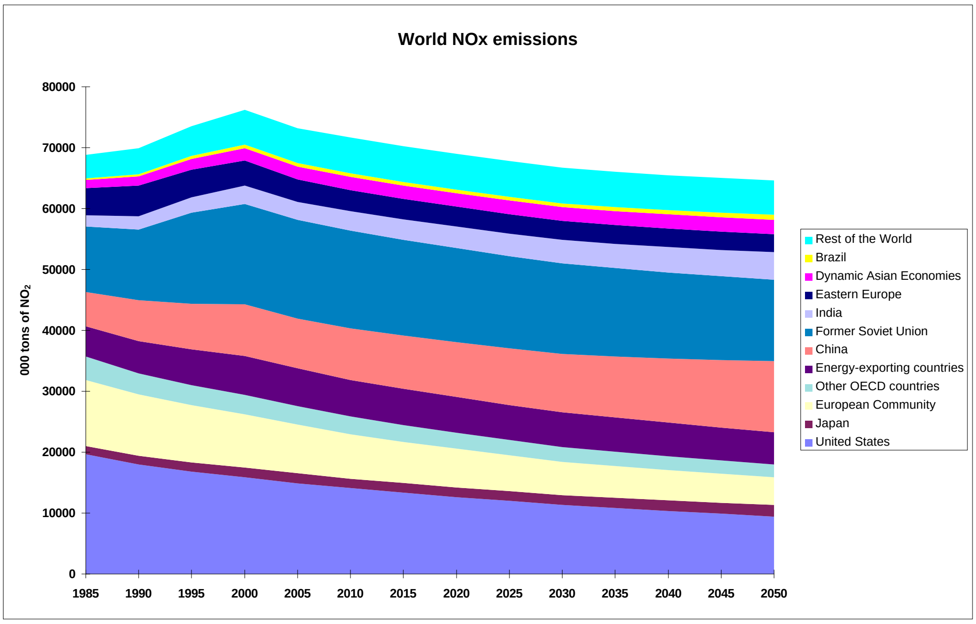
The next scenarios illustrate the secondary effects associated with agreements to curb CO_2 emissions. Two scenarios were considered. In the first scenario, the OECD countries jointly stabilise carbon emissions at their 1990 levels. The second scenario corresponds to the joint stabilisation of emissions by the major CO_2 emitters: the OECD regions, the former Soviet-Union and Eastern Europe, China and India.

The results for the first policy scenario are given in Table 9. The stabilisation of carbon emissions in the OECD requires a carbon tax rising from roughly 80 dollars per ton of carbon in 2000 to 170 dollars by 2050. In OECD countries/regions, carbon emissions are reduced by around 50 per cent relative to Baseline levels at the end-period. This represents a 18 per cent cut in world carbon emissions. The induced changes in regional NO_x and SO_x emissions range between 37 and 65 per cent reductions relative to baseline.

Emission reductions for SO_x emissions are somewhat higher than for NO_x. The explanation of the different spillover is related to the relative impact of the energy substitution and conservation effects. NO_x emissions are mainly located in the transportation sector where there is little substitution possibilities among fuels. Emission cuts are then mainly driven by the overall decrease of energy consumption. For SO_x, the key sector is electricity generation. In this sector, there is a larger potential of substitution from high-sulphur fuels, like coal, towards oil and natural gas. This effect cumulated with energy conservation explains why there is a higher emission spillover in the case of SO_x.

The stabilisation of carbon emissions in the group of major emitters (Table 10) induces a reduction of 45 per cent of world carbon emissions by 2050. NO_x emissions are cut by approximately the same amount. SO_x emission reduction reaches 55 per cent relative to baseline. It is worth noting that, as in the case of CO_2, a significant abatement of NO_x/SO_x at the world level can only be obtained by the participation of the main non-OECD emitters.

Figure 3. Baseline scenario (with removal of energy subsidies).


World NOx emissions

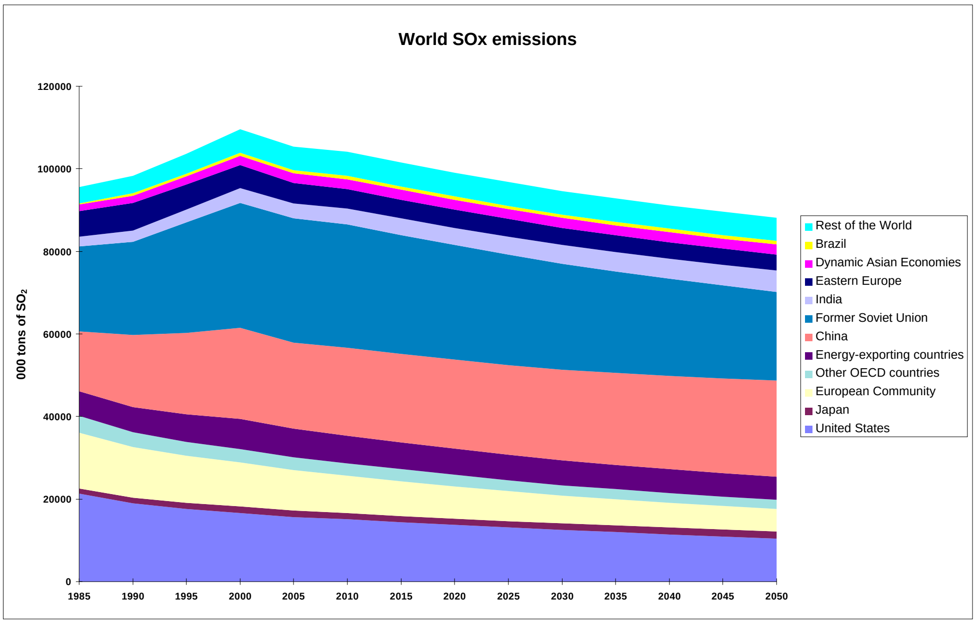
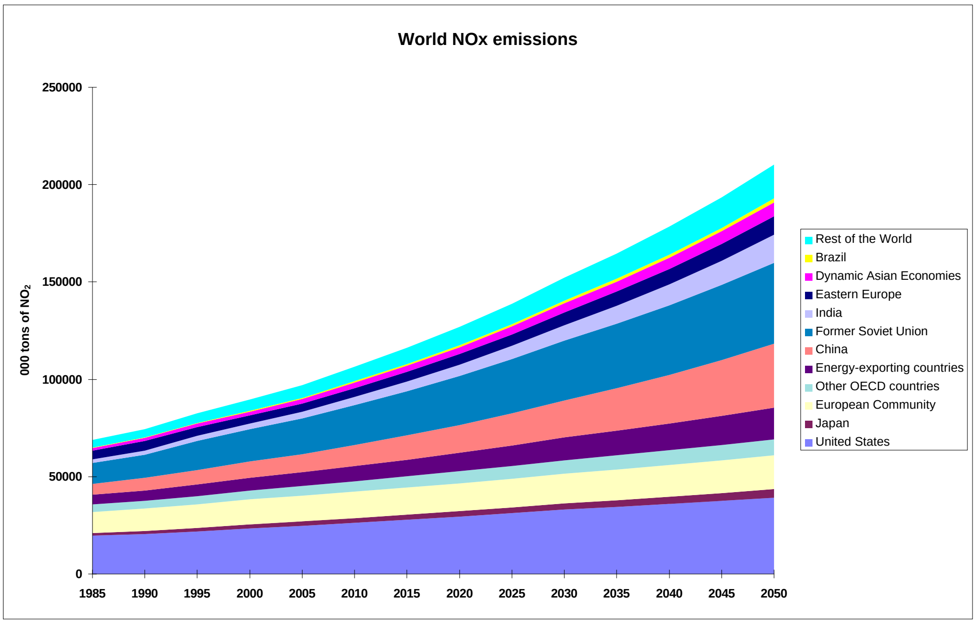

World SOx emissions

Figure 4. Baseline scenario with no autonomous improvement in the emission factors.



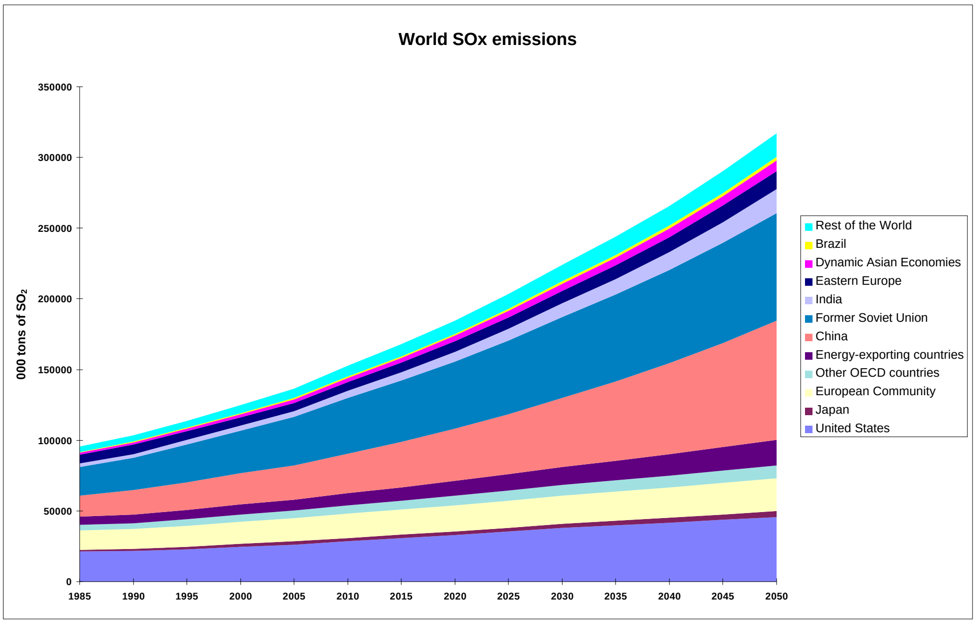


Table 9. **CO_2, NO_x and SO_x emissions reduction under OECD CO_2 stabilisation scenario**

	2000	**2010**	**2030**	**2050**
CO_2 tax (US$ / ton of carbon)	81	66	117	168
(Percentage deviations relative to Baseline)				
CO_2 emission cut				
United States	-18	-28	-43	-56
Japan	-14	-20	-34	-50
European Community	-14	-20	-33	-47
Other OECD countries	-21	-29	-44	-55
World	**-9**	**-12**	**-17**	**-18**
NO_x emission cut				
United States	-17	-25	-38	-46
Japan	-9	-15	-25	-37
European Community	-10	-15	-25	-36
Other OECD countries	-22	-32	-47	-56
World	**-7**	**-10**	**-13**	**-14**
SO_x emission cut				
United States	-28	-40	-58	-66
Japan	-12	-19	-30	-43
European Community	-18	-26	-40	-50
Other OECD countries	-29	-40	-57	-65
World	**-10**	**-13**	**-16**	**-16**

Source: GREEN model simulations.

Table 10. **CO_2, NO_x and SO_x emission reduction under major emitters' CO_2 stabilisation scenario**

	2000	2010	2030	2050
CO_2 tax (US$ / ton of carbon)	22	43	90	156
(Percentage deviations relative to Baseline)				
CO_2 emission cut				
United States	-8	-19	-38	-55
Japan	-4	-11	-28	-48
European Community	-5	-12	-27	-45
Other OECD countries	-10	-20	-39	-54
China	-18	-30	-56	-72
Former Soviet Union	-17	-28	-53	-70
India	-17	-32	-61	-75
Eastern Europe	-11	-18	-38	-56
World	**-9**	**-17**	**-34**	**-45**
NO_x emission cut				
United States	-8	-17	-34	-45
Japan	-3	-8	-20	-35
European Community	-4	-9	-21	-34
Other OECD countries	-11	-23	-43	-55
China	-19	-31	-58	-72
Former Soviet Union	-18	-28	-46	-60
India	-16	-31	-56	-70
Eastern Europe	-11	-20	-40	-56
World	**-10**	**-18**	**-33**	**-44**
SO_x emission cut				
United States	-13	-29	-53	-64
Japan	-4	-11	-25	-41
European Community	-7	-16	-33	-48
Other OECD countries	-14	-29	-52	-64
China	-19	-32	-58	-73
Former Soviet Union	-21	-33	-51	-64
India	-17	-33	-61	-76
Eastern Europe	-11	-20	-41	-58
World	**-14**	**-25**	**-43**	**-55**

Source: GREEN model simulations.

V. Concluding remarks

Using the OECD GREEN model, this paper provides evidence on the reductions of NO_x/SO_x emissions as secondary effects of carbon abatement policies. The methodology followed to introduce NO_x/SO_x in GREEN is a compromise between the "top-down" structure of the model and the very detailed information that, in principle, is required to compute emissions of these pollutants.

Emissions of NO_x/SO_x can be substantially reduced by adoption of new emission control and combustion techniques. However, this would be beyond the present scope of GREEN. Basically, these technology-related aspects could not be taken into account here because technical progress is exogenous in the model. This is an important limitation of this study which only deals with the energy conservation and substitution effects induced by a carbon-based taxation.

With this limitation borne in mind, the results suggest that there is scope for reducing NO_x/SO_x emissions as a positive spillover of a carbon abatement. Indeed, for the policy experiments carried out in this paper, the emission reductions in these pollutants are in the same order of magnitude or are higher than the abatement target imposed on carbon emissions.

Annex

Assumptions on NO_x/SO_x emission factors

Table A.1 **Emission factors per region (in g per GigaJoule) in 1985**

NO_x	**Coal**		**Oil**	**Gas**		**Refined oil**		
Input Sector	*Electricity*	*Other*	*Refineries*	*Electricity*	*Other*	*Electricity*	*Transport*	*Other*
United States	450	300	200	190	70	200	490	160
Japan	60	120	100	60	50	60	230	70
EEC	350	200	150	150	60	140	720	130
Other OECD	500	350	200	190	70	200	450	150
Energy-exp. LDCs	450	300	200	190	70	200	420	150
China	400	250	200	190	70	200	420	150
Former Soviet-Union	450	250	200	150	70	150	420	150
India	450	300	200	190	70	200	420	150
Eastern Europe	450	300	200	190	70	200	420	150
Dynamic Asian Eco.	450	300	200	190	70	200	420	150
Brazil	450	300	200	190	70	200	420	150
ROW	450	300	200	190	70	200	420	150

SO_x	**Coal**		**Oil**	**Gas**		**Refined oil**		
Input Sector	*Electricity*	*Other*	*Refineries*	*Electricity*	*Other*	*Electricity*	*Transport*	*Other*
United States	950	350	650	370	100	550	50	250
Japan	120	150	250	80	70	100	60	80
EEC	950	400	600	370	120	650	70	280
Other OECD	800	400	700	340	85	500	180	180
Energy-exp. LDCs	750	250	600	340	85	500	180	180
China	1100	650	700	450	200	900	200	400
Former Soviet-Union	850	450	700	400	150	600	150	300
India	750	250	600	340	85	500	180	180
Eastern Europe	750	250	600	340	85	500	180	180
Dynamic Asian Eco.	750	250	600	340	85	500	180	180
Brazil	450	300	600	340	85	500	180	180
ROW	450	300	600	340	85	500	180	180

Table A.2 **Minimum (long-run) emission factors per region (in g per GigaJoule)**

NO_x	**Coal**		**Oil**	**Gas**		**Refined oil**		
Input Sector	*Electricity*	*Other*	*Refineries*	*Electricity*	*Other*	*Electricity*	*Transport*	*Other*
United States	30	50	50	20	20	30	50	30
Japan	30	50	50	20	20	30	50	30
EEC	30	50	50	20	20	30	50	30
Other OECD	30	50	50	20	20	30	50	30
Energy-exp. LDCs	30	50	50	20	20	30	50	30
China	30	50	50	20	20	30	50	30
Former Soviet-Union	30	50	50	20	20	30	50	30
India	30	50	50	20	20	30	50	30
Eastern Europe	30	50	50	20	20	30	50	30
Dynamic Asian Eco.	30	50	50	20	20	30	50	30
Brazil	30	50	50	20	20	30	50	30
ROW	30	50	50	20	20	30	50	30

SO_x	**Coal**		**Oil**	**Gas**		**Refined oil**		
Input Sector	*Electricity*	*Other*	*Refineries*	*Electricity*	*Other*	*Electricity*	*Transport*	*Other*
United States	50	50	60	20	20	30	30	30
Japan	50	50	60	20	20	30	30	30
EEC	50	50	60	20	20	30	30	30
Other OECD	50	50	60	20	20	30	30	30
Energy-exp. LDCs	50	50	60	20	20	30	30	30
China	50	50	60	20	20	30	30	30
Former Soviet-Union	50	50	60	20	20	30	30	30
India	50	50	60	20	20	30	30	30
Eastern Europe	50	50	60	20	20	30	30	30
Dynamic Asian Eco.	50	50	60	20	20	30	30	30
Brazil	50	50	60	20	20	30	30	30
ROW	50	50	60	20	20	30	30	30

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