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External costs of aviation

External costs of LTO emissions

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1 External costs of LTO emissions

1.1 Introduction

For the valuation of emissions other than CO₂ different methods are used. The aim of this annex is to survey the recent estimates of the valuation of environmental effects of aviation. The effects that we have incorporated in this survey are the following:

- NO_x (in itself and via ozone);
- PM₁₀;
- PM_{2.5};
- HC, volatile hydrocarbons;
- SO₂;
- CO.

We have searched for studies that value these emissions. We have only sought for valuation of ground level effects, for being able to value the environmental effects of landings and take-offs (LTOs).

In this paragraph, we present the literature sources we have found with their results. To the extent possible, we have also presented the main assumptions and important remarks.

We first present the overview of the findings in paragraph 1.2, with the main conclusions we draw from them. In paragraph 1.3 we then present the full survey. For some literature sources we had to make some additional calculations to arrive at a unit cost, i.e. a cost per kilogram pollutant. We have presented our own calculations in separate text boxes in order to keep the description of the sources as objective as possible.

The one modification we have done for each of the sources is in the currency, because different sources use different currencies and different base years for these currencies. To provide a consistent overview we present all figures in one currency, namely in €₁₉₉₉. For the conversion of the different currencies we have used the following conversion table.

Table 1 Conversion factors from \$ to €, CPI-numbers

Year	CPI (US, 1989 = 100)	CPI (EU, 1989 = 100)	Exchange rate (1 € = .. \$US) ¹
1990	105.4	104.1	1.40
1991	109.8	108.4	1.30
1992	113.1	112.4	1.44
1993	116.5	116.0	1.19
1994	119.5	119.1	1.25
1995	122.9	121.8	1.32
1996	126.5	124.8	1.28
1997	129.4	126.8	1.11
1998	131.4	128.2	1.19
1999	134.3	129.6	1.07

¹ This exchange rate is the end-of-year exchange rate.

In case the original numbers in the report are denoted in another currency, we have given the relevant exchange rate.

1.2 Overview of findings

Qualitative conclusions

From the literature analyses, the following conclusions can be drawn:

- the knowledge about damage costs from other than greenhouse gas emissions has been much improved the last years. Especially on the area of health effects of transport pollutants much progress has been made. Dose-response relationships have been improved, dispersion models as well, and the valuation of (years of) life (lost) is subject to much less controversy;
- the increase in knowledge on these health effects has led to increasing valuations of practically all emissions, lead to a better understanding of variations in valuations, and thus a lower spread of various results if the factors behind the variations are taken into account. For example, several studies show that in an area like the Paris inner city a gram of PM_{2.5} emission leads to several Euros of health damage, and that in sparsely populated areas this is more something like 1 Euro cent. This shows that prices of emissions are very dynamic depending on the circumstances, and that with further scientific insight prices are more likely to increase further than to decrease;
- much of the health effects focus has been shifted to ultra-fine particles (PM_{2.5}). Extensive analysis in the framework of the ExternE programme and the WHO study of 1999 shows robust and significant dose-effect relationships. As a result, air pollution related costs from road transport, especially those of vehicles equipped with diesel engines, are dominated by the health effects of these particles;
- the most relevant health effects besides those of PM_{2.5} come from nitrates and ozone;
- carbon monoxide, 1,3 butadiene, benzene, and benzo(a)pyrene, other pollutants being suspected in the past, seem not to give rise to significant health effects. Either exposure or human sensitivity is relatively low;
- it should be said, however, that possibilities to monetise values like biodiversity and the health of forests, still fall rather short compared to possibilities to value health effects;
- health *damage* costs alone already generally seem to be higher than *prevention* costs that are based on the marginal costs of achieving *politically* agreed targets like the NECs². Due to this phenomenon, combined with the progress made on the valuation of health effects, the prevention cost methodology is becoming a less popular tool for emission valuation.

Quantitative conclusions per pollutant

In this paragraph we present the overview of estimates we have found. We present the results in five tables.

We first present in four tables overviews of the values found per emission (NO_x, PM_{2.5}, HC, and SO₂). For every emission, results from damage cost studies and prevention cost studies are distinguished. Furthermore, we try to explain ranges and we present differences between valuations for emissions emitted in urban areas and in rural areas.

² Theoretically, marginal prevention costs that are necessary to achieve environmentally sustainability targets are equal to marginal damage costs in the optimum).



In the fifth table the results are aggregated and averaged for use in this study.

Damage costs

Recent (ExternE) insights come to damage cost estimates of 12 €/kg NO_x, which includes the damage of the ozone formed out of NO_x. This value is an average and varies between a presented range of 1.9–21 €/kg across the European countries in the study. The range can mainly be explained by differences in health impacts due to differences in exposed population.

The ExternE programme takes a wide range of impact categories into account:

- human health;
- crops;
- timber;
- building materials;
- ecological systems;
- non-timber benefits of forests.

Although the valuation of damage to ecological systems is uncertain, the resulting marginal damage cost per kg NO_x seems to cover most relevant impacts.

Furthermore and the valuation of mortality is quite high. The value of a statistical life, which is used throughout ExternE, is € 3.2 million. This implies that there is no distinction between a life lost, which would have otherwise been lost 1 day later or a life lost, which might otherwise have lasted for tens of years. Some people have therefor suggested to use the Value of Life Years Lost, which presents the discounted value of the expected amount of life years lost. If this valuation methodology were used, the average value presented in ExternE would be lower.

IIASA et al. (1999b) present damage costs as well, in which they distinguish estimates with the 'Value of a Statistical Life' methodology and the (lower) estimate with the 'Value of Life Years Lost' methodology. The estimate using the Value of Life Years Lost for mortality impacts is € 9, the other is 15 €/kg.

SIKA (1999) arrive at a marginal social cost of 9 €/kg NO_x as well for the Swedish case.

The last recent damage cost estimate for NO_x is provided by COWI (2000) and they make a distinction between damage in rural areas and in urban areas. They arrive at 11 €/kg NO_x in rural areas and 12 €/kg NO_x in urban areas.

Prevention cost

Recent work on the estimation of the prevention cost per kg of NO_x can be found in the studies, which were done by IIASA to calculate the costs of achieving the NECs (National Emission Ceilings). The NO_x ceiling implies a 55% reduction of NO_x emissions in Europe in 2010, relative to 1990. Using this ceiling as a basis, IIASA arrives at a marginal social cost of reducing NO_x of 4.7 €/kg.

The reduction target is the most important factor determining the marginal cost in the prevention cost method. Ågren (1999) states that the National Emissions Ceilings, although more ambitious than the targets proposed in the so-called Gothenburg Protocol, still fall short of meeting the environmental targets as set in the Fifth Environmental Action Plan. Those targets

are defined as the targets that need to be achieved in order to have no exceeding ever of the critical loads, for both human health and vulnerable biodiversity. In order to achieve those 'sustainability' targets, the prevention costs will most probably be higher than 4.7 €/kg.

Kågeson (1993) presents prevention costs for NO_x as well and he arrives at a marginal social cost of 4.8 € 4.8/kg. This marginal social cost is the result of calculating the cost of the last measure, which was needed to achieve a 50% reduction in NO_x emissions in Europe in 2000, relative to 1985.

The level of NO_x emissions did not change too much in Europe between 1985 and 1990, so we can conclude that the cost curves in Europe did not change too much either. Kågeson notes that the targets he used to calculate the marginal social costs needed to be seen as interim targets as well.

Total

The conclusion is that with respect to NO_x, the damage cost approach leads to higher marginal social costs than the prevention cost approach based on marginal costs to achieve politically established emission reduction targets. This suggests that reduction targets should be stricter in order to achieve maximum welfare. Therefore, we will base our final estimate of the NO_x emission value on damage instead of prevention costs. We also differentiate for rural and urban effects.

Table 2 Overview of literature on the valuation of NO_x emissions in €1999, including indirect damage via ozone

sources on	average	range	rural	urban	comment
damage costs					
ExternE (1999)	12	0.9-21			mainly depends on population density
ExternE transport (1999)		4-25	4-13	7-25	
IIASA (1999b)	12	9.4-15			depends on valuation of life lost
SIKA (1999)	9	7.7-10	7.4	7.7-10	Swedish case, depending on population
COWI (2000)	11		11	12	basis for estimate could not be found
IVM (1999)	4.4	0.6-32			Dutch case, only health impacts via nitrate and ozone
sources on prevention costs					
IIASA (1999a)	1.5-3.3				depending on scenario, targets probably not sustainable
IIASA (1999c)	4.7				
CE (2000)	5.5		5	7	based on Auto Oil standards
Kageson	4.8				1985-2000 reduction targets

PM_{2.5} / PM₁₀

Damage cost

Because the most important determining factor of PM₁₀ is human health we only deal with the damage cost estimates. These damage costs crucially depend on the amount of people living in a certain area. Two sources are the most relevant for this study:

- the ExternE projects with its numerous spin-off reports;
- the WHO (1999) study used by INfras/IWW (2000) as this gives new information about the dose-response relationships.



In ExternE, a practical approximation formula has been derived: the damage cost of PM_{2.5} per kg is about equal to 10 + 122*population density (in 1.000 people per km²). One should, however, take care that transport is linked to human activity, and that therefore most transport emissions are released in areas that are more densely populated than the national average. For example in the Netherlands with its 450 inhabitants per km² the damage costs are higher than 10+122*0.45 = 65. For example, IVM (1999) comes, on the basis of the ExternE approach, to 130 €/kg, whereas Infrac/IWW (2000) comes to 174 €/kg. In the Paris city centre, the health costs of a kg of PM_{2.5} even amount to several thousand Euro.

As the relevant impact of PM_{2.5} emission is human mortality and morbidity, and as scientific knowledge about the damage of PM₁₀ emission has been greatly improved, and dose-response relationships seem to be well-established, the prevention cost approach seems not suitable any more for the valuation of this emission.

Table 3 Overview of literature on the valuation of PM_{2.5} or PM₁₀ emissions in €1999

source on damage costs	average	rural	urban	comment
Infrac/IWW (2000)	73-194			national averages across EU, based on WHO study
ExternE transport (1999)		18-200	200-2000	depends mainly on population density, high value = Paris, low = Dutch average density
SIKA (1999)			85-915	Swedish case, high value = Stockholm centre
COWI (2000)		24	90	basis for estimate could not be identified
IVM (1999)	130	18-150	200-942	PM _{2.5} from 'low source' (transport), Dutch case

* practically all transport PM emissions fall in the range of smaller than 2.5 micron; therefore the '2.5' estimates seem to fit best the transport emission cost estimates.

VOC/HC

Damage cost

For VOC/HC there exist not too many recent estimates. ExternE leads to estimates of 4-9 €/kg. The higher estimates apply for cities like Stuttgart and Barnsley. For the Paris city centre the value explodes to 33 €/kg. SIKA (1999) presents for the Swedish case the same range of values many to take urban effects into account: € 4-9. COWI (2000) presents a value of 2.7 €/kg.

Prevention cost

IIASA (1999c) calculates the marginal social cost of a kilogramme, but this modelling is not too sophisticated, because most measures that reduce VOC/HC, also reduce NO_x. Therefore, in general all costs are allocated to either one of the pollutants. This results in almost identical prevention costs for VOC/HC as for NO_x. The value IIASA (1999c) presents is € 4.6 per kilogramme.

Total

From the different estimates it seems best to use the value of € 4 as the marginal social cost per kilogramme. The COWI estimate is lower than the other two, and also Bleijenberg et al. (1994) presented an estimate of € 5.

Table 4 Overview of literature on the valuation of HC emissions in €1999

sources on damage costs	average	range	rural	urban	comment
ExternE transport (1999)		3.9-33	4	4-33	depends mainly on population density, high value = Paris
SIKA (1999)		3.6-8.9	3.6	4.1-8.9	Swedish case, depending on population density, 8.9 = Stockholm centre
COWI (2000)	2.7		2.7	2.7	basis for estimate not clear
sources on prevention costs					
IIASA (1999a)	1.5-3.3				depending on scenario, targets probably not sustainable
IIASA (1999c)	4.6				
CE (2000)	5.5		5	7	based on Auto Oil standards

SO₂

Damage cost

Recent (ExternE) insights come to damage cost estimates of 8.5 €/kg SO₂. This value is an average and varies widely across the European countries in the study. The presented range is € 1.5-15.5.

The resulting marginal damage cost per kilogram SO₂ seems to cover all relevant impacts. However, the damage to ecological systems is uncertain.

Other damage estimates come from IIASA (1999b), which presents € 3.5 per kilogram, and Kågeson (2000) who presents a value of € 3.3 as an absolute minimum. The recent COWI-study (2000) calculates values for rural areas (€ 5.5) and urban areas (€ 9.5).

Altogether, it seems that the ExternE-value in general is too high and from the other studies we conclude that the value from Kågeson (2000) and IIASA (1999) can be best used as the lower bound.

Prevention costs

Recent work on the estimation of the prevention cost per kg of SO₂ can again be found in the studies, which were done by IIASA to calculate the costs of achieving the NECs.

The estimate for marginal social cost of a kg of SO₂ which we could derive from IIASA (1999c) was 1.5 €/kg. This value is based upon the target set in the National Emissions Ceilings. This target boils down to a 78% reduction of SO₂ emissions in Europe in 2010, relative to 1990.

It is important to note that this value seems very low, compared to the damage cost estimates. An important factor determining the marginal cost using the prevention cost method is the target. About this target Ågren (1999) makes the following remark: the National Emissions Ceilings are more ambitious than the targets proposed in the so-called Gothenburg Protocol, but they still fall short of meeting the environmental targets, set in the Fifth Environmental Action Plan. Those targets are defined as the targets that need to be achieved in order to have no exceeding ever of the critical loads, for both human health and vulnerable biodiversity.

In order to achieve those 'sustainability' targets, the prevention costs will most probably be higher than 1.5 €/kg. Kågeson (1993) presents prevention

costs for SO₂ as well and he arrived at a marginal social cost of € 1.6 per kilogramme. This marginal social cost is the result of calculating the cost of the last measure, which was needed to achieve a 60% reduction in SO₂ emissions in Europe in 2000, relative to 1985.

However, Kågeson (1993) also calculated the marginal social cost of a reduction of 80% in 2000 relative to 1985. The value he found there was € 3.2 which is substantially higher, whereas this target still cannot be seen as a sustainable level of SO₂ emissions.

Total

When we compare the results from damage cost studies and prevention cost studies, the gap is fairly small. Both the damage cost estimates from IIASA (1999b) and SIKA (1999) can serve as a lower bound, which is € 3 per kilogramme. This value is quite similar to the highest prevention cost estimate.

Table 5 Overview of literature on the valuation of SO₂ emissions in €1999 per kg

sources on damage costs	average	range	rural	urban	comment
ExternE (1999)	8.5	1.3-16			variation across EU Member States
ExternE transport (1999)			6.8-8.5	10-50	mainly depends on population density
IIASA (1999b)	3.5				depends on valuation of life lost
SIKA (1999)	3.3		3.3		Swedish case, minimum estimate
COWI (2000)	7		5.5	9.5	basis for estimate could not be identified
sources on prevention costs					
IIASA (1999a)	1.2				variations between countries, targets probably not sustainable
IIASA (1999c)	1.5	0-5			
CE (2000)	3		3	3	based on Auto Oil standards
Kageson (1993)	1.6-3.2				depending on reduction targets

Table 6 Overview of middle estimates from the recent European literature for the valuation of NO_x, PM₁₀, HC and SO₂, per kilogram emitted, based on damage costs

	average	urban	rural
NO _x	9	12	7
PM ₁₀ / PM _{2.5}	150	300	70
HC	4	6	3
SO ₂	6	10	4

1.3 Full survey of literature

The following literature has been found on the valuation of emissions other than CO₂. For each source we shortly describe the method that is used, and the assumptions that are made. Finally the results are presented.

Infras/IWW, 2000, External costs of transport: accident, environmental and congestion costs in Western Europe, UIC, Zürich/Karlsruhe/Paris

Method: damage cost

The impacts that are distinguished are the following:

- human health;
- materials and buildings;
- agricultural crop losses;
- forest damages³.

Health: the method is based on WHO (1999), based on PM₁₀ as the leading indicator and a value of statistical life for people affected by air pollution of € 0.9 million. The results from WHO for Austria, France and Switzerland were extrapolated by Infrac/IWW by using the weighted PM₁₀ and NO_x emissions in different countries. This is done as follows.

Infrac/IWW extrapolated the health impacts found by WHO (1999) (PM₁₀ as leading indicator, countries Austria, France and Switzerland) to the EU Member States. As for other countries data on PM₁₀ concentrations are not widely available Infrac/IWW have followed an indirect approach. As NO_x emissions in all EU Member States are well known, they defined a correlation between PM₁₀ concentrations and PM₁₀ and NO_x emissions in France, Austria and Switzerland, and use this correlation to establish PM₁₀ concentrations for the other European countries considered. A correction for non-exhaust PM₁₀ emissions was necessary in order to properly fulfil this task.

[Addition by CE: dividing the health costs by transport particulate emission estimates leads to an approximate health costs of approximately 100 € per kg of particulate emitted (urban/rural average for France, Austria and Switzerland). An important factor behind the health impact of PM₁₀ emitted is population density; this amounts 107, 96 and 172, for France, Austria and Switzerland respectively. As a first order estimate, one can put a population density correction factor on the PM₁₀ shadow prices, as exposure per unit of emission is approximately linearly dependent on population density]

The health costs account for an average 81% of external costs from air pollution in the countries under consideration.

Crop losses: the costs that were computed for Switzerland (Infrac/Econcept/Prognos, 1996) are used to calculate the same costs for other European countries. The formula that is used is as follows:

Crop losses = $\alpha * (\text{NO}_x \text{ emissions/country area}) * \text{agricultural production}$
with $\alpha = 0.0037 \text{ [m}^2\text{/ton]}$

On average these costs amount to 1% of external costs from air pollution in the considered countries.

Building damages: the methodology used to calculate these costs is similar to the one used for crop losses. The costs computed in Infrac/Econcept/Prognos (1996) were scaled to other European countries using NO_x exposure levels and building surface. The exposition levels are estimated by dividing the emissions by the country area and the building surface is estimated using population. The following formula results:

Building damage = $\beta * (\text{NO}_x\text{-emissions/country area}) * \text{building surface} * \text{PPP}$
with $\beta = 0.322 \text{ [€/tonne]}$.

³ This last category is only included in the sensitivity analysis.

On average these costs account for 18% of external costs from air pollution in the considered countries.

Addition by CE: using the data on emissions as provided in the Infrac/IWW report for the EU-countries, we have calculated the average cost per kilogram PM₁₀ for the EU-countries. The average cost is equal to the marginal cost, because the dose-response functions are linear: at a certain location, each kilogram is assumed to have the same impact. This resulted in Table 7.

Table 7 Overview of average and marginal damage costs per kg of PM₁₀ emission

Country	Marginal social cost (in € ₁₉₉₉) per kilogram of PM ₁₀
Austria	104
Belgium	143
Denmark	162
Finland	111
France	107
Germany	135
Greece	74
Ireland	109
Italy	129
Luxembourg	194
Netherlands	174
Norway	146
Portugal	73
Spain	78
Sweden	121
Switzerland	172
United Kingdom	140

From the table we see that the marginal social costs of PM₁₀ in the European countries considered varies between 73 and 194 €/kg. The main variables determining this value are population density and society's purchasing power parties, mainly defined by income.

Comparing the results with those from the ExternE bottom up approach

In Infrac/IWW the authors also make a comparison between the top down approach (WHO) and the ExternE bottom up approach. Infrac/IWW states that there are significant differences in these two approaches; WHO leads to higher damage costs than ExternE. However, the study does not directly compare unit values per kg of PM₁₀ emission following from both methodologies.

Comparison by CE of bottom up and top down damage estimates per passenger or tonne kilometre in the Infrac/IWW study leads to the conclusion that the top down values used by WHO are, on average, 2 to 3 times higher than the bottom up values as estimated following the ExternE approach. This conclusion is in line with the results of both studies as discussed in this annex.

Infrac/IWW explain this difference as follows:

- the dispersion models for health costs: Whereas the top down approach, based on the WHO study (1999) uses a particulate based modelling, including as well particulates from tyres and clutches, the ExternE model (see above) is basing their models on exhaust emissions of transport and dividing it into a regional and a local part;

- the adjustment of VSL for health costs: Whereas the WHO-study based on a VSL of 1.4 M€, ExternE bases its assumptions on a VSL of 3.2 M€. The adjustment factors are different however;
- the building damages, based on estimations of a shortage of renovation cycles or damages to cultural buildings are not considered explicitly within the ExternE model. Their approach for material damages might therefore be an underestimation.

Comparison of the health impacts with the two approaches shows that the average values based on the WHO study are similar to the results of ExternE. The uncertainty can therefore not be explained by uncertainties in the dose-response functions.

COWI, 2000, Civil aviation in Scandinavia – an environmental and economic comparison of different transport modes, Lyngby, Denmark

Method: damage cost

The damage cost categories that have been included are the following⁴:

- morbidity;
- premature mortality;
- reduced farming and forestry yields;
- dirty and corroded buildings.

This study has calculated the marginal external costs of emissions. Using dose-response relationships, they arrived at the following values.

Table 8 Damage costs estimates according to COWI (2000)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram	
	Rural area	Urban area
NO _x	11	12
particulates	24	90
HC	2.7	2.7
SO ₂	5.5	9.5
CO	0	0

There is no further information available on the specific functional form of the dose-response relationships that were used.

CE / TNO, Early introduction of cleaner petrol and diesel fuel in the Netherlands; analysing emission reduction potentials and cost effectiveness [‘Vervroegde introductie van schonere benzine en diesel in Nederland: een analyse van emissiepotentieel en kosteneffectiviteit’], Kampman, B.E., J.M.W. Dings, R. Gense, E. van de Burgwal, Delft, 2000

Method: overview of estimates of shadow prices used.

This study in general uses shadow prices used previously in (CE 1999) and (CE 1997). The estimates for NO_x, HC and SO₂ are based on marginal prevention costs based on (CE 1994) and for NO_x and HC additionally on the costs for complying with the newest EU vehicle emission and fuel standards. With respect to PM₁₀ emission a new damage cost estimate is used based

⁴ Damage to the global climate is also considered in this study, but we will go into that, in the section on valuation of greenhouse gases.



on WHO (1999) and Infrac/IWW (2000). CE (2000)⁵ is used additionally in order to split the damage cost estimate for PM₁₀ into a rural and an urban component.

The following marginal social cost estimates are used in CE (2000).

Table 9 Marginal costs estimates used in (CE 2000), based on both damage and prevention costs

Pollutant	Approach	Marginal social cost (in € ₁₉₉₉) per kg	
		Rural area	Urban area
NO _x	prevention	5	7
PM ₁₀	damage	35 – 70	150 – 300
HC	prevention	5	7
SO ₂	prevention	3	3

European Commission, DG XII, ExternE – Externalities of Energy, 1999 (<http://externe.jrc.es/overview.html>), Brussels, Belgium

Method: damage costs

Model: for each pollutant an impact pathway is defined. This means that for each pollutant all possible impacts are taken into account, the exposure levels are identified (how many people are exposed to what concentration for example), the effects are modelled (how many people will die premature for example) and these effects are valued (what is a life lost worth for example). This approach has been followed for all different impacts as far as possible.

The methodology has thereafter been worked out for all EU-countries. The study has focused on the production of energy in different forms. This means that the values should be seen as values that arise for emissions at ground level.

The impact categories have not all been taken into account, but the larger ones have. In the eventual estimate of the damage the following cost categories arise:

- crops;
- timber;
- building materials;
- human health;
- ecological systems;
- non-timber benefits of forests.

Alternative techniques have been developed for valuation of the last three 'goods', the main ones being hedonic pricing, travel cost methods and contingent valuation. For the other goods, it was possible to use the market prices, for timber, crops and so.

⁵ This source is not included in the list of references, because it does not provide shadow prices. It does however provide information on the effects of emissions of particulates on concentration levels in rural and urban areas. Information in ICE 2000I has been used to calculate the difference in marginal social costs in rural areas as opposed to urban areas. This had led to a ratio of 4.5 which means that the marginal social cost in rural areas has been found by dividing the value for urban areas by 4.5.

For each of the pollutants SO₂, NO_x (including the damage through ozone formation), and PM₁₀ the damage costs are identified.

On the ExternE website, the results are given for each country separately. We will here present only the ranges found across Member States and the average value found by applying a weighed average according to each member state's population.

We would like to emphasise that the damage costs, as given in ExternE are strongly dependent on the exposure levels and thus strongly fluctuates not only *between*, but also *within* countries.

Table 10 Damage costs across the EU Member States of NO_x, SO₂ and PM₁₀ emissions according to the ExternE study

Pollutant	Marginal social cost (in € ₁₉₉₉) per kg	
	Medium estimate	Range
NO _x	12	2.1 – 21
PM ₁₀	14	2.1 – 198
PM _{2.5}	23	high estimate: 75
SO ₂	8.5	1.1 – 16

IER, *External costs of transport in ExternE, with contributions by IER, ETSU, IVM, ARMINES, LIEE, INERIS, IEFÉ, ENCO, IOM, IFP, EEE, DLR, EKONO, 1999*

In the transport section of the ExternE research several transport cases have been researched. In this overview study some of these cases are summarised in terms of MEUR per km driven. The values are shown in the table below. Consequently, they are recalculated to units per kg of emission by using emission factors as stated in the German case study (IER 1998, Transport externalities due to airborne pollution in Germany - application of the ExternE approach, Bickel, P. et al., Stuttgart, 1998), and modification factors for these emission factors mentioned in the report.

Furthermore we assume that ozone damage is for 50% caused by HC emissions and for 50% by NO_x emissions.

This approach leads to the results in Table 11.



Table 11 Damage estimates (vehicle use only) for diesel passenger cars in agglomerations, urban areas and extra-urban areas, given as 'best estimate' in 1995 m€/vkm, and recalculated to 1999 €/kg of pollutant

	agglom- erations	urban areas			extra-urban areas		uncer- tainty*
	Paris	Stuttgart	Amsterdam	Barnsley	Stuttgart- Mannheim (motorway)	Tiel	
primary pollutants							
PM _{2.5}	534.09	50.43	78.60	97.40	18.77	29.50	B
SO ₂	0.93	1.12	0.71	0.80	0.60	0.32	A/B
CO	0.02	0.003	0.003	0.005	0.001	0.0004	B
Cancers	4.02	0.54	0.57	1.25	0.18	0.22	B
secondary pollutants							
Sulphates	0.59	0.82	1.30	0.63	0.68	1.10	B
Nitrates	18.18	9.14	2.70	2.82	7.24	3.80	B?
Ozone	1.29	0.96	0.90	0.93	0.78	1.20	B
damage costs per kg of pollutant							
PM _{2.5}	4,800	640	620	560	240	180	B
NO _x	26	17	5.7	7.4	14	4.7	B
SO ₂	54	14	11	20	9.1	7.2	B
HC	36	7.8	5.5	9.3	4.3	4.2	B

* A = high confidence (a factor 2.5 to 4); B = medium confidence (a factor 4 to 6); C = low confidence (a factor 6 to 12); „?” = evidence is weak

It can be seen that the majority of externalities is caused by PM_{2.5} and nitrate.

A study by NTNU/DNV (Environmental performance of transportation - a comparative study, Magerholm Fet, A. et al., IØT-Report nr. 3/2000), is referred to ExterneE damage costs functions expressed in EUR per kg of pollutant per 1,000 inhabitants per square kilometre.

$$\text{PM}_{2.5}: 10 + 122 * \text{pop}$$

$$\text{nitrates}: 2.1 + 6.4 * \text{pop}$$

World Health Organization, 1999, *Health Costs due to road traffic-related air pollution: an impact assessment project of Austria, France and Switzerland*, prepared for the WHO ministerial conference on environment and health, London, June 1999

Method: damage cost

Model: establishing dose-exposure-response relationships between emissions PM₁₀ and human health effects.

This study uses a dose-response modelling exercise. The impact of emissions of PM₁₀ on human health is measured for Switzerland, France and Austria. PM₁₀ is not considered to be the only air pollutant, but from other studies it seems to have the strongest correlation with health impacts and it is used as an indicator for urban air pollution.

The following health effects were included in the assessment:

- total mortality based on cohort studies⁶;
- respiratory hospital admissions;
- cardiovascular hospital admissions;
- chronic bronchitis in adults;
- acute bronchitis in children;
- restricted activity days in adults;
- asthma attacks in children and adults.

A potentially important health effect that is not included is acute mortality.

The dose-response modelling has been done according to the following impact-pathway:

emissions → concentration → exposure → immission → health response (mortality/morbidity) → costs

Some important remarks on the dose-response relationships are the following:

- all air pollution-related health effects are only considered for the age groups assessed by epidemiological surveys and above the lowest assessed exposure level of 7.5 µg/m³ PM₁₀;
- WTP is used for monetary valuation;
- only PM₁₀ has been assessed (the annual average concentration is taken as an indicator for urban air pollution).

The monetary valuation used for (some of the important) health effects is as follows:

- € 0.9 million per prevented fatality (total mortality costs >70% in 3 countries);
- € 0.21 million per prevented case of chronic bronchitis (74% of morbidity costs);
- € 94 per restricted activity day avoided (22% of morbidity costs).

WHO states that the most recent empirical values for the willingness to pay of a risk reduction of fatal road accidents applied is € 1.4 million. WHO corrects this value to € 0.9 million to consider the lower willingness to pay of the higher average age class of air pollution related victims.

Unfortunately, the results are not recalculated into values per unit of emission. This was done by Infrac and IWW (2000) as previously discussed.

SIKA, 1999, Översyn av samhällsekonomiska kalyfprinciper och kalkylvärden på transportområdet, SIKA nr. 6, Stockholm (summary sent in a memo by Kågeson, P., 'Calculation values used by Swedish State Agencies in the transport sector')

Method: damage cost

This memo provides the English summary of values used in Swedish transport policy. The values have been calculated in SIKA (1999)⁷. The values

⁶ Increase in premature mortality is only considered for adults older than 30 years of age. Furthermore, the results from the cohort studies only detect long-term impacts, so acute mortality is not included in the analysis.

⁷ The full reference of this publication is: SIKA, 1999, Översyn av samhällsekonomiska kalyfprinciper och kalkylvärden på transportområdet, SIKA nr. 6, Stockholm.



are agreed upon by the state agencies for the different modes of transport (road, rail, water and air), the Swedish Environmental Protection Agency and the Swedish Institute for Transport and Communications Analysis (SIKA). They are used in cost-benefit analyses.

The values for NO_x, SO₂, VOC and PM₁₀ are based upon the damage cost method. The total damage arises from local damage, as well as regional and global damage. The cost categories that have been included are the following:

- human health;
- damage to forestry and crops;
- material damage.

For the calculation of total (marginal) damage cost the two values can be added. The following table presents the ranges in regional values, local values and total values that are used in Sweden.

Table 12 Marginal damage costs for Sweden, based on SIKA (1999)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram		
	regional damage	local damage*	total
NO _x	7.4	0.3 – 2.9	7.8 – 10
PM ₁₀	0	85 – 915	85 – 915
HC	3.6	0.48 – 5.3	4.1 – 8.9
SO ₂	2.1	1.2 – 26	3.3 – 28

* Mainly depending on population density; figures reflect differences between North-Sweden and the Stockholm city centre

Agren, C., 1999, *Getting more for less: an alternative assessment of the NEC Directive, Air pollution and Climate series 13, T&E 99/9, Brussels*

Method: prevention cost method

This study presents a critical review of IIASA et al. (1999a,b). This study does not present new estimates for the marginal costs for each pollutants, but it presents (lower) estimates for the total costs needed for meeting the National Emission Ceilings (NECs) in the different EU-countries.

We will describe the main points of criticism under the heading of IIASA et al. (1999a,b).

IIASA, DNMI and RIVM, 1999a, *Economic evaluation of a directive on National Emission Ceilings for certain atmospheric pollutants: part A, Cost-effectiveness analysis, Laxenburg, Austria/ Oslo, Norway/ Bilthoven, The Netherlands*

Method: prevention costs

Model used: RAINS (Regional Air pollution INformation and Simulation), focussing on NO_x, SO₂, NH₃ and VOC. For these pollutants emission control options are identified and costs have been determined. The associated costs include investment-related and operating costs. All investments in emission reduction are annualized using a discount factor of 4%.

Not all emission control options are incorporated in the model, only the major ones for the economic activities that contribute the most. For NO_x and VOC, only the emission control options (and emissions) are given for stationary

sources. The omission of control costs of mobile sources introduces an uncertainty in the results.

In the remainder of this description we focus on the emissions ceilings for 15 European countries (EU-15) and the corresponding abatement measures and costs. IIASA et al. also present figures for non-EU-countries in Europe, but these figures are not as reliable and do not show up in the summarizing tables in the report.

Different scenarios have been used, with one central scenario in which the emissions of different pollutants in the EU overall are reduced as follows, compared to the emissions in 1990:

- NO_x: -55%
- VOC: -60%
- SO₂: -78%

These reductions are the results of minimising the costs to achieve environmental targets. These environmental targets arise from the acidification and ozone-exposure strategies that was also adopted in the UN/ECE Convention on Long-range Trans-boundary Air Pollution, where for all areas a target of a '60% gap closure' of excess sulphur deposition was established. However, IIASA states (p. 96) that the targets used in its report will not be sufficient to meet the environmental long-term targets (the no-damage levels) everywhere in Europe within the next one or two decades.

Three scenarios are used:

- 1 A base case 'central' energy scenario, which leads to a 9% increase of CO₂ emissions between 1990 and 2010.
- 2 A 'low CO₂' scenario' which uses the agreements as set in the Kyoto Protocol, which boils down to a cut in CO₂-emissions by 7% in 2010 relative to 1990. This leads to a large reduction in abatement costs for NO_x and VOC, and a cut of 28% in overall costs to achieve the environmental targets for NH₃, NO_x and VOC in Europe.
- 3 A 'low NH₃-scenario' which is based on a 10% cut in livestock all over Europe, following an expected change in the Common Agricultural Policy. This 'new' base case, which is purely hypothetical, results in lower costs for SO₂-measures. The effects on costs of measures to reduce NO_x and VOC are small.

Table 13 Derivation of *average prevention costs* from IIASA (1999a) in three scenarios (all figures relative to the reference scenario)

	central	low CO ₂	low NH ₃
NO _x reduction (ktonne)	927	856	607
HC reduction (ktonne)	1,547	1,312	1,470
NO _x + HC reduction costs (M€)	4,508	2,567	5,538
average NO _x + HC prevention costs in €/kg	2.2	1.5	3.3
SO ₂ reduction (ktonne)	1,050	1,368	827
SO ₂ reduction costs (M€)	861	994	782
average SO ₂ prevention costs in €/kg	1.0	1.0	1.2

As we mentioned under the heading of Ågren (1999), the results of this IIASA-study have been criticised. The main points of criticism in this study are the following:

- the level of ambition is fairly low: although the environmental targets in the central scenario have been strengthened in comparison with the Gothenburg Protocol, the level of ambition is low compared to the first reading of the European Commission. The targets are not sufficient to achieve the objectives laid down in the Fifth Environmental Action Plan. The long-term aim is that critical loads for both human health and vulnerable biodiversity should never be exceeded;
- the costs of achieving the NECs are overestimated because of:
 - the energy scenario which serves as the input for the future emissions is not based on meeting the agreements of the Kyoto Protocol;
 - only end-of-pipe measures are included in the list of measures that can be taken to achieve the environmental targets set, whereas fuel switching and energy and transport efficiency measures have been ignored. This method thus excludes measures that might be achieved at a zero cost;
- technological improvements (including cheaper technology) is not taken into account.

Ågren (1999) presents no other average prevention cost estimates, but presents the cost consequences of an alternative energy scenario, which brings CO₂ emissions in 2010 down with 15% relative to 1990. In this scenario, the overall costs of meeting the NEC-directive come down from the € 7.5 billion (see IIASA, 1999a) to € 2.7 billion.

IIASA and AEA Technology, 1999b, Economic evaluation of a directive on National Emission Ceilings for certain atmospheric pollutants: part B, Benefit Analysis, Laxenburg, Austria/ Culham, United Kingdom

Method: damage cost

Model used: ALPHA, permits analysis of the effects of sulphur/nitrogenous pollutants and ozone on public health, materials, crops, forests, ecosystems and visibility.

Not all categories are quantified in detail, and so the authors emphasize that the benefits, which are presented in the report, are a 'subtotal'. For different policy scenarios in order to achieve reductions in NO_x, SO₂, NH₃ and ozone the emission reductions and benefits are calculated.

The scenarios differ in targets set for the different pollutants.

The larger part of the benefits comes from lower mortality and morbidity. The results therefore crucially depend upon the method used to value these health impacts. Two possibilities are explored in this study, the Value of a Statistical Life (VOSL) and the Value of a Life Year lost (VOLY).

The main difference between these two approaches is the fact that in the case of VOSL each life year lost is valued at the same price, whereas the VOLY-approach uses different values for a life year lost for a young adult and a life year lost for an elder person.

The results for the different policy scenarios are almost identical when looking at the damage cost per tonne NO_x, SO₂ and NH₃ reduced. We therefore only present the average for NO_x and SO₂ below.

Table 14 Marginal damage costs of NO_x and SO₂ found in IIASA (1999b)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram	
	Low estimate (using VOLY)	High estimate (using VOGL)
NO _x	9.4	15
SO ₂	3.5	6.9

Ågren (1999) points out that the following benefits have not been quantified:

- less acidification of soil and water;
- less eutrophication;
- fewer effects on biological diversity;
- less long-term risk for lowered forest productivity;
- reduced direct health effects of NO₂ and VOCs;
- less damage to historical buildings and monuments.

IIASA, 1999c, Further analysis of scenario results obtained with the RAINS model, Laxenburg, Austria

Method: prevention costs

Model used: RAINS (Regional Air pollution INformation and Simulation), focussing on NO_x, SO₂, NH₃ and VOC. For these pollutants emission control options are identified and costs have been determined. The associated costs include investment-related and operating costs. All investments in emission reduction are annualized using a discount factor of 4%.

This report presents for each country the marginal social costs to achieve the environmental targets on acidification and ground-level ozone as put down in the Seventh Interim Report to the European Commission. These targets are the as follows for the EU as a whole:

- NO_x: -55%
- VOC: -60%
- SO₂: -78%

The marginal prevention costs can vary widely between countries (each country has its specific environmental targets) and between economic sectors. In Table 15 below we present two figures: an 'average' marginal prevention cost and a range of marginal prevention costs. In both figures the highest prevention costs across economic sectors are taken as a reference. The ranges presented are ranges of these marginal costs across countries; the 'average' figures represent the averages across these countries.

IIASA presents in table 1.7 of its report the following marginal prevention costs.

Table 15 Marginal prevention costs according to IIASA (1999c)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kg	
	Average over all countries	Range per country over all sectors
NO _x	4.7	0 – 13
VOC	4.6	0 – 11
SO ₂	1.5	0 – 5.0



IVM 1999, *Monetising the benefits of environmental policy: an exploratory investigation* ['Monetarisering van baten van milieubeleid: een verkennend onderzoek'] (in Dutch), Kuik, O.J., C. Dorland, and H.M.A. Jansen, Institute for Environmental Studies (IVM), Amsterdam, 1999

Method: damage cost

This literature survey attempts to estimate the benefits of environmental policy for the Netherlands. In most cases the estimates are based on European studies on dose-response relations and other underlying data.

The following categories of potential effects are discerned:

- climate change;
- human health;
- material damage;
- agricultural damage;
- nature and biodiversity.

The emissions that are taken into account are PM₁₀, PM_{2.5}, NO_x, and CO₂. For these emissions the impact on the different categories are determined and monetised. The authors distinguish between 'high sources' and 'low sources'. Most industrial sources are considered 'high sources', whereas transport is considered a 'low source'.

Furthermore, the authors stress that the impact of a pollutant differs largely between locations. Even for a small country like the Netherlands, this results in a factor 10 difference between high and low estimates. However, in their study they only present the value for an average location in the Netherlands. For 'high sources', this average location is Amsterdam, for the 'low sources' the arithmetic average of emissions on different locations in The Netherlands is used to 'define' the average location.

In the results, the distinction between 'low' and 'high' sources has been made as follows: for low sources, i.e. mainly traffic, the particulate matter emissions are taken as particulate matter with a diameter smaller than 2.5 micron (PM_{2.5}). For high sources, the particulate matter consists of particles with a diameter smaller than 10 micron (PM₁₀).

The resulting marginal social costs that were found in IVM (1999) are presented below.

Table 16 Marginal damage costs found in IVM (1999)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram	
	Medium estimate	Range
NO _x (via nitrate)	2.9	0.4 – 21
NO _x (via ozone)	1.6	0.2 – 11
NO _x (total)	4.4	0.6 – 32
PM ₁₀ ('high source')	12	1.6 – 85
PM _{2.5} ('low source')	130	18 – 942

The most important benefits from environmental protection that IVM (1999) finds are human health benefits. These benefits can be monetised following different methods. The medium estimate in the table above and the associated range are determined with a fixed monetary value for the risk of pre-

mature death, specifically k€ 150 for a 1-year reduction of lifetime from acute mortality and k€ 50 for a 1-year reduction of lifetime from chronic mortality.

The authors note that the intervals presented, reflect uncertainties in atmospheric dispersion, in numbers of exposed population and in exposure-effect relationships. The authors have also compared their estimates with a number of international studies⁸ that go into the damages avoided by environmental protection and they conclude the following from their comparison:

- the medium estimates for PM₁₀ and NO_x are similar with other international sources;
- the medium estimate for PM_{2.5} is near the upper bound of the estimates found in the international literature; this is mainly due to the fact that in other studies the exposure-effect relationships for 'low sources' and thus for PM_{2.5} are not modelled at the same level of detail as is done in Kuik et al.

ECMT, 1998, Policies for internalisation of external costs, ECMT/OECD, Paris, France

This study draws heavily on CE (1994) and CE (1997) and therefore this study is not worked out further.

Delucchi. M.A. 1996-1998, Report series 'The annualized social cost of motor-vehicle use in the United States based on 1990-1991 data', University of California, Institute of Transportation Studies, 1996-1998:

- 1998, The annualized social cost of motor-vehicle use in the United States 1990-1991, summary of theory, data, methods, and results; Report #1 in the series, June 1998.
- 1997, The valuation of non-monetary externalities Report #9 in the series, June 1998.

IWW et al., 1998, Entwicklung eines Verfahrens zur Aufstellung umweltorientierter Fernverkehrskonzepte als Beitrag zur Bundesverkehrswegeplanung, Karlsruhe, Germany

Method: damage costs

This study goes into the damage caused by NO_x, VOC and diesel particulates.

For the following categories the damage has been investigated for Germany for the year 2010:

- health;
- materials and buildings;
- forests;
- crops and animals.

Finally, acute health impacts and damage to crops are valued in terms of average damage costs per kg of pollutant. In Table 17 the results are shown.

⁸ Most of the sources they mention have been covered elsewhere in our overview of the literature.

Table 17 Estimates of average damage costs of pollutants in Germany in 2010, according to IWW et al (1998)

Pollutant	Average social costs (in € ₁₉₉₉) per kg		
	total	of which health	of which crops
NO _x (via ozone)	0,23	0,16	0,07
HC (via ozone)	0,30	0,20	0,1
Diesel particulates*	37 (in urban areas)	-	-

* Based on Planco, Berücksichtigung wissenschaftlicher Erkenntnisfortschritte im Umweltschutz für die Bundesverkehrswegeplanung (BVWP, Schlussbericht im Auftrag des Bundesministeriums für Verkehr, 1995

Note: the study gives no indication on the base year used, but some figures suggest that all monetary values are denoted in DM₁₉₉₅ and the exchange rate to the ECU used in the report itself is one ECU to 1,85 DM. We use this value as well and correct for CPI developments between 1995 and 1999.

The estimates presented may serve as an underestimate for the marginal damage per kg, because:

- not all impact categories have been monetised; only acute health damage and damage to crops is included;
- the values present average instead of marginal damage costs.

CE 1997, *Optimizing the fuel mix for road transport*, Dings, J.M.W. et al., Delft, May 1997

Serves as a basis for CE (2000); therefore see CE (2000).

IPCC, 1996, *Climate change 1995: economic and social dimensions of climate change, contribution of Working group III to the second assessment report of IPCC, UNEP/ WMO*

Overview of different damage estimates: the following ranges are taken from IPCC (1996) in which the social costs of air pollution are mentioned to incorporate the second order benefits of CO₂ reductions.

Table 18 Estimates of marginal damage costs of pollutants in IPCC (1996)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram				
	UK	UN ECE*	Norway	US	US
source	Pearce (1994)	Pearce (1994)	Alfsen et al. (1992)	Ottinger et al. (1990)	Scheraga and Leary (1994)
NO _x	0.2	0.7	2.2 – 44	2.8	0.1 – 1.4
particulates	30	30	2.9 – 39	3.8	0.5 – 16
SO ₂	0.5	0.9	0.7 – 11	6.7	0.4 – 2.6

* Damage done by a tonne of UK emissions to Western and Eastern Europe, including UK (UN ECE region)

ITS 1996, *The full costs of intercity transportation, a comparison of high-speed rail, air and highway transportation in California*, Levinson, D. et al., Institute of Transportation Studies, Berkely, 1996

This study used health cost estimates from various sources from 1977 to 1990. Due to its lack of more recent estimates we do not consider this study.

IWW/Infras, 1995, External effects of transport, UIC, Karlsruhe/Zürich/Paris

We do not go into detail for this study, because it is a similar study as the one, which has been finalised in 2000. We therefor use the update (see In-
fras/IWW, 2000).

Bleijenberg, A.N., Van den Berg, W.J. and G. de Wit, 1994, The social costs of traffic, literature overview, CE, Delft

Method: literature survey

This study provides an extensive survey of existing literature on the valuation of the external effects that occur with transport. The literature deals with WTP-studies, damage cost estimates and prevention cost estimates.

Table 19 Overview of marginal social costs estimates in (Bleijenberg et al., 1994)

Pollutant	Marginal social cost in € ₁₉₉₉ per kilogram		
	Low	Medium	High
NO _x	1.0	5.0	6.4
HC	1.9	5.0	7.3
SO ₂	0.43	1.0	3.7

In these values the results from IOO (1993) have not been included because they were much lower than the values that other studies presented. This is due to the fact that IOO (1993) has not put a value on the deterioration of agricultural land, nature and forest land and leaves aside the damage to buildings.

The following studies were included in this literature survey:

- Grupp, 1986;
- Quinet, 1990;
- Dogs and Platz, 1990;
- Klaasen, 1992;
- Teufel et al., 1993;
- Kågeson, 1993;
- Neuenschwander et al., 1992;
- Maibach et al., 1992.

We have not analysed these sources separately in our study, except for the study by Kågeson (1993).

Pearce, D.W., 1994, Costing the environmental damage from energy production, mimeo, Centre for Social and Economic Research on the Global Environment (CSERGE), University College London and University East Anglia, Norwich

This study has been included in the literature survey of IPCC (1996). We therefor do not present the results separately.

Scheraga, J.D. and N.A. Leary, 1994, Costs and side benefits of using energy taxes to mitigate global climate change, in: Proceedings of the 86th Annual Conference, National Tax Association, Washington DC, USA



This study has been included in the literature survey of IPCC (1996). We therefor do not present the results separately.

Teufel, D., P. Bauer, G. Bekez, E. Gauch, S. Yäkel, T. Wagner, 1993, *Ökologische und soziale Kosten der Umweltbelastung in der Bundesrepublik Deutschland, Umwelt un Prognose Institut, Heidelberg, Germany*

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Kågeson, P., 1993, *Getting the prices right, European Federation for Transport and the Environment*

Method: prevention cost

Environmental targets for SO₂ and NO_x have been established, denoted in emission reduction in 2000 relative to levels in 1985. The targets are different for the different European countries and for each country high and low targets have been set.

IIASA has constructed national abatement curves and the resulting estimates for the marginal social cost of SO₂ and NO_x have been calculated. The following table presents the results for both pollutants and the different targets.

Table 20 Marginal prevention costs according to Kågeson (1993)

Pollutant	Marginal social cost (in € ₁₉₉₉) per kilogram		
	Target (relative to 1985)	Medium value	Range
NO _x (including ozone)	- 50%	4.8	3.2 - 6.4
SO ₂	- 60%	1.6	0.47 - 3.9
SO ₂	- 80%	3.2	0.47 - 21 1.2 - 5.8 ⁹

Note: the value in the report are in DM₁₉₈₅; to arrive at €₁₉₉₉ we have used the following conversion factors: 1 DM₁₉₈₅ equals 1,2 DM₁₉₉₃, exchange rate in 1993 is 1 € = 2 DM and eventually we have used the CPI to come from €₁₉₉₃ to €₁₉₉₉.

Kågeson also mentions that the marginal social cost for NO_x is also applicable for VOC. The IIASA model is not suit to capture targets for VOC separately and construct the abatement cost curve. Therefor, Kågeson suggests to use the value found for NO_x simultaneously for VOC.

Alfsen, K.H., A. Brendemoen and S. Glomsrød, 1992, *Benefits of climate policies: some tentative calculations, Discussion paper no. 69, Norwegian Central Bureau of Statistics, Oslo, Norway*

This study has been included in the literature survey of IPCC (1996). We therefor do not present the results separately.

⁹ Range excluding the extreme cases of Germany (€ 0,47 per kg) and Sweden (€ 21 per kg).

Klaassen, G., 1992, Marginal and average costs of reducing nitrogen oxides and sulfur dioxide emissions in Europe – A contribution to internalizing the social costs of transport, T&E, Brussels, Belgium

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Maibach, M., R. Iten and S. Mauch, 1992, Internalisieren des Externen Kosten des Verkehrs, Fallbeispiel Agglomeration Zürich, INFRAS, Zürich, Switzerland

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Neuenschwander, R., and F. Walter, 1992, External costs of transport: an overview, Ecoplan, Bern, Austria

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Umwelt Bundesamt, 1991, Advantages of environmental protection/ Costs of environmental pollution: an overview of the research programme Costs of environmental pollution/ Advantages of environmental protection, UBA, Berlin, Germany

This set of information sheets provides an overview of different costs (of environmental pollution) and benefits (of environmental protection) that arise in Germany. Categories such as human health, biodiversity impacts, material damage were included, but the costs and benefits have not been related to units of pollution. Therefor, this study is not relevant to our research.

Dogs, E. and H. Platz, 1990, Externe Kosten des Verkehrs, PLANCO Consulting – GmbH, Essen, Germany

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Ottinger, R.L., D.R. Wooley, N.A. Robinson, D.R. Hodas and S.E. Babb, 1990, Environmental costs of electricity, Pace University Center for Environmental and Legal Studies, Oceana Publications, New York, USA

This study has been included in the literature survey of IPCC (1996). We therefor do not present the results separately.

Quinet, E., 1990, The social costs of land transport, OECD, Paris

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

Grupp, H., 1986, Die sozialen Kosten des Verkehrs, in: Verkehr und Technik, 1986/9, nr. 10

This study has been included in the literature survey by Bleijenberg et al. (1994). We therefor do not present the results separately.

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External costs of aviation

External costs of noise emission

Delft, February 2002

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1 External costs of noise emission

Effects of noise

The effects of noise from transport are increasingly studied. Within this study, we distinguish the following categories:

- 1 Effects on human well-being, which can be assessed via WTP/WTA studies and via property price decrease (hedonic pricing) studies.
- 2 Effects on human health, of which knowledge is gradually coming available.
- 3 Effects on indirect land use; governments put restrictions on land that is too heavily affected by noise.

The three effects can be added as higher noise levels in the long term lead to lower property values, more health costs, and more indirect land use.

Noise standards

There is an abundance of noise standards in Europe, and currently attempts are being undertaken to establish EU-wide standards. Currently national standards vary between 40 and 65 dB(A) for day-time noise (average: 52) and 40 and 55 for night-time noise (46 average). Scientist on average recommend 50-55 dB(A) as threshold value for day-time noise, and 40-45 dB(A) as threshold value for night-time noise (Infras/IWW 2000).

1.1 Overview of studies

Infras/IWW, 2000, External costs of transport: accident, environmental and congestion costs in Western Europe, Zurich/Karlsruhe

Method: two methods that have been used internationally are reviewed in this study. These two methods are:

- a the willingness to pay for different noise levels (WTP);
- b the actual health risk of noise (damage cost method).

The first method measures the willingness to pay (WTP) for the reduction of noise levels. These data on willingness to pay are given in relative terms, i.e. relation to the income per capita. This results in linear relations between the (acceptable) noise level and the per capita income. Infras/IWW reviewed 5 studies:

- Pommerehne (1986);
- Soguel (1994);
- Iten (1990);
- IRR (1993);
- Weinberger (1990).

For these studies the gradient is fairly similar: for each incremental dB(A) (on average) 0.11% of per capita income is needed to compensate. Following this approach, Infras/IWW concludes that for determining the total noise cost not the marginal cost per dB (A) is crucial, but the 'target level'. Below this target level, no costs are put on the noise, above this level the cost increases by 0.11% of per capita income per dB (A). The target level can be estimated from the 5 studies, to be 50 dB (A), i.e. below this level no noise cost is apparent. Infras/IWW have decided to take a more cautious target level, namely 55 dB (A).

Table 1 WTP per person per year per dB(A) reduced in € 1999, according to Infrac/IWW (2000), for the case Germany

dB(A)	55-60	60-65	65-70	70-75	>75
WTP	47	142	236	331	425

Additionally Infrac/IWW value the health effects of transport noise. Two studies have empirically examined this relationship and the following table presents the results.

Table 2 Increased risk of cardiac infarctions due to transport noise, according to 2 empirical studies

Source	Location	65 – 70 dB(A)	70 – 75 dB(A)	75 – 80 dB(A)
Babisch et al. (1993)	Caerphilly, Speedwell	+ 20%	-	-
Babisch et al. (1994)	Berlin	-	+20%	+70%
Value used in Infrac/IWW		+20%	+30%	

According to Infrac/IWW the values found using the first method (WTP) and the damage cost (for health) can be added.

The values that are given in Infrac/IWW cannot be easily translated into marginal cost per unit noise production, because noise is an 'extremely local phenomenon' (Infrac/IWW). Therefore, Infrac/IWW give some decisive characteristics for determining the marginal cost. These characteristics include the time zone (day and night), the land use (rural, sub-urban and urban) and traffic conditions (relaxed, dense). This exercise is necessary for each noise source separately. Another important factor is the threshold level, which is determined to be 55 dB(A) in this study. This means that the willingness to pay for a reduction in noise at a level of 55 dB(A) is zero. This threshold level is determined from a number of studies.

For the EU-countries, Switzerland and Norway (EUR17) this exercise is done, which results in (total) noise costs of €M 36,540, of which 59% comes from the WTP-approach and 41% from the health costs. Of this, air transport contributes €M 2,513, of which 62% comes from the WTP-approach and 38% from the health costs).

The amount of LTOs in 1995 in the EUR17 was 3.6 mln (table 82); the costs per LTO are thus € 700.

The total number of passengers is 582 mln (167 mln domestic and 415 mln international, table 82). Using a load factor of 50% for domestic and 65% for international transport the amount of seat LTOs is 486 mln; the costs per seat LTO then arrive at € 5.2.

Furthermore, Infrac/IWW state that the best estimate of the amount of persons exposed to different noise levels is provided in ECMT (1998).

On the estimation of noise damage from air transport, Infrac/IWW states that the marginal cost can be calculated by taking 30 – 60% of the average noise cost.