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UNITE

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marginal costs for Transport Efficiency

Marginal Costs Case Study 9F: Air Transport Case Study

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D.0 Executive Summary

Marginal environmental costs due to a flight from Berlin to London were assessed. Costs related to the emission of air pollutants, greenhouse gases and noise proved to be relevant and quantifiable cost categories. Cost estimates were performed consistently with the other UNITE environmental cost case studies. For air pollution and noise the impact pathway approach was applied. Greenhouse gas emissions were valued based on a shadow value for reaching the Kyoto reduction targets in the European Union. Costs of air pollution and global warming were assessed not only for vehicle operation but as well for fuel and electricity production.

Quantifiable marginal environmental costs for a flight from Berlin Tegel to London Heathrow amount to EUR 391, corresponding to EUR 42 per 100 aircraft kilometres. The shares of the cost categories in the LTO activities of the flight are about the same: air pollution EUR 49, global warming EUR 52.50 and noise EUR 59, adding up to EUR 160.50. The costs of cruising of EUR 230.70 are dominated by CO_2 emissions, costs due to fuel production emissions are only of minor importance. Due to lacking compact models for the impacts of high altitude emissions, the cost estimate for the cruise phase are incomplete, implying a potential underestimation of air pollution costs.

D.1 Introduction

Environmental external effects of transport cover a wide range of different impacts, including the various impacts of emissions of noise and a large number of pollutants on human health, materials, ecosystems, flora and fauna. Most early studies on transport externalities followed a top-down approach, giving average costs rather than marginal costs. The basis for the calculation is a whole geographical unit, a country for example. For such a unit the total cost due to a burden is calculated. This cost is then allocated based on the shares of total pollutant emissions, by vehicle mileage, etc. But marginal environmental costs of transportation vary considerably with the technology of the vehicle, train, ship or plane and site (or route) characteristics. Only a detailed bottom-up calculation allows a close appreciation of such site and technology dependence.

In the ExternE project series (see e.g. European Commission (1999a,b), Friedrich and Bickel (2001)) funded by the European Commission the Impact Pathway Approach (IPA) has been developed, which meets these requirements. In ExternE the impact pathway approach was applied for assessing impacts due to airborne emissions. Starting with the emission of a burden, through its diffusion and chemical conversion in the environment, impacts on the various receptors (humans, crops etc.) are quantified and, finally, valued in monetary terms. In other words, information is generated on three levels: i) the increase in burden (e.g. additional emissions and ambient concentration of SO_2 in $\mu g/m^3$) due to an additional activity (e. g. one additional trip on a specific route with a specific vehicle, train, ship, plane), ii) the associated impact (e.g. additional hospital admissions in cases) and iii) the monetary valuation of this impact (e.g. WTP to avoid the additional hospital admissions in Euro). In the following the application of the IPA for impacts due to aircraft transport is presented. Methods and monetary values applied are the same as in the other UNITE environmental cost case studies.

D.2 Case Study Description

Marginal external costs due to a Boeing 737-400 operated between Berlin and London are quantified. Berlin Tegel and London Heathrow are important international airports, linking the capitals of Germany and the United Kingdom. Both airports are located within densely populated agglomerations, which is important for air pollution and noise costs, which are closely related to the population density in the vicinity of the emission source.

The Boeing 737-400 considered is a medium range aircraft, commonly used by many airlines on domestic and European services. It is fitted with two engines of the type CFM56-3C1, has a maximum range of ca. 3500 km and in its typical configuration offers seating capacity for 146 passengers.

Marginal air pollution costs are quantified for a landing and take-off cycle (LTO-cycle, consisting of the flight modes: approach/landing, taxi-in, taxi-out, take-off, climb out) at each airport. Noise costs are calculated for an aircraft event consisting of arrival and departure at Heathrow. Furthermore, the costs due to a flight from Tegel to Heathrow are quantified per flight, and related to an aircraft kilometre and a passenger kilometre.

D.2.1 Methodology

Marginal costs in this case study are interpreted as the costs caused by an additional aircraft being operated on the specific route from Berlin to London. The approach of looking at the impacts of one additional aircraft requires a detailed bottom-up approach. The methodology follows as far as possible the Impact Pathway Approach, which is described in the following sections. For more detailed information see European Commission (1999a,b) or Friedrich and Bickel (2001). For the assessment of marginal costs due to noise we draw on work done by Pearce and Pearce (2000).

D.2.1.1 Air Pollution

The starting point for the bottom-up approach for quantification of marginal costs is the micro level, i.e. the traffic at a particular airport. Then, the marginal external costs of one additional aircraft are calculated for an LTO-cycle. This is done by modelling the path from emission to impact and costs using the Impact Pathway Approach. It comprises the steps

– emission calculation,
– dispersion and chemical conversion modelling,
– calculation of physical impacts, and
– monetary valuation of these impacts.

These steps are described in more detail in the following sections.

Emissions/burdens

In the first step the emissions from an additional aircraft at a specific airport are calculated. For comparisons between modes, the system boundaries considered are very important. For this reason, emissions due to the provision of fuel are taken into account besides direct emissions from aircraft operation.

Concentrations

To obtain marginal external costs, the changes in the concentration and deposition of primary and secondary pollutants due to the additional emissions have to be calculated. The relation between emission and concentration of pollutants are highly non-linear for some species (e.g. secondary particles). So, air quality models that simulate the transport as well as the chemical transformation of pollutants in the atmosphere are used.

Depending on the range and type of pollutant considered different models are applied: The Gaussian dispersion model ROADPOL for calculation of pollutant concentrations from ground level line sources on the local scale up to 25 km from the emission source (Vossiniotis et al., 1996); the Wind rose Trajectory Model (WTM) is used to quantify the concentration and deposition of non-reactive pollutants and acid species on a European scale (Trukenmüller and Friedrich, 1995); the Source-Receptor Ozone Model (SROM), which is based on source-receptor (S-R) relationships from the EMEP MSC-W oxidant model for five years of meteorology (Simpson et al., 1997), is used to estimate changes in ozone concentrations on a European scale.

These models are applicable for emissions up to the mixing layer height, which is typically around 800 m. Pollutants emitted in higher altitudes, i.e. cruising emissions, have to be treated with different, more complex and thus expensive models, which were not available for this case study.

Impacts

Concentrations then translate into impacts through the application of exposure-response functions, which relate changes in human health, material corrosion, crop yields etc. to unit changes in ambient concentrations of pollutants.

Exposure-response functions come in a variety of functional forms. They may be linear or non-linear and contain thresholds (e.g. critical loads) or not. Those describing effects of various air pollutants on agriculture have proved to be particularly complex, incorporating both positive and negative effects, because of the potential for certain pollutants, e. g. those containing sulphur and nitrogen, to act as fertilisers.

The dose-response functions used within UNITE are the final recommendations of the expert groups in the final phase of the ExternE Core/Transport project (Friedrich and Bickel 2001). The following table gives a summary of the dose-response functions as they are implemented in the EcoSense version used for this study.

Table F-1
Health and environmental effects included in the analysis of air pollution costs

Impact category	Pollutant	Effects included
Public health – mortality	$PM_{2.5}$, PM_{10} [1)] SO_2, O_3	Reduction in life expectancy due to acute and chronic mortality Reduction in life expectancy due to acute mortality
Public health – morbidity	$PM_{2.5}$, PM_{10}, O_3	respiratory hospital admissions
		restricted activity days
	$PM_{2.5}$, PM_{10} only	cerebrovascular hospital admissions
		congestive heart failure
		cases of bronchodilator usage
		cases of chronic bronchitis
		cases of chronic cough in children
		cough in asthmatics
		lower respiratory symptoms
	O_3 only	asthma attacks
		symptom days
Material damage	SO_2, acid deposition	Ageing of galvanised steel, limestone, natural stone, mortar, sandstone, paint, rendering, zinc
Crops	SO_2	Yield change for wheat, barley, rye, oats, potato, sugar beet
	O_3	Yield loss for wheat, potato, rice, rye, oats, tobacco, barley, wheat
	Acid deposition	increased need for liming
	N	fertiliser effects

[1)] including secondary particles (sulphate and nitrate aerosols).

Source: IER.

Impacts on human health

Table F-2 lists the exposure response functions used for the assessment of health effects. The exposure response functions are taken from the 2^{nd} edition of the ExternE Methodology report (European Commission 1999a), with some modifications resulting from recent recommendations of the health experts in the final phase of the ExternE Core/ Transport project (Friedrich and Bickel 2001).

Table F-2
Quantification of human health impacts due to air pollution[1)]

Receptor	Impact Category	Reference	Pollutant	f_{er}
ASTHMATICS (3.5% of population)				
Adults	Bronchodilator usage	Dusseldorp et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.163 0.163 0.272 0.272
	Cough	Dusseldorp et al., 1995	$PM_{10,}$ Nitrates $PM_{2.5}$ Sulphates	0.168 0.168 0.280 0.280
	Lower respiratory symptoms (wheeze)	Dusseldorp et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.061 0.061 0.101 0.101
Children	Bronchodilator usage	Roemer et al., 1993	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.078 0.078 0.129 0.129
	Cough	Pope and Dockery, 1992	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.133 0.133 0.223 0.223
	Lower respiratory symptoms (wheeze)	Roemer et al., 1993	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.103 0.103 0.172 0.172

Receptor	Impact Category	Reference	Pollutant	f_{er}
All asthmatics	Asthma attacks (AA)	Whittemore and Korn, 1980	O_3	4.29E-3
ELDERLY 65+ (14% of population)	Congestive heart failure	Schwartz and Morris, 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates CO	1.85E-5 1.85E-5 3.09E-5 3.09E-5 5.55E-7
CHILDREN (20% of population)	Chronic cough	Dockery et al., 1989	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.07E-3 2.07E-3 3.46E-3 3.46E-3
ADULTS (80% of population)	Restricted activity days (RAD)	Ostro, 1987	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.025 0.025 0.042 0.042
	Minor restricted activity days (MRAD)	Ostro and Rothschild, 1989	O_3	9.76E-3
	Chronic bronchitis	Abbey et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.45E-5 2.45E-5 3.9E-5 3.9E-5
ENTIRE POPULATION	Chronic Mortality (CM)	Pope et al., 1995	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.129% 0.129% 0.214% 0.214%
	Respiratory hospital admissions (RHA)	Dab et al., 1996	PM_{10} Nitrates $PM_{2.5}$ Sulphates	2.07E-6 2.07E-6 3.46E-6 3.46E-6
		Ponce de Leon, 1996	SO_2 O_3	2.04E-6 3.54E-6
	Cerebrovascular hospital admissions	Wordley et al., 1997	PM_{10} Nitrates $PM_{2.5}$ Sulphates	5.04E-6 5.04E-6 8.42E-6 8.42E-6
	Symptom days	Krupnick et al., 1990	O_3	0.033
	Cancer risk estimates	Pilkington et al., 1997; based on US EPA evaluations	Benzene Benzo-[a]-Pyrene 1,3-buta-diene Diesel particles	1.14E-7 1.43E-3 4.29E-6 4.86E-7
	Acute Mortality (AM)	Spix et al. / Verhoeff et al.,1996	PM_{10} Nitrates $PM_{2.5}$ Sulphates	0.040% 0.040% 0.068% 0.068%
		Anderson et al. / Touloumi et al., 1996	SO_2	0.072%
		Sunyer et al., 1996	O_3	0.059%

[1)] The exposure response slope, f_{er}, has units of [cases/(yr-person-µg/m^3)] for morbidity, and [%change in annual mortality rate/(µg/m^3)] for mortality. Concentrations of SO_2, PM_{10} , PM_{10}, sulphates and nitrates as annual mean concentration, concentration of ozone as seasonal 6-h average concentration.

Source: Friedrich and Bickel 2001.

Impacts on building materials

Impacts on building material were assessed using the most recent exposure-response functions developed in the last phase of the ExternE Core/Transport project (Friedrich and Bickel, 2001). This work includes the latest results of the UN ECE International Co-operative Programme on Effects on Materials (ICP Materials) for degradation of materials, based on the results of an extensive 8-year field exposure programme that involved 39 exposure sites in 12 European countries, the United States and Canada (Tidblad et al., 1998).

Limestone:
maintenance frequency: $1/t = [\ (2.7[SO_2]^{0.48}e^{-0.018T} + 0.019Rain[H^+])/R\ ]^{1/0.96}$

Sandstone, natural stone, mortar, rendering:
maintenance frequency: $1/t = [\ (2.0[SO_2]^{0.52}e^{f(T)} + 0.028Rain[H^+])/R\ ]^{1/0.91}$
f(T) $f(T) = 0$ if $T < 10\ ^oC$; $f(T) = -0.013(T-10)$ if $T \geq 10\ ^oC$

Zinc and galvanised steel:
maintenance frequency: $1/t = 0.14[SO_2]^{0.26}e^{0.021Rh}e^{f(T)}/R^{1.18} + 0.0041Rain[H^+]/R$
f(T) $f(T) = 0.073(T-10)$ if $T < 10\ ^oC$; $f(T) = -0.025(T-10)$ if $T \geq 10\ ^oC$

Paint on steel:
maintenance frequency: $1/t = [\ (0.033[SO_2] + 0.013Rh + f(T) + 0.0013Rain[H^+])/5\ ]^{1/0.41}$

f(T) $f(T) = 0.015(T-10)$ if $T < 10\ ^oC$; $f(T) = -0.15(T-10)$ if $T > 10\ ^oC$

Paint on galvanised steel:
maintenance frequency:

$$1/t = [\ (0.0084[SO_2] + 0.015Rh + f(T) + 0.00082Rain[H^+])/5\ ]^{1/0.43}$$

f(T) $f(T) = 0.04(T-10)$ if $T < 10\ ^oC$; $f(T) = -0.064(T-10)$ if $T \geq 10\ ^oC$

Carbonate paint:

maintenance frequency: $$1/t = 0.12 \cdot \left(1 - e^{\frac{-0.121 \cdot Rh}{100 - Rh}}\right) \cdot [SO_2] + 0.0174 \cdot [H^+] \Big/ R$$

with
- 1/t maintenance frequency in 1/a
- $[SO_2]$ SO_2 concentration in µg/m^3
- T temperature in ^oC
- Rain precipitation in mm/a
- [H+] hydrogen ion concentration in precipitation in mg/l
- R surface recession in µm
- Rh relative humidity in %

Impacts on crops

Effects from SO2
For the assessment of effects from SO_2 on crops, an adapted function from the one suggested by Baker et al. (1986) is used as recommended in ExternE. The function assumes that yield will increase with SO_2 from 0 to 6.8 ppb, and decline thereafter. The function is used to quantify changes in crop yield for wheat, barley, potato, sugar beet, and oats. The function is defined as

$y = 0.74 \cdot C_{SO2} - 0.055 \cdot (C_{SO2})^2$ for $0 < C_{SO2} < 13.6$ ppb
$y = -0.69 \cdot C_{SO2} + 9.35$ for $C_{SO2} > 13.6$ ppb
with y = relative yield change
C_{SO2} = SO_2-concentration in ppb

Effects from ozone
For the assessment of ozone impacts, a linear relation between yield loss and the AOT 40 value (Accumulated Ozone concentration above Threshold 40 ppb) is assumed. The relative yield loss is calculated by using the following equation, and the sensitivity factors given in Table F-3:

$y = 99.7 - \alpha \cdot C_{O3}$
with y = relative yield change
α = sensitivity factors
C_{O3} = AOT 40 in ppmh

Table F-3: Sensitivity factors for different crop species

Sensitivity	α	Crop species
Slightly sensitive	0.85	rye, oats, rice
Sensitive	1.7	wheat, barley, potato, sunflower
Very sensitive	3.4	tobacco

Acidification of agricultural soils

The amount of lime required to balance acid inputs on agricultural soils across Europe will be assessed. The analysis of liming needs should be restricted to non-calcareous soils. The additional lime requirement is calculated as:

$\Delta L = 50 \cdot A \cdot \Delta D_A$

with ΔL = additional lime requirement in kg/year

A = agricultural area in ha

ΔD_A = annual acid deposition in meq/m^2/year

Fertilisational effects of nitrogen deposition

Nitrogen is an essential plant nutrient, applied by farmers in large quantity to their crops. The deposition of oxidised nitrogen to agricultural soils is thus beneficial (assuming that the dosage of any fertiliser applied by the farmer is not excessive). The reduction in fertiliser requirement is calculated as:

$\Delta F = 14.0067 \cdot A \cdot \Delta D_N$

with ΔF = reduction in fertiliser requirement in kg/year

A = agricultural area in ha

ΔD_N = annual nitrogen deposition in meq/m^2/year

Monetary Valuation

Table F-4 summarises the monetary values of health impacts used for valuation of transboundary air pollution. According to Nellthorp et al. (2001) average European values were used for transboundary air pollution costs, except for the source country, where country specific values were used. These were calculated according to the benefit transfer rules given in Nellthorp et al. (2001).

Table F-4
Monetary values (factor costs, rounded) for health impacts (€$_{1998}$)

Impact	European average	UK	Germany	
Year of life lost (chronic effects)	74,700	75,900	80,600	€ per YOLL
Year of life lost (acute effects)	128,500	130,600	138,700	€ per YOLL
Chronic bronchitis	137,600	139,900	148,500	€ per new case
Cerebrovascular hospital admission	13,900	14,130	15,000	€ per case
Respiratory hospital admission	3,610	3,670	3,900	€ per case
Congestive heart failure	2,730	2,770	2,950	€ per case

Impact	European average	UK	Germany	
Chronic cough in children	200	200	210	€ per episode
Restricted activity day	100	100	100	€ per day
Asthma attack	69	70	74	€ per day
Cough	34	35	37	€ per day
Minor restricted activity day	34	35	37	€ per day
Symptom day	34	35	37	€ per day
Bronchodilator usage	32	33	35	€ per day
Lower respiratory symptoms	7	7	8	€ per day

Source: Own calculations based on Friedrich and Bickel (2001) and Nellthorp et al. (2001).

Discussion of Uncertainties

In spite of considerable progress made in recent years the quantification and valuation of environmental damage is still linked to significant uncertainty. This is the case for the Impact Pathway Methodology as well as for any other approach. While the basic assumptions underlying the work in ExternE are discussed in detail in (European Commission 1999a), below an indication of the uncertainty of the results is given as well as the sensitivity to some of the key assumptions.

Within ExternE, Rabl and Spadaro (1999) made an attempt to quantify the statistical uncertainty of the damage estimates, taking into account uncertainties resulting from all steps of the impact pathway, i.e. the quantification of emissions, air quality modelling, dose-effect modelling, and valuation. Rabl and Spadaro show that - due to the multiplicative nature of the impact pathway analysis - the distribution of results is likely to be approximately lognormal, thus it is determined by its geometric mean and the geometric standard deviation σ_g. In ExternE, uncertainties are reported by using uncertainty labels, which can be used to make a meaningful distinction between different levels of confidence, but at the same time do not give a false sense of precision, which seems to be unjustified in view of the need to use subjective judgement to compensate the lack of information about sources of uncertainty and probability distributions (Rabl and Spadaro 1999). The uncertainty labels are:

A = high confidence, corresponding to σ_g = 2.5 to 4;
B = medium confidence, corresponding to σ_g = 4 to 6;
C = low confidence, corresponding to σ_g = 6 to 12.

According to ExternE recommendations, the following uncertainty labels are used to characterise the impact categories addressed in this report:

Mortality: B
Morbidity: A
Crop losses: A
Material damage: B.

Beside the statistical uncertainty indicated by these uncertainty labels, there is however a remaining systematic uncertainty arising from a lack of knowledge, and value choices that influence the results. Some of the most important assumptions and their implications for the results are briefly discussed in the following.

- **Effects of particles on human health**
  The dose-response models used in the analysis are based on results from epidemiological studies which have established a statistical relationship between the mass concentration of particles and various health effects. However, at present it is still not known whether it is the number of particles, their mass concentration or their chemical composition which is the driving force. The uncertainty resulting from this lack of knowledge is difficult to estimate.

- **Effects of nitrate aerosols on health**
  We treat nitrate aerosols as a component of particulate matter, which we know cause damage to human health. However, in contrast to sulphate aerosol (but similar to many other particulate matter compounds) there is no direct epidemiological evidence supporting the harmfulness of nitrate aerosols, which partly are neutral and water soluble.

- **Valuation of mortality**
  While ExternE recommends to use the Value of a Life Year Lost *rather than the* Value of Statistical Life *for the valuation of increased mortality risks from air pollution (see European Commission, (1999a) for a detailed discussion), this approach is still controversially discussed in the literature. The main problem for the* Value of a Life Year Lost *approach is that up to now there is a lack of empirical studies supporting this valuation approach.*

- **Impacts from ozone**
  As the EMEP ozone model, which is the basis for the Source-Receptor Ozone Model (SROM) included in EcoSense does not cover the full EcoSense modelling domain, some of the ozone effects in Eastern Europe are omitted. As effects from ozone are small compared to those from other pollutants, the resulting error is expected to be small compared to the overall uncertainties.

- **Omission of effects**
  The present report is limited to the analysis of impacts that have shown to result in major damage costs in previous studies. Impacts on e.g. change in biodiversity, potential effects of chronic exposure to ozone, cultural monuments, direct and indirect economic effects of change in forest productivity, fishery performance, and so forth, are omitted because they currently cannot be quantified. Furthermore, due to a lack of appropriate models for high altitude emissions, the impacts resulting from these cannot be taken into account adequately.

D.2.1.2 Global Warming

The method of calculating costs of CO_2 emissions basically consists of multiplying the amount of CO_2 emitted by a cost factor. Due to the global scale of the damage caused, there is no difference how and where the emissions take place.

A European average shadow value of €20 per tonne of CO_2 emitted was used for valuing CO_2 emissions. This value represents a central estimate of the range of values for meeting the Kyoto targets in 2010 in the EU based on estimates by Capros and Mantzos (2000). They report a value of €5 per tonne of CO_2 avoided for reaching the Kyoto targets for the EU, assuming a full trade flexibility scheme involving all regions of the world. For the case that no trading of CO_2 emissions with countries outside the EU is permitted, they calculate a value of €38 per tonne of CO_2 avoided. It is assumed that measures for a reduction in CO2 emissions are taken in a cost effective way. This implies that reduction targets are not set per sector, but that the cheapest measures are implemented, no matter in which sector.

Looking further into the future, more stringent reductions than the Kyoto aims are assumed to be necessary to reach sustainability. Based on a reduction target of 50% in 2030 compared to 1990, INFRAS/IWW (2000) use avoidance costs of € 135 per t of CO_2; however one could argue that this reduction target has not yet been accepted.

A valuation based on the damage cost approach, as e.g. presented by ExternE (Friedrich and Bickel 2001), would result in substantially lower costs. Due to the enormous uncertainties involved in the estimation process, such values have to be used very cautiously.

In the same study damage costs due to climate changes caused by high-altitude nitrogen emissions from aircraft flying over Europe were estimated. The marginal damage costs reported (337 € per kg of nitrogen emitted) are highly uncertain and are only used as an illustration of the possible order of magnitude of costs that high altitude nitrogen emissions might cause.

D.2.1.3 Noise

For estimating marginal noise costs it is very important to take into account the existing traffic level which determines the background noise level. This is crucial as the perception of sound follows a logarithmic scale, which means that the higher the background noise level, the lower is the effect of additional noise.

In lack of detailed noise modelling results, which would allow to calculate the concrete incremental noise exposure due to an arrival or departure, marginal noise nuisances can be estimated through the share of an aircraft in the total exposure of an average day. Pearce and Pearce (2000) report such marginal noise nuisances for the aircraft movements of an average day in 1997 at London Heathrow. Together with the population affected by aircraft noise from Heathrow airport (see Table F-10) and the marginal willingness-to-pay, noise costs can be calculated.

Monetary valuation

A large number of hedonic pricing studies for quantification of amenity losses due to noise has been conducted, from which NSDI values (Noise Sensitivity Depreciation Index – the value of the percentage change in the logarithm of house price arising from a unit increase in noise) can be derived. NSDI values range from 0.08% to 2.22%.

Due to the lack of data to value annoyance in the population directly, the willingness-to-pay for avoiding amenity losses was quantified based on findings of Soguel (1994). He reports a NSDI of 0.9 on monthly housing rents, net of charges. This value is similar to the average derived from European studies. It is applied to the UK average net rent of €3618 per person per year, resulting in a value of €32.6 per dB(A) per person and year. This value is very close to that used by Pearce and Pearce (2000).

D.2.1.4 Other effects

Air pollution, global warming and noise represent the most important and relevant cost categories for marginal environmental costs. Costs due to "habitat losses and biodiversity" represent the economic assessment of damages the presence traffic infrastructure and its use is causing to the habitats of rare species, and thus to biodiversity. The costs are mostly related to the separation effects due to the existence of airports and thus are fixed in the short run. They are not marginal and therefore not relevant for the quantification of marginal costs.

Most of the damages to soil and water are expected to be small or not relevant for marginal cost estimation. Modelling of the dispersion processes in soil and water of solid emissions by tyre and brake wear (emission of Cd, Zn, Cu) and infrastructure (PAH, heavy metals) abrasion as well as de-icing agents is very challenging and beyond the scope of UNITE. However due to their rather local character damages are expected to be small compared to the exposure to exhaust emissions through the air. Furthermore, most of the runoff water at airports is treated before being released to surface waters.

Some effects of airborne exhaust emissions and their impacts on soil and water (acidification of agricultural soils and fertilisation effects of nitrogen deposition) have been included in the analysis. There is evidence that marginal emissions are unlikely to cause relevant impacts to semi-natural vegetation close to roads (Friedrich and Bickel 2001). However, the impairment of ecosystems due to acidification and eutrophication, currently cannot be quantified in monetary terms consistently.

D.2.2 Data

D.2.2.1 Data for the calculation of costs due to airborne emissions

Besides the emissions from the aircraft considered in the case study, a large number of additional information was required for the calculations. This includes data on the receptor distribution, meteorology, and on the background emissions from all sources in all European countries. Such data is available in the computer tool EcoSense's database and is briefly described in the following.

Table F-5
Environmental data in the EcoSense database

	Resolution	Source
Receptor distribution		
Population	administrative units, EMEP 50 grid	EUROSTAT REGIO Database, The Global Demography Project
Production of wheat, barley, sugar beat, potato, oats, rye, rice, tobacco, sunflower	administrative units, EMEP 50 grid	EUROSTAT REGIO Database, FAO Statistical Database
Inventory of natural stone, zinc, galvanized steel, mortar, rendering, paint	administrative units, EMEP 50 grid	Extrapolation based on inventories of some European cities
Meteorological data		
Wind speed	EMEP 50 grid	European Monitoring and Evaluation Programme (EMEP)
Wind direction	EMEP 50 grid	European Monitoring and Evaluation Programme (EMEP)

	Resolution	Source
Precipitation	EMEP 50 grid	European Monitoring and Evaluation Programme (EMEP)
Emissions		
SO_2, NO_x, NH_3, NMVOC, particles	administrative units, EMEP 50 grid	CORINAIR 1994/1990, EMEP 1998, TNO particulate matter inventory (Berdowski et al., 1997)
Source: IER.		

Receptor data

- *Population data*
  Population data was taken from the EUROSTAT REGIO database (base year 1996), which provides data on administrative units (NUTS categories). For impact assessment, the receptor data is required in a format compatible with the output of the air quality models. Thus, population data was transferred from the respective administrative units to the 50 x 50 km^2 EMEP grid by using the transfer routine implemented in EcoSense.

  For local scale analysis more detailed data on population density close to the airports was used.

- *Crop production*
  The following crop species were considered for impact assessment: barley, oats, potato, rice, rye, sunflower seed, tobacco, and wheat. Data on crop production were again taken from the EUROSTAT REGIO database (base year 1996). For impact assessment, crop production data were transferred from the administrative units to the EMEP 50 x 50 km^2 grid.

- *Material inventory*
  The following types of materials are considered for impact assessment: galvanised steel; limestone; mortar; natural stone; paint; rendering; sandstone; and, zinc. As there is no database available that provides a full inventory of materials, the stock at risk was extrapolated in ExternE from detailed studies carried out in several European cities.

Emission data

As the formation of secondary pollutants such as ozone or secondary particles depends heavily on the availability of precursors in the atmosphere, the EcoSense database provides a European wide emission inventory for SO_2, NO_x, NH_3, NMVOC, and particles as an input to air quality modelling. The emission data are disaggregated both sectorally (‘Selected Nomenclature for Air Pollution’ - SNAP categories) and geographically (‘Nomenclature of Territorial Units for Statistics’ - NUTS categories). As far as available, EcoSense uses data from the EMEP 1998 emission inventory (Richardson 2000, Vestreng 2000, Vestreng and Støren 2000). Where required, data from the CORINAIR 1994 inventory. (http://www.aeat.co.uk/netcen/corinair/94/) and the CORINAIR 1990 inventory (McInnes 1996) are used. For Russia, national average emission data from the LOTOS inventory (Builtjes 1992) were included. Emission data for fine particles are taken from the European particle emission inventory established by Berdowski et al. (1997).

Meteorological data

The Windrose Trajectory Model requires annual average data on wind speed, wind direction, and precipitation as an input. The EcoSense database provides data from the European Monitoring and Evaluation Programme (EMEP) for the base year 1998.

Aircraft emissions

Emission calculation was based on ICAO emission data (ICAO/CAEP 2002), complemented by other sources. Table F-6 shows the emission and fuel consumption indices per engine minute for different engine modes during the LTO-cycle. Cruising emission factors for CO_2 (9.4 kg/km) and NO_x (31.3 g/km) were taken from Pearce and Pearce (2000). The emission indices vary depending on the engine thrust used in the different modes.

Table F-6
Emission and fuel consumption indices per engine mode for a CFM56 3C1 engine

	Unit	Taxi-in, Taxi-out	Take-off	Climb out	Approach/landing	Source
CO	g / min	199.4	62.3	51.5	62.5	ICAO/CAEP (2002)
CO_2	kg / min	23.4	218.1	180.3	63.5	derived from fuel flow
Benzene	g / min	0.2	0.04	0.04	0.03	derived from VOC
1,3-Butadiene	g / min	0.2	0.04	0.04	0.03	derived from VOC
Fuel flow	kg / min	7.4	69.2	57.2	20.2	ICAO/CAEP (2002)
NO_x	g / min	32.0	1433.3	1018.9	183.5	ICAO/CAEP (2002)
$PM_{2.5}$	g / min	0.8	23.3	9.8	2.2	DLR
SO_2	g / min	7.4	69.2	57.2	20.2	derived from fuel flow
VOC	g / min	10.6	2.1	2.3	1.4	ICAO/CAEP (2002)

Table F-7 presents the times spent in different modes, which is required for calculating emissions.

Table F-7
Times spent in different engine modes

Time in Minutes	Berlin Tegel	London Heathrow
Taxi-out	11.0	13.0
Take-off	0.7	0.7
Climb out	1.1	1.1
approach/landing	4.0	4.0
Taxi-in	11.0	13.0
Total LTO-cycle	27.8	31.8

Beside these emissions from vehicle operation the emissions due to fuel provision were considered. The emission factors for crude oil extraction, refining and transport of kerosene are given in Table F-8.

Table F-8
Emissions caused by fuel production processes in g/kg kerosene

CO_2	PM_{10}	NO_x	SO_2	NMVOC
400	0.047	0.96	1.40	0.62
Source: PM_{10}: Friedrich and Bickel (2001); other pollutants: IFEU (1999)				

It is assumed that kerosene tanked in Berlin is produced in German refineries and kerosene taken in London comes from refineries in the UK. Emissions associated with fuel production are valued with average damage factors for emissions in the respective country. These damage factors were calculated based on the assumption that the emission source is not located within densely populated areas.

Table F-9
Damage factors in € per tonne pollutant emitted from refineries

Pollutant	NO_x	NMVOC	SO_2	PM_{10}
Germany	4520	1580	4570	7070
UK	2090	1080	3500	5040
Source: own calculations				

D.2.2.1 Data for the calculation of noise costs

Main inputs to the calculation of noise costs are the marginal noise nuisance caused by an additional aircraft landing and take-off, the number of persons affected by the noise and their willingness-to-pay for a reduction in aircraft noise. The marginal noise nuisance due to an arrival and departure of a Boeing 737-400 at Heathrow Airport on an average day in 1997 is reported as 0.0021 dB(A) by Pearce and Pearce (2000). The number of persons affected is shown in Table F-10.

Table F-10
Contour areas and population affected by noise exposure from Heathrow Airport 1998

L_{eq} Level dB(A)	Area affected (km^2)	Population affected (1000 persons)
> 57	163.7	311.5
> 60	94.6	160.9
> 63	55.4	79.9
> 66	35.2	39.6
> 69	22.8	15.2
> 72	13.1	5.2
Source: Department for Transport (2000)		

D.3 Results

Table F-11 presents the marginal costs due to airborne emissions per LTO-cycle at Berlin Tegel and London Heathrow, as well as quantifiable costs due to a flight from Berlin to London. Total costs of aircraft movements at airports are dominated by direct emissions, costs due to fuel production emissions play only a minor role. For cruising only costs from fuel production and CO_2 emissions could be considered, causing a potentially considerable underestimation of costs. Air pollution costs are clearly dominated by mortality and morbidity effects. Compared to the costs due to health effects, quantifiable costs due to material damages and crop losses are of minor importance.

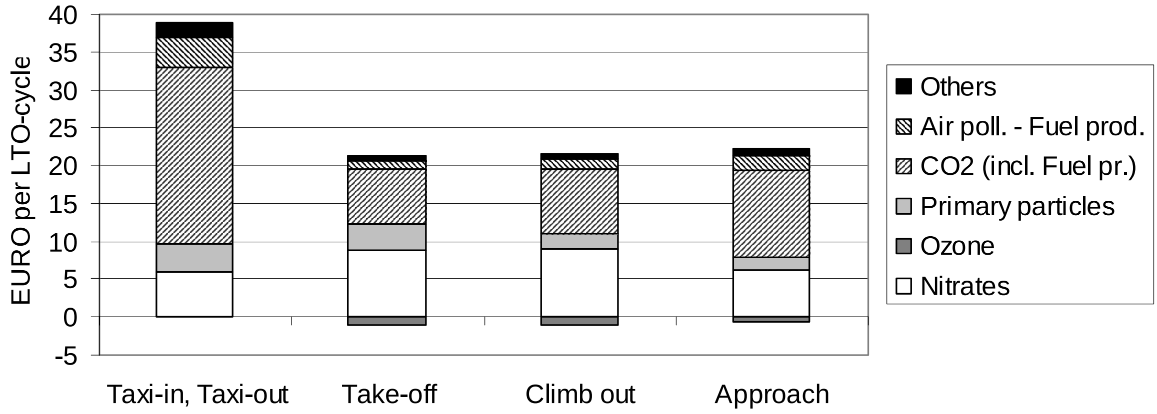
Table F-11
Marginal costs due to airborne emissions of a Boeing 737-400 in EUR

		air pollution			global warming			total
		direct emissions	fuel production	total	direct emissions	fuel production	total	
Berlin Tegel	LTO-cycle	42.18	8.56	50.74	44.74	5.68	50.42	101.16
	Departure	28.29	4.64	32.93	24.26	3.08	27.35	60.28
London Heathrow	LTO-cycle	37.86	6.01	43.87	48.57	6.17	54.74	98.62
	Arrival	13.21	2.77	15.98	22.35	2.84	25.19	41.17
Flight Berlin -	Cruise	1)	33.47	33.47	175.00 2)	22.22	197.22	230.70
London	Total 3)	41.51	40.88	82.39	221.61	28.14	249.75	332.15

1) Costs due to direct air pollution emissions not included; 2) Possible order of magnitude for global warming effects due to high altitude nitrogen emissions: ca. EUR 3000; 3) Consisting of departure at Tegel, cruise, and arrival at Heathrow.

The shares of the different pollutants in the costs are illustrated in Figure F-1 for the impacts of the LTO-cycle emissions of a Boeing 737-400 at Berlin Tegel (the composition is very similar for London Heathrow). Cost composition between different engine modes varies, reflecting the different emission factors. Taxi-in and taxi-out cause the highest share, mainly because most time at the airport is spent in these modes. Nitrates formed from NO_x and CO_2 have the highest share in costs. An interesting effect is the negative cost due to ozone formation from the precursor emissions NO_x and NMVOC. In Germany (as well as in the UK) the situation concerning ozone formation is very special. Caused by the existing NO_x/NMVOC background concentrations an additional unit of NO_x leads to a reduction in ozone and thus a decrease in ozone damages. On the other hand NMVOC emissions cause an increase in the costs due to ozone formation. So the negative costs shown in Figure F-1 are the result of the effects of NO_x and NMVOC, where the NO_x effect prevails, leading to negative costs. But compared to the adverse effects of NO_x emissions via nitrate formation this “benefit” is negligible. In “Taxi” mode the effects of NMVOC and NO_x level out, therefore ozone costs are not visible.

Figure F-1 Composition of costs due to airborne emissions from a Boeing 737-400 at Berlin Tegel



Marginal noise costs for arrival and departure of a Boeing 737-400 at Heathrow amount to almost EUR 59. Together with the costs due to air pollution and global warming the costs for a flight from Berlin to London can be estimated to EUR 391. This assumes that the costs of a starting aircraft at Berlin Tegel are about the same as at Heathrow. As both airports are located within a densely populated area this assumption is justifiable.

The shares of the cost categories in the LTO activities of the flight are about the same: air pollution EUR 49, global warming EUR 52.50 and noise EUR 59, adding up to EUR 160.50. The costs of cruising of EUR 230.70 are dominated by CO_2 emissions, costs due to fuel production emissions are only of minor importance.

With the distance between Berlin and London of about 930 km, the costs can be expressed as EUR 42 per 100 aircraft kilometres. Assuming a number of 117 passengers (corresponding to a capacity use of 80%) the resulting costs amount to EUR 0.36 per 100 passenger kilometres.

D.4 Discussion and conclusions

Marginal costs due to LTO-cycle emissions of air pollutants are similar for both airports considered. This is caused by their location in large agglomerations with a high population density. For airports in sparsely populated areas air pollution costs in tendency would be lower. Furthermore, effects of local meteorology as observed in case study 9D can be expected to play an important role. Estimates of air pollution costs from the LTO-cycle are fully comparable with the corresponding UNITE estimates for the other modes. Due to lacking models for the impacts of high altitude emissions, the cost estimate for the cruise phase are incomplete. This implies a potential underestimation of air pollution costs.

Costs due to the emission of greenhouse gases are not location specific, as they are relevant on a global scale. As a consequence all the variation is caused by the emission factor of the aircraft.

Marginal noise costs were estimated for the mean number of aircraft movements on an average day. In reality marginal costs vary considerably between peak and off-peak times within a day and between days with differing numbers of activities, because of the highly non-linear relationship between background noise and costs of an additional aircraft. For example a rough estimate gives that on a day with only 76% of total aircraft movements the marginal costs of an arrival and departure of a Boeing 737-400 at Heathrow would increase from EUR 59 to EUR 74. In the present case study this variability of marginal noise costs could not be fully explored as the use of a detailed noise dispersion model was not possible due to time and budget constraints. For the same reason, health impacts could not be evaluated even though exposure-response functions are available.

It can be concluded that the cost estimates performed in this study represent the current state of the art. However, the results are subject to considerable uncertainty, mainly because of missing knowledge on the costs due to high altitude emissions. Furthermore the level of detail of the noise cost estimates should be increased. Both areas should be clear priorities for future research.

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