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UNITE

UNIfication of accounts and

marginal costs for Transport Efficiency

Deliverable 11, Appendix

Marginal Cost Case Study 9c: Nordic Maritime Shipping

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Table of Contents

Executive Summary

This case study analyses the marginal environmental costs for atmospheric emissions of a typical passenger ferry travelling from Helsinki (Finland) to Tallinn (Estonia) in the Finnish Gulf. Marginal costs mean the environmental costs caused by an additional vessel on a certain route or visiting a port.

Marginal costs are assessed both for the route, and berth periods at ports. Estimation of the marginal costs is based on the Impact Pathway Method applied by using the *EcoSense* computer model.

The results are presented at the Finnish price level including impacts in Tallinn and Estonia. Therefore, for assessing the costs at Estonian price level, a purchasing power adjustment must be made.

The total marginal cost of emission impacts for the trip from Helsinki to Tallinn is €1622, which means a marginal cost of €18 per kilometer. The share of marginal cost from the fuel chain is approximately 5 % (€1/km). The total marginal costs of emission impacts for the berth periods (8.5 hours) in Helsinki and Tallinn are €2.5 – €2.6.

For a round trip (two route periods + one berth period), the marginal environmental costs due to emissions are approximately €3 247. Health impacts due to regional impact of emissions cause the highest environmental costs, but the costs of global warming are also of significance.

In the case of scheduled passenger ferry traffic discharges of wastes or contaminated liquids to sea are not considered a problem. Because of well-established waste management practices of shipping companies, waste and bilge waters are disposed of at ports.

The results can be generalized and transferred to shipping where the port locations, route length and vessel type along with fuel quality used have similar characteristics as in this case study. The results apply to both passenger and freight transport, taken that the emissions produced by the vessel coincide with the ferry analysed here. Purchasing power adjustments are however needed for performing benefit transfers from Finland to other countries.

C.1 Introduction

This case study estimates the marginal emission costs caused by the movement and berth periods of a single passenger ferry in the Finnish Gulf between Helsinki in Finland and Tallinn in Estonia. The analysis consists of both urban port and open sea environments. Estimation of the marginal emission costs is based on the Impact Pathway Method applied with the *EcoSense* computer model. Noise impacts are excluded from the analysis as insignificant. Discharges of wastes and oils to sea are descriptively discussed based on literature and previous studies.

A representative vessel with respect to size, fuel quality, engine technology and emission abatement technology is analyzed. The analysis covers one trip of the vessel over with berth periods both at the departure and arrival ports.

The marginal emission cost assessment is made at Electrowatt-Ekono Oy with the *EcoSense* model, methodologically supported by IER at the University of Stuttgart. The *EcoSense* model has been developed by IER.

The methodological background of marginal emission cost estimation can be examined in closer detail in European Commission (1999) and Friedrich & Bickel (2001).

C.2 Description of case study

C.2.1 Location

The sea route between Helsinki and Tallinn is an intensive link serving mainly passenger flows on passenger ferries, but also cargo transport in the form of truck and trailers taken on board the same vessels. It is the transcendent link for physical communication between Finland and Estonia. A large number of catamarans and ferries of different sizes operate the route.

The length of the route is 90 km (Figure C-1). At both ports, Helsinki and Tallinn, the berth area is located in the proximity of the city centres. The route entering both ports from the sea is relatively short. There is practically no inhabited archipelago impacted by the route. The inhabited coastal areas impacted are mainly in or in the close proximity of Helsinki and Tallinn. Otherwise, the route is at open sea.

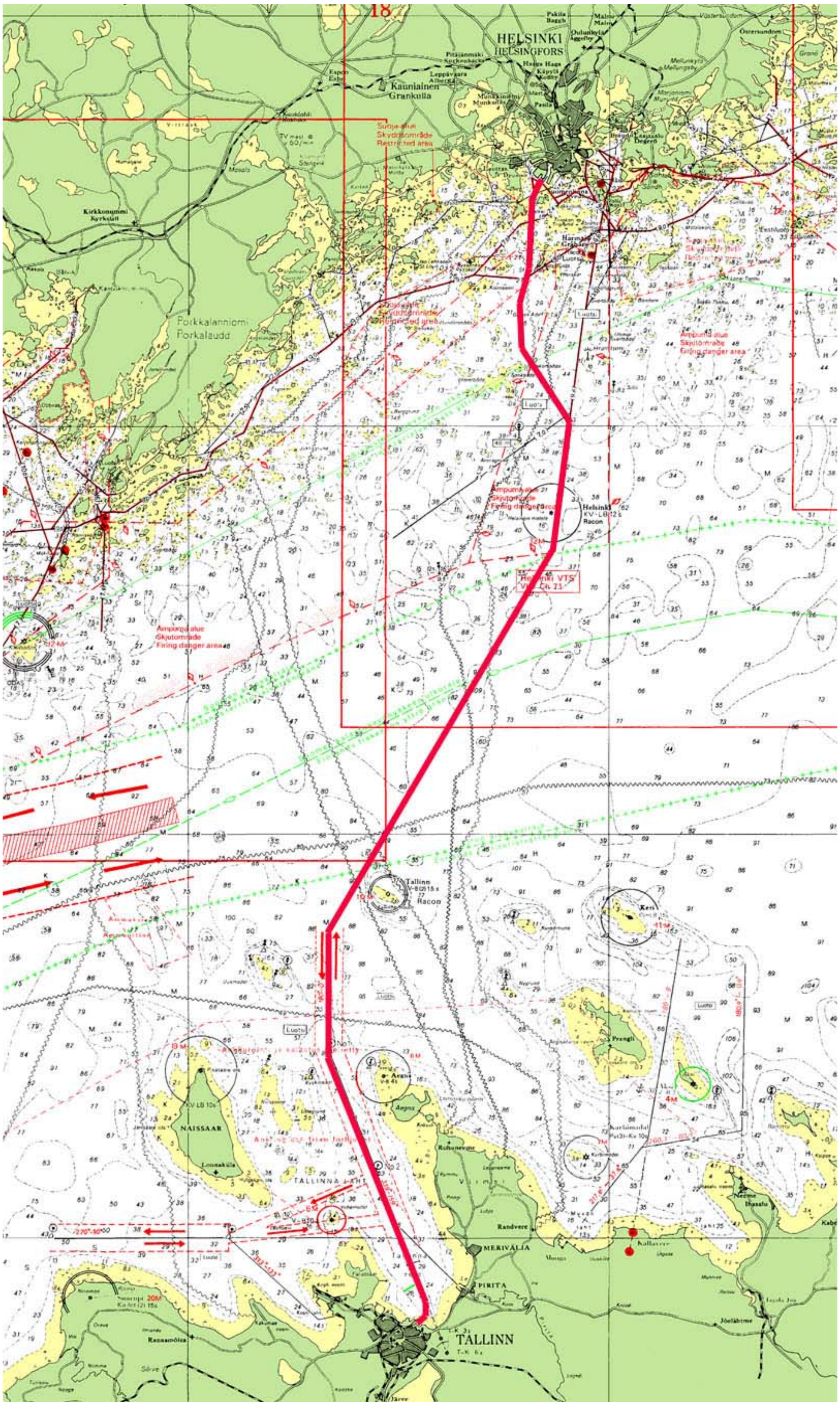

Figure C-1. Sea route from Helsinki (Finland) to Tallinn (Estonia).

C.2.2 Methodology

Marginal costs in this case study means the environmental costs caused by an additional vehicle driving on a certain route. For noise costs the time of day is relevant as well, due to the sensitivity of the receptors (which is different at night than during the day) and the high importance of the background noise level for the results.

This approach of looking at the impacts of one additional vehicle requires a detailed bottom-up approach as it has been developed in the ExternE project series. The methodology follows as far as possible this Impact Pathway Approach, which is described in the following sections. For more detailed information see European Commission (1999a and 1999b), Friedrich and Bickel (2001).

C.2.2.1 Air Pollution

The starting point for the bottom-up approach for quantification of marginal costs is the micro level, i.e. the traffic flow on a particular route segment. Then, the marginal external costs of one additional vehicle are calculated for a single trip on this route segment. It is made by modelling the path from emissions to impacts, and the respective costs. Results of recent bottom-up calculations have shown that the value of externalities may differ substantially from one transport route to another (see e.g. Friedrich and Bickel 2001).

For quantifying the costs due to airborne pollutants the Impact Pathway Approach was applied. 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 vehicle on a specific route are calculated.

For comparisons between modes, the system boundaries considered are very important. For instance, when comparing externalities of goods transport by electric trains and heavy duty road vehicles, the complete chain of fuel provision has to be considered for both modes. Obviously, it makes no sense to treat electric trains as having no airborne emissions from operation. Instead, the complete chain from coal, crude oil, etc. extraction up to the fuel or electricity consumption has to be taken into account.

Concentrations

To obtain marginal external costs, the changes in the concentration and deposition of primary and secondary pollutants due to the additional emissions caused by the additional vehicle have to be calculated. The relation between emission and concentration of pollutants are highly non-linear for some species (e.g. primary 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 line sources on the local scale up to 25 km from the road (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.

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). Table C-1 gives a summary of the dose-response functions as they are implemented in the EcoSense version used for this study.

Table C-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, S	fertiliser effects

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

Source: IER

Impacts on human health

Table C-2 lists the exposure response functions used for the assessment of health effects. The exposure response functions are taken from the 2nd 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 C-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
All	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 (European Commission 1999c). 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

$$y = 0.74 \cdot C_{SO2} - 0.55 \cdot (C_{SO2})^2 \qquad \text{for } 0 < C_{SO2} < 13.6 \text{ ppb}$$
$$y = -0.69 \cdot C_{SO2} + 9.35 \qquad \text{for } C_{SO2} > 13.6 \text{ ppb}$$

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 C-3:

$$y = 99.7 - \alpha \cdot C_{O3}$$

with y = relative yield change
α = sensitivity factors
C_{O3} = AOT 40 in ppmh

Table C-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

C.2.2.2 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. They 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 soluble.
- **Valuation of mortality**
  While ExternE recommends using 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 ExternE 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.

EcoSense model

EcoSense is a standardised integrated computer model developed for the assessment of environmental impacts and resulting external costs of emissions from transport and energy generation systems.[1] It is a computer version of alternatively applying the Impact Pathway Method by separate dispersion modelling and spreadsheet calculations of impacts.

EcoSense can assess the impacts of small 'doses' of emissions created by the movement of a single vehicle, and the resulting rise in pollutant concentrations. This coincides with the principle of assessing the marginal cost of vehicle movement. *EcoSense* has separate line and point source models for assessing mobile and stationary sources of pollutants, vehicles, energy production plants and industrial objects respectively. In this case study the line source model is used.

EcoSense provides relevant meteorological data, dispersion models, receptor data, dose-response functions and unit values for damages, all required for an integrated impact assessment related to airborne pollutants. Only a small set of site and case specific input data is required to be added by the user, namely emission characteristics of the vehicle and route trajectory for the line source model.

EcoSense analyses local and regional impacts separately according to the dispersion and damage characteristics of each pollutant. The environmental impacts assessed include health impacts, damage to forest and crop growth, material damage and climate change.

C.2.2.3 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.

[1] EcoSense. User Guide. Version 2.0. Institut fur Energiewirtschaft und Rationelle Energieanwendung. (IER). Universität Stuttgart.

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.

C.2.2.5 Other effects

Air pollution and global warming represent the most important and relevant cost categories of marginal environmental costs for shipping.

An important environmental risk of maritime transport aside from atmospheric emissions are the discharges of waste oils, other solid or liquid wastes (sanitation waters) and contaminated ballast or bilge waters to sea. Another environmental risk is an accident leading into a leakage of fuels or cargo (oil or chemicals).

It has been estimated, that out off the total oil releases into the Baltic Sea, 20 % at most are from maritime shipping. The illegal oil releases and accidents almost completely involve cargo vessels, not passenger ferries (Gynther et al. 2000).

In scheduled ferry transport in the Baltic Sea, the risks concerning dumping of harmful wastes are low due to both prohibitions by law and established practices. Solid and liquid wastes, as well as ballast or bilge waters are mainly disposed at ports. Thus, no dumping of harmful solid or liquid wastes should take place. It is permissible to dump organic wastes and disinfected sanitation waters at open sea, but due to image reasons, most wastes from passenger vessels are disposed at ports.

On the Helsinki – Tallinn route, the eutrophication impacts of phosphorus and nitrogen in the possible releases are a lesser risk since the route traverses mainly open sea, including only short stretches of shallow coastal waters. Passenger vessels usually do not carry dangerous cargo. Since the passenger vessels in scheduled traffic do not leave the Baltic Sea, there is no risk of importing alien organisms in ballast waters.

C.2.3 Data

General data for the calculation of costs due to air pollution

Besides the emissions of the transport modes in the different countries, a large number of additional information was required for the cost 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 (table C-4) and is briefly described in the following.

Table C-4
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)
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.

- *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.

Vessel characteristics and emission factors

The vessel examined is a passenger ferry with a car deck for carrying passenger cars, buses and heavy goods vehicles. The vessel has the following approximate dimensions:

- Length: 200 m
- Breadth: 25 m
- Tonnage: 33 000 gross register tonnes

- Passenger capacity: 1 500
- Capacity of car deck: 200 – 400 vehicles

The emission factors used here have been defined separately for the route (line source model) and the berth periods (point source model) of the vessel. The factor and other specifics are presented in tables C-5 and C-6.

A common procedure for passenger vessels operating in the Baltic Sea is to use low sulphur fuel oil from a separate tank while arriving and departing from ports, as well as during berth periods. At open sea, heavy fuel oil is used. Thus, at berth the case vessel uses a reserve engine and fuel oil with low sulphur content (0.1 %). At open sea, the main engines and fuel with higher sulphur content (1 %) is used.

Table C-5
Specifics of the assessment on route

Specifics	
Engine (four stroke) power (maximum) Length of trip Speed Engine output of maximum Engine power utilized Energy used per trip Sulphur content of fuel	15 000 kW 90 km/3.5 hours 24.6 km/h 80 % 12 000 kW 42 000 kWh 1 %
Emission factors (g/km)	CO 488 HC 180 NOx 6 017 SO_2 1 953 PM 139 CO_2 296 735
Source: Mäkelä et al. (2001) and own assumptions	

Table C-6
Specifics of the assessment at berth

Specifics of the vessel	
Engine power (so-called reserve engine; four stroke)	1 500 kW
Length of berth period	Helsinki 8.5 hours; Tallinn 8.5 hours
Engine output of maximum	50 %
Engine power utilized	750 kW
Energy used per berth hour	266 kWh
Sulphur content of fuel at berth	0.1 %
Stack height	35 m
Stack diameter	1.6 m
Flue gas volume stream	1195 Nm^3/h
Flue gas temperature	478 K
Emission factors (g/hour)	CO 489 HC 122 NOx 3 740 SO_2 213 PM 101 CO_2 169 203
Source: Mäkelä et al. (2001)	

Population

Population density in the proximity of Helsinki port is approximately 5 000 inhabitants per km^2. Population density in the proximity of Tallinn port is approximately 2 400 inhabitants per km^2 (average for all Tallinn).

Population exposure along the open sea route is non-existent. Passengers and crew on vessels are not considered as population exposed to emissions in the *EcoSense* model.

Values used for assessing marginal costs

Monetary values for health impacts

Table C-7 summarizes the monetary values used for valuing the health impacts of air pollution in UNITE. The impacts on Estonia are now assessed at Finnish cost level in order to allow better comparison with the Finnish results.

Average European values should be used for air pollution costs for generalization purposes. Country specific values can be calculated from the European averages for any country according to the benefit transfer rules given in Nellthorp et al. (2001). Thus, the values presented here should not be applied directly to Estonia, but scaled by purchasing power parity.

Table C-7
Monetary values (factor costs) for valuing health impacts for Europe and Finland (€$_{1998}$)

Impact	Monetary value for Europe (rounded)	Monetary value for Finland (rounded)
Year of life lost (chronic effects)	75 000	76 480
Year of life lost (acute effects)	130 000	131 570
Chronic bronchitis	138 000	140 880
Cerebrovascular hospital admission	14 000	14 230
Respiratory hospital admission	3 600	3 700
Congestive heart failure	2 700	2 800
Chronic cough in children	200	200
Restricted activity day	100	100
Asthma attack	70	71
Cough	34	35
Minor restricted activity day	34	35
Symptom day	34	35
Bronchodilator usage	32	33
Lower respiratory symptom	7	7
Source: Calculations based on Friedrich and Bickel 2001 and Nellthorp et al. (2001)		

Unit values for pollutants at local scale

The health related local damage costs by a tonne of pollutant are presented in tables C-8 and C-9. These values have been used for deriving the marginal cost for local impacts caused by the movement of the case vessel. It should be noted, that these values are used also to represent the values of impacts in Estonia. For assessing the costs at Estonian price level, a purchasing power adjustment must be made to these values.

For Tallinn, the local health impacts from vessel traffic and the harbor are smaller than for Helsinki due lower population density and dominant wind directions away from the city (to north or northeast). For Helsinki, the opposite holds.

Table C-8
Local (health) costs per tonne of pollutant in Helsinki, €$_{1998}$

Health impact/pollutant	€$_{1998}$/tonne
Morbidity	
- PM	884.7
- SO_2	1.07
Mortality	
- PM	2 788.6
- SO_2	132.6
Source: Own calculations	

Table C-9
Local (health) costs per tonne of pollutant in Tallinn, €$_{1998}$

Health impact/pollutant	€$_{1998}$/tonne
Morbidity	
- PM	269.3
- SO_2	0.33
Mortality	
- PM	848.9
- SO_2	40.7
Source: Own calculations	

Unit values for pollutants at regional and global scale

Tables C-10 to C-13 present the unit values used for assessing the costs of the regional impacts of each pollutant. In addition to these, the impact of global warming is valued according to the UNITE convention at 20 euros per tonne by the volume of CO_2 emissions. It should be noted again, that the Finnish are used to represent the values of impacts in Estonia. For assessing the costs at Estonian price level, a purchasing power adjustment must be made to these values.

Table C-10
Regional costs per tonne of NO_2 in south Finland, €$_{1998}$

	Via nitrates (€$_{1998}$)	Via ozone (€$_{1998}$)	Total (€$_{1998}$)
Crops	-	126	126
Materials	-	-	-
Morbidity	372	112	484
Mortality	856	76	932
Health, total	1228	188	1417
Total	**1228**	**314**	**1542**
Source: IER			

Table C-11
Regional costs per tonne of SO_2 in south Finland €$_{1998}$

	Via SO_2 and sulfates (€$_{1998}$)
Crops	-8
Materials	69
Morbidity	212
Mortality	540
Health, total	752
Total	**813**
Source: IER	

Table C-12
Regional costs per tonne of NMVOC in south Finland, €$_{1998}$

	Via ozone (€$_{1998}$)	
Crops	90	
Materials	-	
Morbidity	87	
Mortality	59	
Health, total		145
Total	**236**	
Source: IER		

Table C-13
Regional costs per tonne of $PM_{2.5}$ in south Finland, €$_{1998}$

	$PM_{2.5}$ (€$_{1998}$)
Morbidity	848
Mortality	1952
Total	**2800**
Source: IER	

C.3 Results

Marginal emission costs

The marginal emission costs of a trip of a passenger ferry from Helsinki to Tallinn are presented in tables C-14 to C-16. It is noted again, that the results are presented at the Finnish price level for all assessments, including impacts in Tallinn and Estonia. For assessing the costs at Estonian price level, a purchasing power adjustment must be made.

In table C-14, the marginal emission costs at open sea are presented. The marginal emission cost of a vessel kilometer at open sea is €18, which means that the total marginal cost of emission impacts for the trip (90 km) from Helsinki to Tallinn is €1622. Regional health impacts clearly dominate the costs, but global warming is also significant.

The emission costs of an average berth period (8.5 hours) in Helsinki are presented in table C-15 and for Tallinn in table C-16. The marginal emission cost of the case vessel at berth is €0.3 per hour, which means that the total marginal costs of emission impacts for each berth period (8.5 hours) in Helsinki and Tallinn are €2.5 – €2.6. Again regional health impacts cause the highest environmental cost, but the costs of global warming are also of significance.

Table C-14
Marginal emission costs for the vessel at open sea by damage category, €cent$_{1998}$

Impact category	Cent/case	Cent/km
Local impacts		
Morbidity	1 470	16.3
Mortality	5 506	61.2
Regional impacts		
Crops & material	7 999	88.9
Morbidity	31 142	346.0
Mortality	62 514	694.6
Global warming	53 412	593.5
Fuel chain	119	1.38
Total	162 202	1 803

Local impacts in Tallinn are lower compared to Helsinki due to lower population density and the fact that dominant wind directions carry pollutants away from the town in Tallinn, whereas the opposite holds for Helsinki.

For the whole trip, the marginal emission costs for the open sea part are much larger than the marginal emission costs of the berth periods altogether. At ports the vessel uses reserve engines and low sulfur fuel, whereas at sea the main engines are run on fuel with high sulfur content.

Table C-15
Marginal emission costs for the vessel at berth in Helsinki by damage category, €cent$_{1998}$

Impact category	Cent/visit at port (8.5 hours)
Local impacts	
Morbidity	2.1
Mortality	7.4
Regional impacts	
Crops & material	11.6
Morbidity	46.6
Mortality	91.2
Global warming	81.2
Fuel chain	15
Total	255

Table C-16
Marginal emission costs for the vessel at berth in Tallinn by damage category, €cent$_{1998}$

Impact category	Cent/visit at port (8.5 hours)
Local impacts	
Morbidity	0.7
Mortality	2.3
Regional impacts	
Crops & material	11.6
Morbidity	46.6
Mortality	91.2
Global warming	81.2
Fuel chain	15
Total	249

C.4 Discussion and conclusions

This case study has analysed the marginal environmental costs (atmospheric emissions) of a trip of a typical passenger ferry from Helsinki to Tallinn. Marginal costs where assessed both for the route, and average berth periods at ports.

The results are presented at the Finnish price level for all assessments, including impacts in Tallinn and Estonia. For assessing the costs at Estonian price level, a purchasing power adjustment must be made.

The total marginal cost of emission impacts for the trip from Helsinki to Tallinn is €1622, which means a marginal cost of €18 per kilometer. The share of marginal cost from the fuel chain is approximately 5 % (€1/km). The total marginal costs of emission impacts for the berth periods (8.5 hours) in Helsinki and Tallinn are €2.5 – €2.6. Thus, for a whole round trip (two route periods + one berth period), the marginal environmental costs due to emissions are approximately €3 247. Health impacts due to regional impact of emissions cause the highest environmental costs, but the costs of global warming are also of significance.

In the case of scheduled passenger ferry traffic discharges of wastes or contaminated liquids to the sea are not considered a problem due to the well-established waste management practices of shipping companies, according to which solid and liquid waste is disposed of at ports.

The results can be generalized and transferred to locations for vessel traffic, where the port locations, route length and vessel type along with fuel quality used are with similar characteristics as in this case study. Purchasing power adjustments are however needed for performing benefit transfers from Finland to other countries.

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