Global Nest: the Int. J. Vol 1, No 2, pp 77-89, 1999

THE MARGINAL ENVIRONMENTAL COSTS OF TRANSPORT IN GREECE

G. VOSSINIOTIS
D. ASSIMACOPOULOS

Department of Chemical Engineering,
National Technical University of Athens
Heroon Polytechniou 9, Zografou Campus, 157 80, GREECE

Received: 14/12/98
Accepted: 20/5/99

ABSTRACT

A methodology for the estimation of the marginal external costs of transport is presented and applied to the Greek transport system. A bottom-up approach is used to estimate the impacts of air-pollution for specific transport tasks. Detailed traffic emission modelling, air pollutant dispersion, exposure-response functions, and monetary valuation of impacts are used. The methodology is applied to the analysis of representative transport tasks in Greece, and results in highly aggregated external costs, depending on the transport mode, the technology used, and the location of the transport task. Local, regional and global impacts are analysed, and the contribution of each pollutant to the total damages is specified. The resulting externalities are compared to damages referenced in other European countries.

KEYWORDS: Transport, external costs

1. INTRODUCTION

The transport sector is the major air pollution source in all developed societies with significant impacts on human health, and natural or man-made environment. Environmental costs arising from transport activities of one group of persons and imposed to another group of persons, without being fully accounted for by the first group, are considered to be external. Traditional economic analysis included fixed and operational costs and ignored "externalities". However, the identification and the assessment of externalities is a prerequisite for the introduction of environmental criteria in decision-making processes, the analysis of the costs and benefits of alternative environmental policies, the determination of economically justified pollution control, and the development of environmental performance indices for the various pollution control technologies.

During the last decades a large body of literature concerning the evaluation of transport externalities has emerged. It includes, inter alia, the studies of Gastaldi et al. (1996), Rienstra et al. (1996), Gwilliam et al. (1994). A review on a number of other studies was presented by Verhoef (1994). Most of these studies are empirical and follow a top-down approach providing average values for transport externalities. Moreover, the values provided are in most cases underestimations of the external costs as some important categories of environmental costs have been left out (Verhoef, 1994). A detailed bottom-up approach for the assessment of environmental externalities was introduced in the ExternE project (EC, 1995). The "Impact Pathway" methodology uses detailed site and technology specific data, pollution dispersion models, detailed information on the location of receptors, and exposure-response functions to calculate the impacts of fuel cycle activities. A more recent study (Mayeres et al. 1996) has used the results of the ExternE project for the electricity sector to estimate the externalities of transport. However, the extrapolation of results for electricity generation in the assessment of transport externalities is of questionable accuracy due to the following reasons: (a) transport activities do not produce the same pollutants as electricity generation and the impacts caused are different, (b) line-source dispersion models must be used for the calculation of the pollutants concentration instead of point-source models, (c) the pollutants produced by electricity generation are usually emitted from stacks and are well dispersed, while the pollutants produced by transport activities are emitted in low height and mainly affect neighbouring areas, and (d) the areas around power plants are usually not densely populated while a large proportion of transport occurs within cities.

A methodology for the assessment of the environmental externalities of transport, taking into account all the above-mentioned particularities, is being developed within the framework of the ExternE-Transport project (Friedrich et al., 1998). The most recent studies (De Nocker et al., 1998, Dorland et al., 1998), have used this methodology in Belgium and the Netherlands, and their results include analytical values for various combinations of transport modes, technologies used, and locations of transport tasks.

In the present work, the ExternE methodology is used for the quantification of the marginal external effects of air pollution due to transport in Greece. Impacts and corresponding damages are calculated for all the road transport modes and the technologies used, as well as for a representative set of locations. The resulting damages are compared with corresponding results of case studies in Belgium and the Netherlands, and differences between them are pointed out.

2. METHODOLOGY

In this study, the "Impact Pathway" methodology developed within the framework of the "ExternE" project (EC, 1995) is used for the assessment of the air pollution externalities. This methodology traces the passage of a pollutant from the place where it is emitted to the final impact on the receptors that are affected by it. The principal steps of the approach include:

- *Estimation of emissions*

The estimation of transport emissions is a complex issue due to the multitude of parameters involved. These parameters can be technology oriented (vehicle type, motor and fuel type, emission control technology, engine capacity, age) or related to operational circumstances (speed profile, vehicle load, driving behaviour) and have significant impacts on the quantity and the relative share of each pollutant emitted. A number of national or European research projects are devoted to the determination of emission factors of road transport vehicles. A common feature is that they are based on laboratory measurement studies and that they all attempt to a certain extent to incorporate some of the parameters described above to account for the variability of emission factors. Generally, the models can be divided in two main categories:

1. Models based on average speed emission factors:
   - The Computer Programme to Calculate Emissions from Road Traffic (COPERT I, Egglestone et al., 1993)
2. More complex models based on emission matrices, i.e. emissions as a function of instantaneous speed and acceleration:
   - The Handbook of Emission Factors (HBEFA, Keller et al., 1995)
   - The DRIVE-MODEM project (Jost et al., 1992)
   - The Digitized Graz method (DGV) (Sturm et al., 1994)

The COPERT methodology, used in this study for the calculation of the various transport modes emissions, is based on the analysis of available emission data of individual vehicle tests from different European laboratories. The emission factors provided cover a wide range of pollutants such as nitrogen and sulphur oxides, volatile organic compounds (VOC), methane, carbon monoxide, carbon dioxide, diesel particles and heavy metals. The vehicle categories are split according to the fuel used (petrol, diesel, LPG), the vehicle type (passenger cars, light-duty vehicles, heavy-duty vehicles, buses/coaches and motorcycles), the emission control technology and the engine capacity. The emission factors for each vehicle type are given as functions of the average driving speed, while correcting factors for road gradient and vehicle load are provided. The emission estimates also include cold start and evaporative emissions, mainly depending on the ambient temperature.

• *Calculation of pollutants concentration*

The relationship between changes in the emissions and resulting concentrations is established by atmospheric dispersion models calculating the annual average incremental concentration of the pollutants on local and regional scale. For local range dispersion (up to 25 km far from the road) a Gaussian line-source model is used. The model is based on the numerical integration of the point-source equation along the road trajectory.

The data required include line-source data (start-end coordinates and emission rates for each road segment), meteorological data (annual frequencies of occurrence for each wind speed, wind direction, atmospheric stability class and mixing layer height) as well as the type of the receiving environment (urban, rural).

For regional scale dispersion, the WTM model (Krewitt et al., 1995) is used. WTM is a Lagrangian plume model calculating the concentrations of primary and secondary pollutants over long distances, taking into account atmospheric chemistry, wet and dry deposition mechanisms and meteorological data such as wind speed, wind direction and precipitation. The grid used for the concentration calculations has 50x50 km cells and extends over the entire European continent.

• *Impact assessment*

The impact assessment procedure is focused on the effects of air pollution to human health, building materials and crops, as well as on the impacts of greenhouse gases to global warming. Table 1 gives a brief overview of the pollutants and the impacts considered in this study as well as on the scale that they are examined. Sulphate and nitrate aerosols are generated from chemical reactions of NO_X and SO_2 in the atmosphere. As these secondary particles are formed relatively slowly and have a long atmospheric lifetime, they tend to have effects in regional rather than local scale. Due to the lack of appropriate ozone formation model, the results of a preliminary approach quantifying the damages of ozone per ton of precursor emissions were adopted (Rabl and Eyre, 1996). The estimation of regional scale impacts in this approach was based on results of the EMEP ozone model (Simpson, 1992, 1993).

The set of exposure-response functions used in this study is listed in Appendix A.

• *Monetary valuation*

a) Health Impacts

Mortality: The starting point for mortality valuation was the value of a statistical life (VSL) of 3.1 million EUROs. This estimate is based on a

Table 1: Air pollution impacts

Precursor emission	Pollutant	Scale	Impact
Combustion particulates	Particulates	Local/Regional	Human health
SO_2	SO_2	Local/Regional	
SO_2/NO_X	Aerosols	Regional	
VOC/NO_X	Ozone	Regional	
Benzene	Benzene	Local/Regional	
Formaldehyde	Formaldehyde	Local/Regional	
1-3 Butadiene	1-3 Butadiene	Local/Regional	
SO_2/NO_X	Acidity	Regional	Materials corrosion
Combustion particulates	Particulates	Local/Regional	Materials soiling
VOC/NOx	Ozone	Regional	Crop loss
SO_2/NO_X	Acidity	Regional	
CO_2, N_2O, CH_4	Greenhouse gases	Global	Global warming

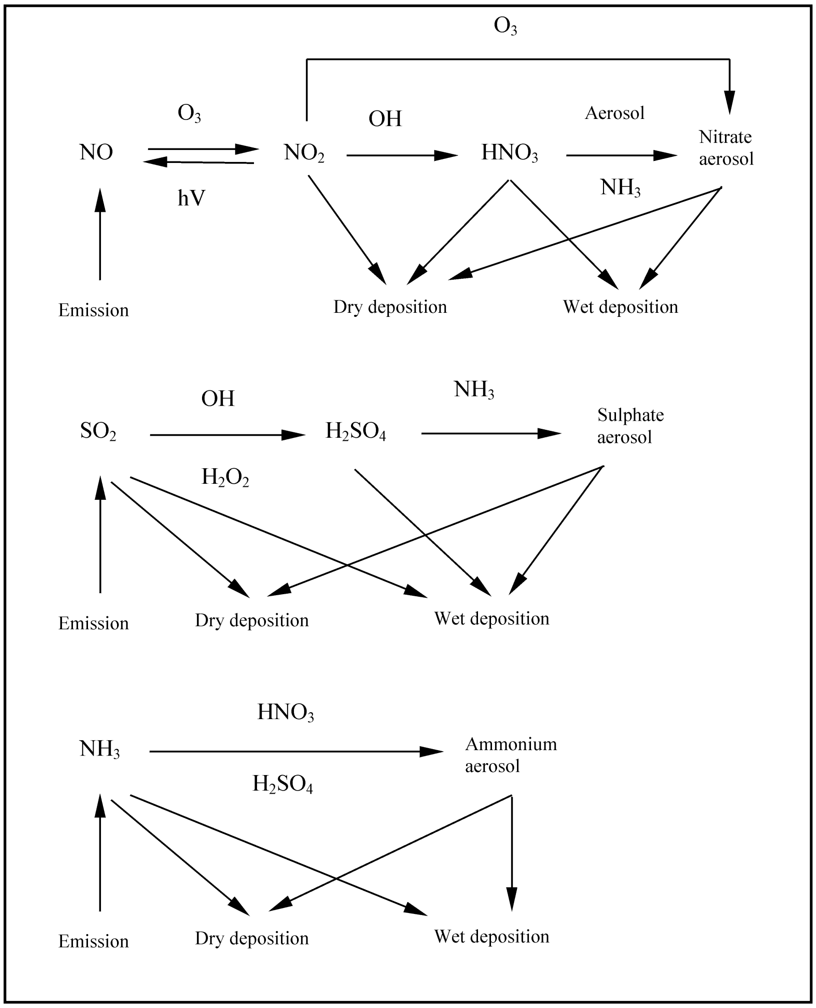

Figure 1: Chemical reactions of the sulphur and nitrogen species included in the WTM model

thorough review of the existing literature on mortality (EC, 1995). However, the use of this value for mortality impacts does not take into consideration the age of the exposed population. An alternative approach is to use the value of life years lost (VLYL), deriving from VSL by dividing it by the average expected years of life remaining. Using estimates of survival probabilities for the EU population, the values of Table 2 were calculated. For chronic mortality, it is assumed that the impact has a uniform distribution over a 30 years period after the exposure.

Morbidity: The monetary values of the morbidity impacts stem from a review of the U.S. literature (EC, 1995). Table 2 lists the morbidity values considered.

b) Crops

The world market prices of the crops examined, were used to value the impacts on agriculture. The monetary values used are listed in Table 3.

c) Materials

The economic valuation of materials corrosion and soiling is based on the frequency and the cost of repairing the induced damages. The cost of the repair works for the main categories of materials examined in this study is listed in Table 4.

d) Global warming

The global warming is one of the most important categories of damages, but also lies amongst the most uncertain, as the effects extend over many generations and affect a very wide range of

Table 2: Monetary values of health impacts - 1995 prices [EURO]

Impact	Value
Mortality from particles	98,000
Mortality from cancer	
Leukaemia	2,410,000
Lung cancer	1,820,000
Stomach cancer	1,720,000
Nasal cancer	1,620,000
Morbidity impacts	
Asthma	105,000
Bronchodilator usage	37
Chronic bronchitis	105,000
Acute bronchitis	225
Cerebrovascular HA	7,870
Chronic cough	225
Congestive heart failure	7,870
Cough	7
ERV for asthma	223
ERV for COPD	223
Hospital visits child croup	223
Chronic bronchitis HA	7,870
Ischaemic heart disease	7,870
Lower respiratory symptoms	7.5
Non-fatal cancer	450,000
Respiratory HA	7,870
Symptom day	7.5
RAD	75

HA: Hospital Admissions, ERV: Emergency Room Visits, COPD: Chronic Obstructive Pulmonary Disease, RAD: Restricted Activity Days.
Source: Friedrich et al., 1998.

Table 3: Monetary values for crop losses - 1997 prices [EURO/t]

Product	Price
Wheat	96
Barley	54
Rye	156
Oats	56
Potato	82
Sugar beet	48

Source: Food and Agriculture Organisation.

Table 4: Cost of repair [EURO/m²]

Material	Cost
Limestone	245
Mortar	27
Natural stone	245
Paint	11
Rendering	27
Sandstone	245
Zinc	22

Source: EC, 1995

resources and human activities such as health, sea level rise, agriculture, water supply, ecosystems and extreme weather events.

The Inter-Governmental Panel on Climate Change (IPCC) has undertaken detailed analyses of the science of climate change, the physical impacts and potential responses, the socio-economic dimensions and the assessment of damages. In the last one of these reports (Pearce et al., 1996), the damage values proposed range between 1-30 EUROs/t CO_2. For the other greenhouse gases (CH_4, N_2O) the same range of values was used, multiplied by the corresponding global warming potential (21 for CH_4 and 310 for N_2O) (Friedrich et al., 1998).

3. APPLICATION OF THE METHODOLOGY TO THE ROAD TRANSPORT NETWORK OF GREECE

3.1. Transport modes and technologies examined

The evolution of the Greek vehicle fleet over the last years is shown in Table 5. The average vehicle age is more than 10 years, and about 55% of the passenger cars are not equipped with catalytic converters. The majority of passenger cars have petrol-fuelled engines as only taxis are allowed to have diesel engines. The most representative modes and technologies, covering the whole range of the Greek transport system, were examined (Table 6).

3.2. Locations examined

Previous studies (Friedrich et al., 1998, Dorland et al., 1997) have shown that transport externalities, and especially local impacts, are site-specific and depend heavily on the population density of the local scale area. Five transport tasks in different locations of Greece were select-

Table 5: The Greek vehicle fleet evolution

Year	1980	1985	1990	1995
Passenger cars	858,845	1,259,335	1,735,523	2,204,761
Buses/Coaches	16,338	19,234	21,430	24,600
Trucks	389,377	595,761	766,429	883,823
Motorcycles	95,785	162,295	256,594	475,668

Source: National Statistical Service of Greece.

Table 6: Modes/technologies examined

Mode	**Fuel**	**Technology**
Passenger Cars	Petrol	ECE 15-04, 1.4-2.0 lt
		EURO I, 1.4-2.0 lt
	Diesel	Uncontrolled, <2.0 lt
		EURO I, <2.0 lt
	LPG	EURO I
Light-Duty Vehicles	Petrol	Uncontrolled
		EURO I
	Diesel	Uncontrolled
		EURO I
Heavy-Duty Vehicles	Diesel	Bus
		Truck 3.5 - 7.5 tn
		Truck 7.5 - 16 tn
		Truck 16 - 32 tn
		Truck 32 - 40 tn
	CNG	Urban bus
Motorcycles	Petrol	Uncontrolled, <250 cc
		Controlled

Table 7: Characteristics of the areas examined

Location	**Geographical characteristics**
Athens	Large urban area, average population density 1500 inhabitants/km^2, urban core population density 20500 inhabitants/km^2.
Thessaloniki	Large urban area, average population density 450 inhabitants/km^2, urban core population density 21500 inhabitants/km^2.
Larissa	Small urban area, average population density 80 inhabitants/km^2, urban core population density 1300 inhabitants/km^2
Rural 1	Rural area with small towns, average population density 260 inhabitants/km^2.
Rural 2	Rural area, average population density 40 inhabitants/km^2.

Each route was split into sections according to the driving conditions. Six different road types were defined, the typical driving speeds of which are shown in Table 8 for each location.

Table 8: Typical average driving speeds of road types examined

Location	Driving Speed [km/h]					
	Urban core principal street	Urban core by-street	Suburbs principal street	Suburbs by-street	Country road	Motorway
Athens	15	20	40	20	-	-
Thessaloniki	15	20	40	20	-	-
Larissa	30	20	-	-	-	-
Rural 1	-	-	-	-	60	90
Rural 2	-	-	-	-	60	90

ed in order to examine the effect of population density and distribution to the externalities of transport. The characteristics of these locations are listed in Table 7.

RESULTS

The resulting environmental damages depend heavily on the technology used and the location of the transport activity. Differences of one order of magnitude are observed between different transport modes or between densely populated urban areas and rural areas.

Figure 2 portrays the externalities of a EURO I petrol passenger car, in mEURO per passenger kilometre (mEURO/pkm), for various urban and rural areas. It is clear that the population density of the area where the transport task takes place, affects significantly the resulting impacts, and that the external cost estimates show a great increase in large urban areas.

In Figures 3 and 4 various vehicle technologies in urban and rural areas are compared. In urban areas among the passenger cars, the worst performing are the diesel engine vehicles. The positive effects of the catalytic converter can be observed when the ECE 15-04 and the EURO I technologies are compared. It must be noted that the EURO I passenger cars have lower impacts per passenger kilometre even from a diesel bus, which in rural areas is the best performing technology. The EURO I passenger cars still have lower externalities than the other passenger car technologies. Old technology and lack of emissions control of the Greek diesel trains is reflected in the external cost, which is quite high, compared to the diesel bus or the EURO I passenger car.

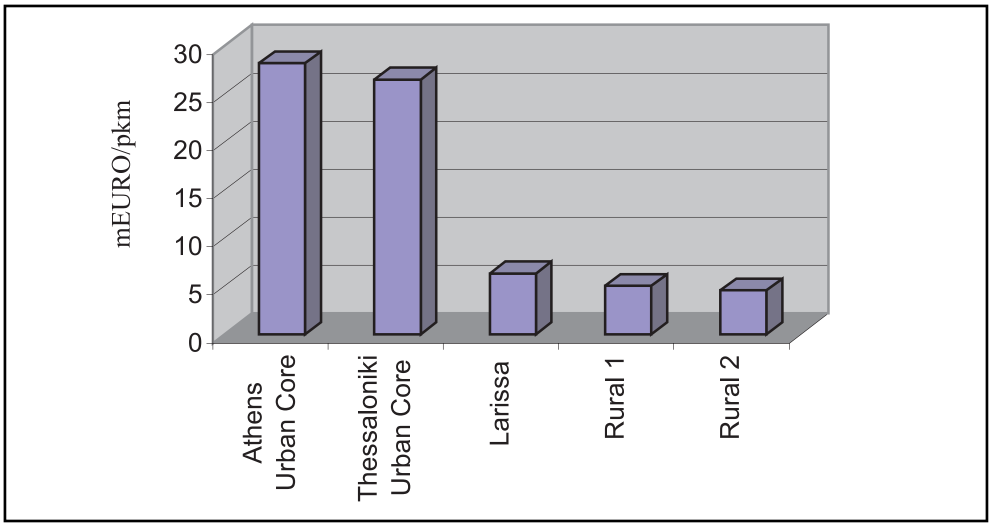

Figure 2: Externalities of EURO I petrol passenger car in mEURO/pkm

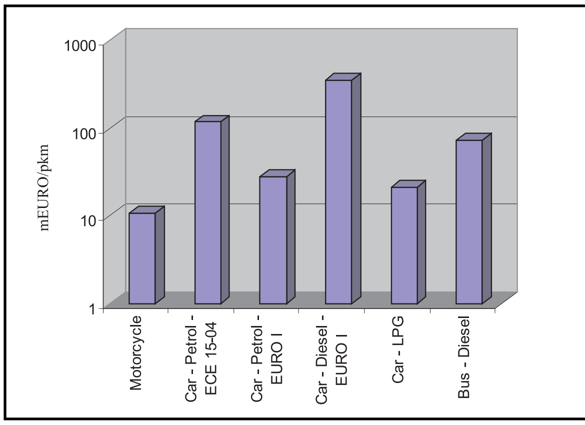

Figure 3: External cost estimates of various vehicle technologies in Athens in mEURO/pkm

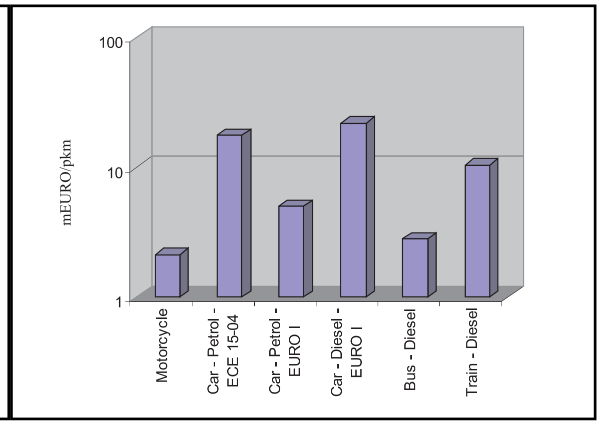

Figure 4: External cost estimates of various vehicle technologies in a rural area in mEURO/pkm

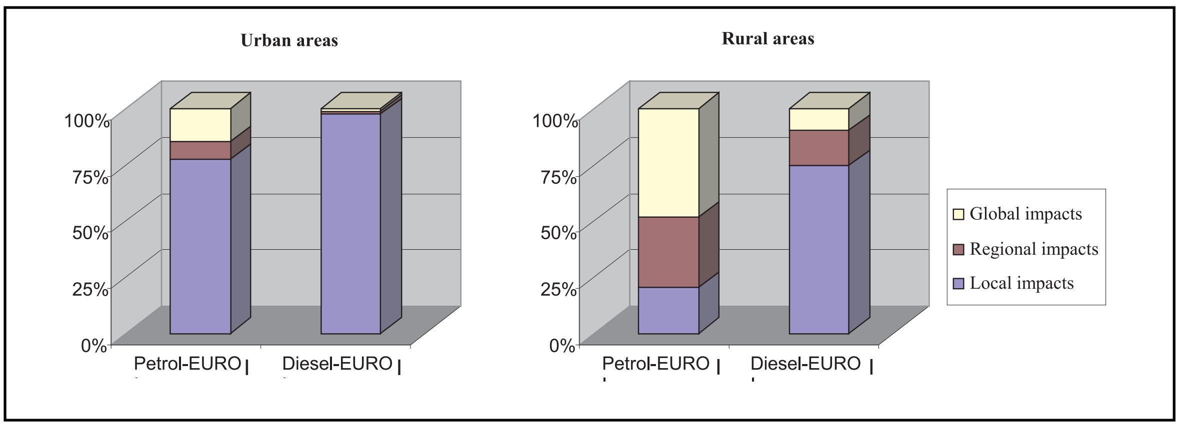

Figure 5: Comparison between local, regional and global impacts

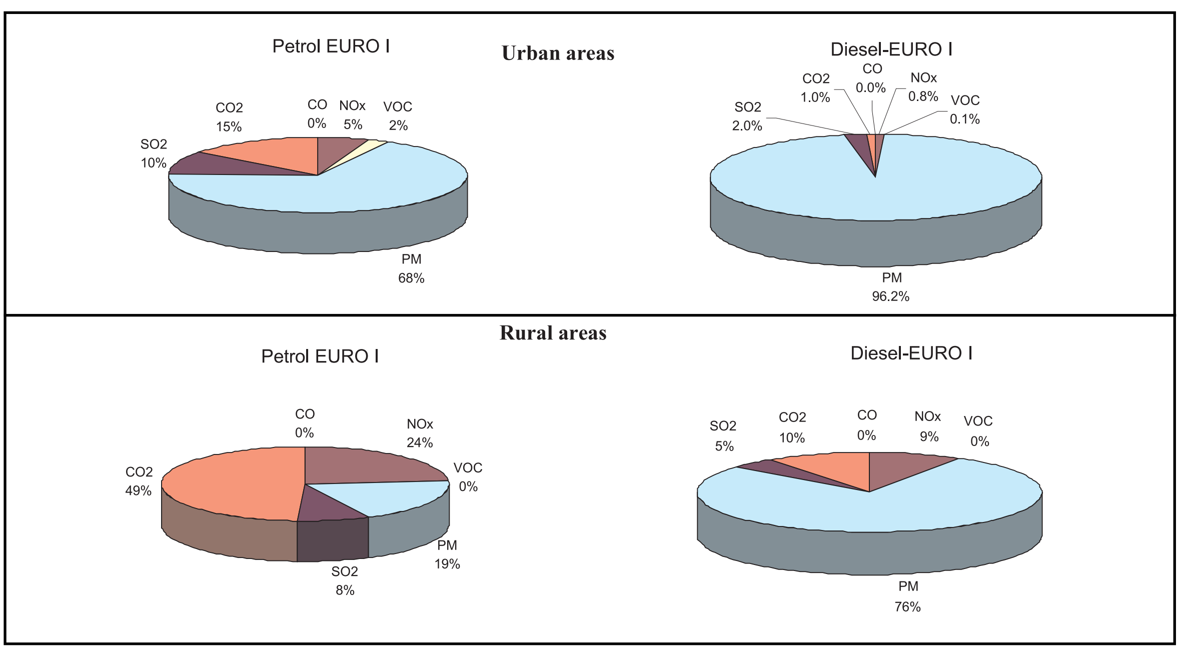

Figure 6: Contribution of pollutants to the total damages

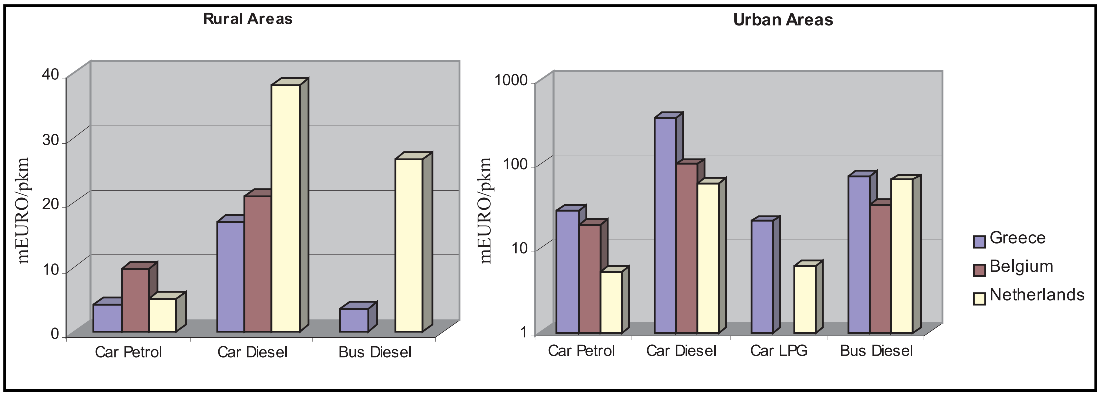

Figure 7: Comparison of results [mEURO/pkm]

Figures 5 and 6 present a comparison between the local, regional and global impacts as well as the contribution of each pollutant to the total damages for petrol and diesel passenger cars. In urban areas, the local impacts contribute most to the total impacts, especially in the case of diesel vehicles. In rural areas, due to the lower local population density, the contribution of the local impacts decreases significantly, and in the case of petrol vehicles, regional and global impacts become dominant.

In densely populated areas the particulate matter (PM) is the most detrimental pollutant, and its impacts are mainly observed in the vicinity of the road. If the population density near the road decreases, the effects of other pollutants, such as CO_2 and NO_X having effects on regional and global range, become more important. However, even for rural areas, the high particulate emissions of the diesel vehicles still retain the importance of local impacts.

4.1. Comparison with similar studies

Two studies using the same methodology for transport tasks in Belgium (De Nocker et al., 1998) and the Netherlands (Dorland et al., 1998) have been selected for comparison to the Greek situation. Results are presented in Figure 7.

The resulting externalities differ significantly between the three studies. These differences are caused by a multitude of factors. The most significant is the population density considered in each study. Transport activity in Greece has considerably higher impacts in urban areas and lower in rural areas. The urban area considered in the present work is Athens, with a population of about 4,000,000 people and urban core population density reaching 20,500 inhabitants/km^2. The corresponding values are 1,000,000 people and 15,000 inhabitants/km^2 for Belgium. For rural areas the population density considered for the Greek transport externalities is 260 inhabitants/km^2, while the rural areas of Belgium are characterised by a population density of 350 inhabitants/km^2.

Other factors affecting the resulting externalities and the differences between the three countries, are the emission models used in each study for the calculation of the vehicles' emissions, the meteorological data used for dispersion modelling, the vehicles' occupancies considered for the calculation of impacts per passenger-kilometre, and the spatial distribution of the population in the areas examined at each study.

5. CONCLUDING REMARKS

The application of the methodology reveals a great variation of the environmental costs of transport depending on the transport mode, the emission control technology used, and the location of the transport task. These variations indicate that the resulting values are not transferable to other locations, as factors such as the spatial distribution of the receptors around the emission source, and the meteorological characteristics are location-specific.

The results showed that the impacts of PM emissions are dominant, especially in densely populated areas. As a consequence, diesel engine vehicles, having higher PM emissions than petrol or LPG engine vehicles, introduce considerably high external cost. The introduction of alternative fuel buses (CNG, LPG) and the replacement of diesel taxis, which are the only diesel passenger cars allowed to circulate in Athens, with LPG vehicles would significantly decrease the environmental impacts in the Athens basin. The environmental performance of passenger cars has improved with the introduction of the catalytic converter. However, as almost 55% of the Greek passenger cars are still not equipped with catalytic converters, there is a pressing need for the vehicle fleet renewal.

The application of the methodology presented in this study, assessing in detail the environmental transport externalities and discriminating between transport modes, technologies used and locations, produces results that assist decision-makers to internalise the impacts of transport, using economic instruments such as vehicle, fuel and road taxes. The internalisation of transport impacts, as a result of accurate transport pricing, is a key element for sustainable transport systems.

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APPENDIX A

Table A-1: Exposure-response functions for human health

Receptor	Impact Category	Pollutant	Reference
ASTHMATICS			
Adults	Bronchodilator usage	PM Nitrates Sulphates	Dusseldorp et al., 1995
	Cough	PM Nitrates Sulphates	Dusseldorp et al., 1995
	Lower respiratoty symptoms	PM Nitrates Sulphates	Dusseldorp et al., 1995
Children	Bronchodilator usage	PM Nitrates Sulphates	Roemer et al., 1993
	Cough	PM Nitrates Sulphates	Pope and Dockery, 1992
	Lower respiratoty symptoms	PM Nitrates Sulphates	Roemer et al., 1993
All	Asthma attacks	Ozone	Whittemore and Korn, 1980
ELDERLY 65+			
	Congestive heart failure	PM Nitrates Sulphates CO	Schwartz and Morris, 1995
	Chronic bronchitis	PM Nitrates Sulphates	Dockery et al., 1989
	Chronic cough	PM Nitrates Sulphates	Dockery et al., 1989
ADULTS			
	Restricted activity days	PM Nitrates Sulphates	Ostro, 1987
	Chronic bronchitis	PM Nitrates Sulphates	Abbey et al., 1995
	Chronic mortality	PM Nitrates Sulphates	Pope et al., 1995

Receptor	**Impact Category**	**Pollutant**	**Reference**
ENTIRE POPULATION			
	Respiratory hospital admissions	PM	Dab et al., 1996
		Nitrates	
		Sulphates	
		SO_2	Ponce de Leon, 1996
		Ozone	
	Symptom days	Ozone	Krupnick et al., 1990
	Cancer risk estimates	Benzene	EPA, 1990
		1,3 Butadiene	
		Formaldehyde	
		Diesel particles	
	Acute mortality	PM	Verhoeff et al., 1996
		Nitrates	
		Sulphates	
		SO_2	Touloumi et al., 1994
		Ozone	Sunyer et al., 1996

Table A-2: Exposure-response functions for agriculture

Receptor	**Impact Category**	**Pollutant**	**Reference**
Barley	Crop loss	SO_2	Baker et al., 1986
Oats			
Potato			
Rye			
Sugar beet			
Wheat			

Table A-3: Exposure-response functions for materials

Receptor	**Impact Category**	**Pollutant**	**Reference**
Limestone	Maintenance surface	SO_2	Kucera et al., 1995
Mortar			
Natural stone			
Paint			Haynie, 1986
Rendering			Kucera et al., 1995
Sandstone			
Zinc			