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External costs of Transportation Case study: maritime transport

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Summary

This report aims at proposing a methodological approach to estimate the external costs of maritime transport. In order to do so, It is organised into two sections: (i)identification of all environmental impacts of maritime transport (at sea and in ports) and a detailed analysis for those already studied in previous researches in literature; (ii)Estimation of identified environmental impacts focusing on those related to air pollutants.

In the first paragraph we review external costs of transportation. Then, a description of maritime transportation activities (par. 2) and vessels (par.3) is provided. This will contribute to clarify the sources of environmental impacts. The central part of this report will be devoted to a detailed analysis of all environmental impacts listed above. The ultimate objective is to highlight the gaps that have to be filled in future research works. All the environmental effects entailed by maritime activities (both in port and at sea) are analysed (par. 4). The following environmental impacts of maritime transport have been considered: emissions to air and water, soil and sediment contamination, erosion, biodiversity loss and habitat degradation, and waste generation. In order to emphasise the complexity and uncertainty about the analysis of environmental impacts entailed by maritime transport, a review of research findings is provided (par. 5) and suggest research directions (par. 6). Next, we make a step forward and discuss the methodological aspects related to the economic valuation of these impacts (par. 7), so as to derive a monetary indicator able to summarise them. In particular, we review the economic literature regarding the valuation of the several environmental impacts discussed previously (par. 8 and 9), to sketch the state of the art. This review will provide a description of proposed methods for measuring each external cost. Then, we focus on impacts on air (par. 10). The strengths and limitations of existing approaches are described, by proposing at the same a methodological approach to estimate maritime pollution activities (par. 11). The proposed approach is tested through a case study, by estimating the external costs of a type of maritime activities in Venice (par. 12). The idea is to determine the relevant parameters that should be taken into account in the definition of an analytical approach, to signal research gaps so as to pave the way to future research activities. This will make possible to propose a methodology to be developed in future research for maritime transport and to test through a case study what are the main steps of such analysis. The last part of the report will emphasise future research directions.

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1. Introduction

In the last years public concerns regarding the environmental impacts of maritime transport have been increasing. This is due to the fact that, despite the better environmental performance of this mode of transport with respect to other modes, its overall impacts will be out weighted by the expected increase in the volume of ship movements. For instance, IIASA *et al*. (2006) estimate that SO2 emissions for international shipping are expected to increase by more than 40% between 2000 and 2020. Despite this scenario, considerable environmental improvements are obtainable by changing shipping practices (Krozer *et al.*, 2003). In order to understand whether the policy actions necessary to decrease the environmental impacts of maritime transport are welfare improving, it is necessary to assess the external costs of maritime transport and find adequate methodologies to evaluate them.

Despite an increasing awareness of the need for policy interventions, a comprehensive framework for the assessment of maritime external costs is still lacking. This study defines a general methodology to estimate environmental costs for maritime transport.

The work carried out consists of two sub-activities:

1) The identification of all environmental impacts of maritime transport (at sea and in ports) and a detailed analysis for those already studied in previous researches in literature.

2) Estimation of identified environmental impacts focusing on those related to air pollutants.

In order to propose a methodological approach to estimate the external costs of waterborne transport, it is necessary to understand all the environmental effects entailed by maritime activities (both in port and at sea). The following environmental impacts of maritime transport have been considered: emissions to air and water, soil and sediment contamination, erosion, biodiversity loss and habitat degradation, and waste generation. Then, a review of existing literature makes possible to sketch the state of the art. This review will provide a description of proposed methods for measuring each external cost. Then, we focus on impacts on air. The strengths and limitations of existing approaches are described, by proposing at the same a methodological approach to estimate maritime pollution activities. The proposed approach is tested through a case study, by estimating the external costs of a type of maritime activities in Venice.

In the first part we emphasise the complexity and uncertainty about the analysis of environmental impacts entailed by maritime transport. In the second section we would like to make a step forward and discuss the methodological aspects related to the economic valuation of these impacts, so as to derive a monetary indicator able to summarise them. In particular, we are going to review the economic literature regarding the valuation of the several environmental impacts and focus only on those on air (e.g. pollution and climate change). In particular, by reviewing the relevant literature, we will summarise the state of the art so as to be able to indicate research directions in this domain.

The report is structured as follows. In the next paragraph external costs of transportation are briefly reviewed, then a description of port activities and vessels (type and size, engine and fuel) is provided. This will contribute to clarify the sources of environmental impacts. The central part of this report will be devoted to a detailed analysis of all environmental impacts listed above. The ultimate objective is to highlight the gaps that have to be filled in future research works.

After the review of existing studies on maritime transportation impacts, the second task will be developed as a preparatory study on a methodology to assess external costs of maritime transport. In order to do that, all the impacts will be analysed (with focus on impacts due to air pollution) and for each of them the methodological aspects relevant in assessing these impacts, together with data used by the available published literature, will be recalled. Finally, methodological weaknesses will be emphasised, so as to underline sources of uncertainties. The idea is to determine the relevant parameters that should be taken into account in the definition of an analytical approach, to signal research gaps so as to pave the way to future research activities. This will make possible to propose a methodology to be developed in future research for maritime transport and to test through a case study what are the main steps of such analysis.

The last part of the report will emphasise future research directions.

2. External costs of transportation

Generally speaking, external costs are defined as those costs which arise when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group (Bickel and Friedrich, 2005). In the case of transport, these costs to society are generated by transport users that, without policy intervention, are not taken into account and borne by the transport users themselves (Maibach *et al*., 2007; Maddison *et al*., 1997; Mayeres *et al*., 1996; Button, 1990). For instance, in the case of transport these costs comprise the costs of air and noise pollution which the individual user will not take into account in deciding how many journeys to make.

In transport sector, external costs emerge because of scarce infrastructure (subjected to congestion patterns) and side-effects borne by other users (such as accidents and environmental impacts).

Before analysing in detail the approaches and methodologies developed to estimate external transport costs, it is necessary to clarify some preliminary methodological issues, such as the fact of considering marginal vs. average costs and the cost components that should be included in the estimation of external costs. In the following analysis we consider all these indexed, by specifying their best use in policy making definition

Table 1 – Specification of cost components according to transport modes

Cost component	Road	Rail	Air	Water
Costs of scarce Infrastructure	Individual transport is causing collective congestion, concentrated on bottlenecks and peak times.	Scheduled transport is causing scarcities (slot allocation) and delays (operative deficits).	See Rail.	If there is no slot allocation in ports/channels, congestion is individual.
Accident costs	Level of externality depends on the treatment of individual self accidents (individual or collective risk) insurance covers compensation of victims (excluding value of life).	Difference between driver (operator) and victims. Insurance is covering parts of compensation of victims (excluding value of life).	See Rail.	No major issue.
Air pollution costs	Roads and living areas are close together.	The use of diesel and electricity should be distinguished.	Air pollutants in higher areas have to be considered.	Air pollutants in harbour areas are complicated to allocate.
Noise	Roads and living areas are close together.	Rail noise is usually considered as less annoying than other modes (rail bonus). But this depends on the time of day and the frequency of trains.	Airport noise is more complex than other modes (depending on movements and noise max. level and time of day).	No major issue.
Climate change	All GHG relevant.	All GHG relevant, considering use of diesel and electricity production.	All GHG relevant (Air pollutants in higher areas to be considered).	All GHG relevant.
Nature and landscape	Differentiation between historic network and motorways extension.	Differentiation between historic network and extension of high speed network.	No major issue.	New inland waterways channel relevant.

Source: Maibach *et al.*, 2007

Table 1 above summarised how the general impacts sketched above should be considered in the different transport modes. Congestion costs are more significant for road transport, especially in urban areas, whilst for scheduled transport it should be intended as excessive waiting time to use the slots. Accidents costs are treated similarly for all means of transport. Air pollution, noise and climate costs highly depend on the distance from polluting source and the exposed individuals and the density of concerned areas, together with the kind of fuel chosen. Nature and landscape impacts are relevant only for new transport networks.

Besides external costs estimation, it is important to understand the degree of internalisation of such costs, so as to give some insights on how to apply policy instruments.

Table 2 specifies which part of the marginal social cost should be considered as the external part, by specifying how to treat different transport modes.

Table 2 – Degree of internalisation per cost component and mode of transport

Cost component	Social Costs	External part in general	External part road	External part road and air	External part water
Cost of scarce infrastructure	All costs for traffic users and society based on the difference between the current traffic situation and an optimal situation Time costs Costs of reduced reliability	Cost entailed by additional demand above a certain traffic volume	Difference between marginal and average costs Congestion costs	Difference between WTP for scarce slots and average airport/air control charges	Difference between marginal and average costs
Accident costs	All direct and indirect costs of an accident, e.g.: Material costs Medical costs Production losses Suffer and grief	Part of social costs which is not considered in own risk anticipation and not covered by insurance	Additional costs for the health sector WTP for fatality risk reduction	WTP for fatality risk reduction (depending on insurance systems)	WTP for fatality risk reduction
Environmental costs	All damages of environmental nuisances Health costs Material damages Biosphere damages Long term risk	All remaining costs	Total damage to society and nature	Total damage to society and nature	Total damage to society and nature

Source: van Essen *et al*. (2007)

Regarding the adopted approaches to estimate transport external costs, in general we can identify two main approach, i.e. the bottom-up and top-down one, both having advantages and pitfalls. For instance, the estimation of marginal costs is usually based on bottom-up approaches, which consider specific traffic conditions (by referring to case studies). In this approach, impacts of emissions to health, water and soil are monetised following the impact pathway approach. For example, in the case of road transport, the impact of a single vehicle will be determined by considering its technical characteristics together with local environmental data (so as to estimate its impact on the pollutant concentrations). Then, through adequate dose-response functions, the impact of the increase of concentrations due to the use of a single vehicle will be assessed. Finally, all the impacts of the single vehicle are summed up to derive the aggregate impact of that mode of transport. Uncertainties about impact estimates (and consequently on external cost valuation) derive from uncertainties related to the slope of the "dose-response" function and the contribution to ambient concentration of a given pollutant emission.

In order to get national averages of external cost, the estimation of average costs are based on top-down approaches using national data. For example, in the case of SO_x, the external cost of a mode of transport will be derived by considering the total concentration of this pollutant (for example at national level) and by determining which part of the total concentration is imputable to transport sector and to the specific transport mode considered.

It is important to note that each approach has advantages and weaknesses, so none of the two is superior to the other. In particular, the top-down approach is more suitable for deriving average costs. On the one hand, they are more representative on a general level and make possible to compare between modes of transport. On the other hand the cost function has to be simplified and cost allocation to specific traffic situations and the differentiation for vehicle categories is rather aggregated. Therefore the extraction of marginal cost is rather difficult.

The bottom-up is more appropriate when dealing with marginal cost valuation: they are more precise and accurate, with potential for differentiation. However, they are costly and difficult to aggregate to get average figures for transport clusters or national averages. In practice a mixture of bottom-up and top-down approaches (with representative data) should be combined.

In order to conclude this brief introduction on external costs of transportation we would emphasize the high variability of the point estimates get from different studies. Quinet (2004: 468) concludes that point estimates differ because of: the specifics of the situations; the type of cost taken into consideration; the types of external effect taken into account; the physical relationships; the hypotheses used by the modelling framework and the unit values.

In fact, some authors (Mayeres *et al*., 1996) question the suitability of cost estimates derive above for policy making purposes. They stress that marginal external costs are always computed for a given equilibrium and that this equilibrium changes due to the implementation of social cost pricing. They conclude that “what is needed is a marginal external cost function, rather than a point estimate of the external cost in the present equilibrium” (p. 111). In this respect, they suggest to express the external cost information as a function of the gram of pollutant.

Regarding maritime transport, the following issues deserve particular attention:

- external cost components that should be considered in empirical studies;
- applicability of methodologies adopted for other transport modes (and their robustness with respect to the sources of variability explained above);
- methodological aspects that should be adapted to maritime transport specificity and occurrence of local effects.

Empirical studies consider congestion, accident, environmental and climate change costs. With regards to maritime costs, it has to be noted that congestion costs are considered a negligible component, due to overcapacity of existing infrastructure with respect to the current demand. Regarding accident costs, the same considerations made for other transport modes hold. Consequences of ship accidents, like victims or severe injuries should be assessed similarly for other transport modes.

Marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because most of the transport activities take place outside densely populated areas.

Environmental impacts regards both air and water pollution. Regarding air impacts, ship emissions on atmosphere comprises ozone and aerosol precursors (NO_x, CO, VOCs, SO_2, etc) and the emissions of greenhouse gases (CO_2). Effects of these pollutants are well known. SO_2 and NO_x can become converted into sulphate and nitrate particles. Exposure to fine particles is associated with increase mortality and morbidity. Shipping emissions contribute notably to the formation of ground-level ozone, especially in the Mediterranean region, with effects human health and crop yields. The deposition of sulphur and nitrogen contribute to exceedances of critical loads of acidity. Nitrogen oxides lead to eutrophication, which affects biodiversity both on land and coastal waters. Finally, emissions from ships contribute to climate change.

With respect to other transport modes, ship emissions let out 150-300 times more sulphur per ton-kilometre than a truck (with low sulphur content of diesel oil) and twice as much NO_x per ton-kilometre than a truck. In the case of ship emissions, the degree of exposure varies considerable with respect to land transport, and depends on ports distance from city centre.

With respect to other transport modes, ship transport has significant impacts on water, due to the effects of ballast water and the use of antifouling varnish. All these impacts will be analysed in depth in the next paragraphs.

Last but not least, maritime transport produce important impacts on soil, due to the high land use consumption entailed by location of harbours and due to sediment deposition.

Indeed the occurrence of these external effects varies according to the different activities entailed by maritime transport (namely cruising, manoeuvring, hotelling, tanker offloading and auxiliary generators).

For what concerns the applicability of methodologies adopted for other transport modes to maritime transport, congestion and noise costs should be left apart, since they are normally assumed to be negligible. For accident external costs the methodologies described above could be adopted.

It is clear that the analytical approach adopted to assess environmental costs (with particular reference to those relating to air emissions) and described above, in order to be applicable to maritime transport have to be adjusted to consider the following aspects:

- The existing literature on climate change external costs focus on shadow price of CO_2. However, in maritime transport other GHGs, such as NO_x, are relevant. As a consequence, a shadow price for NO_x needs to be defined;
- Health effects of ship emissions depend on exposure to pollutants. Of course this occurs only for activities at ports, whilst health effects of other activities (like cruising) could turn to be negligible to the absence of exposure. Dose response function should consider this aspect.

3. Description of maritime transportation activities

With respect to other transportation mode, the assessment of maritime transport environmental impacts is a challenging task, since these impacts are not entailed only by navigation but are dependent on a number of activities carried out in ports (see Figure 1 below) such as:

- The navigation, i.e. the transport (to the port terminal), the storage and loading of goods and passengers. In particular, before arriving at a port, a ship should be driven from open sea to a part of river or a canal, then reach docks. Once the ship is berthed, other (terminal) activities take place, i.e. unloading/loading; storage and unloading/loading of hinterland modes. The sub-activities of the maritime transport are sketched in Figure 1 below. Their environmental impacts will depend on port setting and the management of port operations[1]. The importance of this latter aspect is witnessed by the development of environmental management systems for ports;
- the construction, maintenance, cleaning and dismantling of ships and vessels. This activity can either be carried out at port or in other areas close to it. Despite their physical location, it is undoubted that their side-effects should be computed as maritime transport external effects.
- the construction and maintenance of port terminal (in terms of land consumption and generated waste).

A list of maritime transportation activities is reported below (see Box 1).

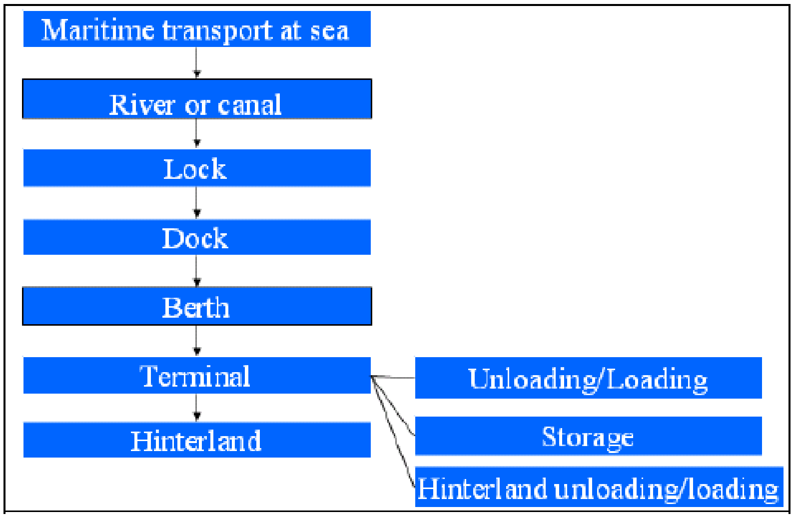
The impacts of maritime transport can be analysed by considering different receptors (air, water, soil, ecosystem and other) or by considering the activities.

As the objective of this work is to analyse the impact of maritime transport, we preferred to combine the two approaches, analysing the impacts on receptors due to the different activities. We thus identify the most relevant impacts and describe them in depth, by referring to published papers, research report, policy documents and any other relevant source that analyse them in a rigorous and scientific way.

Regarding navigation, the activities that deserve more attention are: mooring, docking and leaving from the port.

[1] This point becomes evident if one thinks at the delays caused by congestions. Congestion does not only imply time loss and higher operating costs, but also entails environmental costs, due to the longer navigation time.

Figure 1 - Decomposition of maritime transportation activities



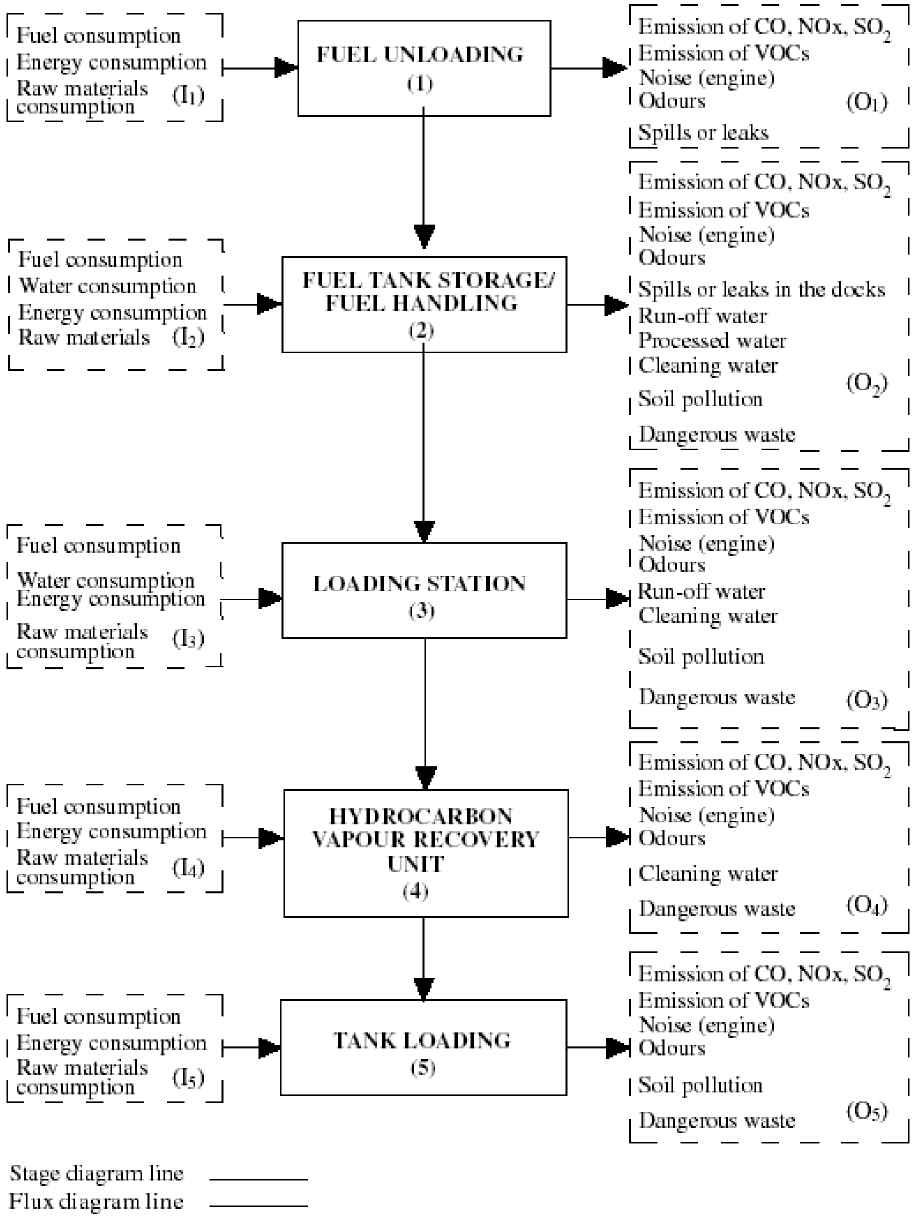
Source: Bickel et al. (2006: 3)

Box 1 - List of Port Activities

1. Sea traffic
2. Land traffic
3. Storage, loading and unloading of oil products
4. Storage, loading and unloading of bulk liquids
5. Storage, loading and unloading of bulk solids
6. Storage, loading and unloading of general container merchandise
7. Storage, loading and unloading of non-container merchandise
8. Fishing activity
9. Handling and converting perishable bulk solids
10. Port services
    - Pilotage
    - Towing
    - Mooring
    - Lock conditioning
    - Waste disposal
    - Preservation of Installations and Infrastructure
    - Security
    - Provisioning of vessels
11. Administrative services
12. Construction and repair of vessels
13. Sanitation services
14. Emergency operations
    - Fire protection system
    - Sea rescue
    - Emergency energy generators
    - Maintenance and cleaning of the port area
15. Maintenance operations
    - Buildings, gardens, workshops, roads, docks, reflecting pool
16. Dredging
17. MARPOL waste treatment
    - MARPOL I: oil
    - MARPOL II: noxious liquid substances
    - MARPOL III: harmful substances in packaged form
    - MARPOL IV: sewage from ships
    - MARPOL V: garbage from ships
18. Civil works
19. Abandoned or unused installations and merchandise
20. Recreational activities
21. Marinas and yacht clubs
    - Land area
    - Sea area

Source: Peris-Mora et al. (2005)

Figure 2 - Analysis of storage, loading and unloading of oil products activities



Source: Peris-Mora *et al*. (2005)

4. Description of Vessels

Ship Type

Ships can be classified according to their purpose and size. Merchant vessels refer to ships that transport cargo and passengers. A simplified classification is that of Lloyds MIU: bulk; container; tanker (and gas tanker); general cargo; passenger; reefer and Roro.

Dry Cargo ships can be classified in bulk carriers and container ships. The former ones are ocean-going vessels used to transport unpacked bulk cargo (iron, bauxite, coal, cement, grain and other), whose dimensions are determined by ports and sea routes that they need to serve. Bulk cargo can be very dense, corrosive, or abrasive, and presents safety problems. For this reasons, new international regulations have since been introduced to improve ship design and inspection, and to streamline the process of abandoning ship. Container ships transport their cargo in truck-size containers (containerization). Modern container ships can carry up to 15,000 TEU[2].

Tankers are designed to transport liquids in bulk (crude oil, petroleum products, liquefied petroleum gas; liquefied natural gas; chemicals; vegetable oils; fresh water, wine and other food). Apart from pipeline transport, large tankers are the only method for transporting large quantities of oil. However, they caused large environmental disasters.

Specialised ships include reefer and RoRo cargo. A reefer ship is a type of ship typically used to transport perishable commodities which require temperature-controlled transportation (e.g. fruits, meat, fish, vegetables and other dairy products). Roll-on/roll-off (RORO or ro-ro) ships are ferries designed to carry wheeled cargo (e.g. cars, trucks, semi-trailer trucks, trailers or railroad cars). RORO vessels have built-in ramps which allow the cargo to be efficiently "rolled on" and "rolled off" the vessel when in port.

Passenger ships are vessels whose primary function is to carry passengers. The category does not include cargo vessels which have accommodations for limited numbers of passengers. Passenger ships include ferries, which are vessels for day or overnight short-sea trips moving passengers and vehicles (whether road or rail); ocean liners, which typically are passenger or passenger-cargo vessels transporting passengers and often cargo on longer line voyages; and cruise ships, which typically transport passengers on round-trips, in which the trip itself and the attractions of the ship and ports visited are the principal draw.

Trozzi and Vaccaro (1998) detail more the classification, as reported in Table 3.

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[2] One TEU represents the cargo capacity of a standard shipping container 20 feet long and 8 feet wide.

Table 3 – Ship type class

Code	Name
SB	Solid Bulk
LB	Liquid Bulk
GC	General Cargo
CO	Container
PC	Passenger/Ro-Ro/Cargo
PA	Passenger
HS	High speed ferries
IC	Inland Cargo
SS	Sail ships
TU	Tugs
FI	Fishing
OT	Other

Entec (2002) proposes an even longer list of vessel categories[3], according to their size and purpose.

Type of Fuel and Engine

As reported by Trozzi and Vaccaro (1998), world ship bunker demand is essentially covered by oil products, ranking from marine distillate to marine fuels.

Two types of marine distillates exists:

- marine gas oil (MGO): a distillate fuel;
- marine diesel oil (MDO): a heavier distillate fuel, which may contain a proportion of residual fuel oil.

The vessels have main engines (MEs), used for ship propulsion at sea and auxiliary engines (AEs), used for generating electrical power on board. When ships are stationary and at berth the MEs shut down. In general, AEs are used continuously except when shaft generators coupled to MEs are available at sea, or when a shore-side electricity link is provided at berth. Cooper (2003) reports that all AEs are four-stroke marine diesel engines operating at engine speeds of 500–2500 rpm (i.e. so-called medium- and high-speed diesels) with power output in the range of 30–3000 kW. The AE power requirement on board a ship can vary. Once in port, however, the power requirement is usually less but can still vary depending on the type of ship activity, e.g. hotelling, loading operations.

[3] Liquefied Gas; Chemical; Oil; Other Liquids; Bulk Dry; Bulk Dry/Oil; Self-Discharging Bulk Dry; Other Bulk Dry; General Cargo; Passenger/General Cargo; Container; Refrigerated Cargo; Ro-Ro Cargo; Passenger/Ro-Ro Cargo; Passenger; Other Dry Cargo; Fish Catching; Other Fishing; Offshore Supply; Other Offshore; Research B31; Towing/Pushing; dredging and other activities.

Marine distillates are normally used for the main engines of small vessels and for the auxiliary engines of larger vessels. Large vessels normally use marine fuels.

The classification used by Trozzi and Vaccaro (1998) for fuel and engine is presented in Table 4 and Table 5.

Table 4 - Fuel classification

Code	Name
BFO	Bunker fuel oil
MDO	Marine diesel oil
MGO	Marine gas oil
GF	Gasoline fuel

Source: Trozzi and Vaccaro (1998)

Table 5 - Engines type class

Code	Name
SE	Steam turbines
HS	High speed motor engines
MS	Medium speed motor engines
SS	Slow speed motor engines

Source: Trozzi and Vaccaro (1998)

Size

Following Entec (2005), the size of a vessel is identified by considering the number of main engines (ME) and auxiliary engines (AE) installed per ship. In particular, this study analyse the Lloyd's Register – Fairplay database reporting on average 1.4 ME and 3.5 AE. Based on these data, it classifies the vessel type as depicted in Table 6.

Table 6 - Assumed engine numbers and engine sizes for three different vessel size classes

	Small	Medium	Large
ME	1 small	1 medium	1 large
AE	4 large	4 medium	4 large

Source: Entec (2005)

Table 7 shows the engine sizes for these three vessel categories.

Table 7 – Main engine size categories and representative engine size for three different vessel size classes

	Small	Medium	Large
ME			
Class boundaries	ME < 6,000 kW	6,000 kW <= ME < 15,000 kW	ME >= 15,000 kW
Representative engine size	3,000 kW	10,000 kW	25,000 kW
AE			
Class boundaries	ME < 1,000 kW	1,000 kW <= ME < 2,000 kW	ME >= 2,000 kW
Representative engine size	530 kW	1,470 kW	3,780 kW

Source: Adapted from Entec (2005)

Entec (2005) also estimates the operating hours per different activities and location, as shown in Table 8 below.

Table 8 - Average operating hours of engines (hours/year)

Operation	**(hours/year)**
Time at Sea	6,000
Time at Berth	700
Time Manoeuvring	20
Total Operating Time	6,720
Not Operating (no relevant load factors on engines) (refurbishment etc.)	2,040
Total hours per year	8,760

Source: Entec (2005)

With these data, it is possible to derive the total power use per engine types per year (Table 9 Table 10, Table 11) and fuel consumption (Table 10).

Table 9 – Main engine power use per vessel and year

Small		**Medium**	**Large**
	(kWh/year)	**(kWh/year)**	**(kWh/year)**
At sea	14,400,000	48,000,000	120,000,000
At berth	21,000	70,000	175,000
Manoeuvring	12,000	40,000	100,000
Total Power Use	14,433,000	48,110,000	120,275,000

Source: Entec (2005)

Table 10 – Auxiliary engine power use per vessel and year

	Small	Medium	Large
	(kWh/year)	(kWh/year)	(kWh/year)
At sea	4·252,000 = 1,008,000	4·666,000 = 2,664,000	4·1,710,000 = 6,840,000
At berth	4·39,200 = 156,800	4·103,600 = 414,400	4·266,000 = 1,064,000
Manoeuvring	4·1,400 = 5,600	4·3,700 = 14,800	4·9,500 = 38,000
Total Power Use	4·292,600 = 1,170,400	4·773,300 = 3,093,200	4·1,985,500 = 7,942,000

Source: Entec (2005)

Table 11 – Total engine power use per a and year

	Small	Medium	Large
	(kWh/year)	(kWh/year)	(kWh/year)
At sea	15,408,000	50,664,000	126,840,000
At berth	177,800	484,400	1,239,000
Manoeuvring	17,600	54,800	138,000
Total Power Use	15,603,400	51,203,200	128,217,000

Source: Entec (2005)

Table 12 – Total engine fuel consumption per vessel and year

	Small	Medium	Large
	(t/year)	(t/year)	(t/year)
At sea	3,082	10,133	25,368
At berth	40	110	281
Manoeuvring	4	12	31
Total fuel consumption per year	3,126	10,255	25,680

Source: Entec (2005)

5. The environmental impacts of maritime transport activities

Each maritime transportation activity occurring in ports, at sea or during ship construction/maintenance/dismantling, presents different environmental impacts, on air, water, ecosystem and other. Together with these impacts also those deriving from accidental events or illegal actions have to be considered when evaluating the overall contribute of the maritime transportation sector to environmental quality.

The interrelation among environmental impacts and activities/events of the maritime transportation sector are reported in Table 13 and the main one are analysed in the following sections, on the basis of a large literature review.

Table 13 – Impacts due to maritime transport activities, including illegal one and accidental events

		AIR					WATER		SOIL/SEDIMENT				ECOSYSTEM		OTHER	
Activities-events/Impacts		Local Air Pollution (NOx, SO2, CO2, CO, VOC, PM)	Noise	Vibration	Odour	Global Air pollution impact	Water pollution	Water turbidity	Soil/sediment pollution	Acidification	Erosion	Land consumption	Biodiv. loss	Habitat Loss/Degradation	Congestion	Waste generati
In ports	Manoeuvring	■	■	■		■		■		■	■					
	Loading & Unloading/ Operations on terminals	■	■	■	■	■	■		■	■						■
	Hotelling (lighting, heating, refrigeration, ventilation, etc.)	■	■	■		■				■						■
	Dredging	■	■			■	■	■		■			■	■		■
	Land traffic (heavy vehicle, railway)	■	■	■		■	■		■	■			■	■	■	
	Waste disposal/illegal dumping	■	■		■	■	■	■	■	■		■	■	■		■
	Port expansion/ Infrastructures construction and maintenance	■	■	■		■	■	■	■	■	■	■	■	■		■
	Fuel deposits				■		■		■			■	■	■		■
	Discharge of ballast water						■	■	■				■	■		■

	Dumping of black (sewage) and gray (shower, sink, and galley) water															
	Bulk handling and Goods movement															
	Industrial activities															
	Spills															
At sea	**Cruise**															
	Ilegal dumping															
	Dumping of black (sewage) and gray (shower, sink, and galley) water															
	Spills															
Ships building, maintenance, dismantling	**Hull paintings**															
	Metal degreasing															
	Demolition															

Impacts on Air

Air Pollution

Maritime transportation is generally considered environmental friendly compared with other transportation means, above all if energy efficiency is measured per tonne transported/per mile (Espo, 2001). Nevertheless emissions from the growing maritime transport sector represent a significant and increasing air pollution source.

Health and environmental impacts of air pollutants are highly dependent on the proximity of the emission sources to sensitive receptor sites. This means that, compared to land-based sources, at least some of the maritime emissions have less health and environmental impacts since they are released sometimes far from populated areas or sensitive ecosystems. However, in harbour cities ship emissions are in many cases a dominant source of urban pollution and need to be addressed, in particular when considering fine particulate matter. Furthermore, as for all other sources, also emissions from ships are transported in the atmosphere over several hundreds of kilometres, and thus can contribute to air quality problems on land, even if they are emitted on the sea. This pathway is especially relevant for deposition of sulphur and nitrogen compounds (Cofala et al., 2007).

In general, all ships activities are responsible of air pollutants emissions and particularly: cruise, ships movement in port, ships activities in hotelling phase (lighting, heating, refrigeration, ventilation, etc.), tanker loading and unloading (Trozzi, 2003).

As concerns ship building/maintenance/dismantling activities, the principal emissions are dust, particles, gases (e.g. from welding), smell, aerosols. Considering specific activities, a main problem is the emission of volatile organic compounds from metal degreasing and painting (European Environment Agency, 2002). As regards hull surface cleaning, paint removal, changes of zinc anodes, and paint application, the important environmental aspects are dust emissions (from sandblasting, grinding etc.) and emission of solvents, where solvents contain volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) (Hayman et al., 2000). Demolition or main modification of ships, produce asbestos, heavy metals, hydrocarbons, ozone depleting substances and others.

As already mentioned, all these ship building/maintenance/dismantling activities can either be concentrated within the port or carried out in other areas.

When focusing on ships, it has to be taken into account that, for economic reasons, many vessels use heavy fuel oil which has very high sulphur content (90% higher than petrol or conventional diesel) (Butt, 2007). The main air emissions from burning this type of fuel are:

- Sulphur Dioxide (SO2);
- Nitrogen Oxides (NOX);
- Volatile Organic Compounds (VOC);
- Primary Particulate Matter (PM);
- Carbon Dioxide (CO2).

The amount of gases emitted from marine engines into the atmosphere is directly related to total fuel oil consumption (IMO, 2000), that depends on different factors, such as the actual hull shape, the loading condition, the hull roughness, the state of the engine, etc. Auxiliary engines also contribute to the total exhaust gas emissions. This contribute is particularly important for cruise ships, that have a continuous need for ancillary power to meet lighting and ventilation demands both at sea and in port. In general, ship emissions in-port depend on manoeuvring time, time spent, and cargo operations (vessel-type dependent) (Endresen et al., 2003).

Emissions can also come from incineration of waste aboard; in this case, dioxins and other heavy metals can be released into the atmosphere.

Focusing on all port operations and air pollution, the main factor to take into consideration is that each category – ocean/sea-going vessels, harbour craft, cargo handling equipment, trucks and locomotives – is mainly powered by diesel engines, that are significant contributors to air pollution.

The most relevant ship activities as concerns air pollution identified by Trozzi (2003) are:

- loading and unloading of petroleum products, produces volatile organic compound emissions;
- dry docks, produce evaporative volatile organic compound emissions;
- passenger car traffic, produces combustion products and evaporative volatile organic compound emissions;
- heavy vehicle traffic, produces combustion products emission;
- railway traffic, produces combustion products emission.

As results, in and around ports harmful pollutants are present, e.g. particulate matter (PM10 and PM 2.5), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and Lead (Pb) (IAPH, 2007).

The presence of these pollutants, on the one hand impacts on local (or regional) air quality, that is mainly linked to pollutants such as PM, NOx and Sulphur. On the other hand the emission of greenhouse gases (e.g. CO2) have global impact on climate.

As concerns the local air pollution, it has to be taken into consideration that port areas have historically grown up very close to urban areas and port operations can affect the people living and working in these areas. As already mentioned, local air quality and the negative effect on human health is largely dominated by the presence of nitrogen oxides, PM (2,5 or 10), acid deposition and nitrogen deposition. Nitrogen (NOx) and particulate matter (PM) contribute to serious health problems such as premature mortality, asthma attacks, millions of lost work days, and numerous other health impacts. (IAPH, 2007)

In particular, NOx and VOC emissions contribute to the formation of ground-level ozone (photochemical smog). While stratospheric ozone protects the surface of the earth from harmful ultraviolet radiation, tropospheric ozone, formed from the reaction of nitrogen oxides and hydrocarbons when combined with sunlight, is a powerful oxidant that damages human lung tissue, vegetation, and other materials. Short-term exposures to high concentrations can cause a range of acute adverse human health effects from irritation and shortness of breath to decreased immune functions and increased inflammation and permeability of lung tissue. Young children, the elderly, and individuals with preexisting respiratory disease are at particular risk of serious acute adverse effects from ozone exposure. The chronic human health effects of ozone exposure are less well known, but there is the possibility of irreversible morphological changes of the lung, genotoxicity, and carcinogenicity. (IMO, 2000)

Also SO_2 emissions negatively impacts public health, in particular sulphate particles can induce asthma, bronchitis and heart failure.

As concerns CO, health effects can result from the reduction of oxygen delivery to the body's organs (such as the heart and the brain) and tissues. Cardiovascular effects are the most serious effects of CO for those who suffer from heart disease. There are also effects on the central nervous system. Breathing in high levels of CO can result in blurred vision, reduced ability to work or learn, and reduced manual dexterity. CO also contributes to the formation of smog. IAPH, (2007)

Also impacts not linked directly to human health can derive from maritime transport emissions. For instance, sulphur and nitrogen compounds emitted from ship, oxidizing in the atmosphere, can contribute to acidification, causing acid depositions that can be detrimental to the natural environment (lakes, rivers, soils, fauna and flora). Emissions of these compounds at sea can exert an influence on land-based objects many thousands of kilometres away and vegetation.

NO_x emissions also can cause nutrient overload in water bodies, with eutrophication impact. The excess of nutrient nitrogen can be detrimental to the fragile balance of ecosystems, including marine ecosystems.

Particles and NO_2 linked to air emissions from maritime transport activities, as highlighted by Holland et al. (2005), can have impacts on visibility, by reducing the visual range.

Considering the global effects, although carbon dioxide is the most important trace constituent as concerns global climate change and shipping is just a small contributor to the world total CO_2 emissions (1.8% of world total CO_2 emissions in 1996, according to IMO (2000)), other pollutants emitted from ships (e.g. nitrogen oxides, carbon monoxide, volatile organic compounds (VOC)) can contribute to the greenhouse effect, leading to enhanced surface ozone formation and methane oxidation (Endresen et al., 2003). Ozone global warming potential occurs because it absorbs both incoming solar radiation in the ultraviolet and visible regions and terrestrially emitted infrared radiation in certain wavelengths. Stratospheric ozone absorbs more energy than it re-radiates, acting as a net source of warming, although it exerts both heating and cooling influences. Ozone resulting from ship emissions – as the NO_x from ships reacts with ship-based and biogenic ocean/coastal VOCs, or mix with land-based emissions and react – can contribute directly to the warming in the surface-troposphere system.

In particular, the study by IMO (2000) highlights that, due to the highly nonlinear response in ozone formation from emissions of precursors like CO and NO_x, with higher efficiency in regions that are affected little by pollutants, ozone formation due to ship emissions over oceans away from industrial regions like the Atlantic and Pacific Oceans are more efficient than emissions over polluted coastal regions (e.g., the North Sea).

Moreover, Schreier et al. (2006), underlines that particle emissions from ships change the physical properties of low clouds, for the so-called indirect aerosol-effect. Particles and their precursors from ship emissions are able to act as cloud condensation nuclei (CCN) in the water-vapour saturated environment of the maritime cloud. Aerosols can re-radiate sun's energy, causing temporary cooling effects that mask the longterm warming of GHGs. This study by Schreier demonstrates that ship emissions modify existing clouds by decreasing the effective radius, while they increase droplet concentration and optical thickness. In particular, these effects seem more relevant in areas where the background pollutant concentration are low, as at open sea. Anyway, modifications of clouds by international shipping can be an important contributor to climate on a local scale, but further studies are needed to assess the global impact of ship-track formation on climate.

Noise and Vibration

Noise is related to all maritime transportation activities, starting from the building processes.

As concerns activities in ports and noise impact, Trozzi (2003) identifies as main areas the following three:

- passenger car and heavy vehicle (trucks) road traffic, that is the most important one;
- goods movement, deriving from machinery such as quay-crane, pumps, etc.;
- rail traffic noise: rail movement in port and in surrounding areas are prevalent to low speed and of consequence the noise level is not so high, however in highly trafficked areas the problem can be relevant.

uMoreover, in general most of the activities in ports produce noise. For instance, the development of specialised container and bulk handling facilities with their 24 hour high-speed operations produces an increase of noise. Also the equipment used for dredging activities produce noise and so on.

Considering the ships, the major noise sources are the main propulsion machinery, the auxiliary engines, the propeller and transverse propulsion unit, and the heating, ventilation and air conditioning system (Holland and Wong, 1995; Yakamini et al.,1995). Machinery generates noise into the surrounding air and also induces vibration into any structure to which it is connected. Noise transmission can either be waterborne, airborne or structure borne. The most important noise for the port area is the airborne noise and particularly the ambient noise in outdoor areas.

Impacts on Water

Water Pollution and Turbidity

Most of the maritime transportation activities impact on water, as can be expected due to their proximity and strict relation with the sea.

In particular, the several chemical products involved in these activities as well as substances transported by ships can end up in the sea, causing water pollution. The discharge can derive from authorised activities, accidents, but also from illegal actions. This is well represented in the list of sources of water pollution from ships and other than ships, in port and in navigation, reported by Trozzi (2003):

- oil of bilge and motor fuel leakage from ships and gasoline and diesel oil leakage from pleasure crafts;
- accidental leakage of oil and chemical substances in loading and unloading of products;

- pollution from slop (residual of chemical products contained in the tanks and of the product used in the washing operations) either in the case in which it is treated and in the case in which it is unauthorized discharged (tanks washing close to the coast);
- leaching of antifouling paints (particularly containing organotin tributyltin) used to coat the bottoms of ships to prevent sea life such as algae and mollusks attaching themselves to the hull thereby slowing down the ship and increasing fuel consumption;
- dumping of black (sewage) and gray (shower, sink, and galley) water;
- operations on terminals and fuel deposits, causing accidental discharge of oil in the sea, loss from deposit tankers and pipeline;
- dry docks operations causing accidental discharge of oil and other chemicals in the sea;
- ships demolition causing accidental discharge of oil and other chemicals in the sea;
- storm water runoff from port parking lots (organic compounds, fine particulate, heavy metals, etc.);
- water thermal pollution;
- water stagnation and eutrophication and anoxia risks due to weak water turnover;
- dredging and excavation of port areas with resuspending of materials and pollutants;
- illegal waste and waste water dumping.

One aspect to be considered when speaking about accidental events, is that, as underlined by Darbra et al. (2006), the continuous movement of ships in a confined and reduced area such as the port, inevitably gives rise to collisions between ships or between ships and the coast at frequent intervals, and to the consequent risk of the release of hazardous materials, which may pollute the marine environment. In some cases, also emergency oil outflows which may happen during navigation in the water area of the terminal are linked to tankers damage and oil spillage from tanks as a result of ships collision in the harbour.

Oil spillages in the course of tanker loading in case of destruction of standers due to mooring ropes rupture and swinging off the berth caused by a sudden, instant squall (particularly in the beginning of the loading process when the tanker has the largest freeboard area) are also possible.

Focusing in particular on ship building and maintenance, different chemical products are involved in the activities. In particular, grinding substances, blasting substances, anti-fouling and coatings can be recognised as main sources of water pollution from these operations.

Due to hull surface cleaning, paint removal, changes of zinc anodes, and paint application important environmental aspects are discharges to water of heavy metals, paint effluent, flush down water and sand blasting substances (Hayman et al., 2000).

The major environmental aspects related to maintaining machinery and auxiliary systems are oil (additives), coolants, gases, electrical/electronic waste, seals, insulation, and scrap-metals. The discharge of oil from dirty ballast tanks, engine room waste and slops results in more oil entering the sea than the major spills from large tanker or bulker accidents. Additional waste results from maintenance activities on machinery and auxiliary systems (Hayman et al., 2000)

Oils and lubricants are products of special interest. Traditionally they are feared pollutants from ships as they might cause much harm to the marine environment. The stern tube may be a significant source of oil leakage into the sea. In general, the stern tube is an environmentally sensitive spot on a ship. This is where the propeller shaft passes through the hull. Seals are installed to hinder leakage of water into the ship. At the same time the propeller shaft has to be lubricated in the stern tube. The lubrication fluid is usually under over-pressure so if the shaft is getting somewhat warped – which often happens over time – fluid is going out of the ship.

Boiler water and cooling water treatment agents are different types of substances added to protect boilers and cooling systems from corrosion and deposits. The reactive and carcinogenic substance hydrazine is traditionally added to the boiler system. Other substances with negative health effects like volatile amines are also common. Sodium nitrite with alkali, borate, chromate salts and aromatic azoles are often added to the cooling water. Carcinogenic nitrosoamines might be formed if cooling water and boiling water get mixed. Both boiling water and cooling water might finally end up in the sea.

As reported in the list above, also dredging can contribute to water pollution. Dredging represents a vital activity for most ports, to guarantee their accessibility. The main environmental issues related to dredging is the contamination of the sediments. Sediments in fact store contaminants deriving not only from ships, but from all the activities insisting on the water basin. Dredging can resuspend these contaminants, producing water pollution. Moreover, dredging can change the water quality also in terms of turbidity and nutrients.

Accidental oil spills represent also an important source of water pollution from maritime transport. One example is represented by the Prestige accident, that saw 59,000 tons of oil spilled close to the Galicia coastline. Several studies were carried out to assess the economic cost of the accident (Garza-Gil et al. 2006, Garza-Gil et al. 2006b, Loureiro et al., 2006, Loureiro and Ojea, 2008).

As already mentioned, together with normal activities and accidents, water pollution can derive from illegal dumping practices, carried out in order to avoid cost, delays and constrictions linked to waste disposal. This illegal dumping in many cases concerns hazardous substances, particularly dangerous for the environment.

Impacts on Soil

Soil and sediment contamination and acidification

Soil pollution from the maritime transportation sector is mainly linked to the terrestrial activities in port areas.

Different sources of soil pollution in port and in its neighbourhood are listed below (Trozzi, 2003):

- operations on terminals and fuel deposits cause accidental discharge of oil in the soil, loss from deposit tankers and pipeline;
- spill from the bulk handling device (oil, rubber etc.) and dust spread during the handling (transports between quay and storage area);
- oil and other spillage from the vehicles dissolve the surface and may cause a homogeneous tarmac to dissolve;

- heat and high loads cause settlements of the surface;
- spill of chemicals from demolition of ships;
- emissions of SO2, NOX cause acid rain and, consequently, soil acidification.

Port area are also often characterized by historiucal soil pollution, related to activities accommodated in the area in the past.

As concerns sediment contamination, it is strictly linked to water pollution. Contaminants can pass from water to sediments. These contaminants do not come solely from port and maritime transport activities but, as already mentioned, can arrive from all those insisting on the water basin, including heavy industry. As results, the sediments in port areas often contain pollutants such as heavy metals, PAH, PCB.

Erosion

Erosion is another impact on soil, linked to the marine transportation sector that can produce degradation of natural habitats and consequent loss of biodiversity.

The presence of a port, by itself, modifies the natural coastal sediment transport. In particular, it can act as a wall obstructing the transportation and thus causing erosion (Saengsupavanicha et al., 2008).

Moreover, the flow induced by the passage of the vessels generates erosive forces that may damage harbour basins, navigable channels, beaches and seaside properties. Increased demand for fast maritime transport in coastal waters, canals and rivers has resulted in rapid evolution of high-speed crafts, with an increase also of this erosive impacts (Trozzi, 2003).

Land Consumption

Ports, activities and related infrastructures present in these areas occupy and consume land. This could have direct effects on ecosystems (see below). Moreover, further development of ports could entail the consumption of more soil, in all cases this expansion does not occur in previously developed areas. If this is the case, it could provoke degradation of natural habitats and biodiversity loss. It has to be noted that port expansion produces land consumption not only because of the expansion of the port terminal, but because normally this expansion is accompanied by transport infrastructure development, which in turn is consume land. It has to be noted that the European Environment Agency considers as an indicator of land use the “direct and indirect take of land”. Specifically, whilst it calculated the indicators related to the other transport means, the one corresponding to maritime transport is not considered.

Impacts on Ecosystems

Biodiversity loss and habitat degradation

Impacts of maritime transportation activities on ecosystems are, in general, interrelated to the impacts already described above, such as air and water pollution, land consumption, noise, etc.

Loss of biodiversity, in particular, is one of the most important environmental impacts due to maritime transportation activities, linked to loss of suitable habitats, caused by port development, as well as by pollution. In addition introduction of alien species, e.g. as a result of ballast water exchange in ships, is of great importance.

Any expansion of port installations, either on land or sea, passes through the consumption of land, implying a certain loss of habitat (Darbra et al., 2004), as already mentioned.

Also dredging have impact on ecosystems. On one side, it can destroy the habitats of marine species (Tull, 2006) and remove subtidal benthic species and communities, on the other one, as already mentioned, it can cause the resuspension of contaminants, with consequent effects on the marine organisms. In general changes in water quality in terms of turbidity, nutrients, contaminants and noise associated with the dredging operation may effect marine floral and fauna (Stojanovic et al., 2006). Moreover, the deposition of suspended material and disposal of dredged material can smother or blanket the sub-tidal communities. In particular, according to the study by Grigalunas et al. (2001), marine disposal of the resulting, non-toxic dredged sediments can adversely affect marine organisms, such as finfish, shellfish and crustacean (primarily lobster).

Transfer of non-indigenus aquatic organisms (including dormant stages of microscopic toxic aquatic organisms such as din flagellates, pathogens such as the bacterium vibrio cholera) with ballast water, used to stabilize vessels at sea is a quite common phenomenon. A wide variety of organisms that are transported in ballast water in ocean trade vessels may establish themselves in new environments when discharged from the ship and alter or impact the receiving ecosystems (Hayes and Sliwa, 2003). Even if they are not toxic, these organisms can enter in competition with the local species, causing heavy environmental impacts. The rate of introductions has been increasing exponentially since the 1800s (Carlton, 2001), this can be also linked to the fact that, as ships travel faster and faster, the survival rates of species carried in ballast tanks have increased; as a result, many introductions of non-indigenous organisms in new locations have occurred, often with disastrous consequences for the local ecosystem - which may include important fish stocks or rare species (Trozzi, 2003).

In general, antifouling have impacts on ecosystems. For instance, copper based antifouling, that are most commonly used instead of TBT, contain organic biocides like chlorothalonil, diuron, triazines, isothiazolinones, zinc pyrithione etc, that are all undesirable in the marine environment (Ahlbom and Duus, 2006).

Beyond the antifouling, there are other, and even more important, contaminants affecting the ecosystems, in particular emissions of SO_x and NO_x, as already mentioned, are major contributors to acid deposition which have demonstrated harmful effects to the natural environment (e.g. lakes, rivers, soils, fauna and flora).

Moreover, as reported in one of the previous sections, NOx deposition can contribute also to the eutrophication, altering the fragile balance of ecosystems.

As seen, emissions from this sector can promote the formation of ozone. The adverse effects of ozone exposure on vegetation include leaf yellowing, premature senescence, reduced growth, and increased susceptibility to pests and other risks. These effects occur with agricultural crops and other vegetation (IMO, 2000).

Water pollution deriving from accidental spills or illegal dumping goes also to impact on ecosystems. In particular, the effect of oil spills can be really heavy for the ecosystems (e.g. prestige accident), bringing to relevant losses of fishes, birds, mammals and other animals.

Finally, the noise produced by marine transportation activities can impact on animals, both in port areas and at sea (US National Research Council, 2003).

Other Impacts related to Waste Production

Maritime transport activities produce a great quantity of waste.

The main sources of waste identified by Trozzi (2003) in port and in its neighbourhood are:

- oil terminals and fuel deposits, producing oily and toxic sludges;
- dry docks operations, producing oily and toxic sludges.

Waste production is also linked to dredging operations. As already underlined, dredging is a fundamental activity to guarantee the ports efficiency. When the dredged material has a good quality, it can be reused, for land nourishment. However, in many cases, mud, silt and sediment dredged from channels or harbour bottoms is highly polluted by hydrocarbons and heavy metals, deriving from a legacy of land based agricultural, industrial and urban activities. This aspect makes costly and complicated the management of this waste.

Also during ships operation a number of waste products are generated onboard the ship.

In particular, cruise ships, though representing less than 1% of the global merchant fleet, are responsible for 25% of all waste, with consequent pressure on the environment (Butt, 2007). This waste consists of glass, tin, plastic, paper, cardboard, steel cans, kitchen grease, kitchen waste and food waste. Generally recyclables are separated and stored for shore disposal or are treated on board (i.e., glass crushing). About 75– 85% of the remaining waste is incinerated (dependent on vessel age and facilities).

In order to avoid the costs, restrictions an delays due to its disposal (Ball, 1999), illegal dumping at sea of waste is practiced by some ships.

Also black water represents waste produced by ships. According to Butt (2007), ships generate between 20 and 40 litres per person per day dependent on passenger numbers.

In the same way, also ballast water represents a waste, when discharged. The analysis of the impacts on ecosystem of this waste was already reported in a previous section.

In ship construction, maintenance and retrofits of older vessels metal pieces, oil contaminated waste, paint, cables, etc., are recognized by Hayman *et al*. (2000) as main sources of wastes. In particular, hull surface cleaning, paint removal, changes of zinc anodes, and paint application produce waste to be treated.

Particularly problematic, as concerns waste production, is the ship demolition phase. Often carried out in developing countries (e.g. India, Bangladesh, Pakistan), it sees the nearly complete absence of facilities for handling waste residues from the demolition process (including heavy metals, PCB, HFC s, asbestos as well as hydrocarbons) (Det Norske Veritas, 1999).

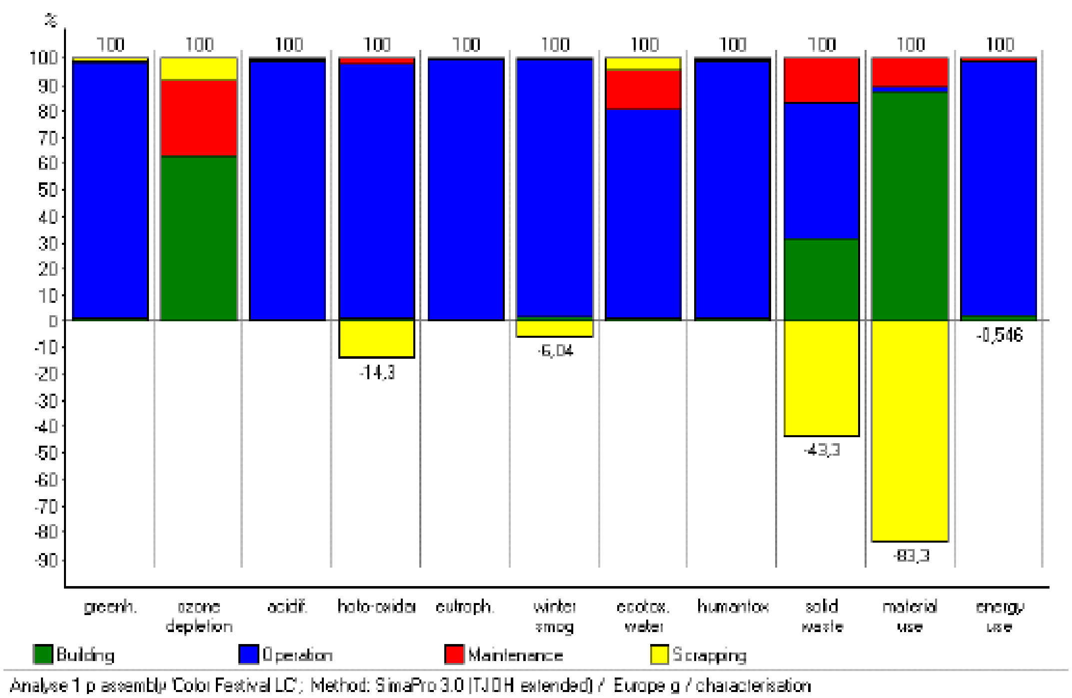
6. Estimated environmental impacts of maritime transport

Particularly interesting when considering the estimate of environmental impacts by maritime transport is the study by Fet *et al*. (2000), within the project "Life Cycle Evaluation of Ship Transportation – Development of Methodology and Testing" that assesses how the different life cycle phases of a ship contribute to different environmental impact categories.

The assessment is based on Eco-indicator 95 classification and characterisation-models in the software SimaPro 4.0. Phases contributing with more than 10% to an impact are considered as important. The study indicates the calculation procedures for exhaust gas emissions, dust/particles, eco-toxicvity, land area occupation, noise exposure.

The results are summarised in the figure below.

Figure 3 – Ship life cycle assessment



Source: Fet et al. (2000)

What emerges from the study is that:

- The operational phase is the only important life cycle phase with respect to greenhouse effect, acidification, photo oxidant formation, eutrophication, winter smog, human toxicology and energy use.
- The operational phase is the most important life cycle phase with respect to ecotoxicological impacts and solid waste. In addition the maintenance phase is important for ecotoxicological impacts. Maintenance and building are also important for solid waste.
- The building phase is the most important with respect to ozone depletion and material use.
- In addition maintenance is important.
- The scrapping phase gives significant negative contributions to photo-oxidant formation, solid waste and material use. This is due to the negative impacts resulting from recycling of materials.

A tool for integrated environmental assessment of ships activities is also proposed by Trozzi (2003).

However, what emerged from the literature review is that, as reported below, most of the recent studies and researches regarding impacts from maritime transportation activities focus on air pollution.

Estimated Impacts on Air

Air Pollution

The literature review highlighted that, in the last decade, several studies were carried out to estimate the emissions from ship activities, at global level, at regional and local level, for specific transportation phases and/or specific pollutants.

In particular, the IMO report (2000) illustrates and compares the estimate for year 1996 of emissions to air from ships resulting from Statistical emission models and fuel consumption methodologies. The results are reported in the tables below (Table 14 and Table 15).

Table 14 - Marine emission in 1996 using fuel consumption methodology based on different emission factors

Gas component		*Supply 138 (Mton)*			*Range (Mton)*
		Low[2)]	CORINAIR[1)]	High[3)]	
CO		0.7	1.00	1.1	0.7-1.1
NMVOC		-	0.33	-	-
CH_4		-	0.04	-	-
N_2O		-	0.01	-	-
CO_2		435.9	437.50	438.2	436-438
SO_2	*Residual*	5.0	5.40	7.0	5-7
	Distillate	0.2	0.40	0.8	0.2-0.8
	Total	5.2	5.80	7.8	5.2-7.8
NO_x		10.1	10.30	11.4	10.1-11.4

[1)] Using "CORINAIR" emission factor, [2)] Using "Low" emission factor, [3)] Using "High" emission factor

Source: IMO (2000)

Table 15 – Model emission results 1996 by statistical emission model, main engine(s), separated by vessel type, using the "CORINAIR" emission factors

Ship type	NO_x (Mton)	CO (Mton)	NMVOC (Mton)	SO_2 (Mton)	CO_2 (Mton)
Liquid gas tanker	0.29	0.03	0.01	0.20	13.40
Chemical tanker	0.32	0.03	0.01	0.20	14.20
Oil tanker	2.00	0.18	0.06	1.44	93.20
Bulk Carrier	2.60	0.22	0.07	1.58	96.00
General cargo	1.77	0.19	0.06	0.70	81.54
Container	1.63	0.15	0.05	0.89	64.39
RO-RO cargo	0.66	0.07	0.02	0.24	30.85
Passenger	0.29	0.03	0.01	0.11	13.37
Refrigerated cargo	0.27	0.03	0.01	0.11	12.34
Sum	*9.82*	*0.93*	*0.30*	*5.46*	*419.30*

Source: IMO (2000)

Air pollution from marine engines in terms of exhaust emission amounts is established by using emission models. These models are based on actual emission factors adopted from onboard engine measurements or theoretical factors arrived from the respective chemical reaction equations and combined with actual fuel consumption (based on international marine bunker fuel sale figures).

Entec reported in 2002 the quantification of emissions from ships associated with ship movements between ports in the European Community, separating the emissions for:

- vessels excluding ferries and fishing vessels;
- ferries; and
- fishing vessels.

The results for the year 2000 of the total emissions of the five main pollutants from shipping movements in the area considered are reported in Table 16.

Table 16 - Total calculated pollutant emissions for 2000

Source	NO_x Kte/annum	SO_2 Kte/annum	CO_2 Kte/annum	HC Kte/annum	PM (in port) Kte/annum
Vessels+ferries	3,535	2,515	153,243	131	21
Fishing	82	63	4,055	2.8	-*
TOTAL	3,617	2,578	157,298	134	21

* Not calculated

Source: Entec (2002)

In-port emission estimates, subdivided into ferries and other vessels (excluding fishing vessels for which no estimates are available) were also estimated in the report (Table 17).

Table 17 - Pollutant Emission Estimates in 2000 for In-Port (includes manoeuvring, loading/unloading and hotelling)

Category	NO_x Kte/annum	SO_2 Kte/annum	CO_2 Kte/annum	HC Kte/annum	PM (in port) Kte/annum
All Vessels (excludes fishing vessels)	158	161	9,686	17	21
Ferries	5.6	5.6	394	0.7	0.8
Total Emissions	3,617	2,578	157,298	134	21
In-Port emissions as % of total	4.5%	6.2%	6.2%	13%	100%*

* only In-Port emissions considered

Source: Entec (2002)

Also, emissions subdivided by port of origin and destination (EU-15, Accession Candidate Countries (ACC) or Non-EU/ACC (NON)) and by the flag status of vessels were calculated.

Based on the published sources (mostly IVL and Lloyds Register Engineering Services data), a new marine emission database ("dataset A") was compiled. By sorting and filtering the data, emission factors (NOx, SO2, HC, PM and CO2) for 5 different engine types and 3 different fuel types, where possible, were derived . This was repeated for 3 different activities or operating modes of the ships; (i) "at sea" (or cruising), (ii) "in port" (includes time spent hotelling, loading and unloading) and (iii) "manoeuvring". Irrespective of ship category (container, passenger ferry etc.), the installed engine type on board a ship and the fuel used largely dictates the ship's emission. In order to present universal emission factors, which represent a given vessel category, information regarding the typical engine types used and fuel used for this category is necessary. Thus Entec UK Ltd has examined the LMIS database for the ships entering the EU study area and provided such data ("dataset B"). Finally, by combining the underlying datasets A and B, weighted emission factors for each specific vessel type can be derived for each of the three activities.

The European Environmental Agency (2002) estimates within the European monitoring and evaluation programme (EMEP) domain that European shipping fleet, using fuels with an average sulphur content of 2.7%, emitted approximately 2578 thousand tons of SO2 for the year 2000. This can be compared to 5750 thousand tons arising from European Community land-based sources and domestic sea traffic.

In 2005, Entec performed also a preliminary assignments of ship emissions to European countries. In particular, the study task carried out by Entec aimed at assigning ship emissions of sulphur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs), particulate matter (PM) and carbon dioxide (CO2) at a national level and to illustrate the significance of ship emissions, in particular in relation to land based emissions.

Seven different methods were applied to assign preliminary ship emissions to EU Member States and candidate countries for the years 2000, 2010, 2015, and 2020. Each of the methods was appraised against several criteria, within an overall multi-criteria analysis. The seven assignment methods are listed below:

1. Assignment according to location of emissions. Ship emissions are estimated for ships within 12 mile and 200 mile zones of countries including ports and inland waterways.

2. Assignment according to flag of ship. World wide ship emissions of ships travelling under a country's flag are estimated.

3. Assignment according to industry fuel sales estimates. Based on a country's marine fuel sales estimates and generic emission factors potential ship emissions are estimated.

4. Assignment according to reported fuel consumption. Based on a country's reported ship fuel consumption and generic emission factors potential ship emissions are estimated.

5. Assignment according to freight tonnes loaded. Ship emissions are allocated in proportion to a country's reported freight tonnes.

6. Assignment in proportion to national emissions. Ship emissions are allocated in proportion to a country's national emissions.

7. Assignment according to country of departure/destination. Ship emissions of each ship movement are allocated based on the country of departure and destination of that movement.

For each method, the report presents figures on:

• Each country's share of total ship emissions of NOx, SO2, VOC, CO2 and Particulate Matter (PM) for the 29 European countries (EU25 + Bulgaria, Romania, Turkey and Croatia);

• Each country's ship emissions of NOx, SO2, VOC, CO2 and PM as a percentage of total emissions for that country (as given in the RAINS model);

• Preliminary NOx ship emissions for each country (for 2000, 2010, 2015 and 2020);

• Preliminary SO2 ship emissions for each country (for 2000, 2010, 2015 and 2020);

• Preliminary VOC ship emissions for each country (for 2000, 2010, 2015 and 2020);

• Preliminary CO2 ship emissions for each country (for 2000, 2010, 2015 and 2020); and

• Preliminary PM ship emissions for each country (for 2000, 2010, 2015 and 2020).

However, it is important to underline that within this study there was not the development of new datasets, but the emissions database developed under the Entec 2002 ship emissions quantification study (Entec 2002) were. As concenrs vessel movements data, the study used the most comprehensive databases available at the time (the Lloyds Maritime Intelligence Unit (LMIU) ship movements database, in combination with the Lloyd's Maritime Information System (LMIS) vessel characteristic database), which includes movements of commercial ships > 500 gross tonnes (GT) (approx. 31,000 ships worldwide).

The emission inventories by Entec (2005) were updated within the "Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive", by Cofala et al. (2007). This study, resulting from a joint effort of three institutions, Entec UK Limited, the Norwegian Meteorological Institute (MET.NO), and the International Institute for Applied Systems Analysis (IIASA), explores the potential for measures to control NOx, SO2, and primary PM2.5 emissions from international shipping in the European sea areas. In particular, it estimates current emissions from different vessel categories in various European sea regions, entailing the compilation and update of ship emission inventories, projects emissions into the future for a range of alternative assumptions about the implementation of emission control measures, and assesses the environmental impacts of the different emission control scenarios. The work under this project draws heavily on the results of previous already mentioned studies, performed by Entec (2002) and its follow-up (Entec, 2005). For this project Entec's databases were updated to include the most up-to date information on the distribution of emission sources and on emission control costs. In particular, the inventory by Cofala et al. (2007) refined the earlier work through more detailed spatial resolution of emissions in the various sea areas, distinguishing national and international emissions, emissions by flag state and emissions within the 12-mile territorial waters.

This inventory estimates emissions in a 'bottom-up' way on the basis of kilometres travelled by individual vessels and uses weighted emission factors for each vessel type as opposed to fuel based emission factors. The underlying vessel movement data for the year 2000 were provided by Lloyds Marine Intelligence Unit (LMIU) and data on vessel characteristics by Lloyds Register Fairplay. With this approach, the inventory was not originally designed to estimate fuel consumption data. To enable separate fuel consumption estimates of residual oil and marine distillates to be made from total emissions, an assumption has been made that approximately 90 percent of fuel consumption is residual oil and that approximately 10 percent is marine distillate. Moreover, available databases and other statistics do not enable the actual split in fuel consumption for ships in European waters to be estimated to a high degree of accuracy. With these assumptions, fuel consumption estimates were derived from the calculated NOx emissions and aggregated NOx emission factors, for residual oil and marine distillates. The results are reported in the table below (Table 18).

Table 18 - Fuel consumption for international shipping in 2000 by sea region, zone and vessel type [PJ]. Source: Cofala et al. (2007)

Ship category / Flag	Fuel[1)]	Baltic Sea <12-mile	Baltic Sea >12-mile	Black Sea <12-mile	Black Sea >12-mile	Remaining NE Atlantic <12-mile	Remaining NE Atlantic >12-mile
Cargo - EU	RO	16.7	61.9	2.7	18.2	7.9	112.9
Cargo - EU	MD	1.9	6.9	0.3	2.0	0.9	12.6
Ferry - EU	RO	0.4	1.1	0.0	0.2	0.2	2.3
Ferry - EU	MD	0.0	0.1	0.0	0.0	0.0	0.3
Cargo - Non EU	RO	13.3	44.4	2.5	17.0	13.4	225.6
Cargo - Non EU	MD	1.5	4.9	0.3	1.9	1.5	25.1
Ferry - Non EU	RO	0.1	0.5	0.0	0.1	0.1	0.6
Ferry - Non EU	MD	0.0	0.1	0.0	0.0	0.0	0.1
Total		33.9	119.7	5.8	39.6	24.0	379.3

Ship category / Flag	Fuel[1]	Mediterranean Sea <12-mile	Mediterranean Sea >12-mile	North Sea <12-mile	North Sea >12-mile	Total European seas <12-mile	Total European seas >12-mile
Cargo - EU	RO	22.6	294.8	19.5	119.7	69.5	607.5
Cargo - EU	MD	2.5	32.8	2.2	13.3	7.7	67.5
Ferry - EU	RO	6.5	34.5	0.9	5.7	7.9	43.8
Ferry - EU	MD	0.7	3.8	0.1	0.6	0.9	4.9
Cargo - Non EU	RO	24.9	394.1	27.0	150.9	81.1	831.9
Cargo - Non EU	MD	2.8	43.8	3.0	16.8	9.0	92.4
Ferry - Non EU	RO	0.7	6.9	0.2	1.6	1.2	9.7
Ferry - Non EU	MD	0.1	0.8	0.0	0.2	0.1	1.1
Total		60.9	811.4	52.8	308.8	177.4	1658.9

[1] Fuel types: RO – residual oil; MD – marine diesel.

The emissions inventory distinguishes emissions for type of vessel (passenger and cargo ships), distinguishing national and international ships (by flag),and emissions (by flag) within the 12-mile territorial waters and outside this zone and considers five sea areas: North Sea, Black Sea, Mediterranean Sea, Baltic Sea, Atlantic Ocean (North-East part, within the EMEP domain).

The pollutants covered are sulphur dioxide (SO2), nitrogen oxides (NOx), total hydrocarbons (HC)1, primary particulate matter (PM), and carbon dioxide (CO2).

As already mentioned, emissions were estimated on the basis of vessel movement data and the underlying vessel emission factors as specified in Entec (2005). For estimating sulphur emissions, sulphur contents in residual oil (RO) of 2.7 percent and for marine distillates (MD) of 0.2 percent was assumed.

The LMIU ship movement database includes all vessels above 500 gross registered tonnes (GRT). Smaller vessels, which are not routinely included in the movement database, were assumed to be operating closer to land and using lower sulphur marine fuels as opposed to heavy fuel oil. The fuel consumption for the range 100-500 GRT is estimated to be less than eight percent of the total estimated consumption for >100 GRT (Endresen et al., 2003). On the basis of uncertainties over the movements of smaller vessels and in line with the scope of the study, a top-down approach has been adopted by assuming that an additional 10 percent of emissions in the 12-mile zones are attributable to vessels <500 GRT. Therefore, gridded emissions estimated for larger vessels in each of the 50 km x 50 km grid cells that include the 12-mile zone have been multiplied by a factor of 1.1.

The spatial distribution of emissions within each sea region has been estimated based on ship movement data along the various routes and on information about the main engine power of the ships, assuming that the main engine power represents a good proxy for total kW power and the associated emissions. Data on main engine power were further categorised by sea area, vessel type (cargo or passenger) and movement type (national or international) to enable emissions to be calculated for the various categories.

Smaller vessels add between two and six percent to total emissions in each sea region, depending on the share of the 12-mile zone in the sea area. This estimate assumes that smaller vessels are predominantly part of national fleets and are not involved in international trade.

The results of these estimates are reported in the tables below (Table 19 and Table 20).

Table 19 - Emissions from larger vessels (>500 GRT) by sea region for the year 2000, in kilotons/year.

Sea area	CO_2	SO_2	NO_x	HC	PMtotal
North Sea	29664	496	693	25	59
Black Sea	3721	62	86	3	7
Mediterranean	75484	1251	1781	61	151
Baltic Sea	12727	212	299	10	24
NE Atlantic	31109	522	764	26	67
Total	152705	2543	3623	125	308

Source: Cofala et al. (2007)

Table 20 - Emissions from all vessels by sea region for the year 2000, in kilotons/year.

Sea area	CO_2	SO_2	NO_x	HC	PMtotal
North Sea	30878	516	720	26	61
Black Sea	3852	65	89	3	8
Mediterranean	77140	1278	1818	62	154
Baltic Sea	13447	224	315	11	26
NE Atlantic	31673	532	777	26	68
Total	156989	2615	3719	129	316

Source: Cofala et al. (2007)

Cofala et al. (2007) estimated also ship emissions for the 12-mile coastal zones by apportioning a share of the emissions of the coastal 50*50 km EMEP grid cells. They assumed that the share of emissions in the 12-mile zones is proportional to the area that the 12-mile zone constitutes in a coastal 50*50 km grid cell. This assumption may tend to underestimate actual emissions in these zones, because national coastal shipping might use routes closer to the coast lines.

The inventory also estimates emissions from national sea traffic, which comprises ship movements between two ports of the same country. The estimates are based on activity data developed by Entec in its 2005 study.

The study by Cofala et al. (2007) derived the atmospheric dispersion of ship emissions, starting from source-receptor relationships. For this purpose, a number of model calculations were conducted in which ship emissions from the various categories were sequentially permutated. The resulting changes in air quality indicators (concentration and deposition over the entire model domain), together with the causative changes in emissions, allowed the construction of reduced-form source-receptor relationships. The model used was the EMEP Eulerian atmospheric dispersion model. The EMEP model is a multi-layer atmospheric dispersion model for simulating the long-range transport of air pollution over several years. The version of the EMEP unified model used by Caofala et al. (2007) includes 70 species and approximately 140 chemical reactions. The model parameterisation of dry deposition enables the calculation of ozone fluxes to vegetation. The model use flexible boundary conditions provided either by observations or modelled results from global air pollution models.

Cofala et al. (2007) analysed separately emissions from international ship traffic for the 4 categories below:

- International shipping emissions within the 12-mile zone;
- International shipping from EU flags;
- International shipping from Non EU flags;
- Emissions from international ferries in the Mediterranean Sea.

Computations were carried out for each class by reducing the contributions from the individual sources by 15 percent for each of the five sea areas (Baltic Sea, Black Sea, Mediterranean Sea, North Sea, and Remaining North-East Atlantic Ocean). Three groups of emissions were considered (SO2, NOx + PM, and VOC + CO), and conditions of five meteorological years were analysed (1996, 1997, 1998, 2000 and 2003). In total, 240 source-receptor model runs were made. Based on these calculations IIASA fully integrated the source-receptor relationships for shipping with those for land-based sources.

The analysis by Cofala et al. (2007) does not include emissions from smaller vessels (below 500 GRT). They stated that, while this simplification is not expected to cause major distortions of the overall dispersion pattern of ship emissions, it might cause certain inaccuracies for the emissions with the 12-mile zones, where most of the smaller ships are likely to operate. However, Cofala et al. (2007) also mentioned that to judge the overall robustness of the approach they used, it is important to remember that, for reasons of consistency with the Europe-wide assessment of land-based and marine emissions, the atmospheric dispersions calculations employ the 50x50 km2 regional scale version of the EMEP model. And, since the 12-mile zone is much smaller, such a resolution is too coarse to determine the actual impact of these sources in coastal areas in great spatial detail, so that this approach can in any case only deliver an initial estimate. However, the numerical diffusion effects from such a simplified approach are to a certain extend compensated by the underestimation of emissions in the 12-mile zones. In summary, they conclude that the overall results could therefore be considered as a valid indication of the order of magnitude of the actual impact of the contribution from the 12-mile zone shipping emissions.

The final outcomes of the study by Cofala et al. (2007) are that maritime activities constitute a significant fraction of anthropogenic emissions of air pollutants in Europe. They estimated for the year 2000 that SO2 and NOx emissions from international maritime shipping in Europe amounted to approximately 30 percent of the land-based emissions in the EU-25. About 20 percent of these ship emissions are released within the 12-mile zones near to the coast line. The vast majority (approximately 95 percent) of emissions is released from larger vessels (>500 GRT). For these larger vessels, roughly 95 percent of SO2 and emissions are estimated to be released from cargo ships. About 45 percent of the sea emissions in the region originate from ships with EU flags. Approximately five percent of SO2 emissions are emitted at berth.

As will be described in the section on impacts on ecosystems, the study by Cofala et al. (2007) assesses also health and environmental impacts of the shipping scenarios.

Endresen and Sørgard (2003) focused on ship emissions from international trade. In particular, they presented detailed model studies of the changes in year 1996 and 2000 in atmospheric composition of pollutants and greenhouse compounds due to emissions from cargo and passenger ships in international trade to analyze the impacts of international merchant fleet emissions. Global emission inventories of NOx, SO2, CO, CO2, and volatile organic compounds (VOC) are developed by a bottom-up approach combining ship-type specific engine emission modeling, oil cargo VOC vapour modeling, alternative global distribution methods, and ship operation data.

In this study the authors first perform new calculations of the fuel consumption and emissions from the international cargo and passenger fleet using a statistical approach These calculations are followed by estimates of bunker fuel consumption for the total world fleet, separated into international and national bunker consumptions; second, they estimate fuel consumption and the global cargo VOC emissions for large crude oil carriers using fleet and cargo volume movement's data. They also verify the modeling results for large crude oil carriers. Methods and traffic data for global distribution of the emission inventories are discussed. Calculations of global distribution of key chemical compounds (ozone, CO, NOx, and sulfate aerosols) and the impacts of the international ship emissions on the distribution of chemical compounds and on radiation balance are finally calculated.

The results are summarised in the table below (Table 21).

Table 21 - Modelled Cargo and Passenger Fleet Fuel Consumption and Emissions in 1996 and 2000 From the Main Engine(s) and Auxiliary Engines

	N_2O, kt		NO_x, Mt		CO, kt		NMVOC, kt		PM, kt		SO_2, Mt		CO_2, Mt		Fuel Consumption, Mt	
Ship Type	96	00	96	00	96	00	96	00	96	00	96	00	96	00	96	00
Liquified gas tanker	0.3	0.4	0.3	0.3	27	31	9	10	24	29	0.2	0.2	13	16	4	5
Chemical tanker	0.4	0.5	0.3	0.4	30	39	10	13	25	34	0.2	0.3	14	19	5	6
Oil tanker	2.4	2.4	2.0	2.1	178	185	57	60	172	180	1.4	1.5	93	97	29	31
Bulk ships[b]	2.4	2.4	2.6	2.6	224	226	73	73	222	223	1.6	1.6	96	97	30	30
General cargo[c]	2.1	1.9	1.8	1.7	190	174	62	57	95	113	0.7	0.8	82	75	26	24
Container	1.6	2.3	1.6	2.3	150	214	49	69	124	166	0.9	1.2	64	91	20	29
Ro-Ro ships[d]	0.8	0.8	0.7	0.8	72	76	23	25	33	48	0.2	0.3	31	33	10	10
Passenger vessels	0.3	0.4	0.3	0.4	31	38	10	12	15	21	0.1	0.2	13	16	4	5
Refrigerated cargo	0.3	0.3	0.3	0.3	29	28	9	9	15	15	0.1	0.1	12	12	4	4
Total ME	10.6	11.5	9.8	10.8	931	1010	302	327	726	829	5.5	6.2	419	455	132	144
Total (ME + AUX)	11.7	12.7	10.8	11.9	1024	1111	332	360	799	912	6.1	6.8	461	501	145	158

[a]Values are in Mt (10^6 t) or kt (10^3 t). ME, main engine(s); AUX, auxiliary engines.
[b]Bulk dry and bulk dry/oil vessels.
[c]Including passenger/general cargo vessels.
[d]Including passenger/RO-RO vessels.

Source: Endresen and Sørgard (2003)

The study highlights that emission from bunker fuel burned by the international cargo and passenger fleet represents a significant contribution to the global anthropogenic emissions, and particularly, for NOx and SOx. The majority of the emissions occur in Northern Hemisphere within a fairly well-defined system of international sea routes. The most accurate geographical representations of the emissions are obtained using a method based on the relative reporting frequency weighted by the ship size. The different modelling approaches show good agreement
with regard to the annual fuel consumption for crude oil carriers.

The model calculations have shown that the response in the atmospheric chemical composition from ship emission is rather complex, and does not reflect the pattern of emissions. Added to this, is the uncertainty associated with plume effects that might reduce the available NOx from the ship emissions. Due to the highly nonlinear response in ozone formation from emissions of precursors like CO and NOx, with higher efficiency in regions that are affected little by pollutants, ozone formation due to ship emissions over oceans away from industrial regions like the Atlantic and Pacific Oceans are more efficient than emissions over polluted coastal regions (e.g., the North Sea). The formation of secondary pollutants and climate compounds such as ozone and sulfate shows large seasonal variations at middle and high northern latitudes due to the large seasonal variation in chemical activity. Furthermore, secondary pollutants are transported over rather large areas leading to enhanced levels well outside the traffic corridors. In parts over the Atlantic and Pacific Oceans, ozone levels are significantly enhanced by ship emissions. The oxidation capacity of the atmosphere (through the effect on the OH distribution) is enhanced by ship emissions, leading to increased rate of methane loss and reduced concentrations. A consequence of this is that RF from NOx-induced changes in ozone and methane is close to zero, and the total RF is small due to several canceling effects. Coastal regions in the vicinity of major ship tracks are affected by sulfur emissions from ship. In some coastal regions the relative deposition of sulfate is enhanced by 3–10%.

A study carried out by Cooper (2003) focused on emissions from ships at berth during normal real-world operation (hotelling, unloading and loading activities). The study included three passenger ferries, one transoceanic container/roro, one transoceanic car/truck carrier, and one chemical tanker. Emissions were measured from 22 auxiliary engines (AEs, medium and high-speed marine diesels) covering seven engine models and ranging in size from 720 to 2675 kW maximum output. The fuels varied from low sulphur gasoils (2:91 cst viscosity) through to residual oils (411 cst viscosity). Both specific emission factors ($gkWh^{-1}$) at a given engine load and total emissions (kg) of nitrogen oxides (NOx); sulphur dioxide, carbon monoxide, hydrocarbons, carbon dioxide, particulate matter (PM) and polyaromatic hydrocarbons during actual harbour stops were determined. In addition, some preliminary measurements to investigate PM size distributions were undertaken.

The results are summarised in the table below (Table 22).

Table 22 - AE measurement results at steady-state engine load operation

Ship/engine	A/AE1–AE5	B/AE1–AE4	B/AE5	C/AE1–AE6	D/AE1–AE2	E/AE1	E/AE3	F/AE1–AE2
Load (% of max.)	45–63%	47–58%	59%	36–50%	43%–48%	41%	39%	63%
Fuel type	MGO	RO	MGO	MGO	MDO	RO	RO	MGO
NO_x (ppm)	930–1393	1002–1232	1559	967–1278	901–926	1225	1005	1502–1620
CO (ppm)	69–102	121–216	—	43–67	139–144	118	97	101–102
CO_2 (vol%)	4.52–5.20	5.61–6.13	6.29	4.78–5.40	6.52–6.66	5.74	5.57	5.98–6.32
O_2 (vol%)	13.29–14.59	12.64–13.28	12.34	13.63–14.47	12.08–12.51	13.11	13.76	12.73–12.10
HC (ppm C)	30–48	17–32	107	42–61	58–68	46	47	81–87
PM (mg nm^{-3})	27–56	62	45	40–57	29–31	98	79	21–26
PM (Bach. soot scale)	4–6	6–7	7	3–5	7	6	6	6
PAH (μg nm^{-3})	—	170–220	—	23–29	370–400	1810	1400	250–290
Ex. flow (wet $nm^3\ h^{-1}$)	3290–4400	4520–4990	4970	2620–3320	3580–4150	7150	5310	2640–2790
Ex. temperature (°C)	301–405	315–335	359	273–340	372–381	361	335	342–363
Fuel cons. (g kWh^{-1})	205–219	238–251	240	216–223	213–214	216	217	214
Charge air temp. (°C)	30–43	33–43	33	30–40	46–49	48	53	—
Charge air press. (bar)	—	—	—	0.20–0.50	7.0–8.5	0.6	0.6	—
NO_x (g kWh_{corr}^{-1} a,b)	14.9–19.2	13.3–17.5	20.2	14.2–18.6	9.6–9.9	15.2	12.9	17.5–17.9
CO (g kWh^{-1})	0.57–0.97	1.06–1.71	—	0.33–0.57	0.92–0.98	0.90	0.77	0.69–0.73
CO_2 (g kWh^{-1})	653–699	763–803	768	686–708	691–694	691	697	676
HC (g kWh^{-1})	0.12–0.21	0.07–0.14	0.41	0.19–0.25	0.19–0.23	0.17	0.19	0.29–0.30
PM (g kWh_{corr}^{-1})[a]	0.21–0.45	0.48	0.31	0.30–0.44	0.17–0.19	0.67	0.54	0.14–0.16
PAH (mg kWh^{-1})	—	0.9–1.5	—	0.15–0.19	1.9–2.0	11	9.5	1.4
SO_2 (g kWh^{-1})	0.33–0.35	2.5–2.7	0.4	5.2–5.3	1.0	9.5	9.6	0.26

[a] Corrected for ambient conditions according to International Organisation of Standardisation (1996b).
[b] NO_x emissions expressed as g NO_2 kWh_{corr}^{-1}.

Source: Cooper (2003)

The specific emissions showed significant variations between the different engine models and also within the same engine model on board the same ship. For example NO_x emissions varied between 9.6 and 20:2 g kWh between all engines and 14.2–18:6 g kWh between engines of the same model and fuel.

AE emissions, other emissions from boiler use and possible ME warmup prior to departure were in general considerably less than those from the AEs, but can be significant especially for SO2 if different fuel qualities are used. Generally, the power consumption of the ships at berth was fairly constant and considerably less (9–49%) than the total installed AE power. Relative to the total time spent at berth, periods with abrupt engine load changes and higher loads engagement of thrusters prior to departure) were insignificant.

Schreier *et al*. (2006), studied the modification of clouds and the influence of the ship exhaust on the radiation budget of a given scene. Satellite data were used to retrieve cloud properties and their modifications due to ship emissions. The result was that ship emissions modify existing clouds by decreasing the effective radius, while they increase droplet concentration and optical thickness. On average, the optical thickness was increased from 20.7 up to 34.6 and the effective radius was decreased from 13.2μm to 10.1μm. The calculated average droplet number concentration increased from 79 up to 210 cm^{-3}.

Other studies, as already mentioned, focuses on specific emissions. For instance, the research by Endresen et al. (2005) estimates global ship SO2 emission inventories. To update the SO2 emission inventories, the authors used a bottom up approach applying an improved calculation methodology, the latest international marine bunker sale statistics and global fuel analysis data.

The SO2 emissions may be calculated by the following equation:

$$M_{g,i} = c_{g,i}F_{g,i} = VS'_{g,i}F_{g,i} \qquad (1)$$

and

$$S'_{g,i} = \frac{1}{Q_{g,i}}\sum_{j} S_{g,i,j}q_{g,i,j}, \qquad (2)$$

where Mg,i denotes the amount of SO2 emitted by type fuel (heavy and distillate fuel oil) in region i (kg SO2), cg,i denotes the fuel-based emission factor in relation to fuel type g in region i (kg SO2 kg^{-1} fuel), Fg,I denotes the sale of fuel type g in region i (kg fuel), V denotes the relation between burned sulphur.

The results show that SO2 emission from international marine transportation is in the range of 5.9–7.2 Tg (SO2). Of this, combustion of international heavy fuel represents about 95%. If the domestic fuel consumption is included, the total emission from all ocean-going transportation is estimated to 7.0–8.5 Tg (SO2).

According to the literature review carried out in this study, a methodology often used as reference for the estimate of air pollutant emissions from ships, in port environment and in navigation, is the MEET, developed by Vaccaro and Trozzi in the framework of MEET Project (Methodologies for estimating air pollutant emissions from transport) under the transport RTD program of the European Commission fourth framework program. A specific software was developed and the methodology has been applied at local and national level in the last years. Depending on the data available either a simplified or a detailed methodology can be applied.

In particular, the data needed for the application of the simplified methodology are the number of working days for each class of ships (Table 3) equipped with engines (Table 5) and using fuel (Table 4).

The emissions are obtained as:

$$E_i = \Sigma_{jkl} E_{ijkl}$$

With

$$E_{ijkl} = S_{jk}(GT) * t_{jkl} * F_{ijl}$$

where:

i pollutant

j fuel

k ship class for use in consumption classification

l engines type class for use in emission factors characterization

E_i total emissions of pollutant i

E_{ijkl} total emissions of pollutant i from use of fuel j on ship class k with engines type l

S_{jk} (GT) daily consumption of fuel j in ship class k as a function of gross tonnage

t_{jkl} days in navigation of ships of class k with engines type l using fuel j

F_{ijl} average emission factors of pollutant i from fuel j in engines type l (for sulphur oxides, taking into account average sulphur content of fuel)

For short passages ferry traffic, in order to take into account also hotelling and manoeuvering emissions, the days in navigation must be increased. As in these modes fuel consumption are about a half of cruising ones, in this case t_{jkl} is estimated as the sum of days in cruising and half of days in hotelling and manoeuvering.

Trozzi and Vaccaro (1998) propose also a default basic emission factors according to the engine type, to use in simplified methodology of the MEET Methodology. These emission factors are reported in the table below (Table 23).

Table 23 - Default basic emission factors (kg/ton of fuel) for using in the simplified Methodology

Engine types	*Nox*	*CO*	*CO_2*	*VOC*	*PM*	*SOx*
Steam turbines - BFO engines	6.98	0.431	3200	0.085	2.50	60
Steam turbines – MDO engines	6.25	0.6	3200	0.5	2.08	20
High speed diesel engines – BFO	70	9	3200	3	1.5	60
Medium speed diesel engines – BFO	57	7.4	3200	2.4	1.2	60
Slow speed diesel engines - BFO	87	7.4	3200	2.4	1.2	60
High speed diesel engines – MDO	70	9	3200	3	1.5	20
Medium speed diesel engines – MDO	57	7.4	3200	2.4	1.2	20
Slow speed diesel engines – MDO	87	7.4	3200	2.4	1.2	20
Gas turbines	16	0.5	3200	0.2	1.1	20

Source: Trozzi and Vaccaro (1998)

In general, several new important data on emission factors were published in the last years. The detailed methodology can be applied when the data of the number of days that a certain type of ship passes in each of the phases listed in Table 24 are available:

Table 24 - Classification of ship activities.

Code	Name
C	Cruising
M	Maneuvering
H	Hotelling
T	Tanker offloading
A	Auxiliary generators

In this case the total emission is equal to:

$$E_i = \Sigma_{jklm} E_{ijklm}$$

With

$$E_{ijklm} = S_{jkm}(GT) * t_{jklm} * F_{ijlm}$$

where:

i pollutant

j fuel

k ship class for use in consumption classification

l engines type class for use in emission factors characterization

m operation phase

E_i total emissions of pollutant i

E_{ijklm} total emissions of pollutant i from use of fuel j on ship class k with engines type l in the phase m

S_{jkm} (GT) daily consumption of fuel j in ship class k in phase m as a function of gross tonnage

t_{jklm} days in navigation of ships of class k with engines type l using fuel j in phase m

F_{ijlm} average emission factors of pollutant i from fuel j in engines type l (for sulphur oxides, taking into account average sulphur content of fuel) in phase m

Trozzi (2003) proposes also a model for integrated environmental assessment of air emissions from all port activities:

$$E_{ijkm} = A_{kj} \times F_{ijm}$$

where:

i pollutant; j activity generating pollution (included fuel); k industrial, transport or territorial unit;

m environmental media;

E_{ijkm} emissions of the pollutant i in the media m for the industrial, transport or territorial unit k with activity j;

A_{kj} is the level of activity j (for example time spent in navigation, consumption of fuels, production of the specific product, number of circulating vehicles, inhabitants' number, quantity of consumed varnish, etc.) for the industrial, transport or territorial unit k;

F_{ijm} is the emission factors of pollutant i in the media m, for activity j, express in grams for unit of activity (for instance the emissions in grams hour).

Estimated Impacts on Water

Water pollution

In general it is observed that there are no detailed information on emissions in water. This is because, contrary to the air emissions, it is difficult to calculate emission factors for water.

However, some estimates indicate that normal shipping operations are responsible for over 70% of the oil entering the sea from marine transportation, but as the oil is often spread over a large number of locations, the effects of operational discharges may appear less dramatic than the often catastrophic localised effects of accidental oil spills. They do, however, give rise to a number of chronic pollution problems, particularly in low energy environments such as ports and harbours. Statistics show that 80% of oil spills occur in harbour waters. Clearly, these are not the only wastes discharged by ships. Other vessel discharges may be equally hazardous but to date have generally received less public attention because they are subtler and less visible, e.g. chemical discharges. Furthermore, there are arguably less hazardous but highly visible discharges in the form of garbage. (Ball, 1999).

Estimated Impacts on Soil

Soil and sediment pollution

Port are often located within industrial areas, where the historical presence of many activities, also linked to heavy industry production, have determined soil contamination.

While it is not easy to assess the impact of the current port activities as concerns this contamination, many studies and research have been carried out to assess the environmental risk in these areas due to soil pollution. This assessment is based on the concentration of contaminants, their patterns and exposure of the targets, therefore the characterisation of the polluted soil is the first step to perform it.

Erosion

Models can help to assess the erosion caused by maritime transportation activities.

A quite recent project, FLOWMART (Fast LOw Wash MARitime Transportation) was supported by European Commission (European Commission, 2002) to develop numerical simulations, model experiments and full-scale measurements about the wake and wash effects linked to ship activities.

Estimated Impacts on Ecosystem

Biodiversity loss and habitat degradation

As already mentioned, the study by Cofala et al. (2007) assesses health and environmental impacts of the shipping emission scenarios, extending the IIASA RAINS/GAINS integrated assessment model. In particular, they used the loss in statistical life expectancy attributable to anthropogenic emissions of PM2.5 as a health impact indicator. The value of that indicator is highly country- and scenario-specific. Moreover, they considered the number of cases of premature deaths attributable to the human exposure to ground-level ozone. As concerns estimates of the protection of ecosystems against acidification for forests, semi-natural vegetation, freshwater catchments and all ecosystems, respectively, they considered as indicators the forest area with acid deposition above critical loads for acidification; semi-natural ecosystems with acid deposition above critical loads for acidification; freshwater ecosystems with acid deposition above critical loads for acidification. Finally, regarding estimates of the protection of all ecosystems against eutrophication, Cofala et al. (2007) included forests, semi-natural vegetation, and freshwater catchments and, in particular, the total ecosystems area with nitrogen deposition above critical loads for eutrophication.

As concerns the negative effects on the ecosystem determined by discharge of ballast water, described in the section on the impacts, the literature review highlights that estimation of ballast water volume have been done. Endresen et al. (2004) speak about a global annual level of 3500 Mton of ballast water discharged, shared between international 2174 Mton and national 1300 Mton. The impacts can be assessed in terms of loss of endemic species versus alien ones. This kind of estimate, when the loss regards species with a value on the market (e.g. fishes and seafood), can bring to an economic evaluation of impacts of invasions by alien species. This is the case of the study by Ruiz et al. (2001), that accounts the loss of zebra mussel for over $500 million/year.

In case of accidental oil spills, the impacts on ecosystem can be assessed in terms of deaths of birds and other animals (e.g. the Prestige oil spill accident), in the short term, and using changes in number of catchments, in a longer term.

Habitat degradation can be also linked to erosion phenomenon. These impacts are also often evaluated in economic terms, using contingent evaluation methods.

Estimated Impacts on Waste

Sweeting and Wayne (2003) estimated that an average cruise ship will generate a minimum of 1 kg of solid waste plus two bottles and two cans, per passenger per day and an average of 50 ton of sewage (black water) per day. A figure of 3.5 kg/passenger/day is quoted by the IMO. While Butt (2007) asses that approximately 50– 70 tonnes of solid waste can be generated each week by a ship carrying 3000 passengers.

More difficult is to estimate the generation of waste from other type of ships. In fact information registered by ports are not sure to account the entire amount of waste produced, as ships discharge where it gives the lowest cost (Trozzi, 2003).

7. Research directions on the quantification of maritime transport impacts

The literature review highlighted that in recent years, researches and studies on impacts from maritime transport activities focused mainly on air emissions. In particular, several researches (Entec, 2002; Trozzi and Vaccaro, 1998; Endresen et al., 2003; Cofala et al., 2007) focused on comparison among emission scenarios linked to new measures. This interest seems driven by new regulations in this sector, e.g. standards on fuel sulphur contents.

Different estimation of emission factors, which are at the basis of the assessments, have been carried out. In order to arrive to consistent evaluation, it is important to estimate these factors for each kind of engine and fuel, while, as underlined by Cofala et al. (2007) for European waters, available databases and other statistics do not enable the actual split in fuel consumption for ships to be estimated to a high degree of accuracy. Therefore, this approach can in any case only deliver an initial estimate (Cofala et al., 2007).

In particular, Cofala *et al*. (2007) highlight that, the most critic assessments are those of the emissions from national shipping. These estimates, in fact, seem particularly burdened with additional uncertainties owing to differences in sectoral aggregations used by individual countries. In some cases even different institutions within the same country use different definitions and aggregations. In general, the study by Cofala et al. (2007) underlines that estimates of emissions from national shipping are quite uncertain because of different classifications used by individual countries for reporting their emissions. Therefore, the overall results of the current assessments can be considered as indication of the order of magnitude of the actual impact of the contribution from the 12-mile zone shipping emissions, more than the real value.

Moreover, as observed by IMO (2000), high attention is given by research to the impact of emissions from maritime transportation activities at local level, while knowledge on global climate impacts from shipping is still scarce and needs to be improved. Improved assessments of global climate impacts from shipping will need to include effects of CO2, NOx, and SOx emissions from ships. The research needed includes additional long-term field campaigns to measure ozone and NOx in the remote marine boundary layer and troposphere. Field research should also investigate the chemical composition and physical dynamics of ship emissions to investigate the small-scale nature of ship plumes and the larger scale effects as the plume gases disperse and react.

As concerns the other impacts, what is observed is that, in general, for their nature, it is hard to separate them from those deriving from other sources, as in the case of water pollution. This is possible when the kinds of pollutants are easily linkable to substances used in the maritime sectors, such as TBT in antifouling, while it is more difficult in the other cases. In general, estimations mainly concern impacts on biological species of water pollution that can be quantified in terms of deaths and reduction in stocks. But, again, it is not always easy to relate them specifically to maritime transport activities. Therefore, further studies in this field are suggested in order to assess them.

8. *Methodological issues concerning the economic valuation of environmental impacts*

The economic valuation of environmental impacts produced by maritime transport represents a challenge for scholars, due to variety of effects that shipping has on the natural environment, both at local and global scale. The analysis of these impacts has been the object of the first part of this report, where they have been analysed qualitatively and quantitatively.

The economic valuation of these impacts is conditioned by the uncertainty and the research gaps emphasised above. In fact, the assessment of the change in welfare measures is based on the comparison of two scenarios, one coincident with the status quo and the alternative one where the environmental quality is affected by human activity (in our case by maritime transport activities). Thus, a fundamental step before starting any economic valuation is to quantify (physically) the change in environmental quality. As emphasised above, this is not a simple task. Furthermore the relation between each impact and the overall environmental quality may be quite complex so that even from the scientific point of view it will be quite hard and even inappropriate to calculate a ‘marginal change’ in welfare as typically required by economic valutation.

Once the environmental impact is identify, then, it is possible to attach a monetary value to it, by applying one of the valuation techniques developed over the last decades[4]. They can be divided into two categories:

1. non-market valuation approaches assess the cost of such environmental impacts, by looking how this impact affects the production of a marketed good. For instance, when a change in the output of a crop occurs due to pollution, this loss can be valued at the market or shadow market prices. Apart from effects on production, these approaches encompass preventive expenditure (i.e. expenses incurred to prevent degradation) and replacement costs (i.e. cost incurred in restoring the environment at its original state after it has been damaged).

2. demand curve approaches estimate the change in consumer surplus by looking at the demand for environmental quality expressed by the public. This demand can be traced by looking at the purchased of goods related to environmental quality in the private market (revealed preferences) or by measuring directly the individual WTP for environmental improvements (stated preferences).

In fact, the choice of a valuation technique is dependent upon the impact to be valued: some of them have direct effects in consumption or production activities and can be valued by referring to substitute or complementary goods or by looking directly at effects that occurred at the market place. Other effects do not produce any direct effects on goods or services but can still be valued because deemed worthy per se. As a consequence, the object of the valuation study (i.e. use or non-use values) would vary accordingly.

[4] For an overview of these techniques the interested reader could refer to Garrod and Willis (1999).

Finally, the economic valuation of the whole spectrum of environmental effects should pay attention to the problem of double-counting. In fact, shipping can impact on environmental media by producing different effects at once. For instance, waves can produce both erosion and degradation of terrestrial habitats. Erosion produces the lost of productive land (and associated services, some productive other environmental), which can be valued e.g. through a hedonic price approach, whilst the lost in terrestrial ecosystem could entail a decreasing in eco-tourism activities or a biodiversity loss. Considering the two effects at once could entail an overestimation of the true welfare change associated with environmental degradation. Thus, it is advisable to adopt, as far as possible, the more comprehensive approach to environmental valuation to avoid this kind of bias.

The economic valuation of impacts on water

Water pollution

Oil and hazardous substances spills frequently result in damage in publicly-owned natural resources such as birds, fish, and beaches. It is noteworthy that studies on this issues proliferated after the episode of the Prestige spill (occurred in 2002), which was responsible for a massive contamination of the Galician coast (Northern Spain), Northern Portugal, and Southern France.

Generally speaking, in the case of oil spills, two approaches have been used in economic valuation literature: the economic damage approach and the stated preferences approach.

The first approach was the most frequently used by economists. The economic damage is assessed on the basis of income losses resulting from restricted or suspended marine resource use. These damage costs are simple opportunity costs of foregone resource use and do not include expenditures related to maintenance, avoidance or restoration, neither do they include estimates of foregone non-use (‘passive use’) values.

One the most comprehensive study is that of Loureiro *et al*. (2006)’s. They quantify overall damages as losses that society faces in terms of utility reductions when any environmental accident occurs. In order to approximate the total social damages caused, they analyze the effects of the Prestige oil spill in each of the affected productive sectors: the rich commercial fisheries and shellfish sectors, the canning and processing fish and shellfish industries, mussel production, and the tourism sector. For instance, to evaluate the economic losses for fish sectors, they use total landings and their respective economic ex-vessel values to approximate the impact of the Prestige oil spill over the fisheries. They found that: (i) losses in the fish and shellfish sectors in Galicia total €38.40 million in 2002 and €41.00 in 2003 (by comparing landing volumes in 2002 and 2003 with respect to those in 2001, i.e. the year before the spill); (ii) losses in mussels farming in year 2003 amount to €3.804 million (by looking at the reduction in the mussels supplied to the fresh market of average and special quality); (iii) they estimate losses in the canning and fish processing sector by looking at the decrease in gross added value suffered by small firms (the heaviest affected by the oil spill). They found that this reduction amounts at of €214,081 during 2003 for the smallest firms; (iv) losses in the tourism sector. The losses in the tourism sector in Galicia which are linked to reductions of domestic visitors are about 29.31 millions in 2002, with respect to the levels in 2001; (v) value of birds and mammals killed by the oil spill. They consider the reposition cost of each species (and they multiply it by the number of killed individuals in that species)[5]. Finally they estimate the clean up and recovery costs, by looking at the money spent in this task. They found that these expenses in Galicia alone were about €199.6 Million.

The Prestige accident was also studied by Garza-Gil *et al*. (2006a; 2006b), who considers only the effects on fishery activities and tourism. Moreover, in their study, Wirtz *et al*., (2007) estimate the total damage costs experienced by fishery, mariculture, tourism and transport. They recognised their maximum loss estimate represents only a lower boundary of all damage costs potentially incurring.

These studies do not assess the losses of use and non-use values caused by the Prestige oil spill. Contingent valuation studies would allow us to approximate these non-use values, as well as to reproduce estimates for natural species which do not count with a transaction value. This has been done in Loureiro and Ojea (2008). In their study, they value a program to recover the guillemot population (Uria aalge) in Galicia, Spain, which was significantly affected by the Prestige oil spill in 2002. They carry out a contingent valuation study by asking residents of 12 municipalities affected by the oil spill about their WTP for a restoration program. The vehicle payment chosen was an increase in the income tax (through an *una tantum* payment). This study is worth mentioning because it testes for the effect of a reminder about substitutes of the same bird species in a valuation exercise conducted with an endangered species (which is one of the main critical issues in stated preferences studies). They found that there are no statistically significant differences between the median WTP per household obtained for the sample uniformed about the existence of colonies in Northern Europe, and the median WTP computed for the sample informed about the existence of substitutes. The median WTP estimates for the recovery program are computed as 18.17 €/household for those who were not informed about the existence of other Northern European colonies, and 19.34 €/household for the sub-sample who received such information. The magnitudes of these quantitative empirical estimates show that there are no clear differences between the welfare estimates obtained with and without the substitute reminder.

All the studies quoted above fail to take into account the loss of future streams of income and, as such, their results represent lower bound estimates of the true economic costs of oil spills. However, they all claim the opportunity to take preventive actions to avoid such episodes in the future. The economic damage assessment, in fact, may also be used as an important decision-making tool when assessing the optimal level of protection that should be employed in marine safety in order to avoid similar disasters in the future.

To sum up, oil spill market damages can be evaluated through the use of secondary data (i.e. data that do not need to be collected ad hoc, since they are available through Statistical Offices) but non-use values can be assessed only through the administration of ad hoc surveys.

The ExternE update considers the WTP for ecosystem losses due to oil spills. It recalls two major accidents (i.e. the 1996 Sea Empress oil spill in South Wales coast, UK) and the Exxon Valdez Oil Spill (in the Gulf of Alaska), by quoting two related evaluation studies. By dividing the total economic damages (including non use values) by the tonnes of oil spilled in the two cases they get an unit damage cost estimate of € 2,368 in the UK case and € 26,333 in the US one. This difference reflects the diversity of local conditions and the elements of the total economic value that were given attention in the two cases. They suggest using these figures as a range limits.

[5] One limitation of this method is that it relies on the market prices of the species being valued. Given that many of the affected birds impacted are classified as being in danger of extinction and commercialization is forbidden, there is no market price associated with these killed species in Europe. Here the lacking of market prices can be filled by referring to the results of the USEPA Conservation programmes for endangered species.

By considering other valuation made in the case of the Caspian sea, they suggest to consider € 2,600/tonne as the central value, whilst € 2,300 / € 24,000 as the maximum (Bickel and Friedrich, 2005).

Threats to biodiversity: ballast water and use of antifouling paints

It is acknowledged that ballast water[6] has an important role in the redistribution of marine organisms (including a range of pests and pathogens). The problem of alien invasive species is increasingly recognised to be one of the main environmental consequences of globalisation, the integration of world markets and the growth of trade. It is argued to be the second-most important cause of biodiversity loss worldwide (USEPA; 2001). While most attention has been paid to human pathogens and the risks of global pandemics, the redistribution of organisms through the transport of goods and services has already resulted in biological invasions that have had major consequences for both terrestrial and aquatic systems (Perrings, 2005). Several examples of transformation of local ecosystems can be reported, with severe consequences for the economic activities dependent on that system. There are no good estimates of the economic costs of invasive alien species (Perrings *et al*., 2000).

There are several different ways of managing ballast water. Currently, the most widely used is ballast water exchange. Ballast water exchange means that ships on their way to the next port release the lower-salinity coastal water they brought aboard and replace it with higher-salinity open-ocean water. Although this measure is not perfect, it reduces the number of potentially invasive species in the ballast tanks and replaces them with oceanic organisms that are less likely to survive in the lower- salinity near-shore waters of the ship's next port. Another approach to ballast water management is treatment. Ballast water treatment is the subject of extensive current research and development, and several technologies and methodologies have been proposed. These include mechanical methods (e.g., filtration and separation), physical methods (e.g., sterilization by ultraviolet light, ozone, heat, electric current, or ultrasound), and chemical methods (using biocides). In addition, treatment may combine several of these methods (Buck, 2005).

A number of technological alternatives to ballast exchange currently exists, but the cost-effectiveness of each is thought to vary widely across vessels due to heterogeneities in vessel characteristics (Rigby and Taylor, 2001). Vessels can adopt various biosecurity techniques to reduce the probability of an invasion. Filtering reduces the likelihood that species will enter or exit a vessel's ballast tanks. The survival of species in transit is affected by intransit ballast management practices. The most promising in-transit practices are ballast exchange via continuous flushing, reballasting, heat, chemical treatments, and ultraviolet radiation. Reballasting is often considered dangerous, whereas ballast exchange via continuous flushing has been shown to be safer and as effective (Rigby and Taylor, 2001). Chemical treatments are usually discouraged due to their high cost and also the safety and environmental hazards associated with their use. UV is only considered to be potentially effective when it is combined with a filtering technology, but even then experts disagree as to its potential.

The external costs entailed by invasive species transport by shipping can be estimated in two ways. First, in cases where a local economy is dependent upon a local ecosystem which is threaten by invasive species (i.e. a fishing), one can consider the market effect deriving from the disappearing of the ecological resource been destroyed by the invasive species. In other words, a damage cost approach is used. This approach makes

[6] Ballast water is held in the ballast tanks and cargo holds of ships to provide stability and manoeuvrability during a voyage when ships are not carrying cargo, are not carrying heavy enough cargo, or require more stability due to rough seas.

possible to consider only biodiversity use value. Born *et al*. (2005) note that many economic studies on biological invasions focus on primary and direct impacts, e.g. production losses in agriculture and fishing, and neglect indirect effects that are not reflected in markets. Second, biodiversity conservation might be considered as an objective without taking into account the economic welfare it contributes to create. In such case, an approach which allows the assessment of total economic value is more suitable.

Alternatively to the above called valuation techniques, the cost of prevention activities could be considered as a lower bound limit of the total economic value of biodiversity conservation (see Table 25).

Table 25 – Costs of various ballast water management technologies

Ballast capacity (m^3)	Control technology					
	Ballast exchange (with x_b=0.75)		Heating (with x_h=1)		Filtration (with x_f=1)	
	Operating costs (U.S. cents/m^3)	Fixed costs (U.S. cents/m^3)	Operating costs (U.S. cents/m^3)	Fixed costs (U.S. cents/m^3)	Operating costs (U.S. cents/m^3)	Fixed costs (U.S. cents/m^3)
12,000	2.814	2.238	2.684	0.432	0.18	19.05
60,000	2.244	0.54	3.355	0.54	0.48	6.564

Source: Horan and Lupi (2005)

Other techniques, such as stated preferences methods, could provide non reliable estimates due to the part-whole effect. For instance, it could be difficult for the researcher to distinguish between the WTP for the conservation of local biodiversity in general and the local biodiversity threaten by invasive species transported through ballast water. Up to author's knowledge, the only study conducting a WTP assessment is Turpie and Heydenrych's one (in Perrings *et al*., 2000).

Water-borne transport has a direct impact on biodiversity in marine environments due to the use of antifouling paints. For over thirty years tributylin (TBT) was the active agent in antifouling paints used extensively in the maritime sector. It has been described as one of the most harmful substances knowingly introduced onto the marine environment. This effect is recognised worldwide, as witnessed by the introduction of a ban on the use of TBT[7]. This proved to have detrimental effects on non targeted marine organisms[8].

It is recognised the IMO ban will need to be gradually introduced and its success depends upon the development of effective substitute paints. Paint manufacturers have been researching and developing alternative paints for some years, with varying degrees of success. At present copper antifouling paints present the best practical environmental option for a TBT alternative available to the marine industry. Although copper is a naturally occurring element which is essential for metabolic processes in living organisms, it is also a widespread pollutant in industrial waters which can be one of the most poisonous heavy metals when present in excess.

In the last years, hydroblasting has become the preferred method to remove antifouling marine coatings from a ship's hull because of the human health risks from breathing sand blasted materials. When a ship is placed in a drydock, the vessel is washed down with freshwater to remove salt and prevent corrosion. This water is

[7] The London Conference held by IMO in 2001 adopted the Convention for the "Control of Harmful Anti-fouling Systems for Ships". This convention prohibits the use of harmful organotins in anti-fouling paints used on ships by 2008 and establishes a mechanism to prevent the potential future use of other harmful substances in antifouling systems. With the directive 2002/62 EC the EU apply these restrictions to all EU boats starting 1 january 2003 and on all other boats after 2008.

[8] Such as deformities in shellfish and mollusc communities, reduced growth of algae and toxic effects in young fish.

discharged directly to estuaries or bays. The hydroblasting can break down the removed paint into paint chips into 10 μm size particles, which can be widely distributed in waterways. Thus, despite declining levels of TBT worldwide, documented hot spots of TBT are registered in bottom sediments in the proximity of shipyards, drydocks, ports and harbours (Champ, 2003).

Champ (2003) reported the extent of use of antifouling disposal. It has been estimated that between 70% and 80% of the ships in global commerce use TBT. Under current practices, the estimated annual increase in wastes in shipyards and drydocks from the treaty will be: 2.3 million tons of contaminated grit, 18,000 tons of spent paint, 1.8 million paint cans, and 1.1 billion gallons of contaminated washwater (low pressure for salt removal), and if the trend increases of using high pressure hydroblasting to remove spent paint, the volume of wastewater could exceed 5 billion gallons of water needing treatment.

Harmful substances should be collected, handled, treated and disposed of in a safe and environmentally sound manner to protect the environment and human health''. For most of the world, TBT in washdown and shipyard wastewaters can legally be discharged directly into local waters. In some places they are circulated (ineffectively) through a municipal waste treatment plant.

The economic value of this contamination patterns can be derived by considering the increased costs for disposal of dredged materials or to treat wastewater water. No figure is available for this.

Of course this contamination has effects on biodiversity, which should be monetised by using other techniques.

The economic valuation of impacts on soil

Erosion

The existence of a port, and the consequent vessel movements, creates coastal erosion which can be considered as a negative externality for local inhabitants. The extent of erosion is dependent upon the dimension of the port and the vessel type that calls at it. The erosion is caused by a combination of human-induced development, global rising of the sea level, occasional violent weather systems and chronic sediment transport by waves.

The variety of erosion causes makes it difficult to isolate the contribution of port and maritime transport activities. In analysing the external effects on soil entailed by water-borne transport, it is thus important to attribute to shipping only the erosion effects caused by navigation and to exclude the other factors. This could be done by observing historical erosion patterns and by using hydraulic models.

Erosion can produce the following changes in economic wellbeing. First, it impacts on the habitat conservation and biodiversity. For instance, port activities induced erosion can compromise many ecosystem services provided by coastal land. Second, it cancels out portions of land which can be used for recreational or productive uses. In the first case, stated preferences techniques can be applied, whilst in the second even revealed preferences techniques (or other market valuation techniques are appropriate).

Environmental benefits deriving from prevention of coast erosion are normally assessed by using a variety of elicitation techniques. As discussed above, the choice is dependent upon the value dimension to be estimated.

Saengsupavanich *et al*. (2008) apply a CVM to assess the monetary value of coast erosion entailed by port activity. In their study, port activities entail an immediate external effect to local residents through the erosion of a nearby beach. Through an on site survey, they estimate the economic benefits of preserving the beach by asking respondents (through a single-bounded dichotomous elicitation format) how much they are willing to pay for the Nam rim beach (Thailand) preservation. This estimation approach makes possible to consider both use and non-use value of the coastal area saved from erosion. It is however criticised for its bias (see above). Stated preferences techniques are also used by Huang *et al*. (2006) who employ e choice-based conjoint survey design to elicit individual choices of beach erosion control programs that can have multiple effects on the environment[9]. They aim at deriving welfare estimates that are adjustable according to different erosion control programs. They use the multiple effects of a beach erosion control program as attribute of the erosion control program. By valuing these attributes, the benefits of these programs can be estimated. They conclude that the economic benefits of an erosion control program to preserve a stretch of sand beach can be grossly exaggerated without taking into account the potential negative impacts of the coastal environment caused by the same program.

However, if one is interested in analysing only use values, she could either refer to market valuation techniques. For instance, recreation values can be estimated by using the travel method cost. In this way the economic benefits deriving from beach erosion protection are estimated by assessing the changes in welfare estimates considering two scenarios (the status quo and the alternative one, where the beach disappears because of the erosion). The aggregate changes in consumer surplus approximate the social benefits deriving from beach conservation.

Some other studies focus on the impact that protection enhanced beach quality has on property values and development in coastal areas (Parsons, 1992; Kriesel and Friedman, 2003; Cordes *et al*., 2001). In particular, Cordes *et al*. (2002) predict the economic effects of providing additional shore protection by applying models of real estate economics. They consider use values by taking into consideration residential developments in areas protected from erosion.

Land use and landscape

Maritime transport has an indirect effect on land use and landscape modification, through port development.

It has to be noted that port facilities create a welfare change (and perhaps an external cost) only if new developments are foreseen. Ports inevitably require large areas of land and shallow water areas, as well as other natural resources. In this case, the port expansion could occur at expenses of other productive (residential use of the corresponding land) or non productive (i.e. habitats conservation). In the former case, the opportunity cost of alternative uses should be considered. In the latter case, ports are often required to restore habitats that have been negatively affected, or to create new habitats as a compensation for those lost through exploitation. The value of ecosystem losses should be included in the analysis. To this aim, a useful insight could be that of the compensation measures that are become more and more often a condition for port expansion. Wetland restoration, dune restoration and construction of new aquatic habitats (artificial reefs, new rocks, etc.) are examples of restoration and compensation measures that are normally undertaken in conjunction with port

[9] These authors recognise that beach erosion control programs can have both positive and negative environmental impacts, such as

development projects. The use of material dredged during port development, and subsequently from maintenance dredgings, has become a widely used method for restoring or creating new habitats. Dredgers and other equipment have been designed especially with the purpose to carefully place dredged material to build wetlands, reefs and beaches. The objective has been to minimize impact during the construction of a "new" habitat. In Europe, examples of these actions (and corresponding costs) could be found in the case of Antwerpt.

There are no studies related to the valuation of the impact of maritime transport infrastructure development and land use, but numerous experiences can be quoted where ports engage in environmental compensation (via habitat restoration). The value of this land lost can thus be inferred by the expenses incurred in restoring natural habitats elsewhere (i.e. by referring to the replacement approach).

9. *The economic valuation of impacts on air*

Pollution

Up to our knowledge, the only studies that carry out a cost-benefit analysis of ship air emissions is Whang and Corbett (2007)'s and Gallager (2005)'s ones.

Gallagher (2005), by using SO_x and NO_x pollution estimates elaborated by Corbett and Fishbeck (2000) and Colton (2003) and statistic figures about cargos calling at US ports, calculates the total SO_2 emissions from ships from 1993 to 2001. In order to estimate the economic costs of these emissions from ships he considers external costs estimated by economic literature for SO_2 and the US permit price for NO_x. In the case of SO_2 external costs range from $750 to $4208, whilst in the NO_x vase they range from $1700 to $9500. He finds that found that total emissions from ships are largely increasing due to the increase in foreign commerce. The economic costs of SO2 pollution range from $697 million to $3.9 billion for the entire period, or $77 to $435 million on an annual basis. The bulk of the cost is from foreign commerce, where the annual costs average to $42 to $241 million. For NO_x emissions the costs are $3.7 billion over the entire period or $412 million per year.

In their paper, Wang and Corbett (2007) conduct a cost-benefit analysis of reducing ship pollution in US west coast. First, they estimate the marine fuel consumption by assigning an amount to each location, proportional to ship traffic intensity, by using GIS. Then they assess the sulphur emission control costs by assuming that the chosen policy option will be the switching from hi- to low-sulphur content fuel. They approximate this cost with the low-sulphur fuel price premium, i.e. the difference in prices between hi- and low-sulphur fuels. Thus the SO_2 emission control costs are calculated as the product of the amount of low-sulphur fuel burned in the control area and the price premium of low-sulphur marine fuel. They also calculate emission reductions so obtainable and converted them to on-land equivalent emission reduction[10]. They finally estimate the environmental benefits of sulphur emissions reduction by adopting per ton unit cost range of $2,252 - $ 22,143[11].

initiating or accelerating erosion on neighbouring beaches or affecting wildlife habitats.

[10] On-land emissions are calculated by multiplying ship emissions to the percentage of these emissions that reach land.

[11] They chose these figures on the basis of a meta-analysis of the relevant literature.

All these studies do not estimate external maritime transport costs on the basis of original studies but use estimates derived from a meta-analysis of the literature. As shown above, the per unit external costs differ and, as a consequence, affect the results.

Moreover, they calculate ship emissions directly from ship traffic statistics and multiply this by the unit external costs, without taking into consideration the fact that external effects are indirectly linked to the overall emissions. As emphasised in the fist part of the report, of pollutants concentration matters in determining the magnitude of external effects. Available studies do not consider the actual concentration of SO_2 and NOx. Simply considering the ship emission is incorrect since it is not automatic that these emissions will produce any health or environmental effects (due to lack of exposed population, for instance).

Looking at the cost estimated these studies referred to, Wang and Corbett (2007) use the results of Holland and Watkiss (2002). They estimate the external costs of air pollution by considering:

- SO_2 (sulphur dioxide): through effects of SO2 and sulphate aerosols on health, and SO2 and acidity on materials
- SO_2 (oxides of nitrogen): through effects of nitrate aerosols on health and ozone on health and crop production
- VOCs (volatile organic compounds): through effects of ozone on health and crop production
- PM (particulate matter, focussed on $PM_{2.5}$, particles with an aerodynamic diamter less than 2.5 micrometre): through effects on health

In particular, they estimate external costs in three situations: rural locations (all sources); urban locations (road transport) and emissions from ships. The figures they obtain are calculated using the ExternE methodology (see D1). The following effects are included:

- Acute (short-term) effects of PM10, SO2, ozone on mortality and morbidity to the extent that these have been reported
- Chronic (long-term) effects of PM10 on mortality and morbidity to the extent that these have been reported
- Effects of SO_2 and acidity on materials used in buildings and other structures (houses, offices, bridges, pylons, etc.) of
- no significant cultural value (i.e. excluding damage to statues, cathedrals and churches with fine carvings, etc.)
- Effects of ozone on arable crop yield

The following ones are excluded:

- Non-ozone effects on agriculture (e.g. through acid deposition, nutrient deposition, etc.). Previous analysis has shown these effects to be small in comparison to those that are quantified.
- Change in visibility (visual range) as a function of particle and NO_2 concentration. It was concluded that the issue is not regarded as being so serious in Europe (possibly because reduced visibility through poor air quality is now less of a problem than it was a few years ago).

- Impacts on ecosystems through exceedence of critical loads and critical levels (including forests, freshwaters, etc.). This would seem to be the most serious of the known omitted impacts, with potentially significant consequences for ecological sustainability. The most evident impact of acidification is the loss of fish, particularly salmon and trout, though terrestrial ecosystems are also affected. Problems of eutrophication, caused by emissions of nitrogen-containing pollutants (NO_x, NH_3) are widespread in Europe, with particular hot-spots in a few countries, such as the Netherlands. The most visible effect is one of reducing the viability of rarer species of plant, allowing other species, particularly grasses, to invade land that was previously too nutrient deficient for them.
- Damage to cultural heritage, such as cathedrals and other fine buildings, statues, etc. Whilst this provided the earliest and clearest demonstration of air pollution effects to many people, its importance has decreased substantially over time, as urban SO_2 levels have reduced substantially. However, it is unknown whether this reduced rate of deterioration is still important or not. Analysis is not possible because of a lack of data on stock at risk (e.g. number of culturally important buildings, their surface areas, number and size of statues, repair and maintenance costs).
- Effects of ozone on materials, particularly rubber.
- Macroeconomic effects of reduced crop yield and damage to building materials.
- Unknown effects. Additional effects are suspected in a number of areas, for example, on morbidity and mortality from chronic (long-term) exposure to ozone.

The authors recognise that specific analyses of pollutant dispersion for ship emissions have not been undertaken. For this reason, they suggest to use urban results for city of the same size as the port city and use rural results for emissions close to the shore. They also calculate offshore emissions external costs for given regions. All the estimates are summarised in the tables below. This assumption is deemed “appropriate for gaining an insight on the order of magnitude of associated externalities”.

Table 26 - Marginal external costs of emissions in cities, year 2000 prices (€/tonne)

		PM2.5	SO2
City of 100,000 people		33,000	6,000

Population	Factors	PM2.5	SO2
500,000 people		5	5
1,000,000 people		7.5	7.5
Several million people		15	15

Source: Holland and Watkiss (2002)

Table 27 - Marginal external costs of emissions in rural areas, year 2000 prices (€/tonne)

	SO2	NOx	PM2.5	VOCs
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	7,200
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	3,000	4,100	5,800	1,500
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
UK	4,500	2,600	9,700	1,900
EU-15 average	5,200	4,200	14,000	2,100

Source: Holland and Watkiss (2002)

Table 28 - Marginal external costs of emissions for countries surrounding sea areas, year 2000 prices (€/tonne)

	SO2	NOx	PM2.5	VOCs
Eastern Atlantic	4,500	4,800	9,100	1,500
Baltic Sea	1,600	2,100	2,500	1,000
English Channel	5,900	5,400	12,000	1,900
Northern Mediterranean	4,700	6,200	10,000	1,700
North Sea	4,300	3,100	9,600	2,600

Source: Holland and Watkiss (2002)

Climate change

It is estimated that seaborne transport contributes 1.5 - 3% of the total emissions of CO_2 (Stern 2006). Regarding climate change, the methodological approaches available to estimate its external costs have been carried out in D1. Economic literature is estimating the damage costs or compliance costs of climate change, as a whole or by considering single economy sectors, is quite abundant. Whilst climate change impacts have been quantified and monetised for agriculture in terms of crop yield losses (Bosello and Zhang, 2005), health (Bosello et al., 2005), sea level rise and tourism (Bosello et al., 2006), it is quite difficult to disaggregate these overall benefits among sectors and a comprehensive study regarding the contribution of maritime transport to these impacts is lacking.

However, due to the global nature of GHG, methodologies used to monetise the impacts of other emissions sources can be adopted.

10. The estimation of external costs of maritime transport in the US experience

The monetisation of environmental impacts have been carried out also in Regulatory Impact Analyses. For instance, the USEPA recently published a comprehensive RIA regarding external costs of maritime transport. In fact, In May 2004, as part of the Clean Air Non Diesel Rule Law, EPA finalized new requirements for non-road diesel fuel that will decrease the allowable levels of sulfur in fuel used in marine vessels by 99 percent. These fuel improvements, which begin to take effect in 2007, will create immediate and significant environmental and public health benefits by reducing PM from new and existing engines. Moreover, in March 2008, EPA finalized a three part program that will dramatically reduce emissions from marine diesel engines below 30 liters per cylinder displacement. These include marine propulsion engines used on vessels from recreational and small fishing boats to towboats, tugboats and Great Lake freighters, and marine auxiliary engines ranging from small generator sets to large generator sets on ocean-going vessels. The rule will cut PM emission from these engines by as much as 90 percent and NOx emissions by as much as 80 percent when fully implemented.

For what concerns gasoline boats, in April 2007, EPA proposed a new emission control program that would reduce hydrocarbon emissions from small spark-ignition engines by about 35 percent. The new exhaust emissions standards would begin in 2011 or 2012, depending on the size of the engine. The proposal also includes new standards to reduce evaporative emissions from these fuel systems.

This Regulatory Impact Analysis[12] provides technical, economic, and environmental analyses of the emission standards for diesel boats. This analysis is mandatory following Executive Order 12866, which requires benefit-cost analysis of major new pollution control regulation. In particular, a whole chapter (ch.6) is devoted to estimation of social benefits deriving from emission reduction. In the rest of this paragraph we will analyse this work. In order to identify the health and environmental effects and monetise the monetary impact, the analysis is structured in three major components:

- the calculation of the impact of the regulation on the national emissions (ozone and PM) inventory for 2020 and 2030;
- air quality modelling for 2020 and 2030 to determine changes in ambient concentration;
- a benefit analysis to monetize changes in human health (mortality and morbidity) and welfare (material damages and adverse effects on agriculture and forestry).

A number of known or suspected health benefits have not been quantified, due to the lack of health impact functions. Ambient concentrations are estimated through the Community Multiscale Air Quality (CMAQ) Model[13]. In order to identify the impacts provoked by emissions, EPA uses Health Impact Functions (HIF) that measure the change in a health endpoint for a given change in ambient ozone or PM concentration. They are derived from epidemiology studies, meta-analyses of multiple epidemiology studies or expert elicitations.

In particular, by reviewing available literature, the analysis derives HIF for premature mortality, respiratory hospital admissions, asthma-related emergency room visits, minor restricted activity, school absences and worker productivity. The impacts not consider in the regulatory impact analysis include effects on vegetation, nitrogen deposition, ultraviolet radiation and climate change.

The following table summarises the unit values used for economic valuation of health impacts.

[12] http://www.epa.gov/otaq/marine.htm
[13] http://www.epa.gov/AMD/CMAQ/

Table 29 – Unit values used for Economic Valuation of Health Impacts

	Central Estimate of Value Per Statistical Incidence		
Health Endpoint	1990 Income Level	2020 Income Level	2030 Income Level
Premature Mortality (Value of a Statistical Life): PM2.5- and Ozone-related	$5,500,000	$6,600,000	$6,800,000
Chronic Bronchitis (CB)	$340,000	$420,000	$430,000
Nonfatal Myocardial Infarction (heart attack) 3% discount rate			
Age 0–24 Age 25–44	$66,902 $74,676	$66,902 $74,676	$66,902 $74,676
Age 45–54	$78,834	$78,834	$78,834
Age 55–65	$140,649	$140,649	$140,649
Age 66 and over	$66,902	$66,902	$66,902
7% discount rate			
Age 0–24	$65,293	$65,293	$65,293
Age 25–44	$73,149	$73,149	$73,149
Age 45–54	$76,871	$76,871	$76,871
Age 55–65	$132,214	$132,214	$132,214
Age 66 and over	$65,293	$65,293	$65,293
Hospital Admissions			
Chronic Obstructive Pulmonary Disease (COPD) (ICD codes 490-492, 494-496)	$12,378	$12,378	$12,378
Pneumonia (ICD codes 480-487)	$14,693	$14,693	$14,693
Asthma Admissions	$6,634	$6,634	$6,634
All Cardiovascular (ICD codes 390-429)	$18,387	$18,387	$18,387
Emergency Room Visits for Asthma	$286	$286	$286
Respiratory Ailments Not Requiring Hospitalization			
Upper Respiratory Symptoms (URS)	$25	$27	$27
Lower Respiratory Symptoms (LRS)	$16	$17	$17
Asthma Exacerbations	$42	$45	$45
Acute Bronchitis	$360	$380	$390
Restricted Activity and Work/School Loss Days			
Work Loss Days (WLDs)	Variable (national median =)		
School Absence Days	$75	$75	$75
Worker Productivity	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day	$0.95 per worker per 10% change in ozone per day
Minor Restricted Activity Days (MRADs)	$51	$54	$55

The major share of total benefit is constituted by the benefits of mortality risk reductions. The study estimates that the final standard would result in between 490 and 1,100 cases of avoided PM 2.5 premature deaths annually in 2020 and between 1,100 and 2,600 avoided premature deaths annually in 2030. For ozone-related premature mortality, a range of between 13 to 62 fewer premature mortalities is estimated. As a result, the total of monetized benefits in 2020 for final standards introduced in the USA is between $3.7 billion and $8.8 billion (assuming a 3% discount rate) and between $3.6 billion and $8.0 billion (assuming a 7% discount rate).

The next largest benefit is for reductions in chronic illness. Then hospital admissions for respiratory and cardiovascular causes, minor restricted activity days and work loss days account for the majority of remaining benefits.

The following table summarises these estimates.

Table 30 – Estimated monetary value in reductions in incidence of health and welfare effects (in millions of 2005$)

		2020	2030
PM2.5-Related Health Effect		Estimated Mean Value of Reductions (5th and 95th %ile)	
Premature Mortality – Derived from Epidemiology Studiesc,d,	Adult, age 30+ - ACS study (Pope et al., 2002) 3% discount rate 7% discount rate	$3,400 ($810 -$7,00) $3,100 ($730 -$6,300)	$8,100 ($1,900 -$16,000) $7,300 ($1,700 -$15,000)
	Adult, age 25+ - Six-cities study (Laden et al., 2006) 3% discount rate 7% discount rate	$7,800 ($2,200 - $15,000) $7,000 ($1,900 -$13,000)	$18,000 ($5,100 - $35,000) $17,000 ($4,600 -$32,000)
	Infant Mortality, <1 year – (Woodruff et al. 1997) 3% discount rate 7% discount rate	$7 ($2 - $14) $7 ($2 - $13)	$13 ($3.5 - $26) $12 ($3.1 - $23)
Premature mortality – Derived from Expert Elicitationc,d,e	Adult, age 25+ - Lower bound (Expert K) 3% discount rate 7% discount rate	$1,500 ($0 - $7,700) $1,400 ($0 - $7,000)	$3,600 ($0 - $18,000) $3,200 ($0 - $16,000)
	Adult, age 25+ - Upper bound (Expert E) 3% discount rate 7% discount rate	$15,000 ($4,100 -$30,000) $14,000 ($3,700 -$27,000)	$36,000 ($9,500 -$70,000) $32,000 ($8,600 -$63,000)
Chronic bronchitis (adults, 26 and over)		$150 ($12 - $500)	$340 ($28 - $1,100)
Non-fatal acute myocardial infarctions 3% discount rate 7% discount rate		$110 ($34 - $230) $110 ($31 - $230)	$260 ($74 - $550) $250 ($69 - $540)

Hospital admissions for respiratory causes		$2.1 ($1.0 - $3.2)	$4.9 ($2.4 - $7.3)
Hospital admissions for cardiovascular causes		$6.7 ($4.2 - $9.2)	$17 ($11 - $23)
Emergency room visits for asthma		$0.15 ($0.08 - $0.23)	$0.33 ($0.18 - $0.49)
Acute bronchitis (children, age 8–12)		$0.08 ($0 - $0.2)	$0.17 ($0 - $0.42)
Lower respiratory symptoms (children, 7–14)		$0.18	$0.40
		($0.07 - $0.33)	($0.15 - $0.73)
Upper respiratory symptoms (asthma, 9–11)		$0.21 ($0.06 - $0.46)	$0.46 ($0.13 - $1.0)
Asthma exacerbations		$0.45 ($0.05 - $1.3)	$1.0 ($0.11 - $2.9)
Work loss days		$8.9 ($7.7 - $10)	$18 ($16 - $21)
Minor restricted-activity days (MRADs)		$22 ($13 – $32)	$46 ($27 - $66)
Recreational Visibility, 86 Class I areas		$ (na)f	$ (na)
Ozone-related Health Effect			
Premature Mortality, All ages – Derived from NMMAPS	Bell et al., 2004	$100 (-$170 - $420)	$440 (-$340 - $1,400)
Premature Mortality, All ages – Derived from Meta-analyses	Bell et al., 2005	$340 (-$360 - $1,200)	$1,400 (-$550 - $3,900)
	Ito et al., 2005	$460 (-$260 - $1,400)	$1,900 (-$120 - $4,700)
	Levy et al., 2005	$480 (-$110 - $1,300)	$2,000 ($280 -$4,400)
Premature Mortality – Assumption that association between ozone and mortality is not causal		$0	$0
Hospital admissions- respiratory causes (children, under 2; adult, 65 and older)		-$0.54 (-$4.6 - $3.3)	$2.7 (-$11 - $17)
Emergency room visit for asthma (all ages)		$0.03 (-$0.03 - $0.1)	$0.09 (-$0.07 - $0.30)
Minor restricted activity days (adults, age 18-65)		$2.5 (-$4.0 - $9.9)	$8.8 (-$7.8 - $28)
School absence days		$2.9 (-$1.5 - $6.8)	$11 (-$1.3 - $21)
Worker Productivity		$0.53 (na)f	$2.9 (na)f

11. A methodological proposal to monetise the effects of air emissions of maritime transportation

After having examined all the environmental impacts produced by maritime transportation activities, having described them both qualitatively and quantitatively, having recalled the main studies that monetise these impacts, we are in a position to propose a methodology that has to be followed to analyse and estimate the contribution of maritime transportation to local air quality.

Since the aim of this report is not to develop all the technical and analytical details of such methodology, we will clearly state what are the actual methodological weaknesses or limits of the above quoted studies, with the ultimate objective of indicating research directions.

In particular, we claim due to the local character of the environmental impacts and the site specificities that make previous results immediately transferable to the local context, that a bottom up approach is the most indicated to assess maritime transport impacts. In particular, we refer to the methodologies proposed by IIASA *et al*. (Cofala *et al*., 2007), used to assess the impacts of maritime transportation at the EU scale, and by the Clean Air for Europe (CAFE) program (Hurley *et al*., 2005), which is the most up-to-date and comprehensive study on health impacts. The Cofala *et al*. (2007) study examines the potential contribution of four emission scenarios from shipping to achieving air quality targets following the EU Thematic Strategy on Air Pollution. These scenarios are defined by considering the implementation of different control measures. The study is composed by three phases:

1. compilation and update of ship emission inventories;
2. development of source-receptor (SR) relationships of atmospheric transport of pollution;
3. Analysis of policy scenarios to control ship emissions.

Regarding the CAFE program, this study covers:

- a comprehensive but generally qualitative review of the health effects of particles, nitrogen dioxide and ozone;
- a quantitative meta-analysis of studies in Europe, regarding mortality from time series studies, hospital admissions, and cough among people with chronic respiratory symptoms;
- specific quantitative guidance on (i) quantifying mortality attributable to PM and to ozone and (ii) extrapolation to low concentrations and the role of thresholds.

As described in detail in D1, in order to monetize the external impacts of maritime transport (with reference to air pollutants) through a bottom up approach, the following tasks should be carried out:

1) estimation of ship emissions
2) estimation of ships contribution to pollutant concentration;
3) estimation of exposure of receptors
4) application of dose-response functions to determine various impacts
5) monetisation of these impacts.

In this section we will recall the methodological issues relating to these tasks, so as to clarify the methodological difficulties that have to be overcome with further research.

Estimation of ships emissions and their contribution to pollutant concentration

Up to our knowledge, the estimation of ship contribution to emission on air has been carried out by considering the simple emissions on the atmosphere of maritime traffic, without considering more in detail the level of pollutant concentration.

The methodologies for estimating ship contribution to air emissions have been described above (see MEET methodology (Trozzi and Vaccaro, 1998) & ENTEC (2002) study). For instance, by applying these methodologies it is possible to estimate the ship emissions (measured as kg/year) of different primary pollutants (namely: SO_2, NO_x, PM_{10}, $PM_{2.5}$, etc), but it is not immediate to understand how these primary pollutants contribute to local environmental quality. In particular, nothing could be said on the production of secondary elements (like ozone).

More research is needed to overcome this limitation, so as to derive, from the known level of air emission, the final level of concentration of different pollutants. Of course, this measurement could be done on a case by case basis, by measuring the level of pollutant concentration for a given port area. It is acknowledged (Cescon and Gambaro, 2008) that from air emissions and concentration there is not a linear relationship, since the pollutant dispersion in the atmosphere is regulated by complex processes, by local meteorological conditions and by the chemical pollutant transformations.

Source-receptor relationships that reflect the response of air quality towards changes in the various emissions could be done through different instruments. For instance, the ExternE project uses the Windrose Trajectory Model (see D1), whilst the CAFE programme adopts the EMEP[14] Eulerian dispersion model as modelled by the recent version (version October 2004).

The EMEP models have been instrumental to the development of air quality policies in Europe since the late seventies, mainly through their support to the strategy work under the Convention on Long-range Transboundary Air Pollution. In the 1990's the EMEP models became also the reference atmospheric dispersion model for use in the Integrated Assessment Models supporting the development of air quality polices under the EU Commission. An open source of the Unified EMEP model version rv3 together with a full input data set for 2005 was released in February 2008 (http://www.emep.int/OpenSource/index.html).

This model, however, should be applied to the impacts of maritime transport activities with caution. In fact, the EMEP models use a resolution that is suitable for assessing effects at the regional level, as the grid has a 50km x 50km dimension. However, especially in the case of maritime transport, there is the need to quantify effects at more local scales, i.e. at city level. As recognised by the CAFE program final report (Holland *et al*., 2005), "it

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[14] EMEP (European Monitoring and Evaluation Programme) is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution for international co-operation to solve transboundary air pollution problems. Initially, the EMEP programme focused on assessing the transboundary transport of acidification and eutrophication. Later, the scope of the programme has widened to address the formation of ground level ozone, persistent organic pollutants, heavy metals and particulate matter. The EMEP programme relies on three main elements: (1) collection of emission data, (2) measurements of air and precipitation quality and (3) modelling of atmospheric transport and deposition of air pollutions. Through the combination of these three elements, EMEP fulfils its required assessment and regularly reports on emissions, concentrations and depositions of air pollutants, the quantity and significance of transboundary fluxes and related exceedances to critical loads and threshold levels.

may be envisaged that the analysis will be carried out for individual cities for which air quality data are available at a much finer resolution, based on results of monitoring and urban-scale modelling" (p. 14).

In fact, recently a study has been undertaken (Amann *et al*., 2007) to develop functional relationships to quantify urban pollution levels in Europe for the purposes of a health impact assessment. For instance, this study introduces functional relationships that connect, for a given city, urban and regional emissions with urban background concentrations of $PM_{2.5}$, as a function of rural background concentrations (as modelled at the regional scale), emission densities in city, and some meteorological and topographic parameters that reflect city-specific dispersion characteristics. The authors conclude that "the size of urban agglomerations, local wind speeds and the frequency of winter days with low ventilation, in addition to the emission densities of urban low-level emission sources, have been identified as critical factors that contribute to the "urban increments" in a given city". They also specify that serious uncertainties that have critical influence on the estimated urban increments are associated with all these data. They suggest that more accurate information on city-specific meteorological data and information on local emission sources and improved monitoring data are prerequisites for a further refinement of the methodology.

To sum up, in the case of the assessment of the ship emissions' contribution to local environmental quality, more attention should be devoted at obtaining results of pollutant concentration at the local scale, since the EMEP grid is to big to be used as a reference for studies with local impacts. Some research is needed to apply this method also at a local scale. In fact, this difficulty is overcome in cases where specific analyses have been carried out, which is not always the case. For all the situations where local studies are not available, a method to transfer the results obtained in other studies should be defined. This is one major research direction that we suggest.

Estimation of receptors' exposure and determination of impacts

In the case of maritime transportation, the estimation of receptors' exposure is crucial, given its characteristics of being a mobile source of pollution. Differently from other transport modes, the most part of shipping activities takes place far away from urban centres or other human settlements. Moreover, for those activities that produce impacts close to urbanised coastal areas, it is necessary to have information on these effects at a high resolution.

Thus in analysing the maritime transport impacts, the first step that has to be taken is to distinguish among local and global pollutants. Whilst in the first case the impact will be local, and thus it is crucial to determine the degree and extent of receptors' exposure, in the second one the determination of impacts can be done in a more straightforward way, especially for pollutants uniformly mixed.

Coming to the local impacts, it is recognised the most relevant ones are those related to consequences of environmental quality on health conditions. They are determined by ozone ground level concentrations and particulate matter (PM). In particular, the CAFE program has focussed its attention on the two main pollutants, namely PM and ozone. This study has referred to work of WHO on "Systematic Review of Health Aspects of Air

Quality in Europe"[15]. For morbidity, various sources have been used, including ExternE, and the WHO-sponsored meta analysis of the acute effects of PM and ozone in Europe[16].

In Annex 1 we report the dose-response functions determined by the above mentioned pollutants on several kinds of health impacts, namely: chronic mortality from PM (amongst those aged over 30 and kids), acute mortality from ozone in general population, morbidity impacts (chronic bronchitis, respiratory and cardiac hospital admission, consultation with primary care physicians, restricted activity day and minor restricted activity day, use of respiratory medication and symptom days). Regarding mortality impacts, the methodology proposed by the CAFE programme considers both the additional deaths provoked by the pollution and the life- years-lost (LYL) across the whole population at risk and suggests referring to LYL[17].

It has to be noted that these functions has to be applied with some cautions. They are derived from epidemiological studies which give rise to the dose-response functions, based on studies of air pollution mixtures, generally in urban areas. The health effects of the mixture as a whole are examined and associations with specific pollutants are assessed. However, the applications of impact pathway approach are, often, to specific pollutants or to other mixtures. Application to mixtures is done by: (1) Disaggregating the mixture into its component parts (i.e. characterising it in terms of the classical pollutants); (2) Estimating effects associated with each component; and then (3) Re-aggregating effects, to give an estimate of the benefits of changes in the mixture. The third passage is the most problematic, since in this phase a double-counting problem could arise. For instance, separating the roles of SO_2, NO_x and PM_{10} is particularly problematic, since they vary together. Regarding the second passage, attention should be paid to the consideration of the whole impacts (some could be relevant but not quantifiable) and on the effects caused by the general air pollution mixture.

Another important methodological aspect that should be taken into consideration in the use of the dose-response functions is the presence of "thresholds at the population level", i.e. the concentration of pollutant such that, at concentrations below that threshold, there is no increase in risk of adverse health effects in any of the exposed population at risk (Hurley *et al*., 2005). They conclude that "epidemiological studies of the pollutants of interests have not supported the existence of thresholds at the population level" and that "it is plausible that at any level of ambient fixed-point concentration, some (possibly small) proportion of the population-at-risk will nevertheless experience some personal exposures that contribute something to an increase in risk" (p. 6).

One important difference of the CAFE program with respect to previous studies (namely ExternE) is that it adopts a staged approach to the consideration of impacts entailed by pollutants. In particular:

1. First the impact pathways linking ambient PM to a wide variety of cardio-respiratory endpoints are considered. This choice is justified by the fact that some aspect of particles are the main drivers of the effects of the pollution mixture as a whole;
2. Second, the effect of ozone is added, considering only daily variations, not for longer term exposure.
3. Third, SO_2 and NO_2 have to be treated with caution, since some doubts exists about the association of these elements with health effects. An evaluation of changes in SO_2 and NO_2 requires considering the effects of the derived secondary particles, nitrates and sulphates. The same could be said for CO.

[15] http://euro.who.int/document/e79097.pdf
[16] http://euro.who.int/document/e82792.pdf
[17] The interest reader can refer to the analysis described in D1.

We are here revising the CAFE program insights since it is considered the most advanced effort at European level to define a methodology on the assessment and evaluation of impacts related to air pollution and because it has common features with analyses carried out by US EPA.

Another relevant effect at local level regards the impacts on ecosystems and crops. They are summarised in Table 31 below.

Watkiss *et al*. (2005), quoting the ExternE conclusions, affirm that these effects are likely to be unimportant, due to the "significant falls in emissions of SO_2 and [to the fact] […] that in most agricultural areas concentrations are now well below those observed to cause damage" (p. 80). However, without questioning the general validity of this claim, it has to be noted that maritime transport entails significant SO2 emission and that at local scale this lack of effect could not occur.

The CAFE program focuses on the following impacts: 1. visible injury to crops; 2. reduction in crop yield; 3. interaction with climate; 4. reduction in livestock production. It refers to the exposure-response functions only for wheat and potato. Other relationships could be found in Holland *et al*. (2002) and are reported in Annex 2.

Considering global impacts, they are mainly driven by GHG emissions and the consequent impact on climate change. For this kind of impacts the considerations made above remain still valid and immediately replicable.

To sum up, the estimation of receptors' exposure has received good attention by recent EU funded studies. Those on human health are the objects of numerous studies[18]. More uncertainties are instead related to the quantification of crop damages from ozone exposure. Ozone critical levels in Europe are defined in terms of an accumulated exposure over a threshold of 40 ppb, AOT40. It is recognised, however, that this mapping is unlikely to be accurate (Smith *et al*., 2005).

Table 31 - Impacts of the principal CAFE air pollutants on agricultural and horticultural production Source: Holland et al. (2005a)

Pollutant	Effect
SO2	Increase in yield at low exposure, decrease in yield at high exposure Visible injury at high concentrations (would make some leaf crops such as spinach or lettuce un-saleable) Enhanced performance of pests and pathogens Acidification of agricultural soils
NOx	Enhanced performance of pests and pathogens Reduced tolerance of other stresses (e.g. drought, cold) Acidification of agricultural soils Fertilisation of agricultural systems with nitrogen Increased nitrogen run-off from agricultural systems
NH3	Enhanced performance of pests and pathogens Reduced tolerance of other stresses (e.g. drought, cold) Acidification of agricultural soils Fertilisation with nitrogen Increased nitrogen run-off from agricultural systems
Ozone	Visible injury to crops Reduction in crop yield Enhanced performance of pests and pathogens Interaction with climate
Particles	Some discussion in the literature of impacts through shading effects of particles deposited on leaf surfaces Decrease in photosynthetically active radiation reaching plants

[18] For a list of the available studies the interested reader could refer to those quoted by Holland et al. (2005a).

Monetisation of the impacts of maritime transportation

In this paragraph we will consider all the main environmental effects identified in the first part of this report, produced by air pollutants entailed by maritime transportation, namely: health impacts (mortality and morbidity); agricultural production; and ecosystems (Holland *et al*., 2005a). In fact, several points of this discussion are not only related to maritime transportation, but have a general validity for all activities entailing air pollution. Nonetheless, we will emphasise the aspects peculiar to maritime transportation.

For what concerns the **valuation of health impacts**, namely mortality and morbidity, Hurley *et al*. (2005) take as a reference point the analysis carried out under the NewExt project and a DEFRA study (2004), both aiming at specifically valuing the willingness to pay for a reduction in air pollution by considering health effects.

Before providing the reference values for monetisation of mortality impacts, they provide a useful discussion about the metric that has to be used to assess these impacts. In fact, one can either refer to the Value of the Statistical Life (VSL) or the Value of a Life-Year (VOLY).. It is noteworthy that, in case of acute effects due to short term exposure, it is difficult to regard air pollution as the primary cause of death. Moreover, people likely to be affected by short term exposure are likely to be in a state of illness already. For this reason, the ExternE project adopted the VOLY as a reference for monetisation of these impacts[19]. The CAFE program shares this point. In fact, VSL and VOLY are linked by the following relationship, where VSL is obtained by discounting and summing up over time the annual like years values.

$$VOSL = VOLY_r \cdot \sum_{i=a+1}^{T} {}_aP_i(1+r)^{i-a-1}$$

Where:

- *a* is the age of the person whose VSL is being estimated;
- aPi is the conditional probability of survival up to year *i* having survived to year *a*;
- *T* is the upper age bound;
- *r* is the discount rate

Hurley *et al*. (2005) clearly suggest that the more appropriate metric is the years of life lost, instead of the number of deaths. Thus VOLY should be used instead of VSL. In particular, they suggest using the estimated obtained in the NewExt project, i.e.:

- central VOLY values of €52,000 (from the study median) and €120,000 (from the study mean);
- Central VSL values of €980,000 (from the study median) and €2 million (from the study mean), both expressed for price year 2000. WTP values from the 1 in 1000 risk change question, combined with the adjustment for health condition gives an upper bound sensitivity value of €5.6 million.

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[19] In fact, this conclusion is not shared by other studies. For instance, the Commission's working group (DG ENV, 2000) suggests referring to the VSL.

Apart for the metric chosen, there is also a problem in valuing the effects on the whole population affected. In particular, whilst the valuation of mortality due to air pollution in adults is well covered by economic literature, the same cannot be said for the valuation of mortality in children.

The difficulties here lie in the fact that, since children cannot be state their WTP for risk reduction, one of the assumptions of microeconomic modelling does not hold. Alternatively, children preferences can be elicited by referring to preferences of: (i) society; (ii) adults placing themselves in the position of children; (iii) parents assessing the risks faced by their own children. All of these present pitfalls, due to the risk of double counting because of altruism. Other aspects that affect the adults WTP are: income, household composition and structure. By reviewing some published research, Hurley et al. (2006) come to the conclusion that the value of children's health is higher than those of the adults.

Monetisation of morbidity impacts is instead done by considering the change in welfare, using the human capital approach, by looking at direct financial costs associated with illness, i.e. primarily medical expenses and lost wages. In this approach, monetisation of morbidity impacts is derived from: medical costs paid by the health service; lost productivity and other social and economic costs including any restriction on or reduced enjoyment of desired leisure activities, discomfort or inconvenience. The CAFE program takes the Ready *et al*. (1994) study as a point of reference. A summary of morbidity unit values is provided in the table below. Few valuation studies are available.

Table 32 – Morbidity unit values

Health end-point	**Recommended central unit values, price year 2000**
Hospital admissions	2,000/admission
ERV for respiratory illness	670/visit
GP visits (event): Asthma Lower respiratory symptoms	 53/consultation 75/consultation
Respiratory symptoms in asthmatics (event): Adults Children	 130/event 280/event
Respiratory medication use . adults and children (day)	1/day
Restricted activity day (adjusted average for working adult) Restricted activity day (adjusted average for age >65) Restricted activity day (days when a person needs to stay in bed) Restricted activity day (work loss day) Minor restricted activity day	83/day 68/day 130/day 126/day 38/day
Cough day	38/day
Symptom day	38/day
Work loss day	82/day
Minor restricted activity day	38/day
Chronic bronchitis	190,000/case

Source: Hurley et al. (2005)

In a brief note, Hoffmann and Krupnick (2004) state that the human capital approach cannot simply be extended to valuation of children health effects because it can be more difficult to estimate the value of the time young children lose to illness because they are not engaged in the labour market.

For what concerns maritime transportation activities, up to our knowledge no studies exist which consider the health effect of the pollution entailed by ships on sailors.

Regarding the monetisation of the effects of air pollution on **crop yields**, a damage cost approach is chosen. It is recognised that ozone is the main pollutant having effects on agriculture and horticulture sectors. Once the effects of ozone on these are isolated, one can consider the value of the lost produce to infer the economic damages entailed by pollution. As for health impacts, this method is valid for all activities entailing air pollution, not only maritime transport.

In particular, the CAFE program suggests multiplying the estimated yield loss by the world market prices. The final report (Watkiss *et al*., 2005) refers to 2000 world prices published by FAO. They use world market prices as the shadow price of crop production (national prices are influenced by subsidies and do not reflect the true market value). The most recent data available are referred to the year 2005.

From a methodological point of view, the valuation of crop damages does not present particular problems, once world prices are known. The only uncertainties lie on the quantification of pollution impacts.

Table 33 – Valuation data for agricultural crops (2000)

	€/tonne		€/tonne
Barley	120	Pulses	320
Carrots	340	Rape	240
Cotton	1350	Rice	280
Fresh vegetables	340	Rye	80
Fruit	680	Soya	230
Grape	360	Sugar beet	60
Hops	4100	Sunflower	240
Maize	100	Tobacco	4000
Millet	90	Tomato	800
Oats	110	Water melon	140
Olives	530	Wheat	120
Potatoes	250		

Source: FAO website

Regarding **effects on ecosystems**, air pollution is the main cause of acidification. Even in this case, methodological issues are not related to maritime transport only but are common to all activities entailing air pollution. Nonetheless, provided the expected trend in the increase in world shipping movement will be confirmed, maritime transportation will be one of the main polluters.

Apart from considering stated preferences approach which infers the WTP for nature conservation, one could infer the benefits of protecting such ecosystems by computing the compliance costs of enforcing emission control measures. This approach, however, has been criticised for being self-referencing (Holland *et al*., 2005). Moreover, compliance costs produce not only effects on ecosystems but on health as well and thus the only effect on ecosystem cannot be isolated. We suggest computing these costs, but then to confront them with benefits calculated using ad-hoc stated preferences approaches[20].

[20] For a discussion of these, the interest reader could refer to A., Miola et al . Review of measurement of external costs of transportation in theory and practice. EUR 23714. ISBN 978-92-79-11279-9.

Sensitivity analysis and Uncertainty

All the difficulties in assessing impacts and monetise them are inevitably source of uncertainty. In order to understand how such uncertainty affects the valuation results.

First of all, it is important to note that a major source of uncertainty is given by those effects that cannot be described quantitatively (and their consequent omission in the assessment), by the use of alternative methodology to assess the same impact or by the transfer of data regarding exposure-response, valuation results, etc. In these cases, a sensitivity analysis could be carried out. Examples of sensitivity analysis cover (Holland et al., 2005):

- Observation of the effect on outputs of a systematic stepwise change in one or more variable(s). This could, for example, involve assessment of the effect of a series of incremental changes of 5% or 10% around the core estimate for a specific variable.
- Use of alternate estimates for a specific parameter based on different methodologies (e.g. monetisation of mortality impacts using VOLY and VSL based methods; use of European average or country specific valuations; use of different approaches to discounting)
- Division of impacts into confidence bands, to differentiate between those effects that can be assessed with greatest confidence and those that can be quantified with less confidence.

However, for those impacts that can be quantified, uncertainty can be addressed through the use of statistical techniques. As underlined above, to estimate environmental costs of air pollution one should have data on pollution concentration; population at risk, incidence rate, the response function and valuation metrics.

The major sources of uncertainties come from the last three points, since pollution concentration and population at risk are generally covered by official statistics and measurements. Holland et al. (2005) address this uncertainty by describing statistically each of these elements, namely, by assuming a distribution of the sample and by deriving the sample means and the standard error. The results for ozone and PM are reported below.

Table 34 - Best estimates and ranges used for incidence data, exposure response functions and valuation data in the analysis of statistical uncertainties in the health impact assessment for ozone effects

Annual incidence rate: distribution – triangular	+/-	Best estimate
Mortality rate (deaths per head of population)	5%	0.011
Respiratory hospital admissions, >64 years (cases/100,000 population)	20%	2,496
Minor restricted activity days (per person)	40%	7.8
Adult use of respiratory medication (days per person)	40%	0.045
Respiratory symptoms, adults (dummy variable)	40%	1
Response function: distribution - normal	**Std deviation**	**Best estimate**
Acute mortality (% change in mortality rate per 10µg.m-3)	0.075%	0.30%
Respiratory hospital admissions (%change in incidence/10 µg.m-3 O3)	0.35%	0.50%
Minor restricted activity days, population 18-64 (%change in incidence/ 10 µg.m-3 O3) Respiratory medication use (days /10 µg.m-3 O3 /1000 adults aged 20+)	0.45% 456	1.48% 730
Minor restricted activity days, (%change in incidence for population aged >64 /10 µg.m-3 O3)	0.45%	1.48%
Respiratory symptoms (symptom days/1000 adults/10 µg.m-3 O3)	175	343
Valuation (all units - €/case): distribution – normal	**Standard error**	**Best estimate**
Acute mortality (VOLY, mean) (€/case)	14,600	120,000
Acute mortality (VOLY, median) (€/case)	3,700	52,000
Respiratory hospital admissions (€/event)	670	2,000
Minor restricted activity days, (€/day)	13	38
Respiratory symptoms in adults (€/day)	13	38
Respiratory medication use by adults (€/day)	0.33	1

Source: Holland et al. (2005b)

Table 35 - Best estimates and ranges used for incidence data in the analysis of statistical uncertainties in the health impact assessment for PM effects.

Annual incidence rate: distribution - triangular	+/-	Best estimate
Mortality rate, >30 years	5%	1.61%
Infant mortality rate, ages 1 to 12 months	10%	0.19%
Chronic bronchitis, % of population aged >27 years affected	40%	0.38%
Respiratory hospital admissions (cases/100,000 population)	20%	617
Cardiac hospital admissions (cases/100,000 population)	20%	723
Restricted activity days (RADs, days / person)	40%	19
Use of respiratory medication by adults (% symptomatic adults)	40%	4.50%
Use of respiratory medication by children (% of children who are symptomatic)	40%	20%
Lower respiratory symptoms, adults (% of adults who are symptomatic)	40%	0.30
Lower respiratory symptoms, children (dummy variable)	40%	1
Consultations asthma (consultations / 1000 children)	40%	47.1
Consultations asthma (consultations / 1000 adults of working age)	40%	16.5
Consultations asthma (consultations / 1000 elderly)	40%	15.1
Consultations URS consultations / 1000 children)	40%	574
Consultations URS (consultations / 1000 adults of working age)	40%	180

Consultations URS (consultations / 1000 elderly)	40%	141
RADs, young + elderly (days/person)	40%	19
Response function: distribution – normal	**Std deviation**	**Best estimate**
Mortality (change in mortality risk / 10 µg.m-3 PM10)	2%	6.00%
Mortality (years of life lost (YOLL)/µg.m-3)	11	65.1
Infant mortality (change in mortality risk / 10 µg.m-3 PM10)	1.00%	4.00%
Chronic bronchitis, >27 years (%change in incidence/10 µg.m-3 PM10)	3.70%	7.00%
Respiratory hospital admissions (%change in incidence/10 µg.m-3 PM10)	0.26%	1.14%
Cardiac hospital admissions (%change in incidence/10 µg.m-3 PM10)	0.15%	0.60%
Restricted activity days (%change in incidence/10 µg.m-3 PM10)	0.03%	0.48%
Use of respiratory medication by adults (additional days of bronchodilator usage per 1000 symptomatic adults per 10 µg.m-3)	900	908
Use of respiratory medication by children (additional days of bronchodilator usage per 1000 children per 10 µg.m-3)	430	180
Lower respiratory symptoms (symptom days / symptomatic adult /10 µg.m-3 PM10)	0.57	1.30
Lower respiratory symptoms (symptom days/child aged 5-14/10 µg.m-3 PM10)	0.45	1.85
Consultations asthma (% increase in consultations amongst children/ 10 µg.m-3 PM10)	1.25%	2.50%
Consultations asthma (% increase in consultations amongst working age adults / 10 µg.m-3 PM10)	0.95%	3.10%
Consultations asthma (% increase in consultations amongst the elderly / 10 µg.m-3 PM10)	2.30%	6.30%
Consultations URS (% increase in consultations amongst children / 10 µg.m-3 PM10)	0.35%	0.70%
Consultations URS (% increase in consultations amongst the working age population / 10 µg.m-3 PM10)	0.45%	1.80%
Consultations URS (% increase in consultations amongst the elderly/ 10 µg.m-3 PM10)	0.80%	3.30%
RADs, young+elderly (%change in incidence/10 µg.m-3 PM10)	0.03%	0.48%
Valuation (all units – €/case): distribution – normal	**Standard error**	**Best estimate**
Chronic mortality (VOLY, mean, €/life year)	14,600	120,000
Chronic mortality (VOLY, median, €/life year)	3,700	52,000
Chronic mortality (VSL, mean, €/death)	235,000	2,000,000
Chronic mortality (VSL, median, €/death)	74,000	980,000
Infant mortality (€/death)	1,000,000	3,000,000
Chronic bronchitis, >27 years (€/case)	63,000	190,000
Respiratory hospital admissions (€/event)	670	2,000
Cardiac hospital admissions (€/event)	670	2,000
Restricted activity days, working age (€/day)	27	82
Lower respiratory symptoms, adults and children (€/day)	13	38
Consultations asthma, URS (€/event)	18	53
RADs, young, elderly (€/day)	23	69
Use of respiratory medication (€/day)	0.33	1

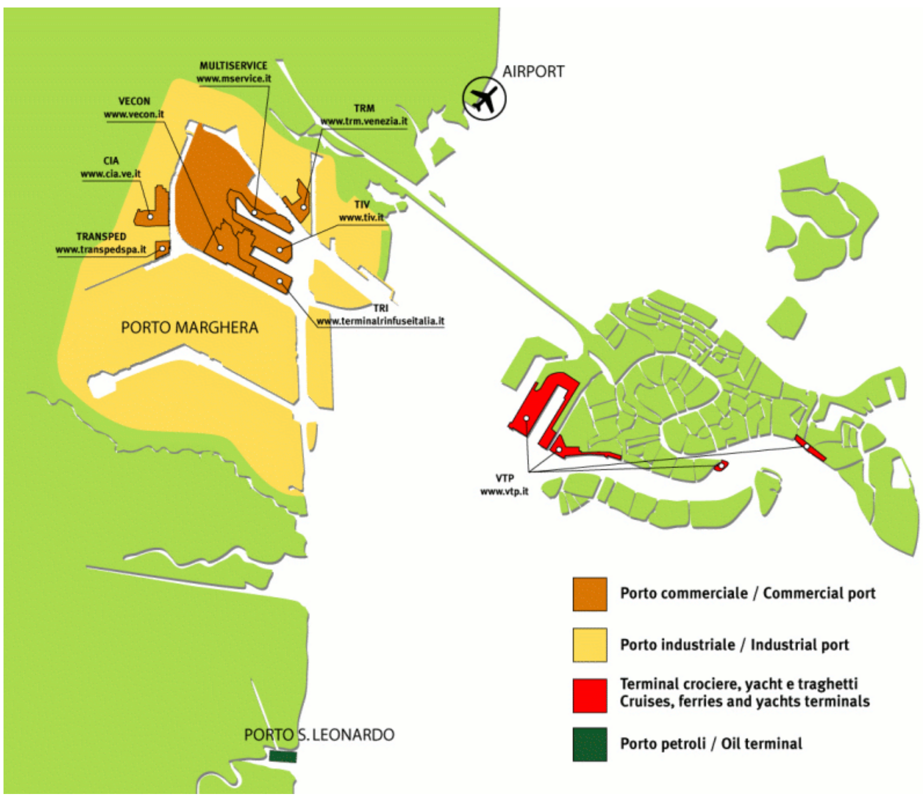
Source: Holland *et al*. (2005b)

12. Testing through the Venice case study

Description of the case study

At European level, the Port of Venice is one of the most important Italian ports. It is interested by ship movements related to oil, commercial and industrial traffic[21]. In the last ten years, the port activities have known an important change, due to the evolution of regional productive features and the change of international scenario. In particular, in the last ten years maritime traffic has been expanding (+24%) and its composition has been changing.

Figure 4 – Map of the Port of Venice



Source: Venice Port Authority website.

Commercial goods transported in the port terminal are as follows:

- cereals (maize and soya, other cereals and flours);
- carbon used in energy production;
- oil and other refining products;
- iron and steel;
- other raw materials (i.e. cement, salt, pyrite, sulphur, sand, clay, bauxite, chalk, etc.)
- other commercial goods transported through containers;
- ro-ro cargo.

The following table shows the composition of non-passenger traffic in the case of Venice.

[21] The difference between commercial and industrial traffic lays on the fact that commercial goods are transported to be transformed elsewhere whilst industrial goods are processed on site, on the nearby Porto Marghera industrial zone.

Table 36 – Composition of ship traffic in the Port of Venice (1997-2007), thousands of tonnes

	1.997	1.998	1.999	2.000	2.001	2.002	2.003	2.004	2.005	2.006	2.007
COMMERCIALE	8.808	10.106	10.320	11.063	12.178	12.475	12.716	13.016	12.722	14.542	14.620
INDUSTRIALE	4 963	4.722	5.797	6.532	5.973	5.799	5.971	5.994	5.835	5.033	4.452
PETROLI	10.606	11.913	11.003	10.581	10.658	11.274	11.440	10.746	10.542	11.361	11.142
TOTALE	24.379	26.743	27.122	28.178	28.811	29.551	30.129	29.758	29.101	30.939	30.217

Source: Venice Port Authority.

In 2005 more than 7,000 transits have been registered. Of these, only 75 have been related to non-commercial traffic (i.e. passengers or research vessels). More than 5,000 vessels have a draught comprised between 5 and 9 meters, whilst only 3% of the vessels have a draught of 9 meters. 97% of the vessels are commercial ships.

Table 35 – Number of transits and cargo (absolut values and %) per vessel type (2005)

Vessel Type	N. of transits	%	Total cargo	%
Bulk Carriers	1087	22,22%	5.718.006	25,71%
Container ships	1192	24,37%	6.563.946	29,51%
Ro-Ro	572	11,69%	2.446.850	11,00%
Tankers	914	18,68%	5.550.984	24,96%
Cargo	1127	23,04%	1.961.113	8,82%
TOTAL	**4892**	**100,00%**	**22.240.899**	**100,00%**

Source: Ufficio di Piano – Venice municipality

The traffic characteristics and volumes are heavily conditioned by the lagoon morphology. Vice versa, the morphology has also an impact on the competitiveness of the port. For instance, the length of the Malamocco Canal obliges the ships to sail for two hours before reaching the docks, and this creates additional costs with respect to other Italian ports. Moreover, the depth of the canals creates a limit for the dimension of vessels that can enter the port: regarding containers, only those with less than 4,000 containers can enter in the port. However, a deepening of the canals until 12m is foreseen by 2011[22].

In the last two years bulk carriers traffic has increased dramatically, especially for what concerns iron and steel (the amount of goods transported in this way increased from less that 2ml tonnes to more than 3ml). The same trend is registered for Ro-Ro, due to the creation of the "sea motorway" between Italy and Greece (from 110,000 tonnes to more than 140,000). Oil transport augmented has well (from 10.5ml tonnes to more than 11.1ml tonnes). At the contrary, in the same period the traffic of the industrial sector has decreased from around 6ml tonnes to 4.5ml tonnes.

For what concerns passenger traffic, the cruise sector is expanding rapidly. In 2008 it was ranked as 13th at world level (and 1st among the Italian ports). As shown in figure below, the number of passengers is augmented 10 times in the last eight years. Only in 2007 the increase in the number of passengers has been of 27.9% and this year is confirming this trend (+11.9% with respect to 2007).

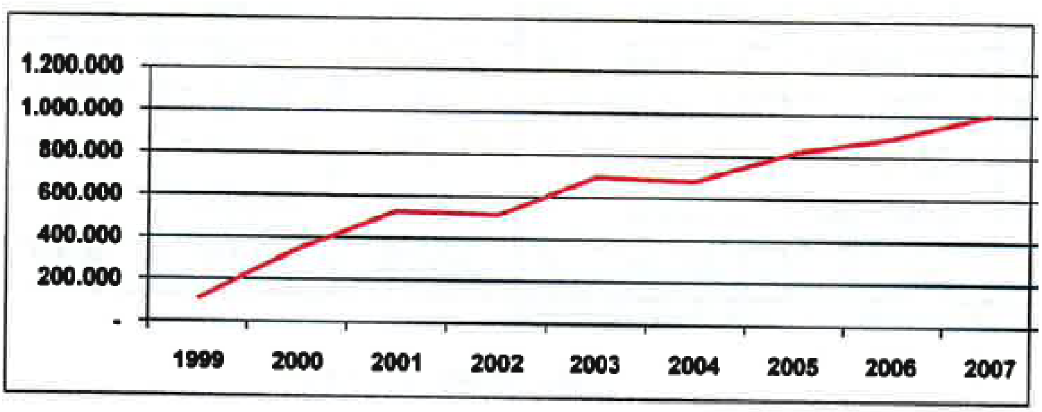
[22] See the "Piano Operativo Triennale", approved by the Venice Port Authority last September 11th 2008.

The environmental impacts of port activities and related maritime transport have received recently great attention. As a response, the Venice Port Authority has developed a series of initiatives to lessen the environmental consequences of maritime transport activities, such as:

- the maintenance of the quays in the Porto Marghera area, to impede the transfer of polluting substances from soil to the lagoon;
- the collection and disposal of washing water in the Marghera harbour, to decrease pollution loads into the lagoon;
- the collection of rainwater in the Levante wharf, through the complete rebuilding of the wastewater pipes and their continue filtration;
- The Framework Agreement “Progetto Vallone Moranzani”, for the dredging sediment management and the requalification of the whole Malcontenta area. The agreement foresees the creation of a site for the disposal of the contaminated materials resulting from port canal dredging, so as to manage 3.2 million m^3.
- The Management Plan for the waste produced by vessels calling at the Venice Port, through a system for the storage and treatment of liquid fuels and bilge waters.

These concrete actions are accompanied by a bunch of studies aiming at improving the available knowledge related to environmental impacts of Port activities, such as the definition of an environmental accounting system, a study on the waves entailed by sailing, on the electrosmog, one regarding the noise, and finally the monitoring of air emissions from cruise vessels (see next paragraph).

Figure 5 – Increase in cruise traffic: number of passengers (1999-2007)



Source: Venice Port Authority

In order to quantify and monetise the impact of maritime traffic it is fundamental to characterise this traffic. The Venice Port Authority has a dataset of all arrival and departures of ships calling at the Venice port. The last version available refers to the year 2006.

Application of the proposed methodology to the Venice case study

In assessing whether the methodological aspects can be applied to the Venice case study, we will recall the analytical steps recalled above.

Regarding the **emissions entailed by maritime activities**, these data are available by considering an ARPAV study published in 2007.

In February 2007 the emissions entailed by port activity have been the object of a study carried out by the Regional Agency for Environmental Protection (ARPAV).

This study estimates the emissions derived from maritime transport in the province of Venice by considering both the national and international vessels calling at the Venice port. Only the internal shipping was excluded.

In order to estimate such impacts, information regarding the vessels calling at the Venice port, their fuel consumption, the ship traffic (movements and manoeuvring time) and on emission factors per vessel type has been collected. Regarding emission factors, this study refers to the findings of ENTEC (2002) study. This study does not report emission factors for fuel and type of engine, but only for the kind of vessel. The following table summarises the data used and their sources.

Table 38 – Data used in the ARPAV study and related sources

Data needed	**Source**
Type of vessel	Venice Port Authority
Shipping phases	MEET project
Daily fuel consumption	MEET project
Number of days for each activity	Venice Port Authority
Emission factors for pollutants, for vessel type and shipping phase	ENTEC (2002)'s study

The study has found that the most important pollutants are NO_x and SO_2, for national shipping and CO2 for international one (see table below).

Table 39 – Emissions of Port of Venice

Shipping activity	Estimate	Emissions (tonnes/year)					
		NO_x	SO_2	CO_2	CO	HC	PM
National	Without tug boat	544.33	518.66	30733.98	71.54	48.78	76.64
	With tug boat	579.14	555.66	33039.87	76.91	52.62	83.67
International	Without tug boat	2952.43	2806.44	166884.15	388.47	259.23	409.59
	With tug boat	3068.75	2930.02	174587.67	406.40	272.07	433.09

Source: ARPAV (2007)

Table 40 – Contribution of each vessel type to emissions (2005)

Vessel Type	Emissions (tonnes/year									
	NO_x		SO_2		CO_2		HC		PM	
	A.V.	%	A.V.	%	A.V.	%	A.V.	%	A.V.	%
Passengers	1038.97	29.71	1104.6	33.22	66610.89	33.71	98.5	31.98	169.02	34.76
Mixed	10.25	0.29	10.21	0.31	603.80	0.31	0.9	0.29	1.47	0.3
Cargo	2447.54	69.99	2210.29	66.47	130403.44	65.99	208.61	67.73	315.74	64.94

Source: ARPAV (2007)

Table 41 – Contribution of each shipping phase to emissions (2005)

Shipping phase	Emissions (tonnes/year)									
	NOx		SO2		Co2		HC		PM	
	A.V.	%	A.V.	%	A.V.	%	A.V.	%	A.V.	%
Manoeuvring	632.04	18.08	611.70	18.4	36781.70	18.61	75.67	24.57	114.86	23.62
Stationing	2864.72	81.92	2713.4	81.6	160836.43	81.39	232.34	75.43	371.37	76.38

Source: ARPAV (2007)

Regarding this first task, we consider the ARPAV study as the most reliable source of information regarding emissions in the case of Venice.

It is important to underline that the dataset built up by ARPAV considers each vessel calling at the Venice port and its respective fuel consumption. In order to calculate the emissions provoked by maritime transport activities, the ARPAV study considers the emission factors calculated by ENTEC 2002.

An alternative way could be to consider the vessels on the basis the number of engines they have installed and then apply the emission factors on the basis of this data, as done by IIASA (2007). A comparison of the two methodologies could be a good mean to test the sensitivity of the estimates to the emission factors used.

After having quantifying the emissions produced by maritime transport activities, the **assessment of pollutants' concentration** is crucial to determine the impacts described in D1.

As already stated above, this task is carried out by applying dispersion models. The limitation of existing models and way to overcome their weaknesses have already described above. In the case of Venice, we can rely on an original study which reports the concentration levels for different pollutants attributable to big cruise vessels, observed along the year.

In their work, Cescon and Gambaro (2008) measure the affective contribution of cruise ships to pollutant concentration in the city of Venice. In particular they considered the following compounds: PM_{10} and $PM_{2.5}$; PAHs; NO_2 and SO_2.

In order to measure the contribution of cruise ship to pollution in the city of Venice, they use a DOAS (Differential Optical Absorption Spectroscopy) system at remote sensing, which makes possible to measure the difference of gases emitted by ships by measuring the difference of concentration due to the ship transit. This technique has also been used in the "QUANTIFY" Integrated Project funded by the FP6-EU.

The results for SO_2 and NO_2 are summarised in the following table.

Table 42 – Daily contribution of ship transit (kg)

		SO_2	NO_2
Big and medium vessels	Measured	205	284
	Estimated	236	327
All vessels	Measured	623	766
	Estimated	841	1034

Note: Estimated figures are obtained by increasing by 15% the measured ones (to take into account the ship transits at not identified).

The study reports also daily concentrations for $PM_{2.5}$, SO_2, and several PAHs in different locations. The results of the study are difficult to interpret, for two reasons that are both underlined by Cescon and Gambaro (2008). First of all, it is problematic to attribute observed concentrations to the causes that determine it, since local climatic conditions play a fundamental role. The study adopts the convention of measuring separately the peak concentrations occurring during the transit of ships and those occurring when the wind blows in direction of the city. The former method probably underestimates the data, while the latter overestimates it (since it includes all pollution, from whatever sources including ships, that is carried by the wind). Second, the study focuses only on ship transits, but is not able to capture the effects of emissions from ship stationing; yet the latter counts up to 4 times in terms of emissions, as shown above in table 39.

As a practical rule of thumb, Cescon and Gambaro (2008) suggest to consider 8% of total concentrations registered in the historical town of Venice to the effect of ship transit.

A third major limitation descends from referring only to category of vessels (the big cruise ships).

These limitations hamper severely the reliability of the results presented below. These should be interpreted very carefully as a first attempt, aimed more at illustrating how the methodology can work.

For what concerns the **quantification of impacts**, in this report we will focus mainly on the effects of $PM_{2,5\text{-}10}$., SOx and PAH, for which concentration data as well a estimates relative to the contribution of ships are available. For other pollutants, namely NOx, O3, the study can be updated in the future as soon as these data will be monitored on a regular base.

We have then followed two alternative ways for calculating impacts.

The first methodology relies on the CAFE/ExternE approach, which, as underlined above, constitutes the most comprehensive and reliable work on this matter. We apply exposure-response functions (FER) to the share of the observed concentration levels that is attributable to ships, multiplied per the relevant population exposed. Table 41 below resumes the FER used in the present study, resulting from the latest updated ExternE recommended values (ExternE 2005) and the CAFE study. Following this approach, all morbidity cases are expressed in cases/year in response to a unit of change in the concentration levels, expressed in µg/m3. Mortality cases, in turn, are expressed in terms of YOLL per unit change.

The second methodology follows the line suggested by Martuzzi et al. (2006). It is based on risk-response functions (RR) that measure the increase of probability of an event following a 10 µg/m3 increase in the concentration levels above the threshold that can be considered as “normal”. For example, assuming that this threshold is 20 µg/m3 for PM10, the methodology first calculates the average exposure as the average of the differences between actually observed values and the threshold (SOMO35). Then it calculates the number of occurrences of the event as an increase above the normal incidence of the same event in the area. We have calculated the SOMO35 values corresponding to actual concentrations, and to the concentrations that would occur without ships; the difference has been interpreted as the contribution of ship transit.

Since data on O3 are not available for Venice, we have limited the application of this second methodology to PM10 and PM2,5 only.

Relevant population exposed, following the CAFE guidelines, is considered for each FER/RR function. The data are derived from the latest official Istat data, from which we have also derived information concerning the normal incidence of mortality and morbidity.

Assumptions have to be made regarding the number of people that is affected by these pollutants. We consider the whole population living in the historical town as affected by these pollutants. This might again create a distortion, given the peculiar nature of the city of Venice, in which many non-residents actually live in the town for long periods (eg students), while touristic flows have an order of magnitude that is far out of the reach of the town size, although their exposure to pollution is limited to the period of the visit.

Table 43 – Exposure-response (FER) functions adopted in the present study

SOURCE	FER NAME	FER SLOPE
PM10	Mortality YOLL [ExternE 2005]"	3,90E-04
	Infant Mortality YOLL [ExternE 2005]"	1,80E-05
	Chronic Bronchitis [ExternE 2005]"	1,86E-05
	net Rad >65 [ExternE 2005	5,87E-03
	net RAD 15-65 [ExternE 2005	5,87E-03
	minor restricted activity days [ExternE 2005]"	2,22E-02
	Work days lost [ExternE 2005]"	8,35E-03
	Respiratory hospitalization [ExternE 2005]"	7,03E-06
	Cardiac hospitalization [ExternE 2005]"	4,34E-06
	Days bronchodilator use adult asthmatics [ExternE 2005]"	3,41E-03
	Days lower respiratory symptoms with cough adults [ExternE 2005]"	3,24E-02
	Days bronchodilator use with cough children [ExternE 2005]"	4,03E-04
	Days lower respiratory symptoms children asthmatics [ExternE 2005]"	2,08E-02
PM2,5	asthma_adults: Bronchodilator usage [CAFE]	2,72E-01
	asthma_adults: cough [CAFE]	2,80E-01
	asthma_adults: Lower resp. symptoms [CAFE]	1,01E-01
	asthma_children: Bronchodilator usage [CAFE]	1,29E-01
	asthma_children: cough [CAFE]	2,23E-01
	asthma_children: Lower resp. symptoms [CAFE]	1,72E-01
	above_65_yrs: congestive heart failure [CAFE]	3,09E-05
	above_65_yrs: Ischaemic heart disease [CAFE]	2,92E-05
	Adults: chronic bronchitis [CAFE]	3,90E-05
	adults > 30: total mortality [CAFE]	1,20E-03
	net Rad 15-65 [CAFE]	4,16E-02
	net Rad >65 [CAFE]	4,16E-02
	Children: case of chr. Bronchitis [CAFE]	2,69E-03
	Children: chronic cough [CAFE]	3,46E-03
	Female neoplasms, non-fatal [CAFE]	1,34E-05
	Female malignant neoplasms [CAFE]	1,21E-04
	Total cerebrovascular hosp. Adm [CAFE]	8,42E-06
	Total ERV for asthma [CAFE]	1,08E-05
	Total ERV for COPD [CAFE]	1,20E-05
	Total hosp. visits child. Croup [CAFE]	4,86E-05
	Total resp. hosp. Admission [CAFE]	3,46E-06
	Total Symptom days [CAFE]	9,51E-02
SOX	Total resp. hosp. Admission [CAFE]	2,04E-06
	Mortality YOLL [ExternE 2005]"	3,90E-04
	Infant Mortality YOLL [ExternE 2005]"	1,80E-05
	Chronic Bronchitis [ExternE 2005]"	1,86E-05
	net RAD 15-65 [ExternE 2005]"	5,87E-03
	net RAD >65 [ExternE 2005]"	5,87E-03
	minor restricted activity days [ExternE 2005]"	2,22E-02
	Work days lost [ExternE 2005]"	8,35E-03
	Respiratory hospitalization [ExternE 2005]"	7,03E-06
	Cardiac hospitalization [ExternE 2005]"	4,34E-06
	Days bronchodilator use adult asthmatics [ExternE 2005]"	3,41E-03
	Days lower respiratory symptoms with cough adults [ExternE 2005]"	3,24E-02
	Days bronchodilator use children asthmatics [ExternE 2005]"	4,03E-04
	Days lower respiratory symptoms with cough children [ExternE 2005]"	2,08E-02
PAH	Total: lung cancer [CAFE]	1,29E-03
	Total: non-fatal cancer [CAFE]	1,43E-04

Note: FER slope = n. of cases attributable to 1 μg/m3 increase in the concentration (source)

Table 44 – Risk-response functions and counterfactual values adopted in the present study

SOURCE	IMPACT	RR
PM10	Total mortality	1,006
	Mortality for acute cardiovascular effects	1,009
	Mortality for respiratory syndromes	1,013
	Cardiac hospitalization	1,003
	Respiratory hospitalization	1,006
	Bronchitis acute <15	1,306
	Chronic Bronchitis	0,000265
	Bronchodilatator usage – children asthmatics (cases)	0,18
	Bronchodilatator usage – adults asthmatics (cases)	0,912
	LRS children (symtoms/day) 5-14 (cases)	1,86
	LRS adults (symtoms/day) >15 (cases)	1,3
PM2,5	Total mortality	1,06
	Mortality for lung cancer	1,08
	Mortality for cardiovascular effects	1,18
	Mortality for stroke	1,02
	RAD Adults 15-64 (cases)	0,902
	WLD 15-64 (cases)	201
	MRAD 18-64 (cases)	0,577

Official statistics report the number of inhabitants for each Venice borough (“sestriere”). We are thus in a position to consider the inhabitants of the historical part, instead of referring to the whole Venice population (i.e. 269,924 inhabitants; see table 41).

Table 45 – Population of the historical city of Venice (October 2008) Source: Venice municipality website

Age	Male	Female	Total
0-4	1126	1057	2183
5-9	1168	1067	2235
10-14	1039	917	1956
15-19	1068	1026	2094
20-24	1145	1061	2206
25-29	1267	1237	2504
30-34	1681	1728	3409
35-39	2171	2224	4395
40-44	2250	2380	4630
45-49	2031	2305	4336
50-54	1971	2252	4223
55-59	1956	2185	4141
60-64	2120	2444	4564
65-69	2162	2492	4654
70-74	1735	2291	4026
75-79	1342	2024	3366
80-84	886	1819	2705
85-89	511	1362	1873
> 90	187	706	893
Total	27816	32577	60393

Considering health condition data, official statistics offer a regional level of disaggregation[23]. We thus obtain health conditions for Venice by assuming that in the city the general patterns observed in the Italian population occur. We then refer these health conditions to age classes, to estimate the impacts on more vulnerable groups (namely children and elderly).

We report in the following table the results obtained for people affected by asthma.

Table 46 – Number of Asthmatics in the historical part of the city of Venice

Age	Asthmatics
0-14	185
15-24	114
25-34	159
35-44	245
45-54	204
55-64	297
65-69	221
70-74	237
75-79	247
80 e più	707

Source: Own elaborations on ISTAT data

In fact, the number of residents in the area interested by the air pollution entailed by maritime transport activities is higher than that reported by official statistics, due to the high number of daily commuters who, living in other places, come to Venice to work, study or for leisure reasons.

Di Monte and Santoro (2008) estimate that the equivalent daily number of visitors and commuters amounts at 59.189[24]. In this analysis we do not consider the effects on tourists and commuters, since we do not have any information regarding their health and age status.

In this study we refer only to the impacts on health, since the port of Venice is located close to an industrial area and the urban centre, and thus pollution of ships does not have an impact on crops.

We do not consider climate change impacts, for lack of data referring to the emissions of CO_2 concentration from ships (as shown above, however, the data on emissions has been estimated through a bottom up approach by Cescon and Gambaro (2008), and could easily be converted into a monetary evaluation by making an assumption on the value of CO2, that can be desumed from international studies such as the Stern report).

Finally, for **monetisation of impacts**, we refer to the monetary values provided in NewExt and recalled by the CAFE program. They are summarised in the following table (where we recall the up-to-date values recommended by the ExternE projects series.

[23] http://www.istat.it/dati/dataset/20080131_00/

[24] This figure is obtained by considering the total number of persons entering in the historical part from its gates (namely: the airport, the bus and railway stations) over the year and by dividing this number by 365.

Table 47 - Recommended central unit values

Health end-point	Price year 2000
Hospital admissions	2,000/admission
ERV for respiratory illness	670/visit
GP visits (event): Asthma Lower respiratory symptoms	 53/consultation 75/consultation
Respiratory symptoms in asthmatics (event): Adults Children	 130/event 280/event
Respiratory medication use . adults and children (day)	1/day
Restricted activity day (adjusted average for working adult) Restricted activity day (adjusted average for age >65) Restricted activity day (days when a person needs to stay in bed) Restricted activity day (work loss day) Minor restricted activity day	83/day 68/day 130/day 126/day 38/day
Cough day	38/day
Symptom day	38/day
Work loss day (WLD)	82/day
Minor restricted activity day (MRAD)	38/day
Chronic bronchitis	190,000/case
VSL VOLY	2,000,000 120,000
Non fatal cancer	450,000/case

Results

With the many caveats that originate from the above discussion, we can try now to provide some figures resulting from the application of the described methodology.

Table 51 below presents the detail of health effects due to ship traffic calculated on the base of the ExternE/CAFÉ methodology and the related external cost.

Table 48 shows the resume of monetary estimates following the two alternative approaches. It can be seen quite easily that the method based on Martuzzi are substantially lower, even if they have a similar order of magnitude. These huge discrepancies suggest that estimates are considered with some care.

Table 48 – Total external cost due to the impact of air pollution of ships (€/year)

	EXTERNE/CAFE	MARTUZZI
PM10	7.188.210	2.160.225
PM2,5	14.044.470	8.403.834
SOX	1.652.142	
PAH	1.066.575	

Table 49 enters in some more detail in order to understand the main differences between the two approaches for the two pollutants for which a comparison can be made (PM10 and PM2,5). A direct comparison cannot be made, since the ExternE/CAFÉ method expresses mortality in YOLL, while the other methodology accounts for the n. of cases. Another major source of difference lies in the fact that RAD, MRAD and WDL are referred to PM10 in one case and to PM2,5 in the other. Anyway, it seems that the order of magnitude of the most important effects is reasonably similar. Nevertheless, differences are apparently due also to the fact that both studies consider different sources and impacts.

Table 49 – Total cases of mortality and morbidity attributable to ship traffic (PM10)

PM10	EXTERNE/CAFE	MARTUZZI et al.
total mortality	53	1
infant mortality	0,26	
chronic bronchitis	3	3
RAD	717	
MRAD	3.030	
WDL	689	
HOSP	1,55	
BRONCDIL	19	410
LRS	187	639

PM2,5	EXTERNE/CAFE	MARTUZZI et al.
total mortality	46	4
infant mortality		
cronic bronchitis	32	
RAD	1.841	3.909
MRAD		2.501
LRS	4.710	
CHF/IHF	0,86	
Non fatal cancer	3,58	
HOSP	0,59	
WDL		24

Legenda: (M)RAD = (minor) restricted activity days; WDL = working day lost; HOSP = hospitalization; CHF/IHF = congestive/ischemic heart failures; BRONCODIL = use of bronchodilatator (asthmatics)

Table 50 finally, derives unitary estimates for both passengers and cargoes. We assume, following the data presented above, that 2/3 of total ship pollution is attributable to cargoes, while the remaining 1/3 to passenger transport. On this basis, we have calculated a ratio between the share of the total cost and the n. of passengers and tonnage transported, respectively. We have also calculated the total cost per ship (table 51).

Table 50 – Total external cost of ship traffic (€/year)

	ExternE/CAFE			Martuzzi et al.		
	Passengers	Cargo	Total	Passengers	Cargo	Total
PM10	2.389.905	4.779.810	7.169.716	720.075	1.440.150	2.160.225
PM2,5	4.681.490	9.362.980	14.044.470	2.801.278	5.602.556	8.403.834
SOX	519.624	1.039.249	1.558.873			-
PAH	355.525	711.050	1.066.575			-
TOTAL	7.946.545	15.893.089	23.839.634	3.521.353	7.042.707	10.564.060

Table 51 – Unitary external cost of ship traffic

	ExternE/CAFE		Martuzzi et al.	
	€/passenger	€/t	€/passenger	€/t
PM10	1,75	0,16	0,53	0,05
PM2,5	3,43	0,32	2,05	0,19
SOX	0,38	0,04	-	-
PAH	0,26	0,02	-	-
Total	5,82	0,55	2,58	0,24

Table 52 – Unitary external cost of ship traffic: Cost per ship

	ExternE/CAFE			Martuzzi et al.		
	€/ship (pass)	€/ship (cargo)	Average	€/ship (pass)	€/ship (cargo)	Average
PM10	1.690	1.383	1.472	509	417	443
PM2,5	3.311	2.708	2.883	1.981	1.621	1.725
SOX	367	301	320	-	-	-
PAH	251	206	219	-	-	-
Total	5.620	4.597	4.894	2.490	2.037	2.169

Table 53 – Total external cost – method 1 (ExternE / CAFE)

Source	FER NAME	FER SLOPE	€/case	CONC	Pop Exposed	N of cases	Total cost
PM10	Mortality YOLL [ExternE 2005]"	3,90E-04	120.000	2,26	60.393	53	6.388.052
	" Infant Mortality YOLL [ExternE 2005]"	1,80E-05	120.000	2,26	6.374	0,26	31.117
	" Chronic Bronchitis [ExternE 2005]"	1,86E-05	190.000	2,26	60.393	3	482.380
	net Rad >65	5,87E-03	68	2,26	17.517	232	15.803
	net RAD 15-65	5,87E-03	83	2,26	36.502	484	40.195
	" minor restricted activity days [ExternE 2005]"	2,22E-02	38	2,26	60.393	3.030	115.149
	" Work days lost [ExternE 2005]"	8,35E-03	126	2,26	36.502	689	86.798
	" Respiratory hospitalization [ExternE 2005]"	7,03E-06	2.000	2,26	60.393	1	1.919
	" Cardiac hospitalization [ExternE 2005]"	4,34E-06	2.000	2,26	60.393	0,59	1.185
	" Days bronchodilator use adult asthmatics [ExternE 2005]"	3,41E-03	1	2,26	2.432	19	19
	" Days lower respiratory symptoms with cough adults [ExternE 2005]"	3,24E-02	130	2,26	2.432	178	23.155
	" Days bronchodilator use with cough children [ExternE 2005]"	4,03E-04	1	2,26	185	0	0
	" Days LRS children asthmatics [ExternE 2005]"	2,08E-02	280	2,26	185	9	2.439
PM2,5	asthma_adultsBronchodilator usage	2,72E-01	1	0,82	2.432	542	542
	asthma_adultscough	2,80E-01	38	0,82	2.432	559	21.230
	asthma_adultsLower resp. symptoms	1,01E-01	130	0,82	2.432	202	26.198
	asthma_childrenBronchodilator usage	1,29E-01	1	0,82	185	20	20
	asthma_childrencough	2,23E-01	38	0,82	185	34	1.288
	asthma_childrenLower resp. symptoms	1,72E-01	280	0,82	185	26	7.299
	above_65_yrscongestive heart failure	3,09E-05	2.000	0,82	17.517	0	888
	above_65_yrsIschaemic heart disease	2,92E-05	2.000	0,82	17.517	0	840
	Adults chronic bronchitis	3,90E-05	190.000	0,82	60.393	2	367.112
	adults > 30 yearstotal mortality	1,20E-03	120.000	0,82	47.215	46	5.577.461
	PM 2,5 - net Rad 15-65	4,16E-02	83	0,82	36.502	1.244	103.267
	PM 2,5 - net Rad >65	4,16E-02	68	0,82	17.517	597	40.601
	Childre ncase of chr. bronchitis	2,69E-03	190.000	0,82	6.374	14	2.671.173
	Children chronic cough	3,46E-03	190.000	0,82	6.374	18	3.434.366
	Female neoplasms, non-fatal	1,34E-05	450.000	0,82	32.577	0,36	161.147
	Femal eMalignant Neoplasms	1,21E-04	450.000	0,82	32.577	3	1.450.324
	Total erebrovascular hosp. adm	8,42E-06	2.000	0,82	60.393	0,42	834
	Total ERV for asthma	1,08E-05	670	0,82	2.618	0	15
	Total ERV for COPD	1,20E-05	670	0,82	60.393	1	399
	Total hosp. visits child. croup	4,86E-05	53	0,82	6.374	0	13
	Total resp. hosp. admission	3,46E-06	2.000	0,82	60.393	0,17	343
	Total Symptom days	9,51E-02	38	0,82	60.393	4.710	178.991
SOX	totalresp. hosp. admission	2,04E-06	2.000	0,48	60.393	0,06	119
	" Mortality YOLL [ExternE 2005]"	3,90E-04	120.000	0,48	60.393	11	1.365.148
	" Infant Mortality YOLL [ExternE 2005]"	1,80E-05	120.000	0,48	6.374	0,06	6.650
	" Chronic Bronchitis [ExternE 2005]"	1,86E-05	190.000	0,48	60.393	1	103.086
	net RAD 15-65	5,87E-03	83	0,48	36.502	103	8.590
	net RAD >65	5,87E-03	68	0,48	17.517	50	3.377
	" minor restricted activity days [ExternE 2005]"	2,22E-02	38	0,48	60.393	648	24.608
	" Work days lost [ExternE 2005]"	8,35E-03	82	0,48	36.502	147	12.072
	" Respiratory hospitalization [ExternE 2005]"	7,03E-06	2.000	0,48	60.393	0,21	410
	" Cardiac hospitalization [ExternE 2005]"	4,34E-06	2.000	0,48	60.393	0,13	253
	" Days bronchodilator use adult asthmatics [ExternE 2005]"	3,41E-03	1	0,48	2.432	4	4
	Days LRS with cough adults [ExternE 2005]"	3,24E-02	130	0,48	54.019	845	109.896
	Days bronchodilator use children asthmatics [ExternE 2005]"	4,03E-04	1	0,48	185	0,04	0,04
	Days LRS with cough children [ExternE 2005]"	2,08E-02	280	0,48	6.374	64	17.930
PAH	Total lung cancer	1,29E-03	120.000	0,08	60.393	6	752.876
	Total non-fatal cancer	1,43E-04	450.000	0,08	60.393	1	313.698

The range of external costs calculated varies between 2,58 - 5,82 €/passenger and 0,24 – 0,55 € / t. In turn, the external cost per ship corresponds to 2.169 – 4.894 in the two methods.

These results should be interpreted with particular care. In fact, Cescon and Gambaro (2008) warn that existing data do not show a correspondence between the concentrations observed and the size of ships: therefore, the average value calculated per passenger and per tonne overestimates the cost of big ships and underestimates that of smaller ones. On the other hand, the same study, while emphasizing the correlation in correspondence with the passage of ships (regardless the size), also shows clearly that the impact cannot be attributed solely to ships, since it depends largely on the particular climatic conditions and the direction of winds. The same ship transiting in two days in which the wind blows in opposite directions would have a completely different impact. These observations might lead to suggest that, being the external cost largely depending on wind directions, an eventual externality charge should be applied only in those days in which the wind blows in the wrong direction.

It is important to stress that the effects calculated in these estimates refer to ship movement and transit only, while neglecting the impact of stationing. As shown above, stationing represents more than 2/3 of calculated emissions; yet it is not possible with the existing data to argue the effects of these emissions on local concentrations. A more refined analysis will have to consider these pollutants, whose effects are nonetheless difficult to single out since they are mixed with the emissions of the whole industrial area surrounding the port.

13. Indications for future research on estimation and monetisation of impacts

The analysis carried out above has highlighted several needs for further research that we recall hereafter. Some of these research indications are specific to the maritime transport, whilst other ones refer to the problem of monetising the non-market impacts and have a more general scope than the simple maritime transport.

We group broadly these research indications in two main sets: (1) estimation of impacts; (2) improvement of impact valuation; (3) enlargement of scope for analysis.

1. Estimation of impacts

The detailed (quantitative and qualitative) description of the impacts on air pollution has clarified how it is possible, with a certain degree of accuracy, to isolate the contribution of ships and vessels to local pollution.

However, one major source of uncertainty (and a crucial point that has to be investigated by future research) is the isolation of the worsening of local environmental quality entailed by ship activities by the concentration of pollutants as measured by local environmental statistics.

All the EU research on emissions from transport is based on models that use a grid having a 50km x 50km grid resolution and, as a consequence, they are not immediately applicable to local conditions. There are two possibilities to overcome this limit: either to refine the resolution of existing models (as suggested above) or to use specific analyses referred to the local context under consideration.

With reference to the last aspects, we would like to emphasise the importance of collecting local environmental quality data in response of some research needs. Our simulation on the Venice case study suggests that, whilst environmental data collected by local authorities are available, they are not always immediately usable for economic valuation and this could represent a problem for the feasibility of research, in cases where financial resources and expertise to collect original data are not available.

In fact, this point is not relevant for maritime transport alone but for all the policy domains that are affected by local air quality.

In the case of maritime transport, however, the problem is emphasized by the twofold nature of impacts. Those arising from ship movement can be assimilated to those occurring in the other forms of transport; they require a model approach that takes into account the shifting location of emission sources and the non-point nature of pollution. In turn, those arising from ship stationing in the port are more similar to point sources; however, the existing models that infer ambient concentrations from emission sources, such as the ECOSENSE model, need to be adapted to the particular situation of ports and are not immediately usable for this purpose. We believe that an effort in this direction would be worthwhile. The capacity of models to capture local climatic feature is decisive, since the direction of winds, the relative positioning of emission sources and impact points, as well as prevailing temperatures seem to have decisive importance. In the lack of readily usable models, the Venice case study shows that the capacity to infer the contribution of ships to observed concentrations is very limited.

2. Improvement of impact valuation

As shown above, all the methodological limitations related to the monetisation of environmental impacts are not common to the maritime transportation alone, but are of interest for the practice of environmental valuation per se.

Regarding health effects, generally speaking the metric of VSL is more robust from a methodological point of view but, as discussed above, it is not indicated for impacts due to air pollution as, differently from other pollution events, this normally does not cause immediate deaths but lower the years of life in persons with pre-existent health problems.

For this reason, the VOLY is the metric that encounters the favour of recent studies. Nonetheless, this is less robust with respect to VSL from a theoretical point of view: it is normally derived from the VSL estimates, although some original papers demonstrate that people do not normally relate VSL and VOLY in the same manner economists theorise the two should be linked. As a consequence, further research is needed to obtain original estimate on this metric that is robust enough to be transferred to other policy contexts.

Moreover, a part from the metric chosen, both VSL and VOLY are estimated having as point of reference the WTP of adults. As discussed above, effects on children health deserve more attention, since kids are more vulnerable to pollutants than adults, due to their metabolism and higher exposure to pollutants with respect to adults (since they take more water and food). Moreover, valuation techniques cannot be directly applied to children nor can they be adapted simply. This because children are not in a position to make a judgement about their own health.

Several empirical studies have resulted in the consistent finding that parents' WTP to reduce children's health risk is two times adult WTP to reduce their own health risk. The interpretation of this result is not straightforward. It could be that: (i) they perceive children's health to be twice as valuable as their own; (ii) parents count the impact on their children and the impact on themselves; (iii) adults' retrospective preferences for protecting their own health as children (Hoffmann and Krupnick, 2004). This is a point that has received great attention, both in US and EU. The OECD has also sponsoring studies in several member countries to examine how values differ across countries[25].

Regarding the effects on crops, the same limitation experienced in other policy contexts remains valid for maritime transportation as well.

3. Enlargement of scope for analysis

The analysis so far as considered the maritime transport in isolation. Nonetheless, we would like to stress that future research should consider enlarging the scope of the analysis. The reasons are two-fold.

One the one side, shipping and port activities constitute only a step in the transport of goods and persons. Once berthed in port, cargos have to be transported to their final destination through other transport means. This requires port terminals to be served by a complex network of infrastructures, from rail to road, that occupies soil and entail a set of environmental effects that have analysed in D1. Considering the intermodality patterns of transport is crucial, since the monetisation of external effects of shipping and port activities is not sufficient to give the complete picture of the impacts entailed by transportation. Moreover, the overall environmental

[25] The interest reader could refer to the VERHI Children Project sponsored by the OECD. More information could be found on line: http://www.oecd.org/site/0,3407,en_21571361_36146795_1_1_1_1_1,00.html

performance of shipping and port activities is conditioned by the choice of the other means of transport. For instance, the choice to serve the port with the rail or through road transport has different consequences on the overall impacts entailed by such activities.

On the other side, the development of maritime transportation is highly correlated with increase in world trade.

Transport at sea is increasing by 5% every year on average, and good opportunities exist for further growth. Since 1970 the world merchant fleet has grown by over 70% and the transport capacity has almost tripled (UNCTAD 2005).

The latter, in turn, is fuelled by economic growth. One basic assumption of all the studies is that environmental burdens entailed by maritime transport will increase as a consequence of the increased volumes of traffic. Up to our knowledge, this assumption has not been the object of any sensitivity analysis. In fact, recently world economic growth has slowed down as an effect of the financial market crisis. We suggest that future research should investigate this aspect more in depth, through statistical techniques and sensitivity analysis.

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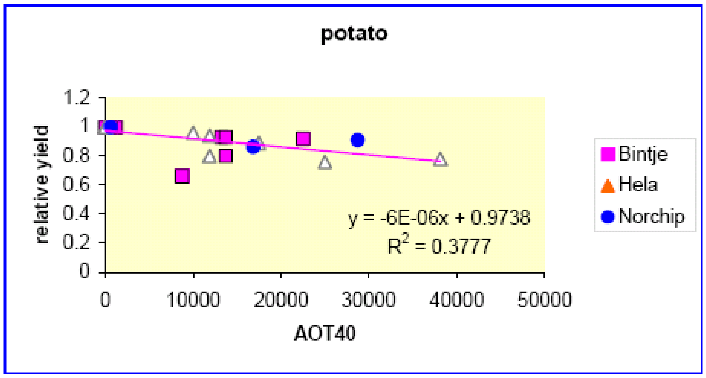
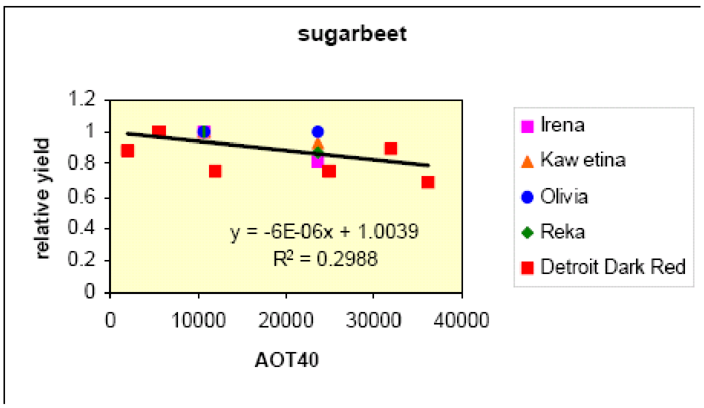
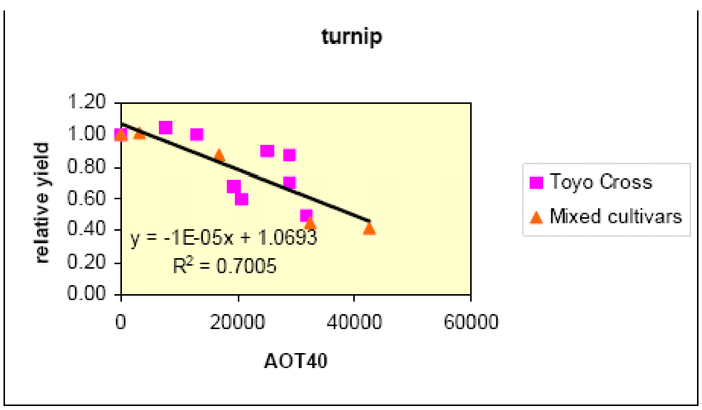
Annex 1 - Yield response functions of several crops to ozone

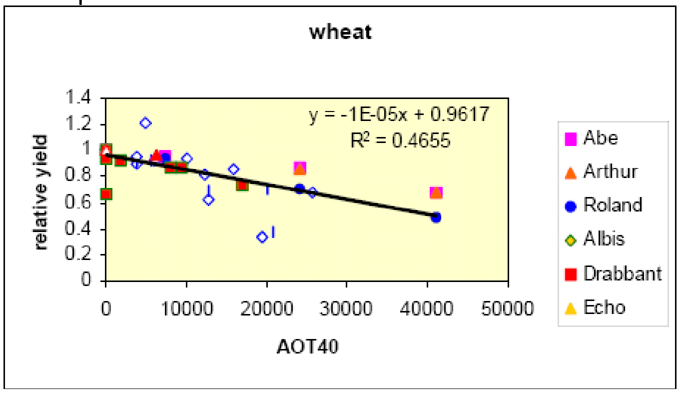
1. The yield response functions of root crops to ozone

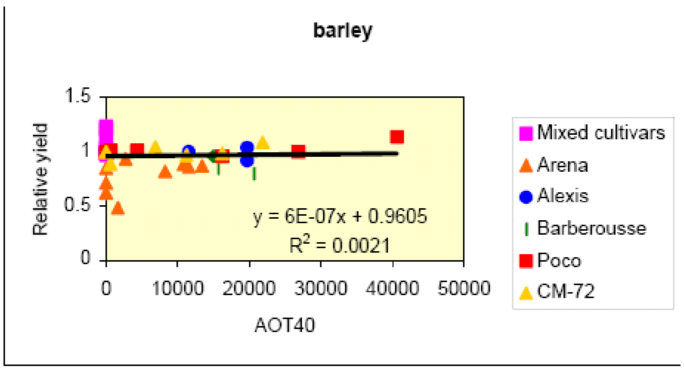


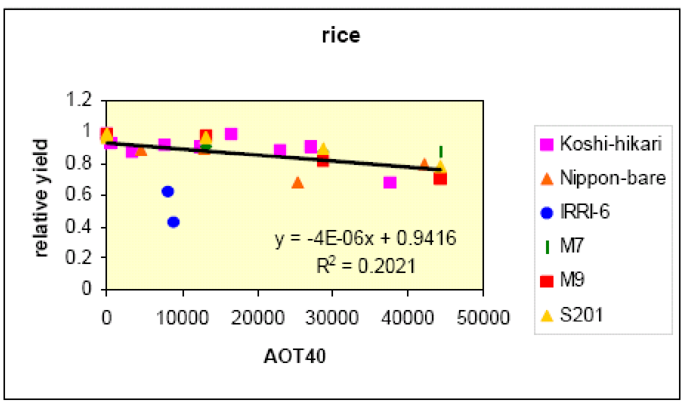


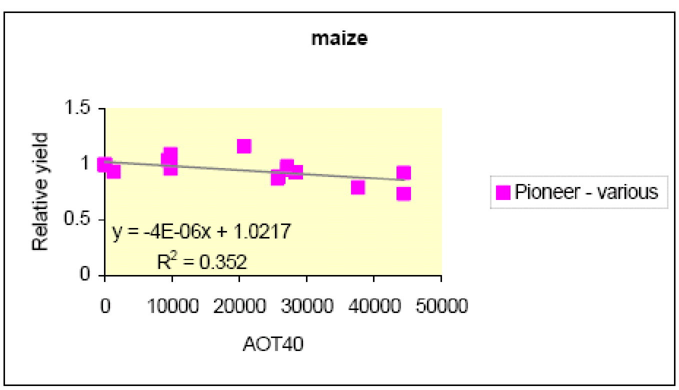


2. The yield response functions of cereals to ozone.

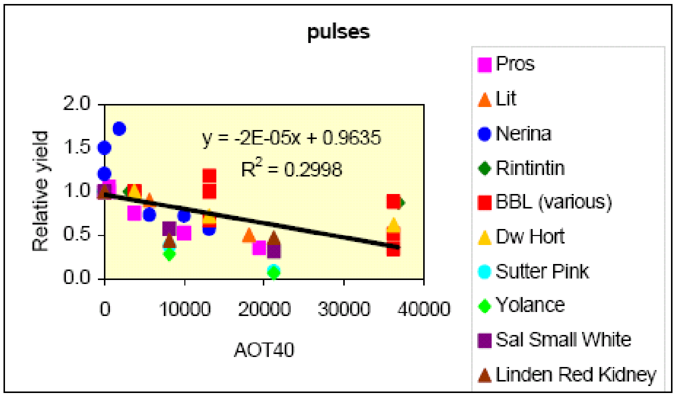


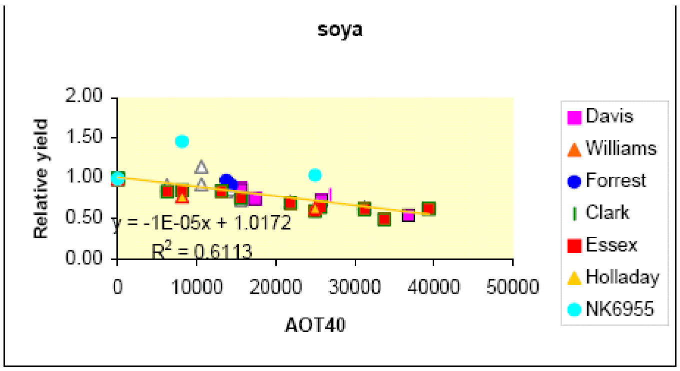


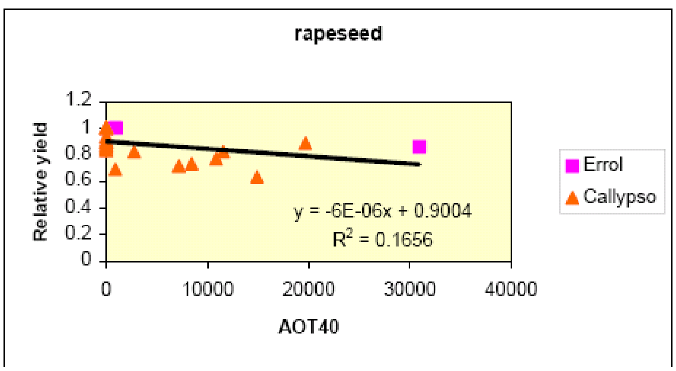




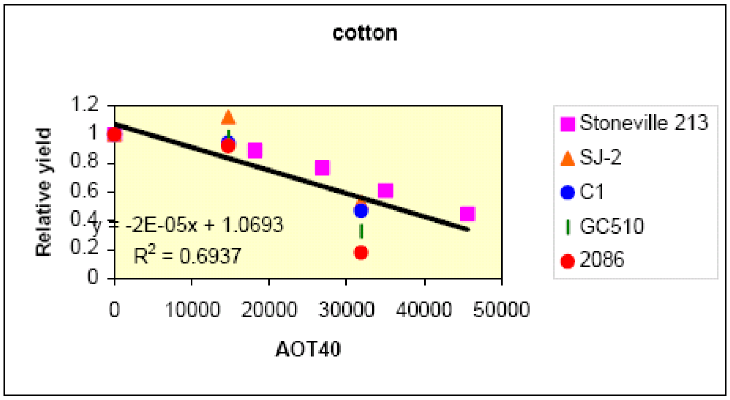
3. The yield response functions of pulses, soya and rapeseed to ozone.

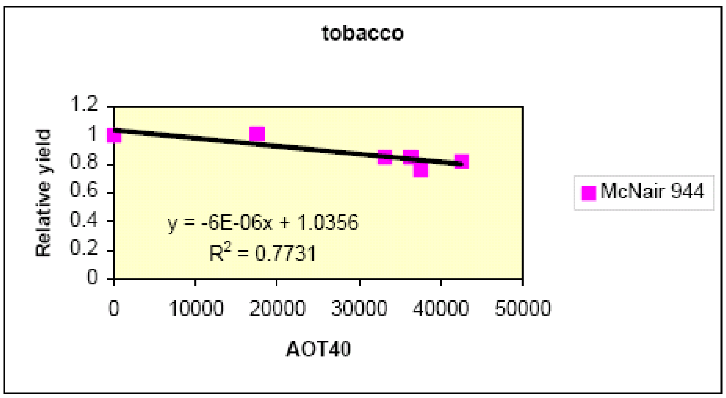


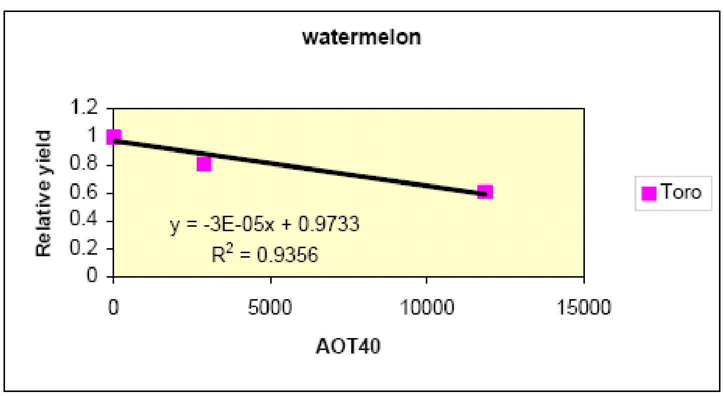




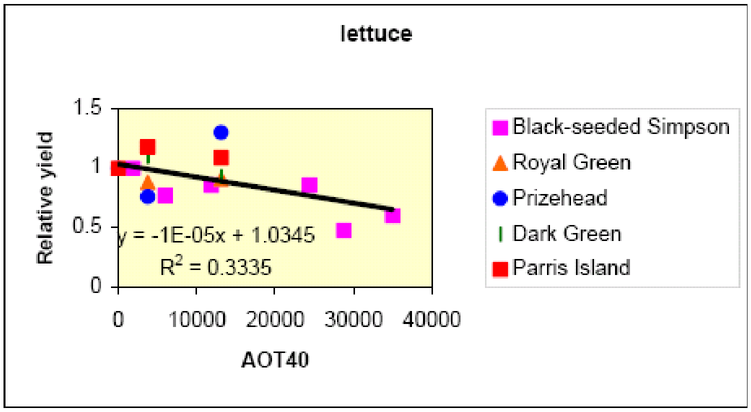
4. The yield response functions of cotton, tobacco and watermelon to ozone.

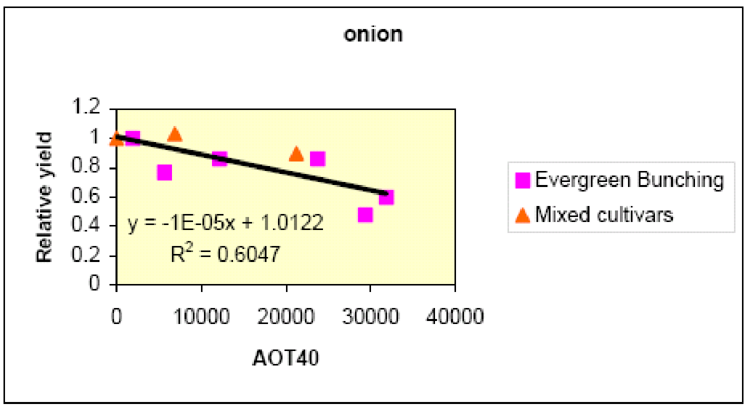


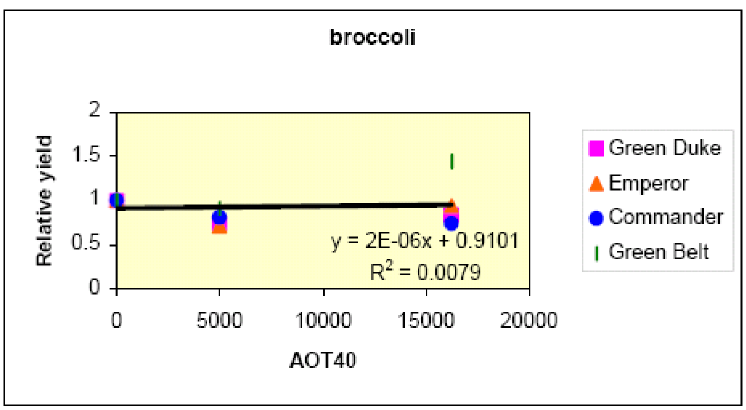




5. The yield response functions of fresh vegetables to ozone.







European Commission

EUR 23837 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: External costs of transportation. Case study: maritime transport (Maritime transport – report 2)
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Abstract

A sustainable transport system needs a cost accounting and full cost-pricing systems reflecting economic factors which originate from transport activity inhibiting sustainable development (namely, externalities; spillover effects and non-priced inter-sectorial linkages; public goods; uncompetitive markets; myopic planning horizons and high discount rates; risk and uncertainty, irreversibility and policy failures) (Panaytou, 1992). The evaluation of the impacts of transport enables policy analysis to formulate tools to avoid, reduce or compensate such costs, as well as to make optimal trade-off between environmental protection and other economic and social objectives (Quinet, 2003). In particular, there is a consensus that environmental effects (externalities) should be included in the assessment of projects and policies in order to define effective policy instruments for dealing with pollution entailed by transport. This report defines a comprehensive framework for the assessment of maritime external costs that has been chosen as case study. In order to do so, this report is organized in two sections: (i) identification of all environmental impacts of maritime transport (at sea and in ports) and a detailed analysis for those already studied in previous researches in literature; (ii)Estimation of identified environmental impacts focusing on those related to air pollutants.

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