Environmental Costs of Maritime Shipping in Europe

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Abstract

The enormous growth presently experienced in maritime transport combined with the use of residual fuel oil is causing major environmental problems. In Europe the external costs of airborne emissions from ships amount to 19.6bn Euro annually. Even if maritime transport remains the environmental friendliest mode of transport, the enormous growth expected is compensating for these advantages. Emission reduction technologies are ready for implementation that can reduce external costs in Europe in the order of 10bn Euro annually. All of the analysed technologies generate environmental benefits than comprise at least double investment costs. The introduction of low sulphur fuels would only marginally increase transport cost, but save the lives of 50.000 people world wide and prevent many more serious health damages.

1. Ships Cause Soaring Environmental Problems

Ships transport 90% of the EU's World trade volume and 40% of its internal commodity exchange. European harbours handle 3.5bn tons annually (EU Commission 2006, p. 7). Between 1970 and 2006 seaborne trade nearly tripled (UNCTAD 2007, p.4) and in the future annual growth rates of 2.5% are estimated (Van Zeebroeck et al, 2005).

Maritime shipping is considered less harmful to the environment than road transport. This is the background, why the European Commission plans an enormous expansion of water transport and intends to implement "Motorways of the Seas". The idea is to shift a share of the expected 70% growth in European goods transport from trucks to ships and thereby provide more efficient, more cost effective, less polluting freight transport; reduce road congestion on key bottlenecks across Europe and provide better, more reliable connections for peripheral regions. Expenditures between 2002 and 2010 are estimated at 5bn Euro. (TEN Invest Final Report 2003, PLANCO)

However, this positive picture is tainted by recent studies on the environmental effects of maritime transport: "It is estimated for the year 2000 that SO_2 and NO_x emissions from international maritime shipping in Europe amounted to approximately 30%

of the land-based emissions in the EU-25 … Under business-as usual assumptions, SO_2 emissions from international shipping are computed to increase by more than 40 percent between 2000 and 2020, NO_x emissions by 47% and $PM_{2.5}$ emissions by 56%" (IIASA 2007, p.60). The European Commission expects that by 2020 the emissions of SO_2 and NO_x from maritime transport might exceed emissions from all other sources. The expected increase in the volume of ship movements will outweigh the remarkable environmental effects of EU air pollution control measures for land based sources.

Already today meteorological surveys (Devasthale et al, 2006) disclose that the increasing air pollution on the Channel and southern North Sea has compensated for the air quality improvements achieved during the last 20 years. Corbett and Winebrake (2007) estimate that world-wide "under-regulated ship emissions" causes 60,000 premature deaths by lung and heart diseases. The authors estimate that "under current regulation and with the expected growth in shipping activity … annual mortalities could increase by 40% by 2012".

The introduction of tight emission standards for road vehicles (EURO I to IV) has entailed a tremendous reduction of road transport emissions in the past 20 years. Comparatively little attention was paid to the increasing problems of maritime airborne emissions. While for land based modes a vast amount of literature on environmental issues exists, little research has been done on the environmental costs of maritime transport. This paper will fill in the gap and assess the external costs of maritime transport.

In this paper the external costs of oil spills, air pollution and climate change are analysed for selected shipping passages and compiled on the EU level. Other effects, such as dredging of access canals, underwater noise and invasive species cannot be included, since the magnitude of the impacts is not known and unit costs are missing. The second part contributes to the ongoing discussion in Europe about measures to reduce marine air pollution by comparing costs and benefits of technical equipments. Special emphasis is placed on the use of low sulphur fuels.

2. External Costs of Shipping in Europe

2.1. Costs of Marine Oil Spills

The world-wide amount of oil spilled has been estimated by Cedre[1] and IMO as given in Table 1. If these amounts are compared to the transport volume, the divergence between the two estimates amounts to only 7%. Using specific spill rates, the total amount of oil spilled in 2005 is estimated at 890,000 tons. Oil spills from tankers contribute with 23% (Cedre) to 48% (IMO) of the total pollution, while the remaining spillage is caused by bilge or fuel oil discharges of other vessels.

Amongst researchers[2]: there is a general agreement that the costs of oils spills depend largely on the following factors i) type of oil, ii) weather and sea conditions, iii) amount spilled and rate of spillage, iv) time of the year, v) effectiveness of cleanup, vi) location of the oil spill (offshore, close to shore), and vii) physical, biological and

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[1] www.black-tides.com, consulted April 2007

[2] White and Molloy (2003), Etkin (1999, 2000, 2003, 2004).Helton and Penn (1999), Grey (1999).

economic characteristic of the location (e.g. recreation area, nature reserve, industrial area, …)

This paper combines three databases on the costs of oil spills, from Helton/Penn (1999), Grey (1999) and IOPC data from 2005. The resulting dataset contains 102 incidents, dating from 1979 to 2005, during which 565,000 tons of oil were spilled. In order to include the IOPC data, two adjustments are necessary: Firstly, liability payments by other parties are added and secondly an adjustment for the Natural Resource Costs is made, according to Helton/Penn (1999).

The generated data are dominated by a large variation, which is due to the above mentioned cost effects of the influencing factors. Since the dataset does not reveal a de- or increase in specific costs over time, average costs for the whole time period amount to 27,000 Euro/ton.

Since the costs are derived from tanker accidents only, a major assumption has to be made: oil released in tanker accidents causes the same damage as oil from on sea discharges or terminal operations. The estimate is a cautious approach, since the cost figures of large accidents are used and specific costs per ton decrease with the size of the oil spills (BMVBW 2002). Applying these assumptions world-wide, the external costs of oil spills amount to 24bn Euro p.a. Since a large share of the oil pollution stems from illegal activities, which are in many cases not put on trial, a strict prosecution can be justified from a macro economic point of view.

Source	Year	Oils Spills	Total Costs	Transport Volume 2000	Specific Spill amount	Specific Costs
		1000 Tons	bn Euro	bn ton-miles	litre/ton mile	cent/1000ton-miles
IMO 1995	1995	570,000	15	20,338	0.028	76
Cedre 2007	2000	712,000	19	23,693	0.030	81
Own Estimate	2005	891,000	24	30,686	0.029	78

Table 1: Estimate of oil spill costs

2.2. Costs of airborne emissions

For the assessment of environmental costs, the Impact Pathway Approach[3] was used: A transport activity causes changes in environmental pressures (e.g. air pollutant emissions), which are dispersed, leading to changes in environmental burdens and associated impacts on various receptors, such as human beings, crops, building materials or ecosystems. This change in impacts leads either directly or indirectly to a change in the utility of the affected persons. Welfare changes resulting from these impacts are transferred into monetary values. Based on the concepts of welfare economics, monetary valuation follows the approach of 'willingness-to-pay' for improved environmental quality.

[3] The impact pathway approach was developed, during ExternE project series (Friedrich and Bickel (2001); European Commission, 1999 and 2005). Models for assessing impacts from noise were provided in the projects UNITE (Bickel et al., 2003) and RECORDIT (Schmid et al., 2001).

Damage factors, describing the specific costs per ton of pollutant emitted, were derived through the impact pathway approach, using the EcoSense software tool, developed and applied among others in the EU-projects ExternE and UNITE. Health effects were calculated using exposure-response functions which were developed during EU research projects[4], and taking into account sector and population densities. Health effects are monetarised using the willingness to pay approach. The costs of green house gas emissions were derived from Tol (2004) who revealed in a literature study a mean estimate of €22/t CO_2[5]. This figure can be regarded as conservative in the sense that only damages that can be estimated with a reasonable certainty are included.

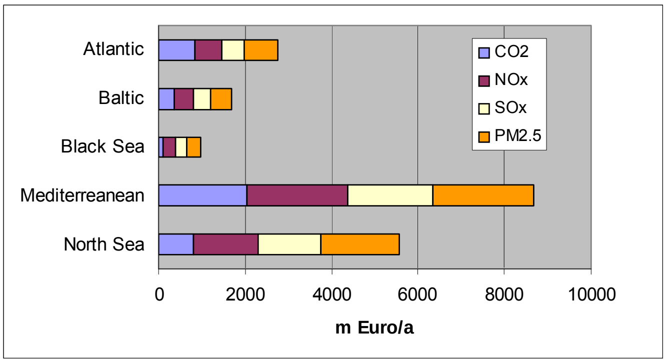


Figure 1: External Costs of airborne emissions of ships in Europe 2005

In order to estimate the costs of maritime shipping, data for pollutant emissions from maritime transport are retrieved from EMEP (2005) and supplemented with CO_2-emission data from IIASA (2007, p10) [6]. Applying the impact pathway approach, the costs of airborne ping emissions in European waters can be estimated at 19.6bn Euro p.a. These costs are distributed as depicted in Figure 1, with 44% of the costs occurring in the Mediterranean and 33% in the North Sea. The share per pollutant ranges between 21% for CO_2 and 29% for $PM_{2.5}$.

2.3. External costs on selected sea passages

This overall assessment is complemented by a detailed analysis of six shipping routes[7] in Europe 2005 as listed in Table 2. The longest passage is between Genoa and Bordeaux measuring 1854 sea miles and the shortest is between Antwerp and Felixstowe with a distance of only 141 sm. The choice of the vessels was done in a manner that includes a large variation of sizes and utilities. The small vessels (2,500dwt) are coasters, while the larger vessels belong to the Panamax class. It is assumed, that all vessels use their loading capacities at 90%.

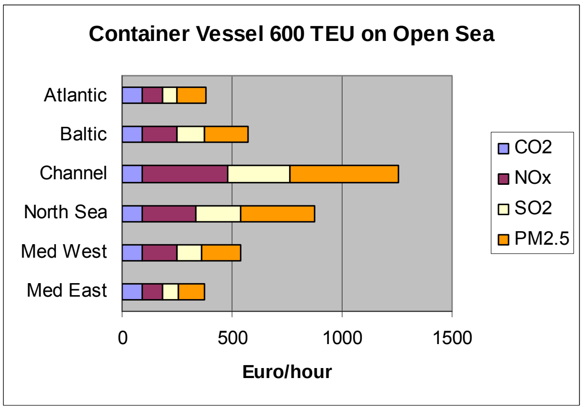
The following inputs were used to estimate specific external cost of airborne emissions of the vessels:

- Average fuel consumption per hour, derived from ENTEC (2002).
- Emission factor, determining the amount of pollutants emitted per ton on fuel, were derived from ENTEC (2005).

[4] Droste-Franke and Friedrich 2003, Link et al. 2001, Preiss et al. 2004, Schmid et al. 2001
[5] The values, cited from Watkiss et al. (2005a, p.29), are adjusted to represent factor costs.
[6] These data based on ENTEC (2005), were adjusted to 2005 using the growth rates in maritime transport (UNCTAD 2007). The most comprehensive report on Green House Gas emissions, written by CE Delft (2006), refers as well to ENTEC (2005).
[7] Sulphur Oxide Emission Control Areas (SECA) established in 2005 and 2006, are not considered in this paper.

- Damage factors derived from EcoSense, as described above.

The left graph in Figure 2 gives the example for the specific air pollution costs of a 600 TEU container vessel during sea passage. Areas, such as the Channel and the North Sea, where a larger population is affected by air pollutant emissions have higher specific costs than vast areas such as the Atlantic Ocean. The figure shows as well the share of costs for the various pollutants caused by one hour cruise. The most important effect is particulate emissions which make up 32% -34% of specific costs. NO_x ranges between 23% and 31%, SO_2 from 18% to 23%. Since CO_2 causes global effects, cost figures are uniform amounting from 8% to 25% of total air pollution costs.



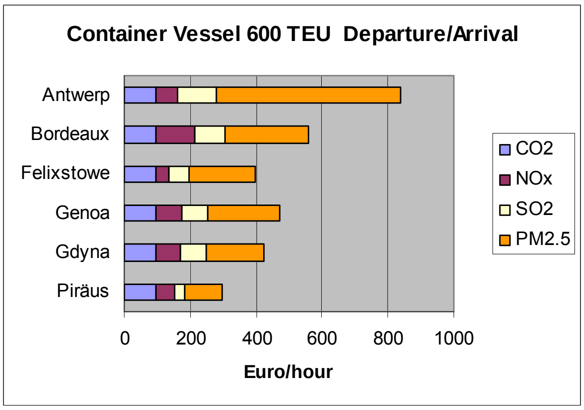


Figure 2: Air pollution costs for a 600 TEU Container Vessel

Higher sensitivities regarding the effects of air pollutant emissions have to be assumed, if ships approach or leave harbours. The specific cost for departure/arrival in harbours is given as well in Figure 2 for the above mentioned example of a 600 TEU container vessel. This ship travels with an average speed of 8 knots compared to 16 knots during sea passage. Consequently, the vessel consumes less than one third of the fuel during departure/arrival. However, machines are running with suboptimal rotations causing more emissions per ton of fuel and specific damage costs per pollutant are higher since the proximity to human populations entails stronger damages. This effect is partly compensating for the low fuel consumption.

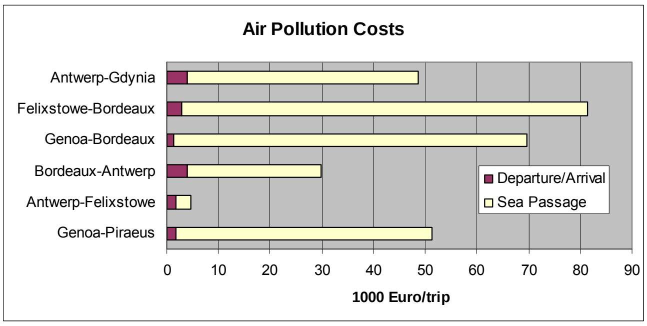


Figure 3: Air pollution costs for selected maritime passages

The costs vary considerably among the harbours. In Piraeus the vessel causes costs, which only amount to 36% of the costs caused in Antwerp. The latter harbour has to be approached through a 47 mile access canal, which conducts through a relatively densely populated area. In Piraeus, Felixstowe, Genoa and Gdyna access is directly from the open sea and thus the impacts on human health are comparatively low. Bordeaux is accessed through the Gironde river, but the container terminal is right at the end of the estuary and thus the access for our 600 TEU container vessel is short. The most important effects are particulate-emissions comprising 39% to 67% of all costs, followed by CO_2 (11%-32%), NO_x (8%-19%), SO_2 (10%-18%) and NMVOC (0-1%).

Air pollution costs on the given shipping routes are depicted in Figure 3: Total air pollution costs vary between 5,000 and 81,000 Euro. The costs for Arrival and Departure depend on the length of the trip and range between 2% on the long voyage between Genoa and Bordeaux and 35% on the short trip between Antwerp and Felixstowe.

In order to assess external costs, oil spill costs have to be added. This is done through the specific value per ton-mile of goods transported as given in Table 1. The resulting relative costs of the sea passages, resumed in Table 2, range between 1 and 10 cent/tkm. The highest costs are generated on the trip between Bordeaux and Antwerp: In this case a coaster transports a small load through sensitive areas, namely the Gironde, the Channel and the Schelde River. This holds as well true for the short trip between Antwerp and Felixstowe. The voyage from Genoa to Bordeaux is conducted with a medium sized 600 TEU container vessel through waters with lower environmental sensitivity. Thus the specific costs amount to only half of the cost of the afore mentioned shipping routes. The lowest costs are produced by the large vessels[8] which have a far better fuel efficiency than smaller ships.

Table 2: External costs of maritime transport on selected shipping routes

Origin	Destination	Distance [sea miles]	Type of Vessel	Capacity (Load 90%)	Air emissions	Oil Spill Costs	External Costs
					[Euro/1000tkm]		
Antwerp	Gdynia	966	General Cargo	45 000 dwt	0.7	0.4	1.2
Felixstowe	Bordeaux	674	Container	3 000 TEU	2.4	0.4	2.9
Genoa	Bordeaux	1854	Container	600 TEU	3.8	0.4	4.2
Bordeaux	Antwerp	748	General Cargo	2 500 dwt	9.6	0.4	10.1
Antwerp	Felixstowe	141	Tanker	2 500 dwt	8.1	0.4	8.4
Other Modes for Comparison:					Air Emissions	Other Extern. Costs	Total External Costs
Light Goods Vehicle		Source: INFRAS/IWW 2004			86.9	163.3	250.2
Heavy Goods Vehicle					38.3	32.9	71.2
Railways					8.3	9.5	17.8
Inland Waterways					14.1	8.4	22.5

In Table 2 the relative costs of ships are compared with land based modes of transport. If only air pollution is compared, a huge gap opens between road modes and ships. However, compared to railways, ships only have a significant advantage if larger vessels are used. Smaller vessels produce on sensitive sea passages the same magnitude of costs caused by airborne emissions as railways and inland waterways.

[8] The size of the ship is given in column 5 of Table 2

This picture, however, is incomplete, since only a share of the external costs is taken into account. For land based modes other effects, such as noise emissions, separation effects and accidents have to be included, which entails a strong increase of unit costs. However, the state of art in research is not able to quantify all environmental effects of maritime transport and therefore, total external costs of maritime shipping might be higher. This paper only represents a minimum approach.

3. Costs and Benefits of Emission Reduction Measures

Even though the environmental effects of shipping are tremendous, there are technologies available that can considerably alleviate environmental impacts. The question is which effects can be achieved and what is the most efficient solution. Up to date, two major reports (ENTEC 2005, IIASA 2007) have analysed the technical and economic feasability of technologies. Based on these findings, a number of technical measures shall be assessed with regard to their costs and environmental benefits. The following technologies are assessed:

- The *Humid Air Motor* (HAM) reduces NO_x formation during the combustion process. The technology had been tested, but was not ready for the market when this article was written.
- *Selective Catalytic Reduction* (SCR) relies on injecting a urea solution into an exhaust gas stream in combination with a catalyst housing in the exhaust channel through which a significant reduction of NOx is achieved. The technology is tested and ready for implementation.
- *Reduction of the sulphur content of marine fuels* is a straightforward method, which reduces end of pipe emissions - not only of sulphur, but as well of particulates – by providing cleaner fuels. Estimates on the additional costs are derived from the present market prices of marine low sulphur fuels (IIASA 2007).

Sea Water Scrubbing has not been assessed here, since only 10% of the ships are eligible for this equipment and a number of technical and environmental problems are related to the new technology[9].

The above technologies have been assessed according to their environmental impacts[10] in the European maritime waters for the year 2020, as given in ENTEC (2005). Technologies are combined in a manner that SO_2 reduction equipments complement measures for NO_x reduction. The monetary benefits of the technologies generated by the reduction of pollutant emissions, are assessed through the reduction of external costs. The benefits are set in relation to the costs for the implementation of the technologies. The results, given in Figure 4, are sorted according to their benefits, which are displayed as pillars on the left axis, while benefit-cost ratios are depicted with diamonds on the right axis.

[9] See as well IMO (2007) p.20f, p37, Annex p. 22, Kågeson (2007), p30., Karle/Turner (2007).
[10] Comparison to a Pre-MARPOL situation, where no SO_x Emission Control Areas (SECA) are introduced.

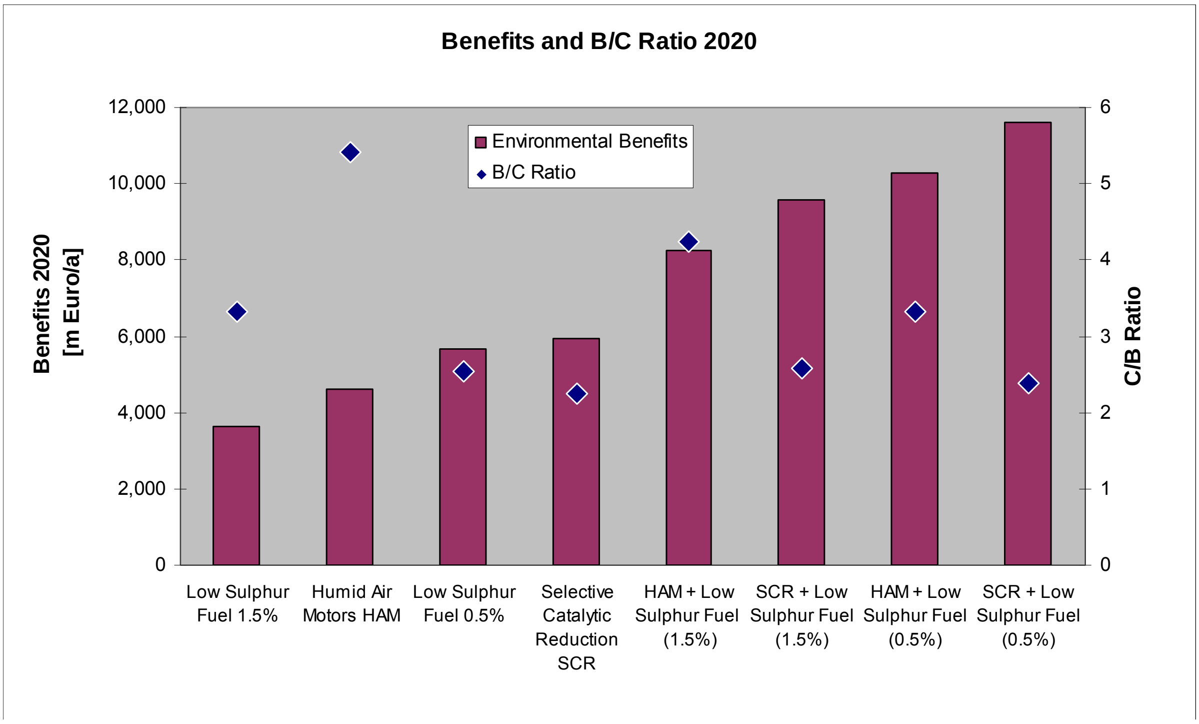


Figure 4: Effects and efficiencies of environmental technologies

The most important result is that all scenarios reap environmental benefits amounting to at least double the costs. Consequently, B/C ratios range between 2.3 and 5.4. Single technologies reap the lowest benefits due to the fact, that they are mainly reducing one pollutant at a time. Larger impacts can be achieved with a combination of technologies that reduce all pollutants.

Low sulphur fuels generate B/C ratios of 3.3 resp. 2.5. The results are comparable to a research by Wang/Corbett (2007) on the SO_2 reduction of cargo ships at the US West Coast[11]. The comparatively low ratios can be explained by the high costs for low sulphur fuels, which were estimated by an analysis of the price differential on the European bunker fuel market. If the price effects caused by investments in the oil industries are taken into account, as described below, differential would be much lower and thus B/C ratios greatly higher.

The biggest impacts are generated by a combination of SCR and low sulphur fuels (0.5%). The scenario reduces SO_2 emissions by 80%, NO_x by 90% and particulate matter by 20%. Total annual benefits comprise over 11bn Euro. However, the B/C ratio of 2.4 ranks at the end of the scale. The highest efficiency is achieved with a HAM. Since the technology only reduces NOx a combination with low sulphur fuels (0.5%) is the most promising scenario. Total benefits amount to over 10bn Euro annually. 45% of all benefits are generated through NO_x reductions and 40% through SO_2. The advantage of this technology combination is that no end-of pipe technologies is used.

One of the main impediments to increase environmental friendliness of maritime transport is the use of 'residual fuel oils', which is the remainder of the petrol distilla-

[11] The authors estimated B/C ratios that vary between 1.8 and 3.36, depending on the size of the control area and the sulphur content limit.

tion process. This bunker oil contains large quantities of pollutants that would force the oil industry to dispose it as hazardous waste, if the ships would not use it. The improved fuel qualities for road vehicles, introduced in the last decade, entailed an enormous reduction of pollutant emissions on one hand and caused a tremendous increase of contaminants in residual heavy fuel oils on the other hand. Consequently, ship emissions increased over-proportionally. Especially the high sulphur content of bunker oils causes large scale pollution. In maritime transport the sulphur content is presently limited to 4.5% (45,000 ppm) and in special zones[12] to 1.5% (15,000 ppm)[13].

Low sulphur contents can be only achieved through distillation of residual oils, which requires major investments. The IMO (2007, p.28) estimates that additional investments for oil refining equipment in the order of 126 bn US$ are necessary. At the first sight, this amount seems to be rather huge, but it has to be assessed against the background of the world wide transport volume. Two assumptions are made: (i) the costs are transferred entirely to the shipping industry and (ii) the depreciation period for the investments is 10 years. Consequently, the specific costs of maritime transport[14] would increase by 0.15 Euro/1000tkm, if low sulphur fuels are introduced world wide. This amount is fairly low compared to the costs of air pollution, given in Table 2. Thus, prevention costs are much lower than damage costs; which again demonstrates the urgent need for action.

The above investments for low sulphur fuels would increase the costs for bunker fuels by 22 Euro/ton, which signifies a price increase[15] of roughly 7%. This seems to be rather high, but the following example shows, that the economic impacts are relatively small. The transport of a 20ft container from Shanghai to Hamburg on the Cape Town route, using a 3,000 TEU container vessel, would cost only 18 Euro more, if low sulphur fuels were used[16].

The environmental impacts of low sulphur fuels would be tremendous: Corbett and Winebrake (2008) estimate that a world wide reduction of the sulphur content to 0.5% would reduce fatalities caused by marine air pollution by 50.000 annually. Not to mention the cases of non fatal diseases prevented.

4. Conclusions

The enormous growth presently experienced in maritime transport combined with the use of residual fuel oil is causing increasing environmental problems, which countervail the European goal to establish Motorways of the Seas as an environmental friendly alternative to land transport.

In the past two decades road transport sector has experienced a tremendous reduction of pollutant emissions, mainly induced by catalytic converters and cleaner fuels. The pollutants were extracted from petrol and diesel, but remained in the residual

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[12] SO_x Emission Control Areas (SECA), where only fuels with a sulphur content of 1.5% are permitted. Established since 2006 in the Baltic and since 2007 in the North Sea and the Channel.

[13] For comparison, the EuroVI standard for cars, valid from 2009 onwards, requires that the sulphur content in fuels is limited to 10 ppm.

[14] Maritime Transport Volume: 30,686 bn ton-miles (UNCTAD 2007, p8)

[15] Price level of bunker fuels on in Rotterdam 12/3/2008, www.bunkerworld.com.

[16] Load factor 90%. Same features of the ship as given in Table 2

fuel oil presently used by maritime ships. In coincidence with the enormous growth, this caused an unprecedented increase in pollutant emissions of ships. Presently external costs of airborne shipping emissions in Europe amount to 19.6bn Euro p.a.

Nevertheless, if these costs are set in relation to the transport volume, maritime transport remains the environmental friendliest mode of transport, compared to planes, trucks, railways and inland navigation vessels. This holds especially true for larger ships over long distances. Smaller vessels crossing sensitive areas, such as the Schelde River, entail air emission costs comparable to those of railways and inland waterways.

However, emission reduction technologies exist that can alleviate environmental effects of shipping tremendously. All of the analysed technologies reap environmental benefits that comprise at least double investment costs. In some cases the benefits amount to more than five fold the costs.

Under given information, the authors consider low sulphur fuels combined with a Humid Air Motor as an appropriate solution. Through this combination NO_x and SO_2 emissions are reduced by 70%-80%. Benefits comprise more than four fold the costs, which are expected to decrease with augmenting demand for low sulphur fuels. Using these technologies total environmental benefits in European waters would amount to over 10bn Euro annually. However, the Humid Air Motor was not widely used, when this article was written.

The oil industry claims that large scale investments would be necessary to supply low sulphur fuels world-wide. However, prices for bunker fuels would increase by only 7% and the impacts on transport costs are negligible. For example: Transport costs for a container from Shanghai to Hamburg would increase by 18 Euro. With this small investment, the lives of 50.000 people can be saved annually and many more serious health damages be prevented.

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