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Ship emissions and their externalities for the port of Piraeus – Greece

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ABSTRACT

Air pollution from shipping is currently dominating the international and European agenda on environmental protection. Although port emissions are not significantly contributing to the overall picture of ship-generated emissions, it is important to note that the impact of ship exhaust pollutants has a direct effect on the human population and built environment of many urbanized ports. The passenger (main) port of Piraeus qualifies for a ship emission and externality study by virtue of its dominant presence in the Mediterranean expressed in terms of the most frequent port calls by coastal passenger ships and cruise ships operating in the region, as well as in terms of being a most crowded port city through hosting a sizeable resident and visiting (employers and otherwise) population over a relatively small area.

An in-port ship activity-based methodology was applied for manoeuvring and berthing of coastal passenger ships and cruise ships calling at the passenger port of Piraeus, in order to estimate the emission of the main ship exhaust pollutants (NO_X, SO_2 and $PM_{2.5}$) over a twelve-month period in 2008–2009. The estimated emissions were analyzed in terms of gas species, seasonality, activity and shipping sector. The application of external cost factors led to the estimation of the emission externalities, in an attempt to evaluate the economic impact of the damage emissions produce mainly upon the human population and the built environment.

The results indicate that ship emissions in the passenger port of Piraeus reach 2600 tons annually and their estimated externalities over this period are around 51 million euro. Summer emissions and associated impacts are more profound and coastal passenger shipping, as opposed to cruise shipping, is the dominant contributor of emissions and associated externalities. Overall, in a port city such as Piraeus, the need to introduce stringent control on the emissions produced by passenger ships, beyond that dictated by the current 2005/33/EU Directive is very urgent.

1. Introduction

Ship transport accounts for the overwhelming majority of world global trade and is widely acknowledged as being environment friendly compared to other transport modes. However, various research studies which attempted the estimation of global emissions from shipping indicate that ship exhaust emissions are an important contributor to global anthropogenic emissions. According to most recent research, between 1990 and 2007, the emissions of basic pollutants (NO_X, SO_2, PM) and GHGs[1] (mainly CO_2) from global shipping increased from 585 to 1096 million tons (Buhaug et al., 2009). With respect to GHGs, research by Psaraftis and Kontovas (2009), estimates the CO_2 emissions from global shipping in 2007–943.5 million tons, whereas according to the report by TRT, (2007) the global shipping inventory of CO_2 in 2006 stood at around 1 billion tons.

Although in-port emissions make up a small percentage of the overall emissions from shipping (Whall et al., 2002; Dalsoren et al., 2009), ports attract shipping traffic and inevitably constitute sources (points) of concentrated ship exhaust emissions. Apart from the global impact of emitted GHG's, the urbanized character of many ports highlights the spatial impact of ship exhaust pollutants such as nitrogen oxides (NO_X), particulate matter (PM) and sulphur oxides (SO_X) upon the health of the human population and the condition of the built environment. Of particular importance to the human health in urbanized ports is the fact that around 95% of the ship-generated total PM is of an aerodynamic diameter of less than 2.5 μ, namely $PM_{2.5}$ (Whall et al., 2007; Sharma, 2006). The need to control air pollution at ports is widely acknowledged as an active policy issue by various authoritative port associations (IAPH, 2007; ESPO, 2003). A fundamental prerequisite of emission control is the ability to measure or estimate emissions and to this extent the need is dictated to develop detailed and accurate emission inventories for ports (ICF, 2006). Without the ability to address the port as an entity, it is difficult to assess opportunities for emission reductions and to quantify reductions over time. In addition, a port

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[1] Green House Gases (GHGs) are responsible for the global climatic change.

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Fig. 1. Aerial view of the main (passenger) port of Piraeus.

emission inventory is necessary to properly assess the impacts of port improvement projects or growth in shipping activity, as well as to plan mitigation strategies. Finally, port emission inventories aid policy makers towards the development of effective regulatory requirements at international, European and national level, whereas they also inform voluntary initiatives such as a collaborative regional pollution assessments or development of port environmental management systems (EMS).

Port emission inventories are usually less refined than those of ship cruising (at sea) or other sectors, because port activities are not usually well defined and emission factors are based on limited data. Port emission inventories to be reliable must be based upon in-port ship activity data, which is often difficult to obtain to a detail that describes ship movements, ship engine ratings and operating times, fuels used etc. However, port emission inventory methodologies have been improving over the last 15 years, as presented in the port-specific research conducted by De Meyer et al. (2008), Saxe and Larsen (2004), Cooper (2003), Isakson et al. (2003) and Trozzi et al. (1995). Whall et al. in 2002 reported to ENTEC the emissions in European ports for the year 2000 and amongst them Piraeus was ranked 7th in terms of NO_X and SO_2 emissions (with 1600 tons each) and third in PM emissions (with 300 tons). However, in that as well as in their subsequent work (Whall et al., 2007) various assumptions concerning port traffic[2] and in-port ship activity[3] are considered responsible for producing an underestimated emission inventory. This argument may be further supported through the fact that the seemingly low reported port calls were not limited to the passenger port, but they also included the calls made by numerous cargo ships to the cargo terminals of the port of Piraeus.

Centrally situated on the Aegean coastline of the Greek peninsula, in the Saronic Gulf, Piraeus is one of the largest freight and passenger ports in Europe. The passenger traffic of the port of Piraeus is the highest in Europe and the third in the world, servicing about 20 million passengers annually.[4] Although the freight terminals of the port of Piraeus are not urbanized, the passenger terminal (also known as the Main Port) is part of the city of Piraeus (Fig. 1). Piraeus is the third most populated municipality in Greece and the second of the Greek capital following the municipality of Athens, with a population of 175 697 people (in 2001) and an area of 11 km^2. This presents a population density of 16 000 residents per km^2, whereas for example the port cities of Singapore, Rotterdam and Hamburg stand at 8350, 2500 and 2300 persons per km^2, respectively.[5] Although this most densely populated area is of prime interest to this study from an emission receptor point of view, it is important to mention that Piraeus urban area extends beyond the administrative city limits to the suburban municipalities.[6]

Piraeus is a city of great commercial and business activity, especially in the shipping industry and services, which attract about 350,000 employees and visitors per day. This human presence is the receptor of the emissions produced by over 10 000 calls of coastal passenger ships and cruise ships at the passenger port of Piraeus every year. With respect to the detrimental influence of emissions from shipping, road traffic and adjacent industries, the author has first hand experience[7] from residing and working in Piraeus for over a period of fifteen years (1992–2006).

In the meantime, policy-making on atmospheric pollution from shipping is evolving and regulations on ship emissions are enforced. The low sulphur European directive[8] for marine fuel use at berth (with less than 0.1% sulphur by weight) is coming into effect from the 1st of January 2010, whereas Greece has been exempted from compliance till the 1st of January 2012. Alternative compliance through the provision of shore-side electricity for ships staying at berth (for more than two hours) will require sizing of this shore-side electricity facility according to the power demanded by the ships at berth. The estimation of ship power requirements at berth forms also the basis upon which the port emission inventory is produced.

Work on ship emission externalities is still in its initial stages, as more research is needed to provide sufficient and precise data for impacts and their external cost estimations. An externality arises 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.[9] Therefore, the

[2] Port calls were assumed to be just over 4500 in 2000, whereas Piraeus Port Authority (PPA) presents an average of 25 000 port calls annually. http://www.olp.gr/EN_PDF/olpProfileEn.pdf.

[3] For example, ferry time at berth was assumed to be on average one hour, contrary to the experience of longer ferry docking at berth during the day and certainly overnight.

[4] Figure includes the Perama terminal. Through the passenger port Piraeus the annual passenger movement stands at around 12 million passengers. (Source: EU Energy and Transport in figures – Statistical Pocketbook, 2009).

[5] http://www.citymayors.com/statistics/largest-cities-density-125.html.

[6] Wider Piraeus area has a population of 466 065 (in 2001) and a land area of 50 km^2 (i.e. population density of 9321 persons per km^2).

[7] Probably linked to author's suffering from lung emphysema.

[8] http://eur-lex.europa.eu/LexUriServ/site/en/oj/2005/l_191/l_19120050722en00590069.pdf.

[9] European Commission (2003): *External costs: Research results on socio-environmental damages due to electricity and transport.* Published by European Commission, Directorate-General for Research.

evaluation of externalities is important towards a cost internalization policy and/or in a cost-benefit analysis, where the costs to establish measures to reduce a certain environmental burden are compared with the benefits, i.e. the avoided damage due to this reduction. The provision of shore-side electricity facilities as opposed to other measures of reducing ship emissions at berth requires a typical cost-benefit analysis (ENVIRON, 2004), for which the estimation of associated externalities is very important.

Indicative recent externality research on transport and particularly on shipping is provided by the work of Kalli and Tapaninen (2008) for Finland, TRT, (2007) globally and regionally and Gallagher (2005) for the USA. Furthermore, CATF[10] has estimated and submitted to the 58th MEPC session at IMO in 2008 the external cost of the death toll from global PM emission from shipping, as found in a recent study by Corbett et al., (2007). Using EPA's[11] figure for "the value of a statistical life", the annual cost to society of the 60 000 annual deaths caused by shipping in 2002 is over US$300 billion per year.

No previous work on ship emissions and their externalities has been detected with specific and detailed reference to the passenger port of Piraeus. To this extent, the current paper makes a unique contribution in addressing the issue of air pollution generated by passenger shipping alone at one of the busiest ports in world, Europe and the Mediterranean. Most importantly, however, it attempts to provide an estimation of external costs of ship-generated emissions in the passenger port of Piraeus and encourage the introduction of urgently needed mitigation measures.

2. Methodology

The activity-based estimation of ship emissions involves the application of emission factors to a particular ship activity, where an emission factor is a representative value that attempts to relate the emitted quantity with the operational status of the ship's engines during that activity. For port emissions, a ship activity profile is a breakdown of a ship's movements into modes of operation (i.e. manoeuvring or at berth), with a representative engine type and size, engine load factor, type of fuel consumed and time spent in each mode. Manoeuvring refers to the slow speed movement of the ship between the port's breakwater (entry/exit) and point of berth, whereas berthing refers to the dockside mooring of the ship.

For every ship call, each of the NO_X, SO_2 and $PM_{2.5}$ emissions produced during the ship's inbound and outbound manoeuvring and while at berth are estimated through the application of the following expressions:

$$E_M = T_M \times [(ME \times LF_{ME} \times EF_{ME}) + (AE \times LF_{AE} \times EF_{AE})] \times 10^{-6}$$

and

$$E_B = T_B \times [(ME \times LF_{ME} \times EF_{ME}) + (AE \times LF_{AE} \times EF_{AE})] \times 10^{-6}$$

where,

E_M or E_B = Ship emissions during manoeuvring or at berth, respectively (tons).
T_M = Time spent during manoeuvring (h).
T_B = Time spent at berth (h).
ME = Main engine power (kW). AE = Auxiliary engine power (kW).
LF_{ME-M} or LF_{ME-B} = Load factor of main engine in manoeuvring or at berth, respectively.
LF_{AE-M} or LF_{AE-B} = Load factor of auxiliary engine in manoeuvring or at berth, respectively.
EF_{ME} = Emission factor of main engine for each of the emitted species (g kWh^{-1}).
EF_{AE} = Emission factor of auxiliary engine for each of the emitted species (g kWh^{-1}).

[10] Clean Air Task Force (CATF) is a US-based environmental non-governmental organization participating in the IMO discussions as part of the Friends of the Earth-International delegation.
[11] Environmental Protection Agency (EPA), USA.

Table 1
Ship traffic statistics at the passenger port of Piraeus (1/6/08–31/5/09).

PERIOD[a]	Coastal passenger ships[b]		Cruise ships	
	Number of ships	Number of departures	Number of ships	Number of calls
Winter	59	1970	124	10
Spring		1918		206
Summer		3545		356
Autumn		2153		330
TOTAL	59	9586	124	902

[a] Winter = December–January–February, Spring = March–April–May, Summer = June–July–August, Autumn = September–October–November.
[b] Ro-Pax and all passenger vessels (hydrofoils, monohulls, catamaran).

2.1. Port traffic statistics

Shipping activity within the passenger port of Piraeus is comprised by the daily itineraries of coastal passenger ships to the Aegean islands and Argo-Saronic islands,[12] as well as cruise ship calls. The Hellenic Ministry of Mercantile Marine (MMM) announces coastal passenger ship departures from Piraeus on a daily basis[13] and for the current analysis the vessel's name, its departure time and its destination(s) were recorded. Furthermore, the Piraeus Port Authority (PPA) provided all the information relevant to cruise ship calls at the port of Piraeus, involving the date of call, the vessel's name, as well as the call duration (i.e. arrival and departure time). Both records of coastal and cruise shipping within the port of Piraeus covered a twelve-month period, namely between the 1st of June 2008 and the 31st of May 2009. The record data was further divided into quarterly intervals in order to capture the influence of seasonality.

Table 1 shows the number of ships involved by type and their seasonal and overall number of calls (or departures) at the port of Piraeus.

2.2. Engine details

On the basis of the vessel's name and type, the Lloyd's Register of Ships (LRS) online[14] was utilized in order to obtain data on main (ME) and auxiliary (AE) engines for all coastal passenger ships and cruise ships active in the port of Piraeus. All 59 coastal passenger ships were mechanically driven and more specifically, 48 ships were driven by MSD[15] (geared to CPPs),[16] 10 employed HSD[17]

[12] Aegina, Poros, Hydra, Spetses, Salamina and Agistri.
[13] http://info.yen.gr/page_en.php?id=1617.
[14] Lloyd's Register of Ships is produced by Lloyd's Register-Fairplay Ltd and includes details of over 170 000 ships of 100 gt & above, through their internet-based database at http://www.sea-web.com.
[15] Medium Speed Engine (MSD).
[16] Controllable Pitch Propeller (CPP).
[17] High Speed Diesel (HSD).

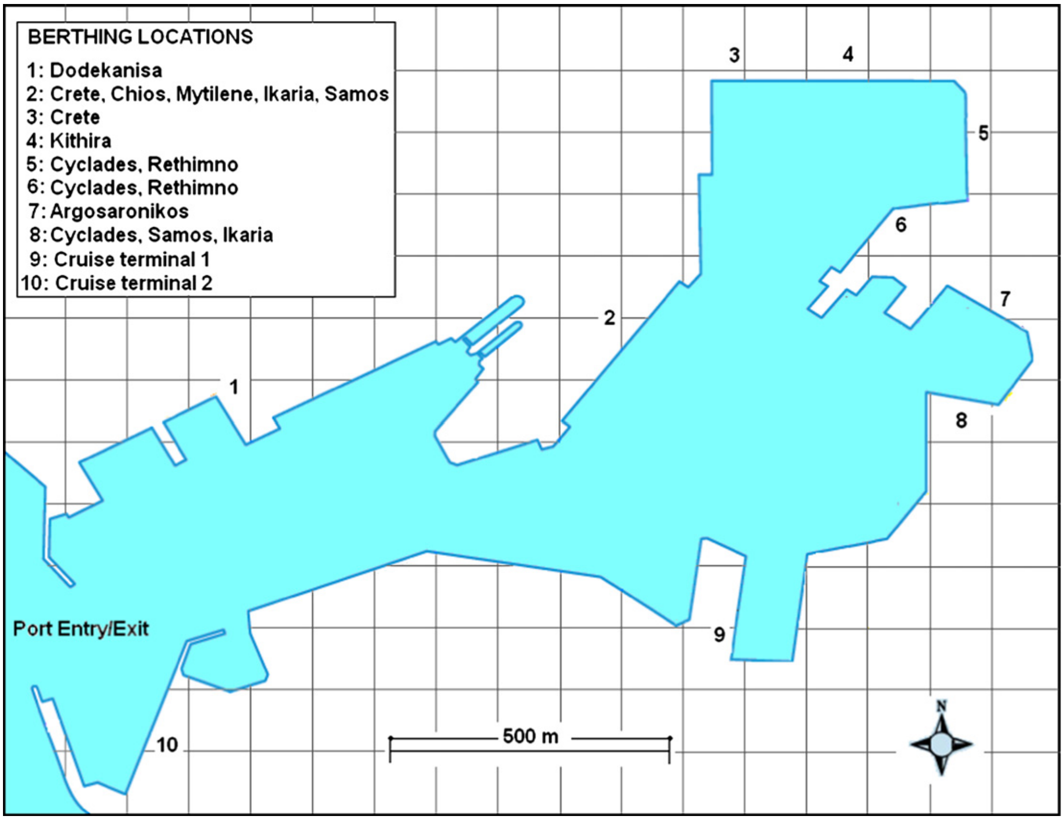

Fig. 2. Berth layout at the passenger port of Piraeus.

(geared to water-jets) and one catamaran was driven by two gas turbines (geared to water-jets). However, the LRS auxiliary engine data for these coastal passenger ships was incomplete in five cases. Utilizing the information provided for the other 54 ships, the missing values for the auxiliary power were assumed to be equal to 15.5% and 3.9% of the main engine power of 4 conventional vessels and one HSC,[18] respectively. Furthermore, with regard to the cruise ships being active at the port of Piraeus, 56.5% were found to be mechanically driven by diesel engines (47.6% and 8.9% by 4-stroke and 2-stroke, respectively), 34.7% made use of the diesel-electric engine configuration (MSD generators) and 8.8% used steam or gas turbine, as well as combined diesel and gas turbine electric configurations. In the case of diesel-electric cruise ships the overall electricity generation is split between propulsion and auxiliary purposes according to demand and auxiliary engine data is not presented as a separate figure. However, auxiliary engine sizing was assumed based upon an auxiliary to propulsion power ratio of 0.278, as proposed by recent auxiliary engine power estimates involving some of the cruise ships calling at Piraeus, as well as a number of their sister ships (Starcrest, 2005a,b).

2.3. Manoeuvring and berthing time

Destinations of coastal passenger ships were important in locating the points of berth in relation to the entry/exit of the port of Piraeus (Fig. 2). Manoeuvring time is calculated as the distance traveled between port entry/exit and berth point divided by vessel's average in-port speed (inbound with an average speed of 5 knots and outbound with 8 knots), plus an average of 9 min of which 6 to dock and 3 min to undock.[19] Manoeuvring times based upon average inbound and outbound vessel speeds and average docking/undocking times are more functional as they can be considered to be relevant for some time and compensate for extreme variations. On the basis of this assumption, the inbound and outbound manoeuvre to and from berth no. 5 being at a distance of around one nautical mile from the port entry/exit takes around 12 and 7.5 min, respectively plus 9 min docking/undocking. Similarly, depending on berth point the manoeuvring times of all coastal passenger ships were estimated, whereas most cruise ships were assumed to berth at cruise terminal 1 (berth no. 9) with the exemption of 15 calls (out of 902 calls) involving very high tonnage vessels (such as QM2 etc) which berthed at cruise terminal 2 (berth no. 10).

Time at berth is also known as hotelling time, since at berth most power requirements are related to onboard hotel services. Time at berth begins when a ship ties-up at a berth and ends when it leaves that berth. The time at berth for cruise ships was specific to individual port calls (as provided by PPA), whereas times at berth for every coastal passenger ship calling at Piraeus were not readily available and hardly reliable.

Therefore, every coastal passenger ship was assigned an average time at berth of 8 h, taking into account short berthing periods between successive itineraries to nearby islands, as well as the overnight docking for most of the Ro-Pax vessels serving the Aegean islands. In the case of coastal passenger ships, this estimation of berthing time is more realistic, because the duration of docking will change the demand of (auxiliary) power at berth.

[18] High Speed Craft (HSC) – Planing Monohull.

[19] Average time for docking and undocking, based upon several in-situ observations.

Table 2
Engine load factors for ship activities within the port of Piraeus.

Activity	Summer engine load factors				Rest of year engine load factors			
	Cruise ships		Coastal passenger ships		Cruise ships		Coastal passenger ships	
	ME	AE	ME	AE	ME	AE	ME	AE
Manoeuvring	0.20	0.75	0.20	0.75	0.20	0.60	0.20	0.60
At berth	0.00	0.60	0.00	0.45[a]	0.00	0.40	0.00	0.30[b]

[a] 0.70 and 0.20 for 50% of time at berth.
[b] 0.40 and 0.20 for 50% of time at berth.

2.4. Engine load factors

Determining main (ME) and auxiliary (AE) engine load factors during in-port ship activities represents an area of characteristic uncertainty. Recent research by De Meyer et al. (2008) proposes auxiliary engine load factors of passenger ships and cruise ships during manoeuvring and at berth, which are significantly higher than the corresponding figures proposed for ENTEC by Whall et al. in 2002. On the basis of this finding, as well as the influence of local climatic conditions (seasonality) upon auxiliary power demand, it was considered necessary to conduct a survey with various ship operators in order to arrive at a more realistic picture with regard to engine load factor figures. It was found that coastal passenger ships and cruise ships employ high auxiliary engine load during manoeuvring in order to maintain electricity supply for hotel services, as well as to support the necessary bow thruster operation. With regard to the summer operation of auxiliary engines at berth, cruise ships produce high auxiliary power in order to cover the electricity demand for hotel services throughout the duration of their stay at berth. On the other hand, the auxiliary engine power of coastal passenger ships during the summer is high for hotelling purposes for 50% of berthing time, i.e. during short berthing times (up to 4 h) and for an hour before departure after an overnight stay. Outside the summer period, cruise ships and coastal passenger ships were found to use significantly lower auxiliary engine power, especially at berth. The proposed main and auxiliary engine load factors of cruise ships and coastal passenger ships for the in-port ship activities of manoeuvring and at berth during summer and the rest of the year are shown in Table 2.

2.5. Fuel type

All ships driven mechanically by MSDs and HSDs use LSFO[20] and 1% sulphur MDO, respectively. About 65% of the auxiliary engines of coastal passenger ships and mechanically driven cruise ships burn MDO (with 1%S), the remaining 35% burning LSFO. Generally, it was observed that most of the older ships require MDO in their auxiliary engines, whereas newer ships can tolerate the heavier fuel oils. The MSD generators of the diesel-electric driven and steam turbines of the steam-electric driven cruise vessels use LSFO, whereas gas turbine driven ships run on MDO (1%S).

2.6. Emission factors

Consideration of part load operation of main and auxiliary engines led to introduction of correction factors, according to the extensive review work on emission factors originally prepared for ENTEC (Cooper, 2002) and included in the recent final report on Ship Emissions Inventory – Mediterranean Sea (Whall et al., 2007). The approach adopted was to multiply main engine emission factors (derived from steady state loads 70–100%) by 0.8 for NO_X and 3.0 for $PM_{2.5}$ for all diesel engines and steam turbines. For gas turbines the corresponding factors were taken as 0.5 for NO_X and 5.0 for $PM_{2.5}$. In addition, SO_2 emissions have been assumed to increase by 10% for engine operation at these low loads. The emission factors applied for the operation of main and auxiliary engines running on specific fuels and load condition, during ship manoeuvring and at berth are shown in Table 3.

Table 3
Emission factors of main and auxiliary engines for in-port ship activities.

Engine type[a]/Fuel type		Emission factor (g kWh^{-1})		
		NO_X	SO_2	PM
Main Engine	HSD/MDO	9.6	4.5	0.9
	MSD/LSFO	11.2	6.6	2.4
	GT/MDO	2.9	6.4	0.5
	ST/LSFO	1.7	9.6	2.4
Auxiliary Engine	MSD/LSFO	14.7	6.5	0.8
	MSD/MDO	13.9	4.3	0.3
	GT/MDO	5.7	5.8	0.1
	ST/LSFO	2.1	8.7	0.1

Diesel Electric (DE) configuration employs MSDs.
[a] HSD = High Speed Diesel, MSD = Medium Speed Diesel, ST = Steam Turbine, GT = Gas Turbine.

2.7. Emission externality factors

The figures used for the external costs of NO_X, SO_2, and $PM_{2.5}$ emissions in this study are based on the work made in the European Commission's DG Research ExternE project (European Commission, 1999), as adapted by NETCEN to provide a simple tool for estimation of the external costs of air pollution (NETCEN, 2004). The external costs include acute and chronic effects of $PM_{2.5}$, SO_2 and NO_X on mortality and morbidity, the effects of SO_2 (acidity) on materials used in buildings and structures (excluding those of cultural value) and the effects of NO_X on arable crop yield. According to NETCEN, for shipping emissions in port, the external cost factors are equivalent to damages imposed upon urban areas of the same size as the port city plus the rural externality figure of the emissions for the country in question. The urban NO_X external cost factor is the same as the rural, given that impacts of NO_X are linked to formation of secondary pollutants in the atmosphere (taking time to be generated) and hence local variation in population density has little effect on results.

According to NETCEN and with specific reference to Greece, the rural external costs of NO_X, SO_2 and $PM_{2.5}$ emissions are 6000, 4100 and 7800 euro per emitted ton, respectively. Furthermore, with the urban external costs of SO_2 and $PM_{2.5}$ emissions for city of 100 000 people quoted to be 6000 and 33 000 euro per emitted ton, respectively, for the city of Piraeus with a population of around 180 000 people, these factors will be linearly increased to 10 800 and 59 400 euro per emitted ton, respectively. By adding the rural values for Greece, the external cost factors of NO_X, SO_2 and $PM_{2.5}$ ship emissions in the port of Piraeus become 12 000, 14 900 and 67 200 euro per emitted ton, respectively. However, these values refer to year 2000 prices and it is considered appropriate to utilize the CPI[21] for Greece in order to bring them in line with the year under consideration. According to OECD country statistical profiles (OECD, 2009), the Greek CPI in 2008 stood at 130.8

[20] Low Sulphur Fuel Oil (LSFO), with maximum 1.5% sulphur content by weight as specified by the Directive 2005/33/EU.

[21] Consumer Price Index (CPI all items).

Table 4
External cost factors of emitted pollutants.

Emitted pollutant	Emission external cost factor (euro per emitted ton, in 2008–09 prices)	
	NETCEN-based	HEATCO-based
NO_X	15 720	2655
SO_2	19 520	1690
$PM_{2.5}$	88 030	253 470

(year 2000 = 100). Therefore, the external cost factors of ship emissions for the port of Piraeus in 2008–2009 will be around 31% higher than those of the year 2000. Therefore, the applied emission externality factors of ship emissions for the port of Piraeus in 2008–2009 were estimated to be 15 720, 19 520 and 88 030 per emitted ton of NO_X, SO_2 and $PM_{2.5}$, respectively.

Similarly, the valuation of air pollution effects according to EU funded project HEATCO (Bickel et al., 2006) is based upon human health impacts, agricultural production losses, as well as soiling and corrosion of building materials. According to the latter, the nominal costs (in 2002 prices) of air pollution from road transport in Greece are quoted to be 2200, 1400 and 210 000 euro per emitted ton of NO_X, SO_2 and $PM_{2.5}$, respectively. Therefore, with the CPI increase of 20.7% since 2002, the 2008 HEATCO-based external cost factors of NO_X, SO_2 and $PM_{2.5}$ for Greece become 2655, 1690 and 253 470 euro per emitted ton, respectively.

The external cost factors according to the NETCEN and HEATCO methodologies are summarized in Table 4, where it is shown that HEATCO proposes significantly lower external cost factors for NO_X and SO_2 and significantly higher for $PM_{2.5}$ emissions. However, it is important to note that HEATCO refers to road transport with release of particulate matter in the street canyon, whereas NETCEN accounts for the particulate matter release from the high stacks of ships. Overall, the NETCEN external cost factors are considered to be more appropriate for the estimation of the examined externalities, since they are case specific not only with respect to shipping but also with respect to the activity of ships within the port.

3. Results – discussion

The seasonal distribution of ship emissions according to emitted species is presented in Fig. 3. NO_X emissions were found to be dominant throughout the year, followed by those of SO_2 and thirdly $PM_{2.5}$ emissions. The emitted SO_2 and $PM_{2.5}$ mass was steadily around 40% and 5% of the NO_X emission, respectively. As expected, summer emissions were almost double than the equally placed autumn and spring emissions, whereas winter emissions were found to be trailing at almost one fourth of the summer ones. This seasonal variation of emissions is very significant in terms of seasonal air quality in the port and city of Piraeus. During the summer, the increased demand for shipping services (increased sea-side port traffic) inevitably leads to increased shore-side traffic and congestion. The exhaust emissions of the various road vehicles (trucks, buses, private cars) operating in and out and around the port of Piraeus are added to the ship exhaust emissions, thus maximizing the detrimental impact upon the city's air.

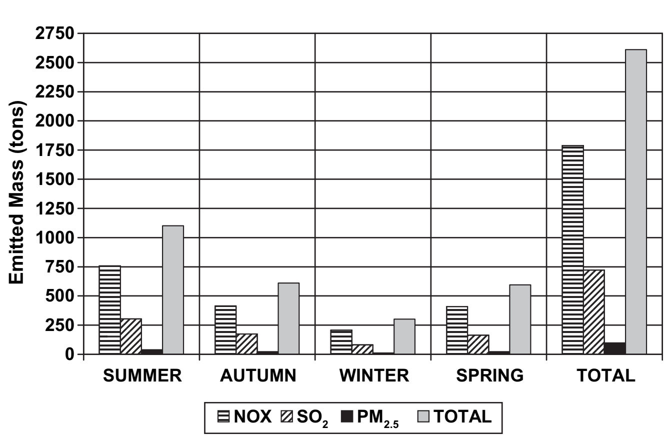

Fig. 3. Distribution of emissions according to season and gas species.

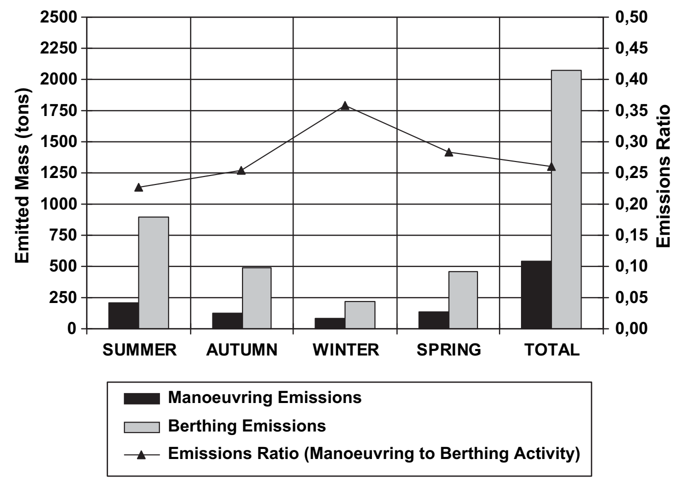

Fig. 4. Distribution of emissions according to season and in-port ship activity.

Throughout the year, ship emissions at berth were between three and five times higher than those produced during the ship manoeuvring activities (Fig. 4). As expected, berthing emissions were highest in the summer when auxiliary engine power demand for hotel services is at a peak and minimum in the winter. During the autumn and spring the ratio of manoeuvring to berthing emissions was almost equal to the annual average.

On average, the in-port activity of coastal passenger shipping produced almost double the emissions of that of cruise shipping (Fig. 5), although significant seasonal variations were observed. More specifically, during the summer and spring the ratio of cruise to coastal shipping emissions was around 0.5. Despite the fact that cruise ships operate their auxiliary engines at high loads throughout their stay at berth, the overwhelming presence of coastal shipping operations during the summer keeps the relative contribution of cruise shipping low. As expected, the cruise contribution

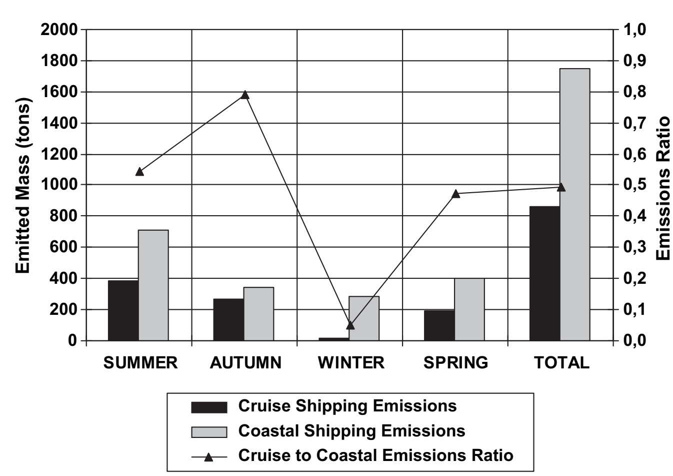

Fig. 5. Distribution of emissions according to season and shipping sector.

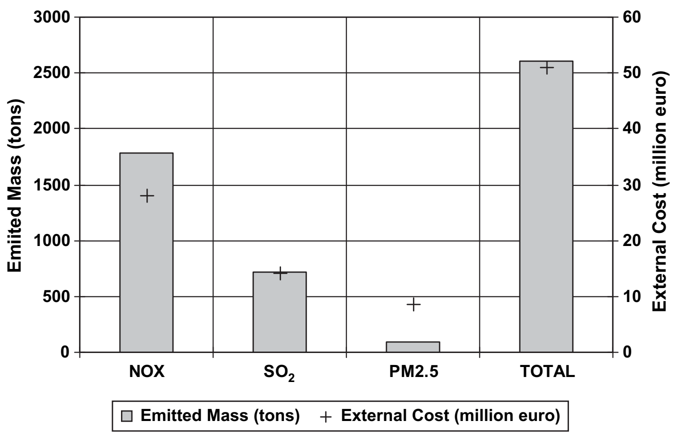

Fig. 6. Ship emissions and external costs.

was minimum (around 5% of that of coastal shipping) in the winter and cruise and coastal shipping emissions came very close in the autumn, when cruise ships generated around 80% of the coastal ship emissions. During the autumn, coastal shipping activity in the port of Piraeus slows down (in comparison to the summer), but calls by cruise ships maintain their summer momentum. Finally, the applied analysis towards the estimation of the emission inventory for the passenger port of Piraeus during a twelve-months period in 2008–2009 shows that in-port ship activity of cruise and coastal passenger ships produced 2610 tons of main exhaust pollutants (NO_X, SO_2 and $PM_{2.5}$ combined) (Fig. 6). NO_X emissions were found to be 1790 tons, whereas SO_2 and $PM_{2.5}$ emissions were estimated at 722 and 99 tons, respectively.

The external costs associated with the damages ship emissions impose mainly upon human health and the built environment around the passenger port of Piraeus were found to be quite significant. More specifically, the overall externalities were valued at almost 51 million euro, whereas the individual contribution of the pollutants was around 28, 14 and 9 million euro for the NO_X, SO_2 and $PM_{2.5}$ emissions, respectively. The external costs of cruise shipping were found to be 16.7 million euro, whereas those attributed to coastal passenger shipping stood at 34.2 million euro. It is important to note that the damage impact of $PM_{2.5}$ emissions is overwhelming, since despite their low emission level present significant external costs. These costs are high because they are mainly associated with pulmonary chronic and fatal diseases. At this point, it should be mentioned that the current IMO and EU legislation makes no particular provision for curbing fine PM (i.e. $PM_{2.5}$) pollution generated by marine engines and its is hereby suggested that this is an issue that needs to be urgently addressed.

According to the annual inventory submission of Greece under the Convention and the Kyoto Protocol for green house and other gases for the years 1990–2007 (MINENV, 2009), the national transport[22] NO_X and SO_2 inventory for 2007 was reported to be 150.4 and 29 thousand tons, respectively. Therefore, shipping activity within the passenger port of Piraeus alone contributes by 1.2% and 2.5% to the national transport NO_X and SO_2 inventory of Greece, respectively. The higher contribution of SO_2 emissions reflects the high sulphur content of marine fuels, as opposed to the significantly lower sulphur content of auto diesels. In this respect, it becomes evident the potential for improvements through lowering the sulphur content of marine fuels used by ships while in port. Furthermore, a reduction in sulphur has the added indirect benefit of reducing the formation of secondary PM and hence weakening its damaging influence upon human health.

[22] Domestic shipping only.

Table 5
Contribution of ship emissions in the passenger port of Piraeus.

Emitted pollutant	Contribution of ship emissions in the passenger port of Piraeus		
	Greater Athens Area (all sources)	National (all sources)	Mediterranean Sea (Shipping)
NO_X	6.3%	1.2%	0.12%
SO_2	56.9%	2.5%	0.08%
$PM_{2.5}$	14.7%	–	0.10%

With respect to NO_X, SO_2 and $PM_{2.5}$ emissions within the Greater Athens Area (GAA) from all sources (including shipping), the emission levels in 2003 were estimated at 28 178, 1267 and 675 tons, respectively (Moussiopoulos and Douros. 2004). On this basis, NO_X, SO_2 and $PM_{2.5}$ emissions due to ship activity within passenger port of Piraeus constitute 6.3%, 56.9% and 14.7% of the total emissions within the GAA. This result indicates the importance of SO_2 emissions from shipping and highlights the need to control the sulphur content of marine fuels.

Finally, in terms of the emission inventory from shipping in the Mediterranean Sea, NO_X, SO_2 and $PM_{2.5}$ emissions for 2005 were reported to be 1448, 862 and 98 thousand tons, respectively (Whall et al., 2007). Therefore, NO_X, SO_2 and $PM_{2.5}$ emissions due to ship activity within passenger port of Piraeus constitute 0.12% 0.08% and 0.10% of the total Mediterranean emissions from shipping. The above mentioned emission comparisons are presented in Table 5.

On the basis of a recorded annual coastal and cruise passenger traffic around 12 million and 1.6 million, the external cost per passenger was found to be on average around 2.9 and 10.4 euro, respectively. Assuming an average fare price of 30.2 euro[23] per passenger for all coastal passenger services from and to Piraeus, the internalization of the external cost of air pollution generated by coastal passenger shipping in the port of Piraeus will lead to an average price increase of 9.6%. With regard to the cruise passenger tariff, the percentage increase is significantly lower (around 1%), since the cost of most cruise services is in excess of 1000 euro per person.

With respect to the reliability of the emission inventory and externality estimation, it should be mentioned that in-port ship activity, engine use (load and fuel), emission factors and external cost factors are based on numerous assumptions made through other researchers, as well as by the current author. They are bound to have considerable uncertainty and therefore they can influence the reliability of the calculated emissions and their externalities. Especially, with respect to the externality estimation, it should be considered that an underestimation is very likely since the population daily exposed to the ship-generated pollutants must include daily visitors and employees which produces a significantly higher number (almost double) than that corresponding to Piraeus residents. Furthermore, although the applied external cost factors are widely used in many research studies, it is acknowledged that there is adequate margin for improvement through the broadening of the range of incurred damages and the refinement of their impact evaluation. More specifically, it is important to note that the applied external factors do not include structures of cultural value (such as antiquities), for which the Attica region (Piraeus and Athens) has a particular sustainability interest.

[23] Based upon the passenger fare for economy class services offered by Blue Star Ferries to all Aegean destinations from Piraeus. http://www.bluestarferries.gr/site/content.asp?sel=634&loc=2.

4. Conclusions

The passenger port of Piraeus was selected to perform an emission inventory and externality study because it combines adequate emitter and receptor characteristics, deriving mainly by the generated port traffic and the urbanized character of the port, respectively. It was found that the in-port emissions of coastal passenger shipping were almost double to those of cruise shipping. Seasonality was found to play a major role, as summer emissions were very high compared to the winter ones. Overall emissions were found to be around 2600 tons annually, with NO_X being dominant, followed at a distance by SO_2 and $PM_{2.5}$ emissions. This inventory contributes by 1.2% and 2.5% to the national transport NO_X and SO_2 emissions. The external costs of emissions were estimated around 51 million euro annually, two thirds of which were found to be attributed to coastal passenger shipping. The internalization of the external costs of air pollution from coastal and cruise shipping in the passenger port of Piraeus will lead to a fare increase of around 10% and 1%, respectively. Although the level of $PM_{2.5}$ emission was found to be low, its externality was found to be relatively high. Human health impacts of $PM_{2.5}$ emissions were therefore found to prevail, thus highlighting the need for relevant policy-making and control action. Overall, in a port city such as Piraeus, the need to introduce stringent control on the emissions produced by passenger ships, beyond that dictated by the current 2005/33/EU Directive is very urgent.

It is generally suggested that apart from the development of improved and standardized methodologies, more accurate supporting data (ship and engine activity, emission factors and external cost factors) is needed in order to improve monitoring and control of emission inventories and their externalities towards effective environmental policy-making in international, European and national shipping.

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