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Mitigating Shipping Emissions in European Ports

Social and Environmental Benefits

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ISSN 2191-530X ISSN 2191-5318 (electronic)
SpringerBriefs in Applied Sciences and Technology
ISBN 978-3-319-40149-2 ISBN 978-3-319-40150-8 (eBook)
DOI 10.1007/978-3-319-40150-8

Library of Congress Control Number: 2016941092

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

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Introduction

Climate change is one of the most challenging environmental issues as it is global with long-term impacts and its mitigation entails major social and technological choices. International agreements related to climate change will require that nations consider mitigation actions aiming at domestic land-based emissions sources and inevitably this will affect the transport sector.

Transport is responsible for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy. More than two-thirds of transport-related greenhouse gas emissions are from road transport. However, there are also significant amounts of emitted air pollutants related to the aviation and maritime sectors and in fact these two sectors are experiencing the fastest growth in terms of emissions. Shipping industry is the most energy-efficient sector in transportation, but on the other hand, the severity of ships' emissions has been proved. International research on shipping emissions reduction is still relatively new. The shipping industry is extremely competitive and financially sensitive and the economic growth of developing countries has increased the demand for larger ships, and led to doubling of trade volumes in adjacent areas. As a result of this evolutionary progress, vessel traffic and related emissions of air pollutants have increased. On a local scale, shipping seriously impacts air quality through the formation and transportation of either greenhouse gases (GHG), viz., carbon dioxide (CO_2), methane (CH_4), nitrous and sulfur oxides (NO_x and SO_x) or health-related emissions, viz., ground-level ozone and particulate matter of various diameters (PM). These air emissions are responsible for serious environmental and public health-related issues (Beck 2007). On the other hand, in harbor cities or coastal areas ship emissions are often the dominant source of urban pollution.

This book focuses on the social and economic impacts of in-port ships' emissions and relevant energy demand, providing an insight of the expected barriers for implementation and formulating recommendations on policy actions that could accelerate the implementation of relevant mitigation measures. The layout of the book is as follows: Chap. 1 is an introduction to the shipping industry and the induced air pollution. In Chap. 2, the current environmental policies focusing on the mitigation of maritime emissions are analyzed. In Chap. 3, the methodology for the accurate estimation of shipping emissions is discussed, as well as some relevant studies on this field. The significant issue of externalities in ports is included in Chap. 4. In the last section, Chap. 5, the available abatement measures for the unwanted environmental impacts of ships at berth are listed.

Reference

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Chapter 1
Shipping Industry and Induced Air Pollution

Abstract Transport is responsible for around a quarter of EU greenhouse gas emissions making it the second biggest greenhouse gas emitting sector after energy. More than two thirds of transport-related greenhouse gas emissions are from road transport. However, there are also significant emissions from the aviation and maritime sectors and these sectors are experiencing the fastest growth in emissions.

1.1 Shipping Industry and Induced Air Pollution

The transport sector accounts for about 24.3 % of global GHG emissions. Although the total GHG emissions in the European Union (EU) during the years 1990–2007 decreased by 15 %, the corresponding transport sector's emissions increased by 36 % (EC 2016). Environmental experts stress out that the current CO_2 concentration in the atmosphere exceeds natural limits most probably in extremely high levels. With ongoing increase of population, rising incomes in lower and middle income countries, as well the availability of cheaper vehicles, the level of GHG concentration in the atmosphere will continue to increase during the next decades unless strict measures are enacted (OECD 2009). As presented in Fig. 1.1, in 2009, European transport sector (including aviation and shipping) was responsible for 24 % of total GHG emissions, with the road sector largely dominating in terms of emissions volume while shipping and aviation present highest growth rates (Maragkogianni et al. 2013). In 2012, the transport sector was responsible for 24.3 % of total GHG emissions, while road transport has been increased 0.5 %. International aviation was 3.1 % and international maritime sector was 3.4 % (EC 2016). Due to the fact that transport is the second biggest GHG emitting sector after energy, significant mitigation actions are required in order to achieve long-term environmental policy goals either in EU or globally.

As far as the maritime transport sector is concerned, it is a vital component of the worldwide economy, being responsible for a large fraction of the international transportation of goods. Exhaust gases and particles emitted from ships' engines contribute a significant part to total emissions of the transport sector. But, due to its

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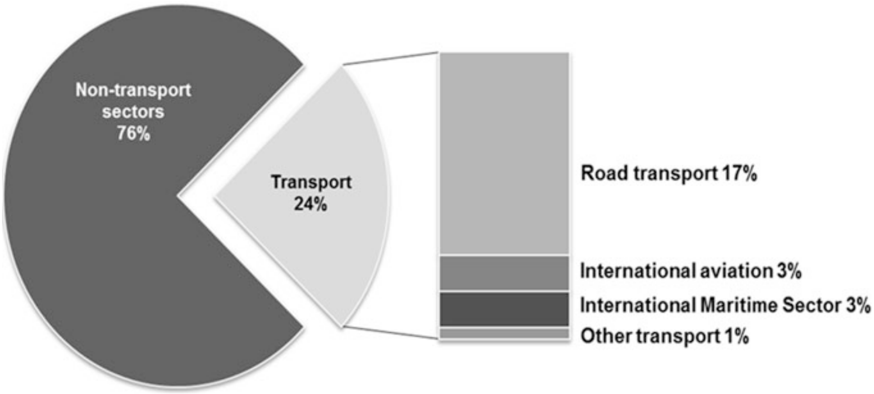

Fig. 1.1 Transport sector contribution to total GHG emissions

dependence on fossil fuel combustion and the fact that it is one of the least regulated anthropogenic emission sources, the maritime transport sector contributes significantly to air pollution and climate change (EEA 2013). Maritime transport is the fifth largest contributor to air pollution and carbon emissions, and the growing rate of trade makes the problem even more pressing. As far as the global CO_2 inventory of shipping is concerned, it exceeds 1 billion tons and if shipping were a country, it would be the 6th largest producer of air emissions (Buhaug et al. 2009; Harrould-Kolieb and Savitz 2010). There are three major emission sources from vessels: main, auxiliary engines and boiler. All ship activities are responsible of air pollutants emissions and particularly ships movement in port or ships' activities during their staying in ports (energy for lighting, heating, etc.), loading and unloading (Trozzi 2003).

Various research studies reveal alarming estimates regarding ship emissions: according to the International Maritime Organization (IMO), in 2007 shipping was estimated to have contributed about 3.3 % to global CO_2 emissions, on a par with aviation and about 5 times less than road traffic (Buhaug et al. 2009). Furthermore, IMO in 2012 reports that total shipping emissions were approximately 949 million tonnes CO_2 and 972 million tonnes CO_2-eq (in terms of total for GHG, combining CO_2, CH_4 and N_2O). International shipping accounts for approximately 2.2 and 2.1 % of global CO_2 and GHG emissions on a CO_2 equivalent (CO_2-eq) basis (IMO 2014). The contribution of ship emissions has been increasing (15 and 4–9 % of globally emitted NO_x and SO_2 respectively can be attributed to ships), while on the other hand, that of the emissions from other sources is declining. Mid-range emissions scenarios show that, by 2050 and in the absence of relevant policies, ship emissions might grow by 150–250 % (with 2007 being the base year), due to the continuing growth in international seaborne trade (Buhaug et al. 2009; Eyring et al. 2005). In Europe, where SO_2 emissions have shown a decreasing trend for 25 years, the emissions from ships are particularly important: in the year 2000 emissions from international shipping in the seas surrounding the European Union were between 20

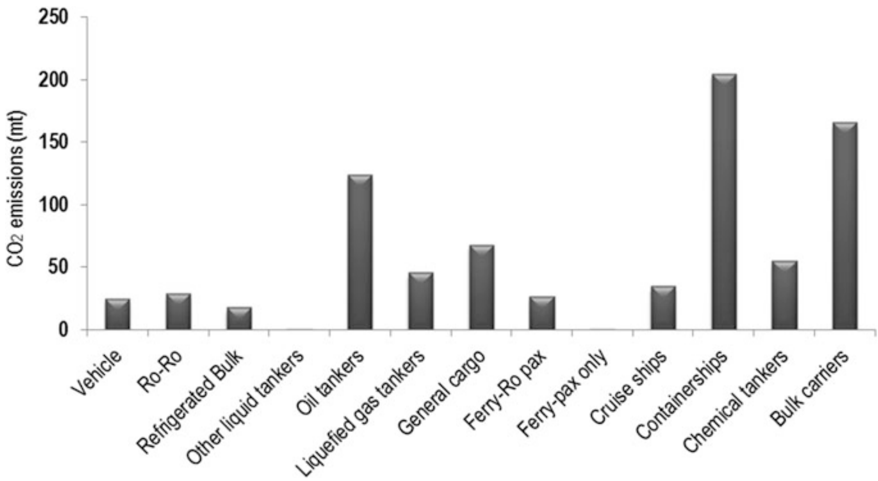

Fig. 1.2 CO_2 emissions by ship type, in 2012 (IMO 2014)

and 30 % of the land-based emissions, while in 2020 emissions from maritime activities are projected to be about as large as those from land-based sources (Schembari et al. 2012). Figure 1.2 shows the total CO_2 emissions of each ship type, for the year 2012, as estimated using the bottom-up methodology (IMO 2014).

Regarding SO_x and NO_x emissions, the maritime sector is among the top emitters corresponding to 5–8 % and around 15 % (for SO_x and NO_x respectively) of the world's total amount. On the other hand the amount of PM released by ships globally is much lower than that of SO_x or NO_x emissions, but these emissions pose much more severe health effects (Helfre and Boot 2013). An additional contribution of shipping to climate change is due to black carbon (BC), which absorbs energy of incoming sunlight, and is particularly potent in the Arctic and Antarctic areas where it plays an important role in the acceleration of snow and ice melting (Eyring et al. 2010).

1.2 Potential Impacts of Maritime Transport Air Emissions

It is clear that the contribution of shipping to air pollution, in the open seas, is lowest; on the other hand, there are various activities (i.e. land-based operations) that contribute to issues related to the problem of air quality. The impact of shipping on air quality is to some extent related to the fact that the majority of maritime emissions occur close to the coastal areas. According to global annual estimates, nearly 70 % of the global emissions due to shipping occur within 400 km from land (Endresen et al. 2003; Chang and Wang 2012). In EU waters, a larger share of emissions takes place closer to the shoreline, 89 % of North Sea ship emissions are within 50 nautical miles (nm) and 97 % within 100 nm from shore (Hammingh et al. 2012). The increased flow of commercial ships into and out of ports does not only affect major ports, but also medium- and small-scale ones (Viana et al. 2009). Ship emissions are known to have impacts on human health, ecosystems and air quality (EEA 2012). In the EU only for 2010, annual premature mortalities due to poor air quality amounted to over 400,000. In addition, the health related economic costs are enormous, amounting to between €330 and €940 billion for the year 2010 alone (EC 2013a, b). Air pollution can cause serious health problems including lung cancer, cardiovascular disease, and birth defects. Particulate Matter emissions from marine vessels are related to increased cardiovascular hospitalizations (Tian et al. 2013) and have been estimated to be responsible for about 60,000 annual cardiopulmonary and lung cancer deaths mostly along European, East Asian, and South Asian coastal areas (Corbett et al. 2007). According to US Environmental Protection Agency (EPA) the figure for "the value of a statistical life", the cost to society of the abovementioned annual deaths caused by shipping is over US $300 billion per year. The EPA has also forecasted that NO_x emissions from ships would more than double to 2.1 million tons a year over the next two decades, while PM emissions would triple to 170,000 tons by 2020 (EPA 2010).

Furthermore, recent studies investigate the impact of gases and particles emitted by ships on acidification and eutrophication of water and soil in coastal regions due to deposition of sulphur and nitrogen compounds (Derwent et al. 2005; Kalli et al. 2010; Sutton et al. 2011). Maritime transport also poses negative externalities to natural habitats and economic losses to coastal areas in the form of shipping disasters, notably large-scale accidental oil spills (Ng and Song 2010). The contribution of ships and harbor emissions to local air quality, with specific focus on atmospheric aerosols, has been investigated using models (Trozzi et al. 1995; Gariazzo et al. 2007; Eyring et al. 2005; Marmer et al. 2009), or using experimental analysis at high temporal resolution (Ault et al. 2010; Contini et al. 2011; Jonsson et al. 2011; Diesch et al. 2013; Donateo et al. 2014) or using receptor models based on identification of chemical tracers associated with ship emissions (Viana et al. 2009; Pandolfi et al. 2011; Cesari et al. 2014; Bove et al. 2014). The emissions from international maritime transport do not only depend on the total traffic but also on the characteristics of the fleet (Campling et al. 2013).

1.3 Growing Rates of Shipping Trade and Environmental Profile of Maritime Industry

In the age of "just in time" logistics and global supply chains, the fast and efficient movement of goods is an economic imperative. Ocean-borne commerce has been steadily increasing through the last two decades and is expected to continue to play a significant role in the globalized world economy. World fleet, for ships with gross tonnage (GT) larger than 100, comprises 104,304 ships adding 1,043,033 million GT with an average age of 22 years. About half of these are general cargo ships,

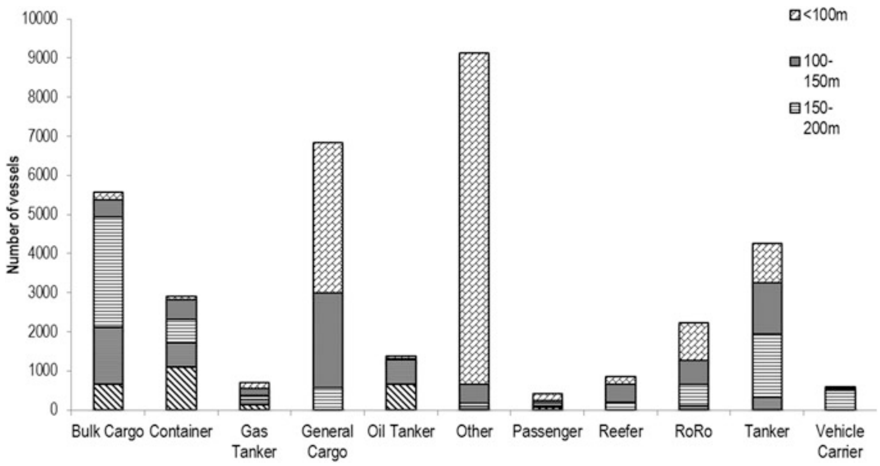

Fig. 1.3 Number of vessels

estimated in 2012 to 55,100 ships of 1,483,121,493 deadweight tonnage (DWT) (IMO 2009; UNCTAD 2012). World seaborne trade figures have increased considerably since the 70s; in 2008 globally loaded goods were 8.2 billion tonnes, while till 2060 handled cargo is anticipated to reach 23 billion tonnes (Stopford 2010). Developing countries continued to account for the largest share of global seaborne trade (60 and 56 % of all goods loaded and unloaded respectively), reflecting their growing resilience to economic setbacks and an increasingly leading role in driving global trade (IMO 2009; UNCTAD 2011). The worldwide container traffic reached a total of 564 million twenty foot equivalent container units (TEU) in 2011, equal to a year on year growth of 8.9 % (UNCTAD 2011), with China being the biggest exporter (31.3 MTEU), while the biggest importer of containerized cargo was USA with 17.6 MTEU (WSC 2013). Figure 1.3 illustrates the distribution of the fleet in terms of vessel type and size for 2010, where 35,000 vessels were operating in the EU seas (Campling et al. 2013).

The anticipated growth in ship traffic will add significantly to local air quality problems and global climate-change risks unless ship emissions are further controlled. To date, improvements in ship environmental performance have not proceeded at the same pace as the increase in shipping activity and ship missions remain largely unregulated (Han 2010).

1.4 The Role of Ports

Ports are the main gateways to almost all trans-European transport networks: they are the focal points between land and sea, they receive and handle huge amounts of goods, cargo, passengers and fuel (in liquid or gaseous forms). Their vital role is expected to be significantly upgraded, even in the presence of a severe economic crisis, and large amounts of funds are anticipated to be invested to modernizing existing or creating new infrastructures in important ports (Vergara et al. 2012).

The EU is highly dependent on seaports for trade with the rest of the world and within its internal market. There are 329 European commercial ports from which 74 % of goods imported and exported, and 37 % of exchanges within the Union transit through them. Ports guarantee territorial continuity of the Union by servicing regional and local maritime traffic to link peripheral and island areas. They are the nodes from where the multimodal logistic flows of the trans-European networks can be organized, using short sea shipping, rail and inland waterways links to minimize road congestion and energy consumption. The EU requires ports well developed and efficient by international standards in all its maritime regions and for this reason, and has emphasized in the need for well-connected port infrastructure, efficient and reliable port services and transparent port funding (EC 2011, 2013a, b).

On a local scale, shipping (through ports) seriously impacts human health contributing in the formation and transport of ground-level air emissions (Corbett et al. 2009). Although emissions due to ships' activities around ports account for almost 5 % of the total emissions from navigation activities (Dalsoren et al. 2009), the continuously increasing amount of goods and passengers transported between ports during the last years has led to increased air pollution in ports.

Although the vast majority of emissions from ships are created at sea, their most directly noticeable part is emitted in port areas and consequently in adjacent cities. Although, in-port ship air pollutants contribute only a small share of the global shipping emissions, they have serious environmental effects on densely populated coastal regions with intensive shipping activities in Europe, Asia and North America (Dore et al. 2007; Corbett et al. 2007; Dalsoren et al. 2009). In harbor cities or in cases where ports are located near to densely populated areas, ship emissions could often be the dominant source of urban pollution. Significant studies have been conducted regarding the impact of ship exhaust emissions upon the health of human population near port areas. As it is mentioned above, nearly 70 % of the PM emissions due to shipping (ranging between 0.9 and 1.7 million tons) occur within 400 km of the coast (Chang and Wang 2012; Endresen et al. 2003). Furthermore, emissions from ships (either docked, moving or maneuvering in port) are transported in atmosphere hundreds of kilometers away, thus contributing to air quality deterioration on land, even if they are emitted at sea (Eyring et al. 2010). Table 1.1 presents average concentration of the main atmospheric pollutants over sea surface and coastal areas. Based on these results it becomes clear that, to date, ship emissions are responsible for about half of the NO_2 and SO_2 concentrations found over sea surface (EEA 2013).

Significant progress in terms of global policy-making has been made with respect to operational and technical measure, but only a few ports have developed infrastructure, regulation and incentives aiming at mitigation of air pollutants. In order to reduce projected emissions, not only strong policy measures will be needed but also structural changes. Some solutions have been proposed for improving air

Table 1.1 Average concentration of the main atmospheric pollutants over sea surface and coastal areas (EEA 2013)

	Sea surface		Coastal areas	
	Annual mean ($\mu g/m^3$)	% contribution of shipping sector	Annual mean ($\mu g/m^3$)	% contribution of shipping sector
NO_2	1.99	42	3.98	14
SO_2	0.41	44	0.66	16
SO_4	1.42	15	1.51	10
BC	0.18	8.6	0.3	3.4
$PM_{2.5}$	6.52	6.3	6.92	4.9

quality in coastal areas and ports. These include the establishment of reduced speed zones (RSZ), emissions control areas (ECAs) and adaptation of alternative maritime power (AMP) technologies for vessels while they are at berth (Buhaug et al. 2009). Nevertheless, there is a pressing need for ports to collaborate towards the creation of a sustainable port strategy. The need to control air pollution at ports is widely acknowledged as an active policy issue by various authoritative associations.

Potential abatement measures might include: improved energy efficiency, cold ironing (i.e. provision of shore power facilities that allow ships to shut off their engines while at berth) and the promotion of alternative fuels such as Liquefied Natural Gas (LNG). Last but not least, incentives (through lower tariffs) for further reductions of vessels' speed while approaching ports could be an additional measure. Self-regulation of ports can work but wider application of policy measures would be necessary in order to obtain significant reduction in ports related ships emissions (Merk 2014).

The EU has expressed its serious concerns regarding air pollution in ports on the White Paper on Transport Policy, establishing a stringent sulphur regulation through the Directives: 2012/33/EU, 2005/33 and 1999/32 (EC 2012). Also, the European Commission has recognized the need for a global approach by setting out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic emissions. For this reason, a Monitoring-Reporting-Verifying (MRV) system has been proposed to apply to all shipping activities as of 2018 (EU 2015).

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Chapter 2
Mitigation of Air Emissions: Existing Policy Actions and Legislation

Abstract "Climate change is a serious problem and an international response is demanding, which must be based on a shared understanding of long-term goals and agreement on frameworks for action" (Stern in The economics of climate change-the stern review. Cambridge University Press, UK, Stern 2006). Reducing the environmental burdens of maritime transport is a challenging task, since such impacts are not only due to navigation but also due to activities carried out inside ports. In 2011 the IMO's Marine Environment Protection Committee (MEPC) adopted mandatory technical and operational energy efficiency measures for all ships irrespective of flag and ownership status. Also, the European Commission has recently settled down to a strategy for progressive inclusion of the GHG emissions from maritime transportation in the EU's policy for reduction of overall emissions. As a first step in implementing this strategy, the Commission has proposed a Regulation which would establish an EU-wide system for the monitoring, reporting and verification (MRV) of CO_2 emissions from large ships effectively starting in 2018. The EU has also expressed its concerns about the impact of transport on air quality through the Strategy for Sustainable Development published on its White Paper on Transport Policy, leading to the establishment of stringent sulphur regulation for marine fuels.

2.1 Environmental Legislation on Air Pollutants and Greenhouse Gases Related to the Maritime Sector

Climate change is the new term that triggers the common interest, which has been discussed broadly around the world and has been regarded as a factor contributing to all global issues (Shi 2016). GHG emissions are the largest contributors to climate change and therefore the international community has focused in adopting measures in order to mitigate such emissions effectively. Under the 2011 amendments to the Kyoto Protocol and UNFCCC, seven types of GHGs are listed: CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 and NF_3 (IPCC 2007).

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In 2007, CO_2 emissions from maritime sector accounted for 3.3 % of the global amount of emissions while in 2012 shipping emits 949 million tonnes of CO_2 annually and is responsible for about 2.2 % of global greenhouse gas emissions (Buhaug et al. 2009; IMO 2014a, b). Shipping emissions are predicted to increase between 50 and 250 % by 2050—depending on future economic and energy developments. This is not compatible with the internationally agreed goal of keeping global temperature increase to below 2 °C compared to pre-industrial levels, which requires worldwide emissions to be at least halved from 1990 levels by 2050. The EU and its Member States have a strong preference for a global approach led by the IMO as this will be most effective. Considerable efforts to agree such an approach have been made over recent years within both the IMO and the United Nations Framework Convention on Climate Change (UNFCCC) (EU 2015).

The formulation of legislation related to the environmental impacts of the shipping sector is a serious challenge due to the unique characteristics of the shipping sector, the global operations in trade, the differences in the registration and owners' origins of ships and the fact that marine fuel can be bunkered throughout the world. These difficulties are evident in the ambition level set by the EU to tackle GHG emissions from international shipping which strongly differs from the targets set by the IMO (EEA 2013).

There are currently more than 150 countries belonging to the IMO, which is the most powerful international organization in the field of ocean shipping. The objectives of the IMO include sustaining safety in sea transportation, promoting navigational efficiency, and protecting the ocean environment (Han 2010). The IMO is responsible for drafting various international conventions related to maritime affairs, with regulations covering navigation, marine rescue, and ships' structural and equipment requirements. The Marine Environment Pollution Committee (MEPC), is a sub-organization of the IMO which is specifically responsible for drawing up relevant regulations to prevent ships from polluting the ocean and the atmosphere. As the rapid development of international commerce increased the number of shipping vessels, the pollution induced by these ships has become an issue of great concern. To address this, the IMO amended the International Convention for the Prevention of Pollution from ships in 1973. As the 1973 MARPOL Convention had not yet entered into force, the 1978 MARPOL Protocol absorbed the parent Convention (referred as MARPOL 73/78). It represents the main IMO Convention, currently in force, regarding the protection of the marine environment. The Convention's principle articles deal mainly with jurisdiction and powers of enforcement and inspection. More detailed anti-pollution regulations are given in the annexes, which were adopted or amended by the MEPC, with the positive opinion of a number of parties, representing 50 % of the GT of the world's merchant fleet. This protocol regulates the draining standards for used oil, sewage, and waste materials. Air polluting exhaust fumes, from marine power plants, have also become a cause for concern within the international community in recent years (IMO 2013). Six (VI) annexes of the Convention cover the various sources of pollution from ships and provide an overarching framework for international objectives but, without ratify caution and implementation by sovereign states, they are not sufficient to protect the marine environment from waste discharges. A State that becomes party to MARPOL must accept Annexes I and II, while acceptance of Annexes III–VI is voluntary. All six Annexes have been ratified by the requisite number of nations. Each signatory nation is responsible for enacting domestic laws to implement the Convention and effectively pledges to comply with the Convention, its annexes, and the related laws of other member nations.

In the late 1980s, IMO started its work on prevention of air pollution from ships. These efforts were based on scientific information on adverse effects of atmospheric emissions from a multitude of sources (ships being one of them) on human health and vulnerable ecosystems. This was something of a departure, as IMO's focus, along with that of national regulators and of the society as a whole, had previously been on more visible sources of ship-sourced pollution—for example, on oil spills resulting from major ship accidents. The harmful long-term effects of exhaust gases on human health and ecosystems were not so immediately visible and had not earlier been fully recognized (IMO 2011a, b). The seventeenth session of the IMO Assembly, in November 1991, recognizing the urgent necessity of establishing an international policy on prevention of air pollution from ships, considered and decided to develop a new annex to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention). In 1997, IMO acknowledged the importance of air pollution and through the MARPOL Convention of 1997, it added a new Annex VI, Regulations for the Prevention of Air Pollution from Ships, to the MARPOL Convention (MARPOL Annex VI). Annex VI, setting limits on sulphur oxide (SO_x) and nitrogen oxide (NO_x) emissions from ship exhausts and prohibiting deliberate emissions of ozone-depleting substances. Annex VI was ratified by 60 contracting States with 84.04 % of the world's merchant shipping tonnage. MARPOL Annex VI came into force on 19 May 2005. These regulations aiming at the prevention of ships' air pollution include the following:

1. Emission standards for NO_x according to the power output of marine diesel engines and required installation of exhaust gas cleaning systems to reduce NO_x emissions (Table 2.1);
2. Limits in sulfur content of fuel oil used in ships to reduce SO_x emissions and requirements for exhaust gas cleaning systems or technologies to limit SO_x emissions to 6.0 g SO_x/kWh or less;
3. Provision for vapor collection systems, or other vapor emission control systems to reduce the emissions of VOCs;
4. Requirement for shipboard incinerators;
5. Restricted use of CFC refrigerants, halon, and other ozone-depleting substances.

Moreover, Annex VI defined two sets of emissions and fuel quality requirements: global requisitions and stricter requirements for ships in Emission Control Areas (ECA). Existing ECAs include:

- The Baltic Sea for SO_x; was adopted in 1997 and entered into force in 2006.
- The North Sea (which also includes the English Channel) for SO_x; was adopted in 2005 and entered into force on 22 November 2007).

Table 2.1 NO_x emission limits (IMO 2016a, b, c)

Tier	Date	NO_x Limit (g/Kwh)		
		n < 130	130 ≤ n ≤ 2000	n ≥ 2000
		n = engine's rated speed (rpm)		
Tier I	2000	17	$45 \cdot n^{(-0.2)}$	9.8
Tier II	2011	14.4	$44 \cdot n^{(-0.23)}$	7.7
Tier III	2016	3.4	$9 \cdot n^{(-0.2)}$	1.96

- The North American ECA (including most of US and Canadian coast) for NO_x and SO_x; was adopted in 2010 and entered into force in 2011.
- The US Caribbean ECA (including Puerto Rico and the US Virgin Islands) for NO_x and SO_x; adopted in 2011 and came into force in 2014.

The first two areas, designated for SO_x restrictions only, are commonly known as SECAs, while areas with limitations on the NO_x emissions are designated as NECAs.

A revised Annex VI of the Convention was adopted in 2008, entered into force in 2010 and led to a progressive reduction in SO_x from ships and further reductions in NO_x emissions from marine engines. By October 2008, Annex VI was ratified by 53 countries (including the Unites States), representing 81.88 % of tonnage. NO_x emission limits are set for diesel engines depending on the engine maximum operating speed (n) as shown in Table 2.1. The IMO emission standards are commonly referred to as Tier I–III standards. The Tier I standards were defined in the 1997 version of Annex VI, while the Tier II/III standards were introduced by the Annex VI amendments adopted in 2008, as follows: 1997 standards applied retroactively to new engines greater than 130 kW installed on vessels constructed on or after 1 January 2000, or which underwent a major conversion after that date. Tier I and Tier II limits are global, while the Tier III standards apply only in NO_x ECAs. Ships built between 2000 and 2011 need to comply with NO_x emissions at maximum engine speed of about 9.8–17 g/kWh (Tier I), those built after 2011 need to comply with 7.7–14.4 g/kWh (Tier II), and ships operating after 2016 in NECAs need to comply with emissions of 2.0–3.4 g/kWh (Tier III). To date there is no NECA in Europe, although assessments have been performed evaluating the potential impact of establishing, for example, a North Sea NECA (EEA 2013; Danish 2012). Due to the lack of NECAs and the fact that the NO_x emissions limits refer to new ships, the impact of IMO NO_x regulations seems to be limited at present.

As far as the reductions of SO_x are concerned, under the revised Annex VI, the main change is a progressive reduction in SO_x emissions with the global Sulphur cap being reduced initially from the current 3.5 % to, progressively, 0.5 %, effective from 1 January 2020, subject to a feasibility review to be completed no later than 2018. The limits applicable in SECAs have been reduced to 1 %, beginning on 1 July 2010, being further reduced to 0.1 %, effective from 1 January 2015 (IMO 2016a, b, c). One method to control these limits is via Port State Control

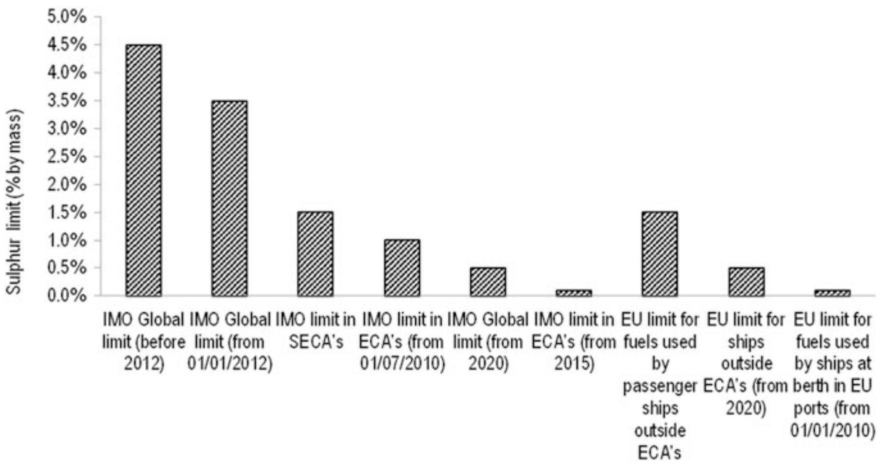

Fig. 2.1 Overview of sulphur limits under IMO and EU legislation

by checking the so-called bunker delivery note (EEA 2013). Also, all passenger ships operating on scheduled services to or from any EU port should not exceed 1.5 % sulphur limit and all vessels calling an EU port should use low sulphur fuel (less than 0.1 %) during port stays longer than two hours. Figure 2.1 presents an overview of the different implemented and planned sulphur limits for marine fuels under IMO and EU legislation (EEA 2013).

It is also important to mention that Regulation 12 of Annex VI prohibits deliberate emissions of ozone depleting substances, including halons and chlorofluorocarbons (CFCs). New installations containing ozone-depleting substances are prohibited on all ships. But new installations containing hydro-chlorofluorocarbons (HCFCs) are permitted until 1 January 2020. According to the 2008 amendments, as of 1 July 2010 vessels should also keep on board a list of equipment containing ozone depleting substances and a Record Book in which ozone depleting substances resulting from certain operations are instantly recorded, including, for example, the full or partial recharging of equipment containing ozone depleting substances.

2.1.1 International Mechanisms for Reducing Maritime Transport Emissions: The Current Debate

As far as the GHG emissions are concerned, the IMO is the entity responsible for their regulation within its MEPC. The most significant achievement is the adopted technical and operational measures in the form of amendments to revised MARPOL Annex VI in 2011 and 2014. Three categories of measures have been discussed within the IMO to tackle GHG emissions from ships: technical measures, operational measures and market-based measures (MBMs) (IMO 2011a, b).

In order to fully deliver its mandate as stipulated in Article 2.2 of the Kyoto Protocol to the UNFCCC,[1] the MEPC also analyzed the potential constraints of a new legally binding instrument addressing GHG emissions from international shipping. In particular, the Committee voiced concerns about the compatibility between the Kyoto Protocol's "common but differentiated responsibilities" approach, according to which legally binding emissions reduction commitments should apply only to Annex I Parties,[2] and the Paris MoU's concept, according to which relevant legal instruments (i.e. conventions) should apply also to ships which are under the flag of a State which does not participate to that convention. Using the obtained revenues to assist developing countries in addressing climate change would be in line with the provisions of the UNFCCC. The amounts that could be generated by maritime transport in reducing its carbon footprint are substantial with estimate over four billion US dollars per year (IMO 2009; Miola et al. 2010). A second way of combining both principles is to differentiate commitments for Annex I and non-Annex I countries without relying on the nationality of ships. A solution could be to differentiate responsibilities according to the route of the vessels or depending on the ship size. A justification for differentiated responsibilities in maritime policy is that the policy should not interfere with the growth potential of developing countries. As some countries are dependent on maritime transport for their exports, and countries are thought to develop based on periods of export-led economic growth, global coverage of the described policies could lead to lower economic growth (Faber and Rensema 2008). Kageson (2008), highlights that it may not be possible to achieve complete global coverage of an international maritime emission trading scheme, as support from developing countries might be limited. He therefore envisages three possible stages of implementation: Firstly the set-up of a scheme by the IMO and the UNFCCC that is open for voluntary participation by States and ports, and secondly, a scheme that covers all traffic in the ports of Annex I countries, which can finally be extended to a scheme covering all maritime traffic on a global level (Kageson 2008). The same could be applied on the basis of a tax or a levy system, although careful analysis of the effects is needed as a major threat to the environmental effectiveness of these systems is carbon leakage due to incomplete coverage. For the voluntary sectoral crediting option, this is not an issue. The debate is still open. However, within the evaluation of the best

[1]Article 2.2 of the Kyoto Protocol to the UNFCCC: "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively".

[2]The group of countries included in Annex I (as amended in 1998) to the UNFCCC, including all the OECD countries and economies in transition. Under Articles 4.2 (a) and 4.2 (b) of the Convention, Annex I countries committed themselves specifically to the aim of returning individually or jointly to their 1990 levels of ghg emissions by the year 2000. By default, the other countries are referred to as Non-Annex I countries.

possible IMO regulatory framework on GHG emissions from ships, in particular CO_2, parties already agreed on a list of principles to be adhered to (Miola et al. 2010):

1. Effective contribution to the reduction of total GHGs;
2. Binding and equally applicable to all Flag States in order to avoid evasion;
3. Cost-effectiveness;
4. Limitation, or at least, effective minimization of competitive distortion;
5. Sustainable environmental development without penalizing global trade and growth;
6. Goal-based approach and not a prescriptive specific method;
7. Supportive of promoting and facilitating technical innovation and R&D in the entire shipping sector;
8. Accommodating to leading technologies in the field of energy efficiency;
9. Practical, transparent, fraud-free and easy to administer.

2.2 Recent Developments in Regulating Greenhouse Gas Emissions from International Shipping

According to IMO, the definition of international shipping is "shipping between ports of different countries, as opposed to domestic shipping", excluding military and fishing vessels (Buhaug et al. 2009). Consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006 Guidelines), this definition also indicates that the same ship under an international voyage may frequently be engaged in both international and domestic shipping operations (IPCC 2006; Buhaug et al. 2009). This constitutes the main obstacle, to integrating the GHG emissions from international shipping in the State-based Kyoto Protocol to the UNFCCC, due to the difficulty of allocating ships' emissions in a country. The UNFCCC's Subsidiary Body on Scientific and Technological Advice (SBSTA) worked on this emission-allocation issue from 1995 to 1996, but failed to reach consensus among different States (Oberthür 2003). Currently, the IMO is the main international organization working on the regulation of GHG emissions from international maritime sector. It started its institutional work in 1997 and in the same year, MARPOL adopted Resolution 8 on "CO_2 emissions from ships", which requested the IMO to undertake a study on GHG emissions from ships and consider feasible CO_2 reduction strategies (Shi 2016; Buhaug et al. 2009). In 2003, the IMO Assembly adopted a resolution on "IMO policies and practices related to the reduction of greenhouse gas emissions from ships", urging the MEPC to identify and develop the mechanism or mechanisms needed to achieve the limitation or reduction of GHG emissions from international shipping (IMO 2003). Since then, the IMO has been working on this issue by means of negotiations and discussions within its MEPC.

Within MEPC 58 and 59, Parties adopted a list of guidelines for calculation and trial purposes and agreed on the fact that Energy Efficiency Design Index (EEDI) should be comprised of the following three components for better enforcement and compliance:

- Requirements: the EEDI should be calculated for each new ship following IMO guidelines
- Verification and certification: ships should be subject to surveys for verification of their compliance with the EEDI's requirements
- State Port control: ships may be subject to inspection by the Authority of the Parties when entering their ports or offshore terminals.

During the latest MEPC 61, Parties debated about whether to get the Secretary-General to circulate proposed amendments to MARPOL Annex VI in order to make the EEDI mandatory, but no consensus about how to proceed on this issue was reached. The EEDI was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (MEPC. 203(62)), by Parties to MARPOL Annex VI. This was the first legally binding climate change treaty to be adopted since the Kyoto Protocol (IMO 2011a, b).

At the 66th MEPC meeting in April 2014, amendments to Annex VI to MARPOL 73/78 were adopted to extend the application scope of the EEDI to include an extra five types of ships. They are LNG carriers, roll-on/roll-off (Ro–Ro) cargo ships (vehicle carriers), Ro–Ro cargo ships, Ro–Ro passenger ships, and cruise passenger ships having non-conventional propulsion (IMO 2014a, b).

The main technical measures, adopted by the IMO, refer to the creation of the EEDI and the SEEMP. EEDI is applicable only to new ships of more than 400 Gt (bulk carriers, containers, Ro-Ro, cargo ships, and tankers). EEDI represents a non-prescriptive, performance-based mechanism that leaves the choice of technologies in specific ship designs to the industry. EEDI requires that the design of new ships needs be energy efficient and thereby lead to less greenhouse gas emissions. As long as the required energy efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions so that ship to comply with regulations. The mandatory implementation of EEDI will create a new more efficient and effective design status for ships. In considering how to improve the efficiency of ships, it is important to understand the relationship between EEDI and efficiency improvement measures, i.e., how each improvement measure affects the EEDI. Figure 2.2 illustrates the relationship between EEDI and improvement measures. Simply put, there are three approaches to improve the value of EEDI (Bose 2012).

On the other hand, SEEMP obligates the ship-owners to reconsider their operational techniques and upgrade technology in their ships in order to achieve improved energy performance. Other technological measures aim at the following categories: ship design, machinery and propulsion (Wartsila Corporation 2010). These measures include: greener fuels, weather routing, optimised trim and

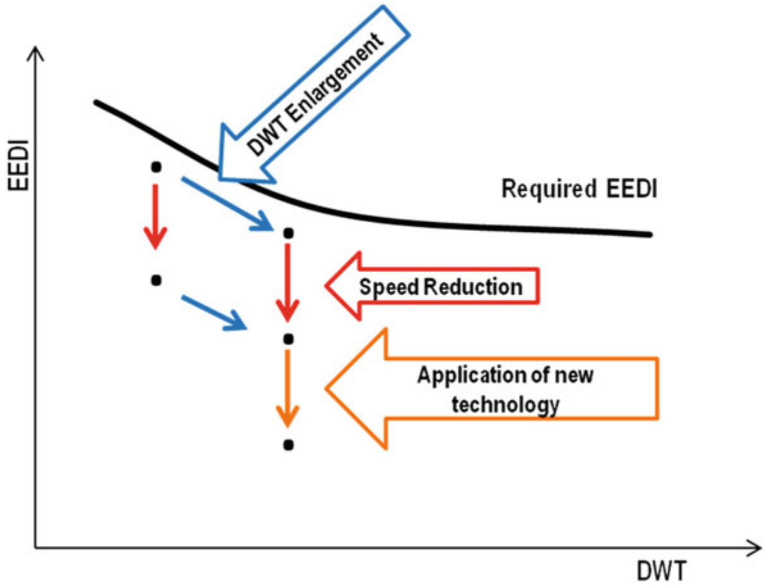

Fig. 2.2 The conceptual relationship between EEDI and improvement measures (Bose 2012)

ballasting, fleet planning, improvements in propellers and engines, speed reduction (Maragkogianni et al. 2013). Both EEDI and SEEMP enter into force on 1 January 2013 (IMO 2013).

In line with the work plan adopted at MEPC 55 (October 2006), potential Market-Based Measures have been considered in-depth since MEPC 56 (July 2006). MEPC 55 work plan ceased at MEPC 59 (July 2009), where the Committee recognized that technical and operational measures would not be sufficient to satisfactorily reduce the amount of GHG emissions from international shipping in view of the growth projections of world trade. It was therefore agreed by overwhelming majority that an MBM was needed as part of a comprehensive package of measure for the effective regulation of GHG emissions from international shipping (IMO 2016a, b, c). At the MEPC 60 it has been established an Expert Group to evaluate the several proposals of possible MBM presented to the Committee. The Expert Group has analysed ten proposals (IMO 2016a, b, c):

1. An International Fund for GHG from ships (GHG Fund) proposed by Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA.
2. Leveraged Incentive Scheme (LIS) to improve the energy efficiency of ships based on the international GHG fund proposed by Japan.
3. Achieving reduction in GHG from ships through Port State arrangements utilizing the ship traffic, energy and environment model, STEEM proposal by Jamaica.
4. The United States proposal to reduce GHG emissions from shipping, the Ship Efficiency and Credit Trading (SECT).

5. The Vessel Efficiency System (VES) proposal by World Shipping Council.
6. The Global emission trading System (ETS) for international shipping proposal by Norway.
7. Global Emission Trading System (ETS) for international shipping proposal by the United Kingdom.
8. Further elements for the development of an Emission Trading System (ETS) for international Shipping proposal by France.
9. Market-Based Instruments: a penalty on trade and development proposal by Bahamas.
10. A rebate Mechanism for a market-based instruments for international shipping proposal by IUCN.

Each proposal was assessed considering nine criteria: (**i**) environmental effectiveness; (**ii**) the cost effectiveness of the proposed MBM and impacts on trade and sustainable development; (**iii**) potential impacts on innovation and technological change; (**iv**) practical feasibility of implementing the proposed MBM; (**v**) the need of technology transfer to, and capacity building within, developing countries; (**vi**) the MBM proposal's relation with other relevant conventions; (**vii**) potential additional burdens, and the legal aspects for the national Administrations by implementing the proposed MBM; (**viii**) the potential additional workload, economic burden, and operational impact for individual ships, the shipping industry and the maritime sector; (**ix**) the MBM's compatibility with the existing enforcement and control provisions under the IMO legal framework (IMO 2010).

The results of this analysis has been discussed during the last MEPC 61 and the Committee set out the Terms of Reference for an inter-session Meeting of the Working Group on GHG Emissions from Ships, to be held in March 2011 and its report was submitted to MEPC 62. However, due to time constraints and the busy agenda of MEPC 62, it was agreed to postpone the consideration of MBMs to the next MEPC session, but MEPC 63 continued its consideration of proposed MBMs, and agreed on the need to undertake an impact assessment of the MBM proposals with focus on possible impacts on consumers and industries in developing countries, in general, and in particular, least developed countries, small islands developing States and remotely located developing countries with long trading distances, and considered in detail the methodology and criteria it should be based on. MEPC 65, in noting several submissions on this matter, agreed to suspend discussions on MBMs and related issues to a future session (IMO 2016a, b, c).

Although the transport sector has a significant abatement potential regarding its environmental consequences, there are some challenges that need to be overcome in order to make such a policy successful. These challenges include deciding on a method to allocate ship emissions to countries, diminishing the risk of carbon leakage, and designing a policy that is administratively and politically feasible with respect to allowance distribution and treatment of the great variety in ship type, size and usage. A global policy could overcome most of the above-mentioned challenges.

It is still very controversial whether MBMs should be adopted to further the reduction of GHG emissions from international shipping. For example, many States and shipping organizations welcome MBMs, whereas large developing States, India as an example oppose the possible adoption of any MBMs by the IMO because it is feared that they would jeopardize the interests of their shipping industry.

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The Commission's 2011 White Paper on Transport suggests that the EU's CO_2 emissions from maritime transport should be cut by at least 40 % from 2005 levels by 2050, and if feasible by 50 %. However, international shipping is not covered by the EU's current emissions reduction targets. In 2013, the European Commission recognized the need for a global approach by setting out a strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic emissions. For this reason, the EC proposes a Monitoring-Reporting-Verifying (MRV) system to apply to all shipping activities as of 2018. This system may serve as the first step, while the ultimate goal is to reach a global agreement that may be achieved under the auspices of the IMO. The regulation 2015/757 of the European Parliament and of the Council, institute rules for the accurate monitoring, reporting and verification of CO_2 emissions and of other relevant information from ships arriving at, within or departing from ports under the jurisdiction of a Member State, in order to promote the reduction of CO_2 emissions from maritime transport in a cost effective manner (EU 2015). This MRV regulation, in which the first reporting period will start on 01/01/2018, requires large ships (over 5000 gross tons), to collect and later publish verified annual data on CO_2 emissions and other relevant information. In accordance with Articles 8–12 of 2015/757, companies operating large ships in EU ports, irrespective of where the ships are registered, will monitor and report, in an annual basis, the verified amount of CO_2 emitted to, from and between EU ports. Also, companies ought to monitor and report all the additional parameters, such as distance, cruising time, emission factors, activity data, and to submit to the Commission an emission report. Ships must carry a document of compliance, issued by an accredited verifier, proving that the ship is in compliance with the MRV obligations.

The MRV system is estimated to cut CO_2 emissions from the journeys covered by up to 2 % compared with a 'business as usual' situation, according to the Commission's impact assessment. The system would also reduce net costs to owners by up to €1.2 billion per year by 2030 (in average about 900 million per year), while costs of implementation are estimated at around 26 million € per year. Overall, the relative benefit/cost ratio of this option is very high (EC 2013a, b). In addition, it will provide useful insights into the performance of individual ships, their associated operational costs and potential resale value. This will benefit ship owners who will be better equipped to take investment decisions and obtain finance (EU 2015).

For the future projection (2012–2030), it is assumed that both technical measures and operational measures will be applied to new ships, and that operation measures will be applied to existing ships. For the remaining vessel categories; ferry-pax, yacht, offshore, service, fishing and other, it is assumed that the abatement potential is 50 % of the average for the cargo vessels (TNO 2015).

2.3 Regulating Ships' Emissions in Ports

Undoubtedly, ports can play an important role in the economic development of a country, allowing a more efficient transport system. During the last decade, ports have increased their competitiveness by enhancing their productivity, providing better quality services while reducing operating costs. In addition, due to the increasing awareness of stakeholders arising from global climate change issues, more ports are trying to operate in a more environmentally friendly way. But, while some European ports operate under high efficiency (either commercial or environmental), other ports continually underperform or are in structural decline (EC 2013a, b). Under this concept, one of the main goals of port authorities should be economic, social and environmental viability, or in other words port sustainability which would ensure economic competitiveness, prosperity and cohesiveness with local urban environment, social acceptance and a continuously adapting environmental plan. Thus port authorities should adopt specific policies in order to bridge the gap between environmental practice and theory, verify the environmental risks and take specific actions towards their minimization. Due to this problem, ports have been active, either collectively or individually, in adopting voluntary measures, which aim at improving the air quality and achieving emission reductions of greenhouse gases.

Although most of air emissions take place at sea, the most directly noticeable part of shipping emissions takes place in port areas and port-cities (Merk 2014). Harbours are particularly influenced by emissions from ships and this can cause relevant contributions to local air pollution (Isakson et al. 2001; Cooper 2003; Saxe and Larsen 2004). However, the only European law concerning the reduction of emissions is the 2005/33/EC, which requires all ships at berth in European ports to use fuels with sulphur content less than 0.1 % by weight. The directive is not applied to ships that are due to stay at berth for less than 2 h and to those that switch off all engines and use shore-side electricity (Schembari et al. 2012; EC 2005). Because of the fact that the port industry is continually evolving, there is an increasing need for adaptation of new requirements on infrastructure and investments. Ports require the extension of berths, new quays, deepening of basins, new terminal passengers. Furthermore, stricter requirements on environmental performance and alternative fueling technologies (e.g. shore-side electricity, or LNG) are necessary. The Commission's Clean Power for Transport initiative and the proposal for a Directive on the deployment of alternative fuels infrastructure requires that all maritime ports of the Ten-T Core network are equipped with LNG refueling points according to common technical standards by 2020 (EC 2013a, b). Also, as far as the environmental performance of ports is concerned and the significant developments in the energy trade, with a shift from oil towards gas, there is a need for significant LNG facilities in ports (EC 2013a, b). EU Commission welcomes the initiatives taken by the port sector to promote excellence in environmental management and performance by publishing guides for good practices. As it has been mentioned before, some ports have already adopted plans to better manage their environmental footprint and such initiatives should be encouraged. Ports should consider whether to reward operators who anticipate or exceed the application of mandatory environmental standards and promote the use of door-to-door low-carbon and energy efficient logistics chains. Last but not least, those ports that have already raised their environmental image should continue to be supported (EC 2013a, b).

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Chapter 3
Current Methodologies for the Estimation of Maritime Emissions

Abstract Over the years, the quantity and geographical characterization of emissions have been considered for valuation in maritime transport. Activity-based (bottom-up) or fuel-based (top-down) methodological approaches have been applied over time, to quantify emissions. In the present study a "bottom-up" or "activity-based" method has been used to estimate emissions based on detailed individual activities of cruise ships, in Greece.

The existing approaches for creating ship emission inventories are divided in "top-down" and "bottom-up" (or "activity-based") approaches. The former are fuel-based methods that estimate emitted air pollutants relying on the reported amounts or marine bunker fuel sales, while for the latter fuel consumption-based or ship movements-based methods are employed (Maragkogianni and Papaefthimiou 2015). The top-down method is applied by several countries preparing emissions from domestic and international shipping to UNFCCC. This approach combines bunker fuel statistics with the technology-based emissions factor, in order to estimate the total amount of emissions (EEA 2013). A bottom-up approach is referred to calculations based on fleet activity. This can be done by using port calls and estimated vessel operative or, through vessel tracks and real time operative. Regarding the geographical characterization of emissions and the level of detail achieved, this is also dependent on the approach followed (bottom-up and top-down). Hence, with a bottom-up approach, individual information of vessels and its position are taken into consideration while with a top-down approach valuation is based without, or with partial information on the position of vessels (i.e. the geographical activity of shipping is estimated based on a single shipping route or a particular geographic activity cell, no matter which vessel carries out the activity). Bottom-up approaches would generally be more accurate than top-down, but significant effort is required for data mining and management especially for large scale studies (Miola and Ciuffo 2011; Buhaug et al. 2009; Tzannatos 2010b). Data scarcity, and assumptions in literature result in an open debate on adequacy of approaches and contexts analyzed so far. Buhaug et al. (2009), attempted to homogenize the results from different

A. Maragkogianni et al., *Mitigating Shipping Emissions in European Ports*, SpringerBriefs in Applied Sciences and Technology, DOI 10.1007/978-3-319-40150-8_3

Table 3.1 Brief overview of the available studies on maritime emissions, based on the top-down approach

Reference	Base year	Study areas	Studied pollutant
Corbett and Fischbeck (1997)	1973	Global	NO_x, SO_2
Corbett et al. (1999)	1993	Global	NO_x, SO_2
Skjølsvik et al. (2000)	1996	Global	CO, NMVOC, CH_4, N_2O, CO_2, NO_x, SO_2
Endresen et al. (2007)	1925–2002	Global	CO_2, SO_2
Lucialli et al. (2007)	2004	Port of Ravenna	PM_{10}, NO_x
Hulskotte and Denier van der Gon (2010)	2003	Rotterdam	HC, SO_2, NO_x, CO, CO_2, PM_{10}
Tzannatos (2010a)	1984–2008	Greece	CO_2, NO_x, SO_2 and PM

Table 3.2 Brief overview of the available studies on maritime emissions, based on the bottom-up approach

Reference	Base year	Study areas	Pollutant
Georgakaki et al. (2005)	1997–2000	EU-15	SO_x, NO_x
Wang et al. (2007)	2002	North America	SO_2
Buhaug et al. (2009)	1990–2007	Global	CO_2, NO_x, NMVOC, CO, PM, SO_x and GHG
Jalkanen et al. (2009)	2007	Baltic Sea	NO_x, SO_x, SO_2
Tzannatos (2010b)	2008–2009	Port of Piraeus	NO_x, SO_2, $PM_{2.5}$
Yau et al. (2012)	2007	Port of Hong Kong	NO_x, SO_2, PM_{10}
Song and Shon (2014)	2006–2009	Port of Busan	NO_x, SO_2, VOC, CO_2
IMO (2014)	2007–2012	Globally	CO_2, NO_x, NMVOC, CO, PM, SO_x and GHG
Maragkogianni and Papaefthimiou (2015)	2013	Ports of Piraeus, Santorini, Mykonos, Corfu and Katakolo	NO_x, SO_2, $PM_{2.5}$

studies (Miola et al. 2010; Buhaug et al. 2009). Tables 3.1 and 3.2 present the main relevant studies based on the top-down and bottom-up approach respectively.

The detailed activity-based modelling has been defined as the best practice for creation of port and regional inventories usually separating on different ship types and size categories, to establish categories with mostly the same characteristic of the input variables. On the global scale, activity-based modelling is challenging. Uncertainties in the calculated emission totals arise from the use of average input parameters in the selected ship type classes, for example in input parameters like marine engine load factor, time in operation, fuel consumption rate, and emission factors, which vary by size, age, fuel type, and market situation (ICF Consulting 2005; Eyring et al. 2010).

The selection of methodology for the estimation of air emissions varies depending on the subject of study. A top-down approach based on fuel sales is used when refined traffic information is not available, while on the other hand, a bottom-up approach based on traffic information (obtained from vessel tracks or port calls, when and where these are available) should be typically employed due to the accuracy of input parameters such as ship type, location, size and technical particulars.

This chapter presents a "bottom-up" or "activity-based" study, based on a detailed analysis of the technical characteristics of the vessels, i.e. main and auxiliary engines' power, fuel consumption, cruising speed, and distance traveled within the port and duration of stay in port, thus providing high accuracy results. The technical characteristics of vessels have been obtained from the IHS Sea-web database, which provides information for over 180,000 ships over 100 GT (IHS 2014), and a full description for at least 10,000 ports and terminals, with detailed information about: Ship type-category-length-tonnage, ownership, flag, routes covered, characteristics of the ship's main and auxiliary engines (power in kW, age, consumption in g/kWh, running hours, load), service speed, fuel type, emission factors, etc. All necessary data regarding ship calls and other non-technical features of the vessels (i.e. name and type of the ship, passengers capacity, date and time of arrival/departure from the port, cruising speed and distance travelled in port) have been collected from local port authorities.

Specifically the interest in this study focuses on cruise ships which constitute one of the most energy intense forms of touristic activities (Eijgelaar et al. 2010; Winkel et al. 2016). This is due to the fact that cruise ships act as luxurious resort hotels throughout their journeys and this so called "hoteling" function is mainly responsible for the excessive energy demand. On the other hand, significant proportion of the total energy spent is used for the onboard activities of the crew, thus being a part of the operating cost of the vessel and significantly increasing the emissions per passenger. There has been extremely limited research to date for calculating emissions and creating relevant inventories for individual sectors of the maritime transport industry, such as cruise ships. Howitt et al. used data for 84 cruise ships moving in journeys to and from New Zealand and calculated carbon emissions per passenger-kilometer (p-km), confirming that cruises emit significantly more carbon emissions and use more fuel per p-km than economy class aviation. The operation of a cruise ship (mainly due to the "hoteling" amenities included) is still about five times higher than the average energy use for the most luxurious of hotels per visitor night, which would include many of the same comforts, such as swimming pools, casinos, gyms and restaurants (Howitt et al. 2010).

The emissions estimation methodology can be graphically represented as depicted in Fig. 3.1. Survey data can be provided by the studied Port authority according to what is the information needed for this study and the technical literature contains emission factors, load factors and fuel correction factors (Oladokun 2015).

The detailed methodology for the estimation of emissions is described in the following. The total emissions of a specific ship are estimated during its stay in a port, based on the following formula:

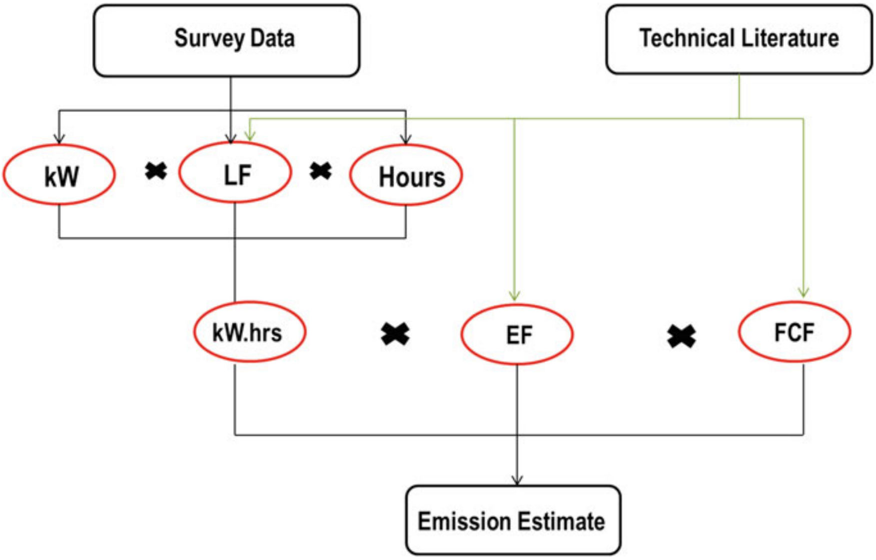

Fig. 3.1 Emission estimation flow chart

$$E_{total} = E_{cruising} + E_{maneuvering} + E_{hoteling}$$

For every ship call, each of the studied air pollutants (i.e. NO_x, SO_2 and $PM_{2.5}$) produced during the ship's activity inside port (inbound-outbound moving or cruising, maneuvering and at berth) have been estimated through the application of the following expression:

$$E_i = \sum_{j,k} \left(T_j \cdot P_k \cdot LF_{j,k} \cdot EF_{i,k} \right)$$

where:

- *E* denotes the amount of ship emissions (tons)
- *i* is the specific type of emissions (NO_x, SO_2 or $PM_{2.5}$)
- *j* is the ship's activity stage (i.e. moving–maneuvering or hoteling)
- *k* is the engine type, i.e. main (ME) or auxiliary (AE)
- *P* is the engine power (kW)
- *LF* is the engine load factor during the specific activity
- *EF* is the emissions factor (g/kWh)
- *T* is the time spent at each of the ship's activity stages (hours) (for maneuvering *T* = *D/U*, where D is the distance travelled by the ship in the port before docking, U is the moving velocity of the ship during moving-maneuvering.

Typically in harbor areas ships' auxiliary engines are the main sources of emissions as their main engines are switched off or running at low load. Ships use auxiliary power whilst being at berth. The maximum power of auxiliary engines in a vessel is estimated based on auxiliary engine power ratios and an estimation of a vessel's main engine horsepower as a function of dead weight tonnage (Merk 2014). For the in-port emissions, a traffic breakdown is drawn up for each vessel, depending on the operation mode. Furthermore, a load factor of each engine, as well the fuel type and the spending time in different phases (hoteling-maneuvering) are recorded.

Therefore according to the above mentioned, the total emissions generated by ships in a port, are estimated by summing the emissions produced by each ship individually during its moving, maneuvering and hoteling in port. The sum will cover either a whole year or to a specific time period. In order to estimate the shipping emissions, according to the above formula, the following steps are required:

1. Record the ships' traffic inside the studied port for the specified time period. Necessary data include the name of the ship, time of arrival and of departure from the port, etc.
2. Determine the route of the ship from reaching the port until the anchorage point, in order to estimate the traveled distance.
3. Determine the average cruising speed and the speed during maneuvering for each ship category.
4. Calculate the cruising and maneuvering time, while hoteling period starts from the moment the ship anchors till its departure.
5. Determine the technical characteristics for each ship main and auxiliary engines.
6. Determine the engine load and emission factors per operation phase factors for the main and auxiliary engines, according to the technical characteristics of the ship.

3.1 Time of Maneuvering and Berthing Mode

The operational modes and related paths of cruise ships approaching a port or moving between its entry/exit and berthing point (including moving, maneuvering, and hotelling either at a berth or at an anchorage), were considered and categorized for all studied ports based on Automatic Identification System (AIS) data, in-port observations and detailed personal communications with local port authorities and ship operators. Typically it was evident that in each port, cruise ships generally follow the same path in approximately the same way, with observed variations depending only on weather conditions and increased vessels circulation issues. In general, maneuvering times based upon average inbound and outbound vessel speeds and average docking/undocking times are more functional as they can compensate for extreme for extreme variations (Miola et al. 2010; Tzannatos 2010b). The average speed for inbound and outbound cruise ships has been estimated to five (5) and eight (8) knots, respectively. On the other hand, berthing mode refers to the vessel's operation in a specific anchor point. The time at berth (berthing time) is also known as time "host" (hoteling time) as at that time, all the power demands of the ship associated with the services (hotel services) offered by the ship. Hoteling mode starts when the ships moor at the pier and finish when they depart.

For the current study, based on AIS data, in-port observations and detailed personal communications with local port authorities and ship operators, a careful evaluation of available routes and velocity patterns that cruise ships follow in-ports was conducted, and a "generic" cruise ship path has been created and assigned to each studied port. This path has been employed to calculate moving and maneuvering times, while hotelling times for all cruise ships calls were extracted from relevant detailed data provided by local port authorities for the studied period of time.

3.2 Load Factors

The ME load factor vary over time as a result of a ship's operation and specific activities—operational mode (e.g. at berth, anchoring, maneuvering, cruising), speed, loading condition, weather, etc. (Moreno-Gutiérrez et al. 2015). Uncertainties in the main engines' load factors has been reported by IMO as the second most important parameter affecting confidence in the bottom–up emissions estimations (IMO 2014). The precise recording of ships' engines details does not in any case ensure the determination of main and auxiliary engine load factors for in-port ship activities. This value is in general uncertain and is influenced by port specific characteristics and local climatic conditions (especially for auxiliary power demand). Various studies have proposed main and auxiliary engine load factors for cruise ships during maneuvering and while at berth (see Table 3.3) (Buhaug et al. 2009; Starcrest 2012; Howitt et al. 2010; De Meyer et al. 2008; McArthur and Osland 2013; Whall et al. 2007).

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. Outside the summer period, ships were found to use lower auxiliary engine power, especially at berth (Tzannatos 2010b).

Table 3.3 Load factors for main and auxiliary engines

	Main engine (ME)		Auxiliary engine (AE)	
	Summer	Rest of the year	Summer	Rest of the year
Maneuvering	0.2	0.2	0.75	0.6
Hotelling	0	0	0.6	0.3

Table 3.4 Emission factors for main and auxiliary engines

		NO_x	SO_2	$PM_{2.5}$
Main engine (ME)	SSD/MDO	13.6	4.1	0.9
	MSD/LSFO	11.2	6.6	2.4
	HSD/MDO	9.6	4.5	0.9
	GT/MDO	2.9	6.4	0.5
	ST/LSFO	1.7	9.6	2.4
Auxiliary engine (AE)	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

3.3 Emission Factors

Emission factors can vary by pollutant, engine type, duty cycle and fuel. Specific emissions tests are employed to develop emission factors in g/kWh and they are converted to fuel-based values (grams pollutant per grams of fuel consumed) by dividing by the brake-specific fuel consumption (BSFC) or specific fuel oil consumption (SFOC) corresponding to the test associated with the emissions factors (IMO 2014). Emission factors vary between 2-stroke diesel, 4-stroke diesel, steam turbine and gas turbine. Two-stroke diesel engines are also referred to as slow-speed diesels (SSD) because they operate at about 100 rpm and are directly coupled to the propeller. Two-stroke diesels power 26 % of the vessels and consume 60 % of the fuel because of their higher power (Corbett and Koehler 2003). Four-stroke engines can be medium speed or high speed diesel (MSD or HSD), while most auxiliary engines are HSD. They provide 67 % of all vessels with electrical or hydraulic power. Only 1 % of all ships are powered with turbines. The SFC depends on the load factor, the fuel and the build year of the engine, but not all models take this into account (EEA 2013). Emission factors vary by: engine type (main, auxiliary, auxiliary boilers), engine rating (SSD, MSD, HSD), and whether engines meet pre-IMO Tier I, or IMO Tier I or II requirements. Emission factors are adjusted further for fuel type (HFO, MDO, MGO, and LNG) and the sulphur content of the fuel being burned. Finally, engine load variability is incorporated into the factors used for estimating emissions. All these variables were taken into account when estimating the bottom-up emissions inventory (IMO 2014). The emission factors corresponding to the operation of ME and AE, for specific fuels during maneuvering and at-berth mode, are presented in Table 3.4.

3.4 Air Emissions in Ports

There are a limited number of studies which contain estimations regarding in-port emissions. ENTEC has estimated emissions from ships associated with movements between ports in European countries, while Dalsøren et al. used an approximation

Table 3.5 Studies on maritime emissions in port-areas

Port	Method	Emissions by	Source
Venice, Piombino	Fuel consumption	Marine ships in port area	Trozzi et al. (1995)
Goteborg	Air quality measurement	Ships entering the inner part of port	Isakson et al. (2001)
Copenhagen	Air quality measurement	Vessels in ports	Saxe and Larsen (2004)
Taranto	Air quality measurement	Shipping, industry and urban traffic	Gariazzo et al. (2007)
Ravenna	Fuel consumption	Vessels in port area	Lucialli et al. (2007)
Aberdeen	Air quality survey	Ships and trucks in the port area	Marr et al. (2007)
Shangai	Activity based	OGV and inland barges	Yang et al. (2007)
Mumbai	Activity based	OGVs in port area	Joseph et al. (2009)
Rotterdam	Fuel consumption	Ships at berth	Hulskotte and Denier van der Gon (2010)
Piraeus	Activity based	Vessels in port area	Tzannatos (2010b)
Venice	Air quality measurement	Vessels in port area	Contini et al. (2011)
Busan	Activity based	Vessels, equipment, port trucks, trains	Shin and Cheong (2011)
Barcelona	Activity based	Vessels, electricity, heating, cargo handling, vehicles, trucks, waste	Villalba and Gemechu (2011)
Kaohsiung	Activity based	Vessels and trucks in port area	Berechman and Tseng (2012)
Hong Kong	Activity based (AIS)	Ocean going vessels (OGV) in territorial waters	Yau et al. (2012)
Hong Kong	Activity based (AIS)	OGVs in territorial waters	Ng et al. (2013)
Izmir	Activity based	Vessels in port area	Saraçoglu et al. (2013)
Kaohsiung	Cargo capacity, activity time	Merchant vessels	Liu et al. (2014)
Yangshan	Activity based (AIS)	Vessels in port area	Song (2014)
Busan	Activity based	Vessels in port area	Song and Shon (2014)
5 ports of Greece	Activity based	Cruise ships	Maragkogianni and Papaefthimiou (2015)
Las Palmas	Activity based	Cruise and ferry ships	Tichavska and Tovar (2015)

of in-port time to calculate the in-port emissions but they do not provide details on individual ports, except for Singapore. Although these studies certainly have their merits with regards to calculation of ship emissions in ports, they both suffer from relatively inexact data or assumptions on the time that ships spent in a port. The former study uses port time data based on a questionnaire survey in ports; and although the second paper is more accurate in that it takes actual time in ports, it cannot be very precise because of the employed time interval (i.e. days) (ENTEC 2002; Dalsoren et al. 2009). On the other hand, there is a noteworthy amount of studies that estimate the shipping-related emissions on the port-area. But, because of the different methodologies they use, it is not only difficult but also inaccurate to compare their outcomes. The basic difference is in methodology, as calculations based on either fuel consumption or they are employ activity-based methodologies. The most important studies are illustrated in Table 3.5.

The largest part of emissions in ports originates from shipping activity. However, there is a difference between ports in developed and developing countries. About 70–100 % of emissions in ports in developed countries can be attributed to shipping; trucks and locomotives represent up to one fifth, whereas emissions from equipment rarely exceed 15 %. On the other hand, in developing countries, where regulations in fuels are less tough, a larger share of the total emissions in ports is taken up by trucks and locomotives (Merk 2014). Nevertheless, as different countries use different approaches, there is a pressing need for ports to collaborate towards the creation of a sustainable port strategy. The need to control air pollution in ports is widely acknowledged as an active policy issue by various authoritative associations. A fundamental prerequisite of emissions limitation is the ability to accurately measure them. In addition, a comprehensive and reliable port emissions inventory is necessary to properly assess the impacts of port improvement actions or growth in shipping activity, as well as to plan mitigation strategies and assess ports environmental impacts (Chang and Wang 2012).

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Chapter 4
Economic and Social Cost of In-port Ships' Emissions

Abstract A meaningful way to assign economic impact (i.e. monetary values) to air emissions from ships is the estimation of related external costs or externalities. 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. Globally in 2006, SO_x, NO_x and PM emissions externalities, from global shipping, added up to 183 billion €, while for the Mediterranean region the corresponding total value was almost 11 billion €. Research efforts to present port related externalities have already been published but they are affected by the lack in sufficient and precise emissions data. This chapter contains a review of the methodological and empirical state of the art on the methodologies for the estimation of external costs due to ships' emissions in ports.

4.1 Review of External Cost of Maritime Emissions at Port

Over the past years, the concern about the negative effects related to the air emissions resulting from the growth of the shipping industry has increased. It has been established that operative ships do not only contribute to the negative effects on a global climate scale due to the rising temperatures, but also to hazardous consequences experienced in local communities, in the form of detriment of health, crops and built environment. Negative impacts derived from air pollution can be quantified and monetized as external costs. Nevertheless, their estimation contains an inevitable source of uncertainty, mostly conditioned by methodological uncertainties and information gaps on available knowledge. Indeed, this is mainly due to the complex relation between factors involved in air quality valuation, the induced costs (such as: the overall levels of pollution, the geographical location and height of emission sources, local meteorological conditions, the chemical reaction and the dispersion of atmospheric hazardous substances) and the physical harm that these might cause to human health, crops and urban infrastructure. Despite of limitations, it is possible to estimate the external costs of market based (crops loss and material

A. Maragkogianni et al., *Mitigating Shipping Emissions in European Ports*, SpringerBriefs in Applied Sciences and Technology, DOI 10.1007/978-3-319-40150-8_4

damages) or non-market-based (human health) negative impacts by applying statistical valuation techniques. Namely, market prices are used to estimate the yield loss of products in agriculture and material damages while human health is addressed with a willingness-to-pay (WTP), to accept (WTA) or to be compensated (WTC) for the externality in question. GHGs remain as a different challenge since these relate to long term effects and risk patterns that are hard to anticipate. Therefore it is difficult to make a detailed assessment on the related damage costs of individual countries (Maibach et al. 2008; Miola et al. 2009; Cullinane and Cullinane 2013; Tabi and Del Saz-Salazar 2014).

Detriments on human health are considered as the most important effect in terms of quantifiable costs (mortality and morbidity). For this assessment, either the Value of Statistical Life (VSL) or the Value of the Life-Year (VOLY) is usually taken into consideration. Nevertheless, it is difficult to quantify and thus account the exposure to air pollution as a main cause of death. For this, the use of the VOLY and the reduction of life expectancy in terms of Years of Life Lost (YOLL) are widely preferred in literature (i.e. ExternE and CAFE). Top-down and bottom-up approaches are widely recognized in a variety of research subjects over literature. These include the quantification of air emissions and in a next step the calculation of external costs. Each approach captures transportation technology in an aggregated (top-down) or disaggregated form (bottom-up) reflecting differences in results due to complex interplays between purpose, structure and data input. In both emissions and external costs estimation, top-down approaches use aggregated economic variables while bottom-up approaches consider refined and disaggregated information, mostly based on technical performance (Sabatier 1986).

The way the technical approach is applied depends based on the subject of the study. For instance, on emissions estimation, a top-down approach based on fuel sales is preferred when refined traffic information is not available. On the other hand, a bottom-up approach based on available traffic information (usually obtained from vessel tracks or port calls) is used when the accuracy of input parameters (i.e. ship type, location, size and technical specifications) is considered satisfactory.

The estimation of external costs can be classified in three categories. The first one relates to an external cost comparison between transport modes, the second to cost-benefit analysis on emission reduction technologies and the third one to case studies that exclude the two previous cases. For all three categories, a bottom-up approach is usually preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nevertheless, costly and complex requirements are also recognized to obtain external costs from a bottom-up approach (Jiang and Kronbak 2012). Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies cannot be applied or they are not available. Indeed, literature on harbour external costs due to vessels' emissions is exclusively based on the use of cost factors and aggregated economic variables (top-down approach).

In general, the methodology for the estimation of external costs might lead to underestimation since the population daily exposed to the ships generated pollutants should also include daily visitors and employees which produce a significantly higher number (almost double in some ports) than that corresponding to permanent residents. For ports located close to densely populated residential areas, the induced external costs are extremely significant as they quantify the long term consequences of air pollution to the local society (i.e. cost of acute and chronic effects of pollutants on mortality and morbidity, effects on buildings and structures, and effects of on arable crop yield (Tzannatos 2010b).

It should be noted that this chapter does not mean to provide a decisive result regarding the performance of selected ports, but instead it intends to demonstrate the methodological approach that can lead to a complete evaluation. Thus for these purposes only emissions to air from cruise ships have been taken into account for the evaluated ports. The accuracy of the evaluation practically depends on the provided data and mainly to emissions values (as the other data are common and easily accessible).

4.2 Impact Pathway Approach (IPA) Methodology

Presently and due to the complexity and costly resources required to generate bottom-up studies on shipping and ports, it has been widely accepted to estimate these based on a top-down approach and per-unit cost factors obtained from major European reports and recent literature. Indeed, most studies exclusively address emissions estimation making assumptions on vessels operating at port and do not further evaluate the associated external costs. Limited research has been found on the valuation of external costs from shipping emissions at port. Regardless of methodological limitations, the internalization of external costs in transport has been an important issue for research and policy development. Indeed, research supported by the European Commission towards a competitive and resource efficient transport system suggests that in order to generate considerable benefits and aims for a fair and efficient pricing in transport, command and control measures and market-based instruments should be defined from marginal cost pricing. Externalities due to air pollution and their monetary valuation have been studied broadly in scientific research. Therefore the basis for calculating air pollution costs is solid and the relevant methodologies are widely accepted. To calculate the external costs caused by air pollution, there are two different approaches: the bottom-up and top-down.

4.2.1 The Bottom-Up Approach

The estimation of marginal costs can be accomplished through bottom-up methodologies, which are more precise, entail potential for differentiation but they are costly and demand complicated implementation. The first attempt to

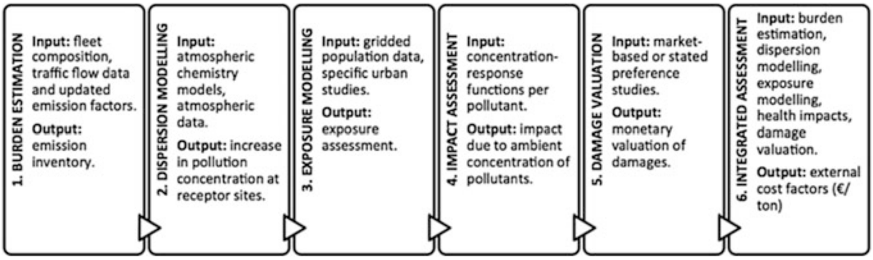

Fig. 4.1 IPA approach to air pollution (Bickel and Friedrich 2005)

develop a bottom-up approach to address air emissions was integrated in the External Costs of Energy (ExternE) project series (1990–2005) under the DG Research of the European Commission. Thus, a bottom-up methodology referred to as Impact Pathway Approach (IPA) has been conceived, following a pathway process, which requires: emission estimation, dispersion and exposure modelling, impact, and damage valuation. The IPA follows a logical, stepwise progression from the estimation of pollutant emissions to the determination of impacts and subsequently to the quantification of economic damage in monetary terms. The key steps of the IPA are illustrated in Fig. 4.1 (Holland and Forster 1999; EC 2011; Jiang and Kronbak 2012; Korzhenevych et al. 2014).

The IPA is considered as the most comprehensive and best in practice methodology for calculating site-specific external costs[1] derived from air emissions. It has been widely adopted in major European studies addressing or estimating the external costs in transport, such as the Benefits Table database (BeTa); the Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO); the Clean Air for Europe (CAFE) and the New Energy Externalities Development for Sustainability (NEEDS). In terms of ports and shipping related emissions, the literature addressing the external costs mostly relies and accepts major bottom-up European studies (BeTa, CAFE and NEEDS) that follow the IPA with methodological variations and differences on input values such as modelling scenarios, emissions baseline by country and pollutant, dispersion of model used, impact assessment methodology and others (Holland and Watkiss 2002; Holland et al. 2005; Amann et al. 2005; Bickel et al. 2006; Preiss and Klotz 2007).

BeTa was developed for the European Commission and includes the external costs of EU-15 (excluding Luxemburg) due to specific air pollutants (SO_2, NO_x, VOCs and PM) estimated with a basis year (i.e. 1998). Three scenarios have been addressed, namely: emissions from all sources in rural locations for EU countries, emissions at ground level in cities with varying size; and emissions from shipping (based on data for urban areas of various sizes). In order to address emissions close to shore, BeTa suggests the use of national urban and rural cost factors. Also, it

[1]External costs related to air pollutants hazardous in a local context are addressed differently than the climate change costs.

Table 4.1 Marginal external costs in rural areas based on BeTa results (values are in €/tonne and refer to prices for year 2000)

	SO_2	NO_x	$PM_{2.5}$
Greece	4100	6000	7800
EU-15	5200	4200	14,000

Table 4.2 Marginal external costs in urban areas based on BeTa results (values are in €/tonne and refer to prices for year 2000)

	$PM_{2.5}$	SO_2
City of 100,000 citizens	33,000	6000

Table 4.3 Factors of calculating urban externalities based on BeTa

Population (in people)	$PM_{2.5}$	SO_2
500,000	5	5
1,000,000	7.5	7.5
Million people	15	15

provides offshore cost factors for countries surrounding sea areas[2] weighted by straight-line length of coast for bordering countries. In BeTa, dispersion of pollutants and environmental chemistry, exposure of sensitive receptors, impacts (using exposure-response functions) are based on the ExternE/IPA. Finally the economic valuation is pursued through a willingness to pay estimation (Holland and Watkiss 2002).

For Greece, the marginal external costs of emissions in rural areas are presented in Table 4.1 and the marginal external costs of emissions in cities, in Table 4.2. Urban results for NO_x is taken to be the same as the rural effects, given that quantified impacts are linked to formation of secondary pollutants in the atmosphere (ozone, nitrate aerosols). Urban externalities for $PM_{2.5}$ and SO_2 for cities of different sizes are calculated by multiplying results for a city of 100,000 people by the factors shown in Table 4.3. Results scale linearly up to 500,000 people but not beyond. The results are independent of the country in which the city is located (Holland and Watkiss 2002).

CAFE combines information on expected trends in energy consumption, transport, industrial and agricultural activities with validated databases describing the present structure and the technical features of the various emissions sources for 25 Member States of the European Union. Air quality issues in CAFE include damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NO_x and VOCs from each EU25 Member

[2]Eastern Atlantic, the Baltic Sea, the English Channel, the Northern Mediterranean and the North Sea.

Table 4.4 Marginal external costs based on CAFE results (values are in €/tonne and refer to prices for year 2013)

	NO_x	SO_2	$PM_{2.5}$
Greece	840	1400	8600
CPI (2013)	914.676	1524.46	9364.54

State (excluding Cyprus) and surrounding area (Amann et al. 2005; Holland et al. 2005). In CAFE, the marginal external costs are evaluated for 29 European countries based on four sensitivity combinations. Moreover, costs are also provided for four European regional seas, namely the Baltic Sea, Mediterranean Sea, North East Atlantic and North Sea (Jiang and Kronbak 2012). The variation comes from methodologies used to value mortality (mean or median values to estimate the value of a life year or the value of statistical life). Also, the range of health effects and the cut point for ozone impact assessment also changes in each of the sensitivity scenarios. To examine the robustness of CAFE results against important exogenous assumptions, operative vessels were included as a sensitivity case but no related cost factors were provided. In CAFE, shipping results are also included as a sensitivity case. Table 4.4 depicts the external costs for each pollutant provided by CAFE for Greece, according to Value of a Life Year (VOLY) scenario.

HEATCO, on the other hand, focuses on Cost-Benefit Analysis for Transport Infrastructure and proposes harmonized guidelines in order to value changes in travel time, accident risks and environmental costs (air pollution damages, noise, global warming). The most important outputs are valuation factors for different air pollutants in euro per tonne of pollutant for altogether 26 countries (EU-25 + Switzerland), cost factors for noise exposure and accident casualties (Essen et al. 2011). Even though HEATCO does not entail any sensitivity test, its marginal external costs of $PM_{2.5}$ for urban, metropolitan and outside built-up regions are more detailed. $PM_{2.5}$ exposure is highly associated with the site of release, where other pollutants have less local effects and national values would be adequate. Although external costs related to shipping are not considered in HEATCO, it is suggested that country-specific cost factors can be used to address specific areas when no state-of-the-art cost factors (resulting from bottom-up studies) are available.

In NEEDS only the average damage values are available. This is the most updated methodology for the evaluation of externalities and the values provided by NEEDS have some significant features:

- They refer to all European sea territories, thus they are extremely suitable for correctly calculating the external costs of maritime transport.
- They refer not only to health effects (that typically correspond to over 90 % of the total external effects), but also quantify the side effects of emitted NO_x and SO_2 on materials (e.g. buildings), biodiversity, and crops.

Additionally, the latest update of the NEEDS presents unit cost values for maritime transport by types of vessel (although some important vessel categories

Table 4.5 Marginal external costs based on NEEDS results (values are in €/tonne and refer to prices for year 2013)

	NO_x	SO_2	$PM_{2.5}$		
			Rural	Suburban	Urban
Greece	3851	8210	19,329	50,605	197,845
CPI (2013)	4193.35	8939.87	21,047	55,104	215,433

are not included) (as shown in Table 4.5).These are estimated based on specific emission factors and non-urban damage cost factors. For the maritime transport, in NEEDS, specific damage cost values for all major pollutants have been calculated for all European sea regions using the EcoSense model (Holland et al. 2005; Preiss and Klotz 2007; Maibach et al. 2008; Korzhenevych et al. 2014).

To summarize, the external costs derived from shipping are exclusively addressed in the BeTa, the CAFE and the NEEDS reports. In NEEDS, cost factors for EU sea areas are presented, while in CAFE shipping is presented as a sensitivity case without presenting anticipated costs per emissions tonne. On the other hand, in BeTa the cost factors per sea area and per EU country (aiming at seaports) are provided, but dispersion modelling for shipping is not undertaken due to the lack of relevant modelling practices.

4.2.2 The Top-Down Approach

The top-down method estimates the health effects due to the exposure of air pollutants and evaluates with specific costs the cases of mortality or morbidity. Cost allocation of emissions' externalities to different transport modes and vehicle categories requires additional information regarding the contribution of each mode and vehicle category to the overall ambient concentration of the respective pollutant. An important precondition for the application of this approach is the availability of detailed country specific exposure data for the relevant air pollutants and at least for $PM_{2.5}$ or PM_{10} (Essen et al. 2011).

A report by European Commission recalls the main studies that estimate the economic cost of air emissions from shipping and proposes a pathway of steps based on international studies (top-down approaches) to address external costs (Miola et al. 2009). Martuzzi et al. estimated the emissions for the port of Venice based on a bottom-up approach, and determined the monetized impacts for $PM_{2.5}$, PM_{10} and SO_x based on the CAFE methodology. Results reflect total external costs equal to around 24 million €, when using cost factors from CAFE. The range of external costs calculated varies between 2.58–5.82 €/passenger and 0.24–0.55 €/ton. In turn, the external cost per vessel corresponded to 2169–4894 €/ship (Martuzzi et al. 2006).

Emissions of NO_x, SO_2 and $PM_{2.5}$ due to cruise ships and passengers' vessels have been studied for a period of twelve months (2008–2009) for the port of Piraeus, in Greece. The externalities were estimated based on cost factors from the BeTa. The estimated overall externalities valued almost 51 million €, whereas the individual contribution of the pollutants was around 28, 14 and 9 million € for NO_x, SO_2 and $PM_{2.5}$ respectively (Tzannatos 2010b). Tzannatos also estimated air emissions of NO_x, SO_2, PM and CO_2 and the related external costs (based on BeTa) for domestic and international shipping in Greece from 1984 to 2008. For domestic shipping, emissions estimations were based on total fuel sales (i.e. top-down approach) while estimations for international shipping were based on port calls and estimated operative of vessels at port (bottom-up approach). In 2008, the CO_2, NO_x, SO_2 and PM emissions reached 12.9 million tons in total (of which 12.4 million tons of CO_2) while the corresponding externalities were around 3.1 billion €. Based on the utilization of a fuel-based (fuel sales) analysis for domestic shipping and an activity-based (ship traffic) analysis for international shipping, the author concluded that ship generated emissions reached 7.4 million tons and the related externalities reached 2.95 billion €. Finally, the internalization of external costs for domestic shipping was found to produce an increase of 12.96 and 2.71 € per passenger and transported ton respectively (Tzannatos 2010a).

In port of Kaohsiung the external costs due to emitted NO_x, CO_2, PM_{10}, $PM_{2.5}$, SO_2, VOC and HC were estimated by Berechman and Tseng based on BeTa and a bottom-up approach. The largest externalities were assigned to tankers, followed by container ships and bulk carriers. In terms of external costs due to vessels' emissions 2,499,000 $ were associated to NO_x, 153 $ to CO, 898,000 $ to CO_2, 45,911,000 $ to PM_{10}, 61,647,000 $ to $PM_{2.5}$, 8,218,000 $ to SO_2, 297 $ to HC and 26,146,000 $ to VOC (Berechman and Tseng 2012).

An emissions inventory for NO_x, SO_2, VOC and $PM_{2.5}$ based on a bottom-up approach was presented in a study by Castells et al. for Spanish ports during 2009. The authors estimated the external costs for both hoteling and maneuvering phase, for Ro-Ro, passenger and container vessels employing BeTa and CAFE. The average total of costs were 227,426,765 €, while 97,231,633 € were associated to $PM_{2.5}$, 48,700,862 € to SO_2, 80,962,011 € to NO_x and 534,510 € for VOC (Castells et al. 2014). McArthur and Osland quantified various ship emissions (NO_x, NMVOC, SO_2, PM_{10}, $PM_{2.5}$, and CO_2) at berth in the Port of Bergen in Norway for 2010. Authors used a bottom-up approach for the emissions calculations and a top-down method for the external cost estimations (BeTa and CAFE) (McArthur and Osland 2013).

A bottom-up approach has been employed by Song to estimate the air emissions (CO_2, CH_4, N_2O, PM_{10}, $PM_{2.5}$, NO_x, SO_x, CO and HC) and the external costs for vessels traffic in the Port of Yangshan, China during 2009 (Song 2014). The external costs of the respective emissions were calculated using a weighted average of cost factors, which were determined through a series of expert judgement/survey (Delphi process). Higher weights (over 70 %) were given to the studies which were conducted for China or Chinese cities, while lower weights were set for other countries and worldwide. Results reflect a contribution of 578,444 tons from vessels' emissions in Yangshan port area equal to a total external cost of 287 million \$. From the latter, 16,485,649 \$ were associated to CO_2, 8432 \$ to CH_4, 242,748 \$ to N_2O, 114,974,587 \$ to NO_x, 69,324,202 \$ to SO_x, 1,301,601 \$ to CO, 1,549,119 \$ to HC and 82,862,158 \$ to PM_{10} from which 73,656,489 \$ relate to $PM_{2.5}$ (Song and Shon 2014).

Following a bottom-up approach Maragkogianni and Papaefthimiou presented a detailed NO_x, SO_2 and $PM_{2.5}$ emissions inventory for cruise ships in the five busiest Greek ports (i.e. Piraeus, Santorini, Mykonos, Corfu and Katakolo) for year 2013. The total in-port emissions due to cruise ships accounted to 2742.7 tons; NO_x was dominant (1887.5 tons), followed by SO_2 and $PM_{2.5}$ (760.9 and 94.3 tons respectively). For the estimation of external costs a top-down approach based on CAFE has been used, followed by externalities estimated through NEEDS. The anticipated health impacts due to ships' emissions can reach to 24.3 million € or to 5.3 € per passenger, proving the necessity of control of the emissions produced by cruise ships in port cities or policy and measures towards a more efficient cruise industry (Maragkogianni and Papaefthimiou 2015).

In their study Tichavska and Tovar present the external costs and eco-efficiency parameters associated to ships' exhaust emissions in Las Palmas Port, Spain.

Table 4.6 Overview of academic studies regarding the top-down external cost estimation

Reference	Base year	Area of study	Methodology for emissions estimation	Methodology for external costs estimation
Miola et al. (2009)	2006	Port of Venice	Bottom-up	Top-down
Tzannatos (2010a)	1984–2008	Greece (domestic and international shipping)	Top-down (for domestic shipping) and Bottom-up (for international shipping)	Top-down
Tzannatos (2010b)	2008–2009	Port of Piraeus	Bottom-up	Top-down
Berechman and Tseng (2012)	2010	Port of Kaohsiung	Bottom-up	Top-down
McArthur and Osland (2013)	2010	Port of Bergen	Bottom-up	Top-down
Castells et al. (2014)	2009	Spain	Bottom up and Top-down	Top-down
Song (2014)	2009	Port of Yangshan	Bottom-up	Top-down
Maragkogianni and Papaefthimiou (2015)	2013	Port of Piraeus, Santorini, Mykonos, Corfu, Katakolo	Bottom-up	Top-down
Tichavska and Tovar (2015)	2011	Port of Las Palmas	Bottom-up	Top-down

Emissions inventory was obtained through a full bottom-up methodology based on the Ship Traffic Emission Assessment Model and data received through the Automatic Identification System for the year 2011. The overall external costs for NO_x, SO_x, VOC and $PM_{2.5}$ provided by BeTa when using urban and rural values were 174,288,076 € while the use of urban cost factors from BeTa and rural cost factors from CAFE provides an average cost estimate of 180,930,427 €. In the case of NEEDS figures are considerably lower, i.e. 21,750,913 € for NO_x; 11,567,621 € for SO_2, 87,901 € for VOC and 68,186,804 € for $PM_{2.5}$ (Tichavska and Tovar 2015) (Table 4.6).

4.3 Assumptions of Research

Typically for the evaluation of external costs a bottom-up approach is preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results. Nevertheless, costly and complex requirements are necessary in order to estimate external costs through a bottom-up approach. Thus, the use of a top-down methodology is often suggested and is widely accepted when bottom-up studies cannot be performed or are not available. The IPA is considered as the most comprehensive bottom-up methodology and the best practice for calculating site-specific external costs derived from air emissions. It has been widely adopted over major European studies such as: CAFE, BeTa, NEEDS and HEATCO. Nowadays, studies regarding the evaluation of external costs from vessels' emissions in port are in an early stage. However, some interesting conclusions can be extracted and they can be useful for the improvement of future studies.

Summarizing, the results for emission inventories and estimated costs are significantly different and complicated to be compared due to methodological variations and assumptions. Available literature does not always specify port calls as their source of traffic information nor describe the level of detail accounted from ship movements but provide an overall description of activity-based (bottom-up) methodology to estimate emissions. Regarding the estimation of external costs, the literature review has also shown that every study followed a top-down approach. This is probably due to costly and complex requirements to obtain external costs from a bottom-up approach. For this reason, it is paramount to review these differences in order to highlight the best approach to follow or identify the drawback when a second best alternative needs to be applied.

This book adopts the marginal external costs for $PM_{2.5}$ proposed by HEATCO and NEEDS, and the external costs for NO_x and SO_2 from CAFE and NEEDS. CAFE was preferred due to the multitude of the academic studies based on this methodology, while NEEDS is the most updated process covering all major pollutants and all EU Member States. In addition for the maritime transport, in NEEDS specific damage cost values for all major pollutants have been calculated for all European sea regions using the EcoSense model.

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Chapter 5
The Case of Greek Ports

Abstract The future of tourism development is largely dependent on the natural environment and its preservation (Hall and Lew in Sustainable tourism: a geographical perspective. Prentice Hall, New Jersey, 1998). Thus environment is not only an important foundation for tourism sustainable development, but it can also be the foundation for unique attractions for tourists (Zi in Tourism Management 46:11–19, 2015). Tourism by its very nature is a resource dependent industry and some commentators argue that sustainable tourism is unachievable given the industry's ability to pollute and consume resources (Johnson in Marine Policy 26(4):261–270, 2002). This view has been summarized as follows: "Tourism contains the seed of its own destruction; tourism can kill tourism, destroying the very environmental attractions which visitors come to a location to experience" (Glasson et al. Towards visitor impact management: visitor impacts, carrying capacity and management responses in Europe's historic towns and cities (urban and regional planning and development). Avebury, Surrey, 1995). The tourism industry is of great importance for Greece and cruising is considered as a major part of it. The estimation of detailed NO_x, SO_2 and $PM_{2.5}$ emissions to air due to cruise ships approaching Greek ports is presented in this chapter. The methodological approach is based on detailed technical data and records every cruise ship movement in the studied ports for the year 2013 in order to estimate air emissions and their anticipated social costs. The emissions were analyzed in terms of gas species, seasonality and activity.

5.1 The Sustainability of Cruise Industry

Sustainable tourism is defined as seeking equilibrium between tourism, environmental protection and satisfying the needs of both tourists and the local population (UNEP and UNWTO 2005). The concept of sustainability was developed as a reaction to the negative impact of tourism on ecosystems and local populations (Hunter and Green 1995). Until recently there has been little scrutiny on the increasingly important cruise tourism sector. Cruisers tend to concentrate their activities in interesting and specific coastal regions and ports. Hence their impact on

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sensitive areas may be significantly higher than their proportion in terms of global shipping numbers (Caric 2010).

Cruise ships constitute one of the most energy intense forms of touristic activities (Eijgelaar et al. 2010). This is due to the fact that cruise ships act as luxurious resort hotels throughout their journeys and this so called "hoteling" function is mainly responsible for the excessive energy demand. On the other hand, significant proportion of the total energy spent is used for the onboard activities of the crew, thus being a part of the operating cost of the vessel and significantly increasing the emissions per passenger.

While cruising currently represents only 2 % of the total tourism industry, it is growing rapidly and appears to be more flexible to economic and social changes due to its mobility (Brida et al. 2012). Due to its rapid growth in recent years, it has been becoming one of the most dynamic and faster growing segments of the tourism industry (Sun et al. 2011). These features make cruise industry very attractive to developing economies, but extremely difficult to monitor and control with regards to pollution (Klein 2011). Worldwide tourism involving cruise ships embodies not only the problems of significant transport pollution, but also new pollution phenomena associated with a small mobile city or a tourist destination (Copeland 2008).

The cruise industry has enjoyed dynamic growth over a period of 30 years, driven initially by demand from North America and more recently by growing demand from Europe and the rest of the world. While the global financial crisis of 2008–2009 had a major impact over maritime shipping, cruise shipping and cruise ports continued to enjoy a steadily rising number of passengers. While the image of cruising has not changed substantively, the industry has become a highly efficient business with the Caribbean and the Mediterranean Sea being the most popular destinations. Cruises are becoming an ever more global business with large-scale developments also taking place in Asia and Africa. Thus the globalization of the cruise industry appears to be unstoppable (Pallis et al. 2014).

Over the ten years from 2003 to 2013 demand for cruising worldwide has increased from 12.0 million passengers to 21.3 million (+77 %). Over a similar period, global land-based tourism has risen by around 57 % to an estimated 1.087 billion tourists in 2013, 5 % up compared to 2012. Europe is now the second largest market for cruise packages with the Mediterranean being the most popular destination for European travelers (Perucic and Puh 2012). In 2012, there were 207 cruise ships active in the Mediterranean with capacity of 249,000 passengers and annual total of 5.7 million passengers and 28.7 million visits to its ports (CLIA 2014; Marusic et al. 2012). The European market has grown by 162 % over the 10 years from 2002 to 2012, and despite the economic downturn cruising is expected to reach 10 million passengers by 2020. The economic impact of the cruise industry in EU countries is estimated to be almost 38 billion Euro, employing 326,904 people (CLIA 2014). Globally in 2014, 410 cruise ships (including river cruise) operated, totaling 467,629 beds, 21.6 million passengers and contributing almost 37.1 billion $ in revenue. In 2013 in Europe, the vast majority of cruise ships visited ports in the Mediterranean and the Baltic regions, generating 31.2 million passenger visits at a total of around 250 European port cities, an 8.7 % increase over 2012 (CLIA 2014).

The Mediterranean is the world's second largest cruise shipping market: it represented 21.7 % of the annual cruise capacity for 2013 while the anticipated value for 2014 was 18.9 % (CLIA 2014; MedCruise 2014). It can be broken down into four regions: the Western Med, the Eastern Med and the Adriatic, but the fourth region, the Southern Mediterranean, is sparsely serviced mainly due to political instability (some activity in Tunisia and Egypt). The proximity of the Mediterranean to European countries provides the advantage of a large pool of customers with discretionary spending. It is a perennial market with an intense summer peak season. The Mediterranean offers at the same time seaside resort destinations (e.g. Palma de Mallorca, Mykonos, Santorini) as well as world class cultural amenities, as several cities are museums by themselves (e.g. Venice). The Eastern Med lacks in airport capacity and connectivity with main cruise terminals, except for the Greek islands which are regularly serviced from Piraeus with smaller ships. In 2013 a total of 166 cruise ships were active in Mediterranean waters, with a capacity of 220,352 beds and an average of 1327 beds per ship (CLIA 2014; MedCruise 2014; HPA 2014). The breaking of all records of cruise passenger movements is evidence that cruise in the Mediterranean and its adjoining seas performs remarkably well in a challenging economic climate. According to MedCruise member ports in 2012, it is evident that the highest number and percentage shares both for passengers and cruise calls take place in West Med (around 67 and 57 % respectively) (see Figs. 5.1 and 5.2). The Adriatic (19 and 21 %), the East Med (13 and 17.5 %) and the Black Sea (0.6 and 1.8 %) correspond to the remaining one third of total traffic (Medcruise 2014). It is very important to mention the significance of seasonality for the cruise industry. As regards traffic seasonality in the Mediterranean, the highest share of cruise passengers' movements in 2014 was recorded in October (13.8 %). Notably, the same had happened in 2013 as well, as October 2013 hosted 14 % of the cruise traffic that year. As regards cruise calls, the highest share was also registered in October (14.7 %).

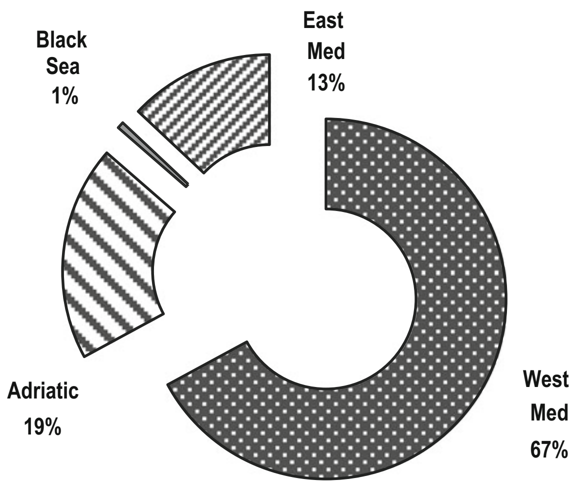


Fig. 5.1 Passengers movement distribution in Mediterranean (2012)

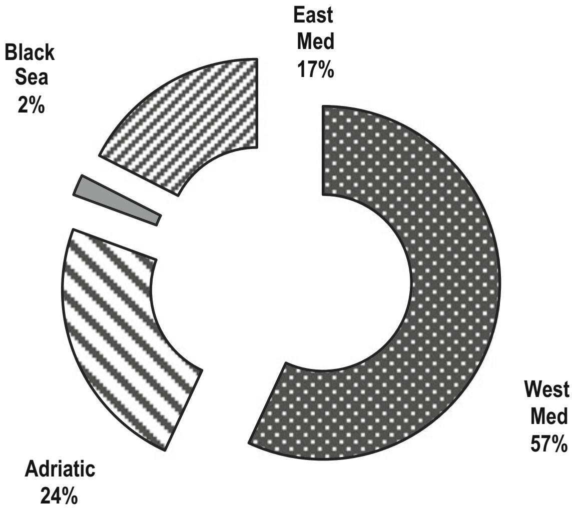


Fig. 5.2 Distribution of cruise calls in Mediterranean (2012)

Table 5.1 Cruise tourism passengers in Mediterranean (2014)

Months	Pax (%)	Months	Pax (%)
January	2.67	July	11.61
February	2.06	August	12.73
March	3.03	September	13.12
April	8.89	October	13.82
May	10.50	November	6.78
June	11.07	December	2.81

A year earlier, October 2013 had hosted 14.9 % of the total annual calls, being also the most populated month of the year. September of 2014 was the second busiest month of last year, with 13.1 % of annual passenger movements and 13.7 % of annual cruise calls recorded during this month.

Each month of the May to October period host, traffic shares of 10–12 %. In total, 81.3 % of the 2014 cruise passenger movements happened during the specific 6 month period. The hare of the total passenger movements registered during the three winter months (January, February, December) of 2014 was 7.5 %, whereas in 2013 the respective share equal to 6.2 % of the total annual movements (Medcruise 2014). The following table contains the passengers' traffic, registered month by month in the member ports with their respective shares (Table 5.1).

5.2 The Case of Greece

Both the Ionian and the Aegean are semi enclosed seas within the Mediterranean basin. Both regions are easy to access, with high biodiversity, cultural and historical significance, and they are adjacent to areas politically stable. The tourism industry is of great importance for Greece and cruising is considered as a major part of it. Cruise tourism in Greece started to grow steadily, with Piraeus port being the prime destination for cruises within the Aegean Sea. Greek seas are in general attractive for cruising. Both Ports of Piraeus and Santorini are among the busiest cruise ports in the Mediterranean.

Despite the fact that Greece is a traditional shipping nation, paradoxically, it has placed little attention on ports and the relevant infrastructure development. The ideal geographic location of Greek ports (i.e. at the crossroad of three continents), and their potential to become important nodes in the commercial route connecting the Far East with Europe through the Suez Canal, has either not been appropriately appreciated or has been ignored.

In 2013 Greece was the third most popular destination in Europe following Italy and Spain (keeping a 14.8 % share of the total cruise passengers), while the direct annual expenditure from the cruise industry for Greece was 574 million €. On the other hand 5,661,867 cruise passengers visited Greek ports, while for Italy and Spain the relevant numbers were 6,970,000 and 5,236,000 respectively. It is estimated that 11,215 workers were employed in the Greek cruise industry in 2013. For the year 2013, 139 cruise ships (83.7 % of the total cruise ship fleet in the Mediterranean) visited 42 Greek ports (related to cruise sector) which handled 4288 cruise ship calls (CLIA 2014; SETE 2014).

All details regarding cruise ship calls in Greece during 2013, i.e. vessels' names, date and call duration (arrival and departure time), were carefully collected from local Port authorities and compared with similar data of other sources to harmonize any discrepancies (MedCruise 2014; HPA 2014). Relevant data were either not available or unreliable for all 42 cruise related Ports in Greece. Thus, this study contains data for 18 ports (3 in the Ionian Sea islands, 8 in the Aegean Sea islands and 7 in mainland Greece), which received 3666 cruise ship calls that stayed in ports more than 36,000 h and moved almost 5.4 million passengers. These values represent a share of 85.5 and 95.2 % in ship calls and total passengers respectively, for the cruise industry in Greece during 2013. In Fig. 5.3 and Table 5.2 the location and detailed cruise statistics for the studied Greek ports are presented.

Figure 5.4 shows the seasonal distribution of ships that visited the studied Greek ports for 2013. Most of the ship calls were during the summer period (June–August), while autumn followed with 35.08 % (mainly due to the increased number of cruise ships reaching Greek ports during September, as shown in Fig. 5.5). September is the busiest month with 16.74 % of the total calls, and August is following with 15.64 %.

In general, the cruise ships season in Greece extends from April to October (3358 calls or 92.5 % of 3631 in total). During this period, each week the majority of cruise ship visits occur between Thursday and Saturday, and most arrivals and departures are observed in the morning hours (from 07:00–10:00 and between 18:00–20:00 respectively). The average time that each cruise ship spent in port per call varied depending on the port: in Piraeus vessels stayed for 12.4 h in average, while in Santorini and Mykonos this time period was 8.8 and 11 h respectively.

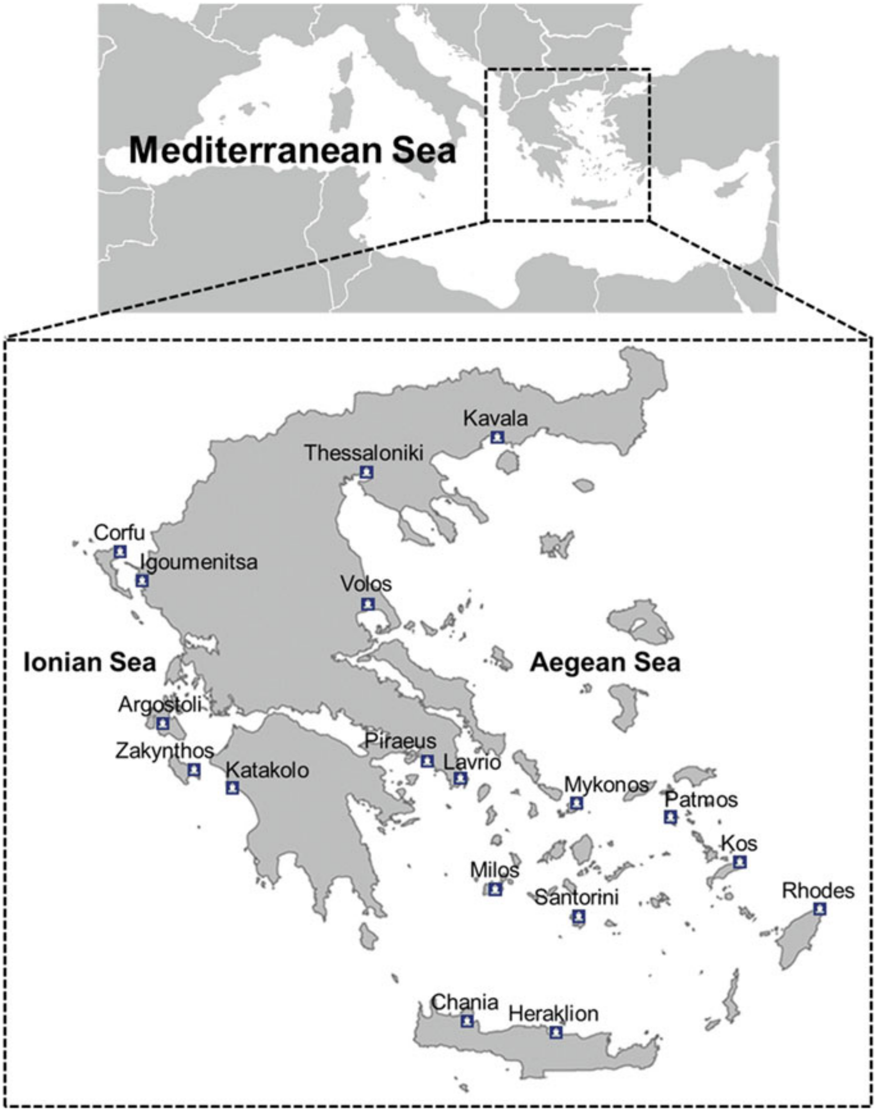


Fig. 5.3 Studied Greek cruise ports

Table 5.2 Detailed cruise statistics for the studied Greek ports

	Port	Ship calls	Revenue passengers (year 2013)	Total ships visiting
1	Piraeus	711	1,302,581	113
2	Santorini	582	778,057	62
3	Mykonos	485	587,501	67
4	Corfu	480	744,651	76
5	Rhodes	373	409,991	46
6	Katakolo	307	763,966	51
7	Heraklion	177	270,020	36
8	Patmos	177	113,339	31
9	Argostoli	100	135,659	23
10	Kos	86	64,756	11
11	Chania	47	124,205	8
12	Zakynthos	34	34,143	10
13	Volos	31	20,227	20
14	Lavrio	20	13,504	1
15	Thessaloniki	18	14,585	11
16	Kavala	14	6995	9
17	Igoumenitsa	14	4650	5
18	Milos	9	2962	2
Total		3666	5,391,792	
All Greek cruise ports for 2013		4288	5,661,867	

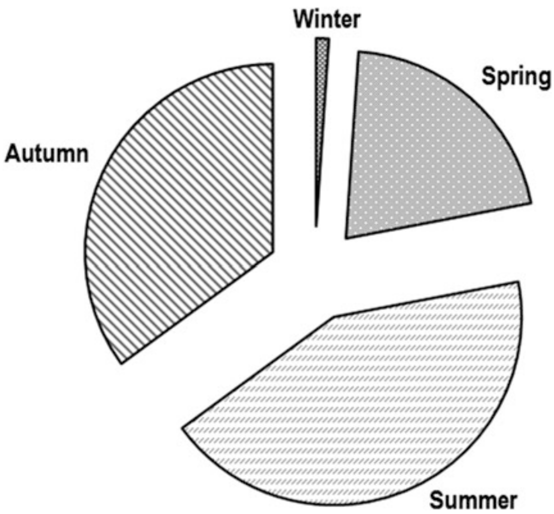


Fig. 5.4 Seasonal distribution of ship calls in Greek ports

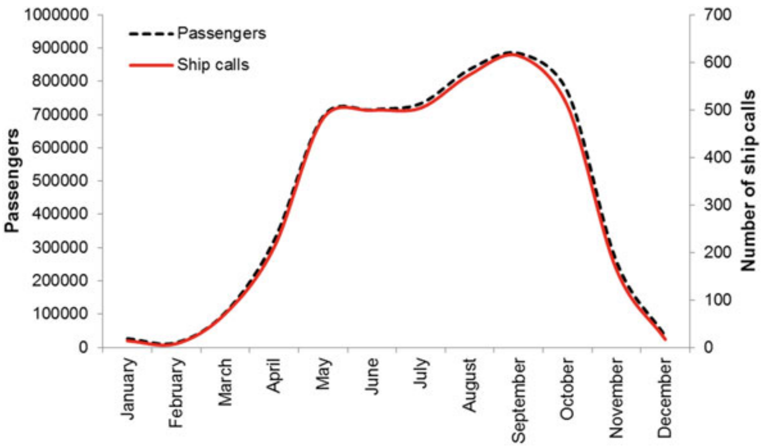


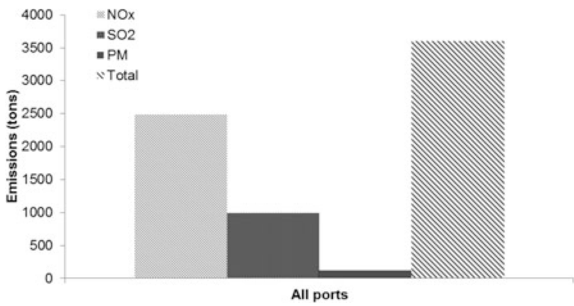
Fig. 5.5 Yearly distribution of passengers and ship calls in Greek ports

5.3 Estimation of Shipping Emissions in Greek Ports

The quantities of major air pollutants (i.e. NO_x, SO_x, $PM_{2.5}$) due to cruise ships in Greek ports were estimated, for the year 2013, taking into account ships' activities within the port (moving, maneuvering and hoteling). The aggregated emissions values are presented in Fig. 5.6. The total in-port inventory of cruise shipping accounted to 3604.5 tons, with NO_x being dominant (2487.9 tons) followed by SO_2 and of $PM_{2.5}$ (995.3 and 121.3 tons respectively).

The estimated emissions were analyzed according to the type of pollutant, the seasonality and the operational mode of the ship (i.e. moving—maneuvering and hoteling). Detailed emissions values for each pollutant and for all studied ports are presented in Fig. 5.7. Port of Piraeus leads in total emissions followed by port of Santorini (927 and 619 tons respectively), while Mykonos and Corfu are next (being very close to each other; with 475 and 467 tons respectively. In all cases NO_x emissions are dominant throughout the year, followed by those of SO_2 and

Fig. 5.6 The total amount of emissions from cruise industry in Greek ports (year 2013)



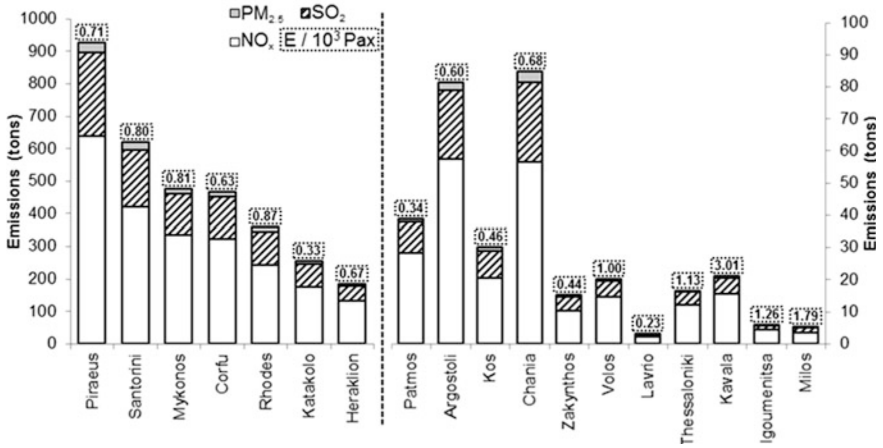


Fig. 5.7 Cruise ship emissions for Greek ports

thirdly $PM_{2.5}$. On average the mass ratio of SO_2 and $PM_{2.5}$ to NO_x was 38.1 % and 4.3 % respectively and was kept almost constant throughout the year.

The values of the ratio of total emissions per thousand passengers for all ports are also depicted in Fig. 5.7. The total emissions per thousand passengers are important as they depict the ratio of environmental burden to carried passengers from arriving cruise ships. The passenger density of arriving cruise ships, as well the size and the capacity of the cruise ship, can be of crucial importance for the induced health impacts in local inhabitants, especially for ports with adjacent cities with high population density (Maragkogianni and Papaefthimiou 2015). For most of studied ports this ratio was between 0.5 and 1, while for five of them the ratio is above 1 (Volos, Thessaloniki, Kavala, Igoumenitsa, and Milos). Kavala exhibits the highest values (3.01), pointing out the low passenger capacity of visiting cruise ships which stay long time in port.

Figure 5.8 summarizes the emissions from all studied ports under the two different operational modes within the port. The estimated emissions were 2487.9 tons of NO_x, 995.3 tons of SO_2, and 121.3 tons of $PM_{2.5}$, adding up to a total of 3604.5 tons. Emissions during hoteling (3216.4 tons corresponded to 89.2 % of total) significantly outweighed those produced during the ships maneuvering activities (388.1 tons or 10.8 % of total). This is due to the fact that hoteling times for cruise ships are extended while they also operate their auxiliary engines at high loads throughout their stay at berth. For NO_x, the percentage shares of hoteling and maneuvering emissions were 90.1 and 9.9 %, while for SO_2 and $PM_{2.5}$ the corresponding values were 88.5, 11.5 and 78.0, 22.0 % respectively.

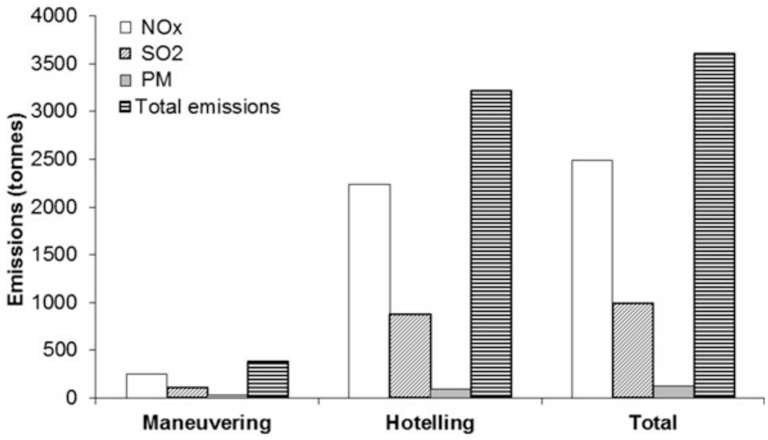


Fig. 5.8 Total amount of emissions, according operational modes within port

Table 5.3 External cost factors used for Greek ports

	Year prices	NO_x	SO_2	$PM_{2.5}$		
				Rural	Suburban	Urban
CAFE	2000	840	1400	19,329	50,605	197,845
	2013	915	1524	21,047	55,104	215,433
NEEDS	2000	3851	8210	19,329	50,605	197,845
	2013	4193	8940	21,047	55,104	215,433

5.4 The Social Cost of Shipping Emissions

For an accurate estimation of the total external costs due to air emissions in the studied ports, the results from two relevant methodologies have been combined: CAFE and NEEDS. They both model the $PM_{2.5}$ factors employing the HEATCO methodology and the values are expressed as damages per ton of emitted PM, SO_2 and NO_x. In Table 5.3, the employed external cost factors are depicted (starting form prices on 2000 and using the CPI to obtain values for 2013).

The lowest estimates result from the application of CAFE (i.e. 14.6 million €) while in the case of NEEDS the anticipated total external cost reach 30.1 million €. The average cost for all ports per cruise passenger is 2.31 € and 6.05 € for CAFE and NEEDS respectively (see Table 5.4 and Fig. 5.9).

Shipping emissions have considerable external costs in ports: almost 12 billion € per year in the 50 largest ports in the OECD for NO_x, SO_x and PM emissions (Merk 2014). Our cost estimates can be compared to results found in other studies. Tzannatos estimated for Piraeus in 2008–2009 the external costs from in-port cruise ships activity to 16.5 million € or 10.4 € per cruise passenger, while in the current study the per passenger values are 9.1 € and 6.0 € for CAFE and NEEDS

Table 5.4 Estimated external costs

	Port	NEEDS (million €)	CAFE (million €)
1	Piraeus	11,884,328	7,884,035
2	Santorini	4,611,726	1,936,895
3	Mykonos	2,835,345	799,223
4	Corfu	3,354,019	1,340,808
5	Rhodes	2,632,411	1,078,050
6	Katakolo	1,568,877	462,546
7	Heraklion	1,201,096	431,115
8	Patmos	224,230	60,157
9	Argostoli	484,128	135,772
10	Kos	184,255	53,907
11	Chania	529,651	159,874
12	Zakynthos	93,700	27,977
13	Volos	133,990	48,599
14	Lavrio	17,614	4790
15	Thessaloniki	155,969	86,633
16	Kavala	135,527	46,722
17	Igoumenitsa	33,003	8439
18	Milos	33,077	9909
Total		30,112,946	14,575,451

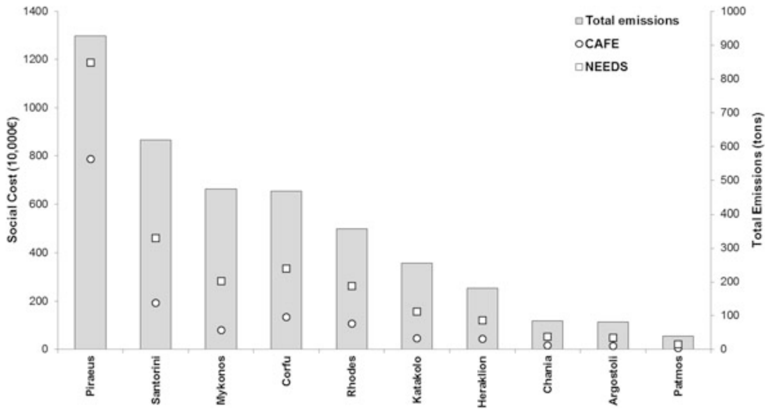


Fig. 5.9 Distribution of externalities (for both methodologies) and emissions in the studied Greek ports

respectively (Tzannatos 2010). McArthur and Osland for the port of Bergen-Norway indicated a total social cost between 10 and 21.5 million € or ranging between 6.79 € and 14.63 € per cruise passenger (McArthur and Osland 2013). Berechman and Tseng found that the cost of emissions from ships at berth in

Kaohsiung-Taiwan, was 119.2 million $ in 2010 (Berechman and Tseng 2012), while Song estimated the total social cost of air emissions for the Yangshan port of Shanghai equal to 287 million $ (Song 2014; Maragkogianni and Papaefthimiou 2015).

The estimated external costs associated with the damages that vessel emissions contribute upon human health and the built environment surrounded the cruise ports of Greece were found to be significant.

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Conclusions

Port and ship related specific technical data were employed to create a NO_x, SO_2 and $PM_{2.5}$ emissions inventory for cruise ships approaching 18 major Greek ports during 2013. An activity-based model was implemented, and emissions were estimated during ships' moving—maneuvering in port and hoteling. The total in-port inventory of cruise shipping accounted to 3604.5 tons: with NO_x being dominant (2487.9 tons), followed by SO_2 and $PM_{2.5}$ (995.3 and 121.3 tons respectively). Emissions during hoteling (3216.4 tons corresponded to 89.2 % of total) significantly outweighed those produced during ships' maneuvering activities (388.1 tons or 10.8 % of total). Seasonality was found to play a major role, as emissions during summer prevailed due to the augmented in-port presence of cruise ships. An obvious increase in autumn emissions was observed as the touristic season has been extended towards October and November in almost all major ports. The estimated inventory proves the necessity of measures towards careful control over the emissions produced by cruise ships in port cities through effective environmental policy-making. This inventory reveals that the emissions of 18 studied ports, contributed 8.2 and 4.0 % respectively to the relevant national NO_x and SO_2 inventory, while it would roughly constitute 1.2, 0.95 and 0.87 % of the total emissions from shipping for the three main exhaust pollutants in the Mediterranean basin. The results prove the importance of careful control over the emissions produced by cruise ships through effective environmental policy-making.

This study renders a review on the methodological and empirical state of the art on external cost estimation from harbour emissions estimated from vessels. A bottom-up approach is preferred as it enables a refined assessment based on detailed information, differentiation possibilities and an improved precision in derived results (marginal external costs). Nowadays, literature regarding the valuation of external costs from vessel emissions at port is in its early steps, as is easily deducted by the fact that the first paper appeared in 2009.

The total social cost for all Greek ports for 2013 was estimated to 30.11 million €, accounting for 0.013 % of the national annual GDP. Regarding the ports and related cruise industry, the estimated social cost practically imposes an average extra cost to the local societies of 8213 € per ship call or 5.6 € per

A. Maragkogianni et al., *Mitigating Shipping Emissions in European Ports*, SpringerBriefs in Applied Sciences and Technology, DOI 10.1007/978-3-319-40150-8

passenger. Port-related exhaust emissions, as any negative externality, reflect a real cost accruing from an economic activity and lead to a suboptimal outcome.

The need to control air pollution at ports is widely acknowledged as an active policy issue by various authoritative port associations. 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. In addition, a port 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. Detailed port emission inventories are scarce, and only during the last 5 years various port authorities have realized the necessity of presenting their environmental profile.

In order to reduce the emissions, strong abatement measures will be needed. These could be classified in two different categories: technological improvement and operational changes. Firstly, technical interventions could help to reduce (both local and global) ships related emissions by replacing or upgrading older, less-efficient and higher polluting engines with more efficient and lower-emitting propulsion systems. Operational changes can reduce local emissions by modifying how vessels operate while entering and berthing in harbours. Some solutions have been proposed for improving the air quality in coastal areas and ports. These include the establishment of reduced speed zones (RSZ), emissions control areas (ECAs), adaptation of shore-side electricity and LNG in ships. Nevertheless as different areas use different approaches there is a pressing need for ports to collaborate towards the creation of sustainable port related strategies and synergies. As a first step comprehensive and reliable emission inventories are necessary for each port in order to assess its environmental impacts.