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Ship emissions and their externalities in cruise ports

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ABSTRACT

This paper presents an estimation and analysis of ship exhaust emissions and their externalities in the popular cruise destinations of Dubrovnik (Croatia) and Kotor (Montenegro) along the eastern coast of the Adriatic Sea. To this extent, the recent record (2012–2014) of cruise ships calling at these ports is used to model and estimate the ship exhaust emission inventories and externalities within the associated bays and ports.

The results indicate that cruise ship traffic produces continuously increasing air pollution in both ports over recent years. More importantly, however, the analysis of the ship operating characteristics reveals that for any given ship traffic involving specific vessels using marine fuel of a given quality, the presence of other factors (e.g. berth availability, berth accessibility etc) can also influence the ship emission levels. This is particularly evident in the case of the port of Kotor where berth space insufficiency dictates the need for ship anchorage thus leading to increased air pollution and costs of associated damage.

The application and results of the aforementioned ship activity-based methodology to the ports of Dubrovnik and Kotor improves our understanding of ship emissions in cruise bays and ports, and contributes toward the implementation of port policies for the effective control of air quality in such environmentally sensitive locations.

Introduction

Within the general challenge of controlling the exhaust emissions produced by ships, navigation in bays and ports has attracted over the last decade increasing attention due to the significance of air pollution on the natural and built environment of coastal regions. The ability to reliably model, estimate and analyze ship emissions in these regions and particularly in ports is a fundamental prerequisite for exploring the feasibility of adopting supplementary emission control measures beyond those dictated by the regulations for the prevention of air pollution from ships under the international framework of Annex VI MARPOL 73/78 and at European level according to the provisions of Directive 2012/33/EU.

For the navigation in ports, the structure of the emission modeling methodology relies on the distinction of the various activity phases performed by each port-calling ship and the emission estimation utilizes real and empirical data with regard to the operating characteristics of each ship during its approach, stay and departure from the port. Over the last decade, representative research of this approach constitutes the work of Saxe and Larsen (2004) for three Danish ports, Yang et al. (2007)

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for the port of Shanghai and De Meyer et al. (2008) for four Belgian ports. Most recently, Deniz et al. (2010) and Deniz and Kilic (2010) addressed the issue of ship emissions for Candarli Gulf and the port of Ambarli, in Turkey, respectively. Hulskotte and Denier van der Gon (2010) estimated ship emissions at berth in the Port of Rotterdam, Yau et al. (2012) and Ng et al. (2013) for the port of Hong Kong, whilst Chang et al. (2013) and Song and Shon (2014) addressed the Korean ports of Incheon and Busan, respectively.

Furthermore, the in-port ship activity constitutes the basis for modeling the evaluation of the air pollution damage caused by ships in ports, as applied by Tzannatos (2010a) for the passenger and cruise terminal of the port of Piraeus in Greece. Similarly, the work of Chang and Wang (2012) compared the techno-economic effectiveness of ship speed reduction and shore-side electricity in lowering the ship emissions in the port of Kaohsiung in Taiwan, whilst Berechman and Tseng (2012) evaluated the emission damage of ships and trucks for the same port. Most recently, the ship activity-based approach was applied by McArthur and Osland (2013) for the evaluation of the emission damage in the port of Bergen, by Castells Sanabra et al. (2014) for the Spanish port network, by Song (2014) for the Shanghai Yangshan port and finally by Tichavska and Tovar (2015a) for Las Palmas Port.

Taking into account that cruise vessels because of their high propulsion and hoteling energy requirements are the most fuel demanding amongst all ship types (Howitt et al., 2010) and cruise destinations by virtue of their natural and cultural attractiveness are highly sensitive to air pollution, the assessment of ship emissions produced in ports of high cruise activity has attracted particular attention. More specifically, cruise ship emissions in ports has been the focus of the work by Maragkogianni and Papaefthimiou (2015) for five Greek ports evaluating the external costs of air pollution, Tichavska and Tovar (2015b) for ferry and cruise vessel air pollution in Las Palmas Port, Poplawski et al. (2011) for the impact of cruise ships in James Bay at Victoria, Canada, and finally by Tzannatos (2010a,b) for the emission inventories, externalities and control options associated with the cruise and ferry operations within the main port of Piraeus.

The aforementioned research work generally covers the estimation of the ship emission inventories whilst in port, the evaluation of their associated damage costs and the examination of their control through the use of low-sulfur fuel, the installation of scrubbers or the provision of shore-side electricity. However, with regard to ship emission control, it is important to note that the level of engine exhaust emissions is primarily dependent upon the fuel consumption during the various phases of ship activity. This is particularly important for cruise ships because as opposed to cargo vessels they need to constantly produce adequate power to support the high demand for the provision of their onboard hoteling services and whilst in port they opt for self-reliance in covering the power requirements for maneuvering, berthing or anchoring in order to avoid the additional costs which an external assistance for such frequent operations would incur. Ease of maneuvering, berthing or anchoring, as well as berth availability influence the fuel consumption and hence the level of ship emissions whilst in port. Therefore, port traffic vis-a-vis port basin features and facilities is a critical factor of ship exhaust emissions in cruise ports and the need of further investigation on this issue is fully justified.

It is within this background of research interest, regulations and practices for controlling the ship emissions in ports that Dubrovnik and Kotor are considered to be a suitable reference for conducting a ship activity-based research on ship emissions in an effort to enrich the relevant knowledge and experience beyond the issues addressed by the currently available research literature. More specifically, in the current case, the ship activity-based approach is utilized to capture and analyze on a comparative basis the influence of the ship operational factors in the two ports. Although by vitrue of their vicinity the ports are exposed to similar cruise market characteristics within the Adriatic and Eastern Mediterranean region, they have distinct port calling demand and port characteristics which can affect the emission inventories and their externalities, as well as the control of the produced air pollution. In terms of the port importance, the Adriatic hosts currently the second (after the West Med.) cruise market within the Mediterranean, accounting for nearly 22% of all port calls (MedCruise, 2015). Dubrovnik is the third Mediterranean cruise port in terms of calls (following Civitavecchia and Barcelona) and Kotor occupies the 13th place, whereas they are the first and fourth busiest ports of call within the Adriatic–Ionian region, respectively.

The structure of the paper is as follows. The first section presents and compares the port characteristics and practices, as well as the ship traffic data in both ports. The methodology for estimating ship emissions and their externalities is explained in the second section. The following section reports the results of emission inventories, related externalities results and alternative scenarios in the case of the port of Kotor. Concluding remarks are included in the last section.

Cruise shipping in Dubrovnik and Kotor

Adriatic gates and routes contain more than twenty cruise ports with almost five million passenger movements based on the report from ASF (2015), where is Croatia a second ranking country by achieved cruise traffic with 1247 port calls while Montenegro hits the fourth place with 353 calls in 2014. Dubrovnik and Kotor have diverse cultural-historical attractions and are a part of UNESCO World Heritage (Carić, 2015; Carić and Mackelworth, 2014; Carić et al., 2014).

Over recent years, Dubrovnik has become a leading Croatian cruise port with more than 500 port calls involving more than 700,000 visiting passengers per year. As shown in the port layout of Fig. 1, this trend followed the various stages of port development through the recent reconstruction of berth facilities of more than 1 km in length (berths 8–12) and a depth of 11 m capable of accommodating more and larger cruise ships (DPA, 2014), whilst plans for further berth extensions are also

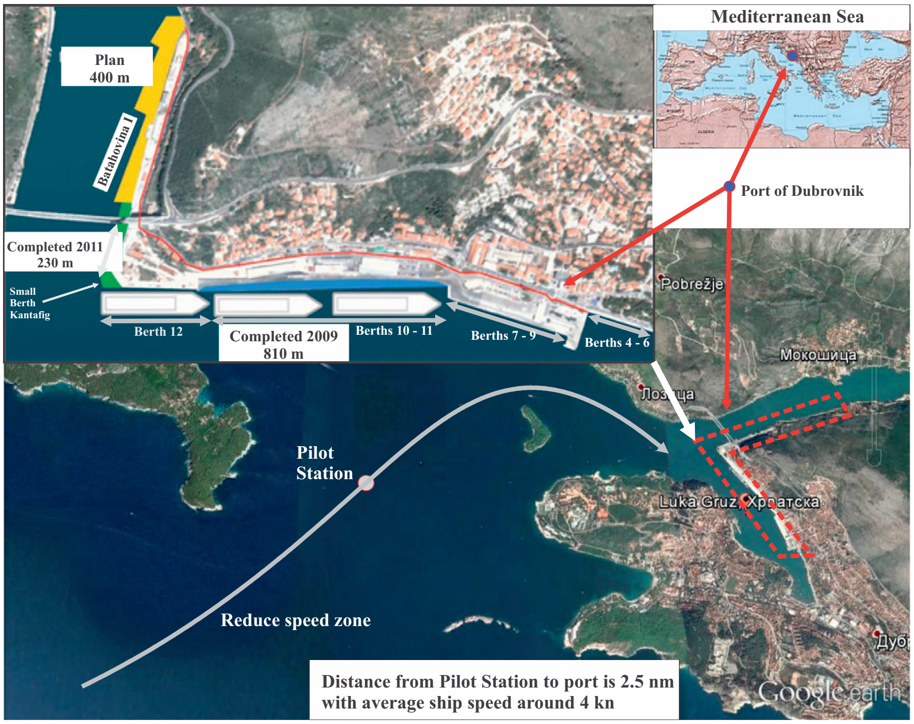

Fig. 1. Layout of the port of Dubrovnik.

in place to cover the increase in future cruise demand. Prior to berthing ships normally perform a maneuver and approach the berth by stern, except in the case of bad weather conditions.

Over the same period, the port of Kotor located at about 50 nautical miles on the south of Dubrovnik along the Adriatic coast has also benefited from the growing interest of the cruise industry in the wider region and is currently recording over 300 port calls and 250,000 cruise passengers per year. Kotor city besides being an attractive cruise destination *per se* offers the experience of transiting through a fjordlike landscape while sailing inside Boka Kotorska Bay (Dragovic et al., 2014; PKAD, 2014). The layout of the port of Kotor is shown in Fig. 2.

Cruise ships at the port of Kotor are served at two berth locations (Main Berth and River Berth) and at two anchorages (Anchorage 1 and Anchorage 2) given in Fig. 2. At the Main Berth is possible to service a ship with average draft of 8 m. Sometimes, this berth is available to receive two smaller cruise ships simultaneously. Also, a river berth is used for servicing ships up to 4.5 m draft and 125 m length. The anchorages are at distances of 0.28 and 1.1 nautical mile from the location of the berths. Both anchorage areas are highly accessible and do not have ship length or draft limitations within the range of dimensions for all cruise ships calling at Kotor. In this case, passengers are embarking and disembarking to and from the ship by tendering service. Prior to berthing, ships normally perform a maneuver and approach the berth by bow (Dragović et al., 2014; Kofjac et al., 2013). Anchoring in the port of Kotor involves dynamic position adjustment for safety reasons due to the narrowness of the inner bay basin. Ships are not allowed to move freely at the anchorage because of the danger of collision with the local traffic and/or grounding at the shallow waters near the shore. Smaller cruise ships are served by the River Berth, while larger vessels use the Main Berth or anchorages, with those of higher gross tonnage being exclusively anchored due to the Main Berth limitations.

A ship activity-based approach for the estimation of ship emissions requires the integration of traffic data (vessel movements, port calls) and technical characteristics of vessels. The detailed information of cruise ship and passenger traffic data during 2012–2014 at Dubrovnik and Kotor was obtained by the port authorities, whereas the gross tonnage (GT) as well as engine details of the cruise ships was obtained from the ship register of the IHS Fairplay Sea-web on line service. For the electrically driven ships, which on average constituted around 85% of all the (individual) ships involved in the port traffic data and almost exclusively in the larger vessel size range, it was assumed that the ratio of auxiliary to propulsion power stands on average at 0.278 (ISF 2009).

With regard to the annual cruise ship traffic in both ports, Table 1 presents the number of (individual) ships which called at the ports and their average gross tonnage (GT/ship), as well as the total number of port calls including those which involved the use of anchorage, as well as the total gross tonnage (Called GT), total number of passengers (Called PAX) and their weighted value per call. Furthermore, the total time and the average time per call spent in each of the ship activity phases (i.e.in maneuvering, at berth and anchorage) is included (DPA, 2014; MONSTAT, 2015; PKAD, 2014). Dubrovnik has higher values for most of the presented parameters during the whole period under consideration. For example, Dubrovnik

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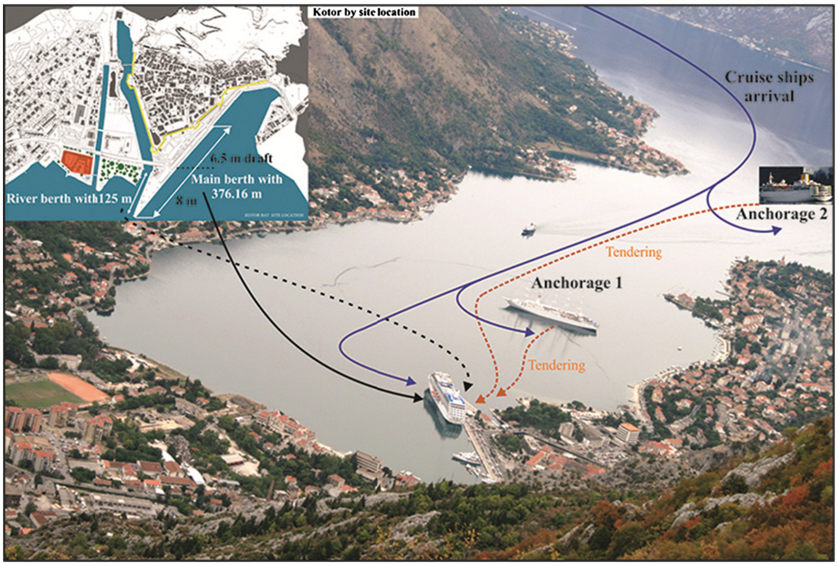

Fig. 2. Layout of the port of Kotor.

Table 1
Cruise ship and port traffic data at the ports of Kotor and Dubrovnik (2012–2014).

	Kotor			Dubrovnik		
Year	2012	2013	2014	2012	2013	2014
Ship data						
No. of ships	57	66	73	86	81	73
GT/ship	32,117	33,626	34,748	47,779	48,820	50,714
Port data						
No. of calls	334	364	334	459	521	442
Anchored calls	99	148	137	2	1	5
Called GT	9,980,058	12,330,245	11,851,148	26,343,940	33,340,649	28,742,730
Called PAX	289,709	352,970	345,440	791,931	998,231	860,064
Called GT/call	29,880	33,874	35,482	57,394	63,993	65,028
Called PAX/call	867	969	1034	1725	1915	1945
Total time (h)	Kotor			Dubrovnik		
	2012	2013	2014	2012	2013	2014
In Maneuvering	134	160	150	366	433	368
At Berth	2784	2749	2248	5580	6888	6003
At Anchor	1003	1257	1229	42.6	24.3	60.4
Total	3921	4166	3627	5989	7345	6431
Average time per call (h)	Kotor			Dubrovnik		
	2012	2013	2014	2012	2013	2014
In Maneuvering	0.40	0.44	0.45	0.80	0.83	0.83
At Berth	11.8	12.7	11.4	12.2	13.2	13.7
At Anchor	10.1	8.5	9.0	21.3	24.3	12.1

has been visited by more individual ships exempt in 2014 during which both ports recorded the same number of ships, whilst the size of the ships which called at Dubrovnik is generally higher than those at Kotor by 46.6% on average. Dubrovnik has 32.3%, 142.5%, 149%, 83.3% and 88.1% higher values for port calls, Called GT, Called PAX, Called GT per call and Called PAX per call, respectively. For 2014, these differences are the lowest between the two ports, being even higher in 2012 and 2013. Despite the fact that the number of port calls does not show a monotonically increasing trend for both ports during the period under consideration, it should be noticed that the parameters of Called GT per call and Called PAX per call are monotonically increasing. This indicates that with the passage of time ships of higher GT and passenger carrying capacity are calling in both ports. Despite the higher number of port calls at the port of Dubrovnik the use of anchorage was negligible (with a maximum of five anchored calls in 2014), whereas the anchorages of the port of Kotor were used for an annual average of 37.1% of the calls, rising from 29.6 in 2012 to over 41% in 2014.

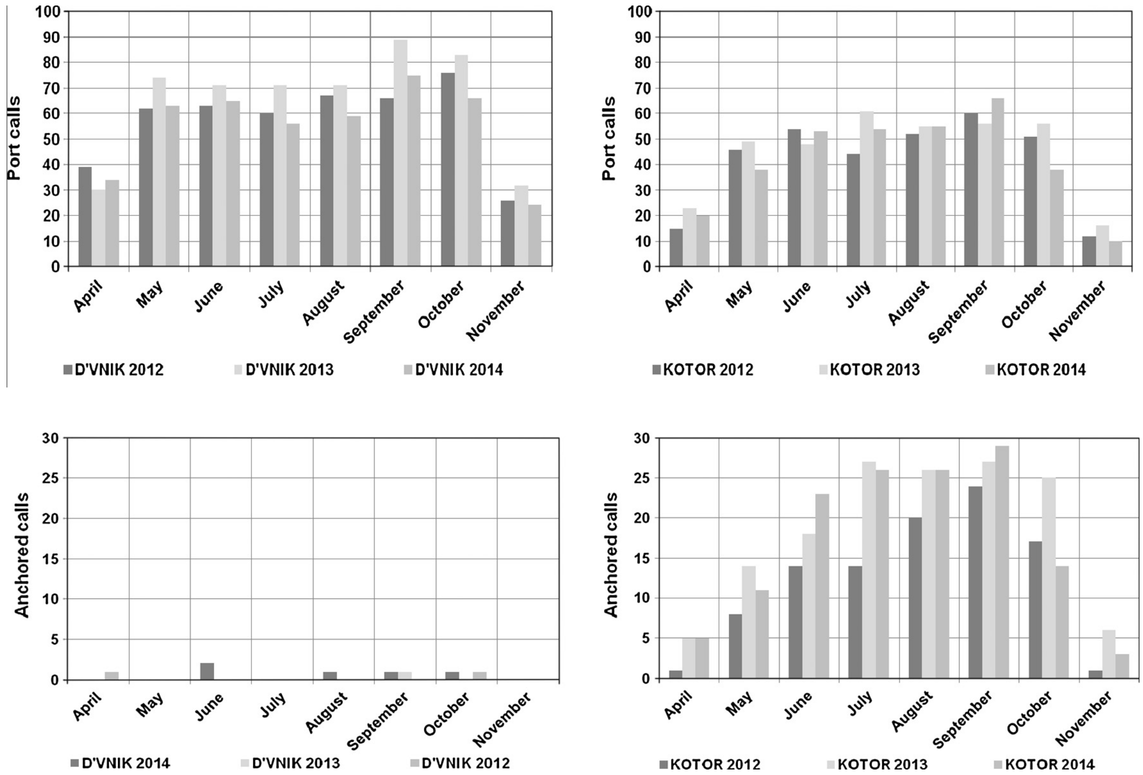

Fig. 3. Monthly distribution of port calls and anchored calls.

The total time spent by ships calling at Dubrovnik is on average 59.5% higher than that at the port of Kotor, whereas the total time spent at anchorage whilst in Kotor has been found to be between 20 (in 2012 and 2014) and 50 (in 2013) times higher than that at Dubrovnik. The average time per call during any specific ship activity is comparable between the two ports, with the exemption of maneuvering which is almost double in Dubrovnik reflecting the need for the astern maneuver normally performed by cruise ships during berthing at this port. Furthermore, with regard to the average time at anchorage it should be mentioned that the significantly higher values for the port of Dubrovnik (in 2013 and 2012) do not provide a reliable comparison because they correspond to the use of anchorages in the case of single and two annual calls, respectively.

The monthly distribution of port calls and anchored calls for the port of Dubrovnik and Kotor during 2012–2014 is shown in Fig. 3, where the busiest months in both ports are from May to October and the use of anchorages at the port of Kotor is becoming particularly high during the months from July to September, with noticeable intensification in 2014. The analysis of the annual number of port calls and GT with respect to the location of the ships during their stay in the ports, i.e. at berths and anchorages, is shown in Fig. 4. Amongst the cruise only berths (8–12) of the port of Dubrovnik, Berth 11, is the busiest followed by Berth 10, Berth 12, Berth 9 and Berth 8. In Kotor, Main Berth and Anchorage 1 are predominant, followed by Anchorage 2 and River Berth. In this port, it is also important to note that the Main Berth has a decreasing trend of number of calls and GT per call, whilst the general utilization of anchorages with time has increased in terms of calls and average GT per call.

The seasonal distribution of ship activity times while in port is shown in Fig. 5. Despite the generally lower number of calls at Kotor throughout the years, the time spent at the Kotor's anchorage is very high compared to Dubrovnik and predominately for the months of July to September when berth availability at Kotor is scarce due to the high port calling demand. Anchorage time is mainly in proportion to the anchored calls at Kotor over the same period, as the anchorage time per call does not normally present any port or seasonal variations. Apart from the higher maneuvering times at Dubrovnik due to the higher number of calls but also due to the berthing difficulty (already mentioned), there is no a noticeable seasonality with regard to maneuvering times which indicates that the prevailing weather conditions in the two ports and the berth or anchor location of the port calling ships do not play a major role in maneuvering.

Methodology for emission and externality estimation

The emission estimation model relies on the distinction of the various activity phases performed by each cruise ship calling at the ports of Dubrovnik or Kotor. According to the EU regulation, passenger ships burn fuel oil with maximum 1.5% sulfur during sailing and maneuvering, while at berth the use of distillates is limited to maximum 0.1% sulfur. In developing

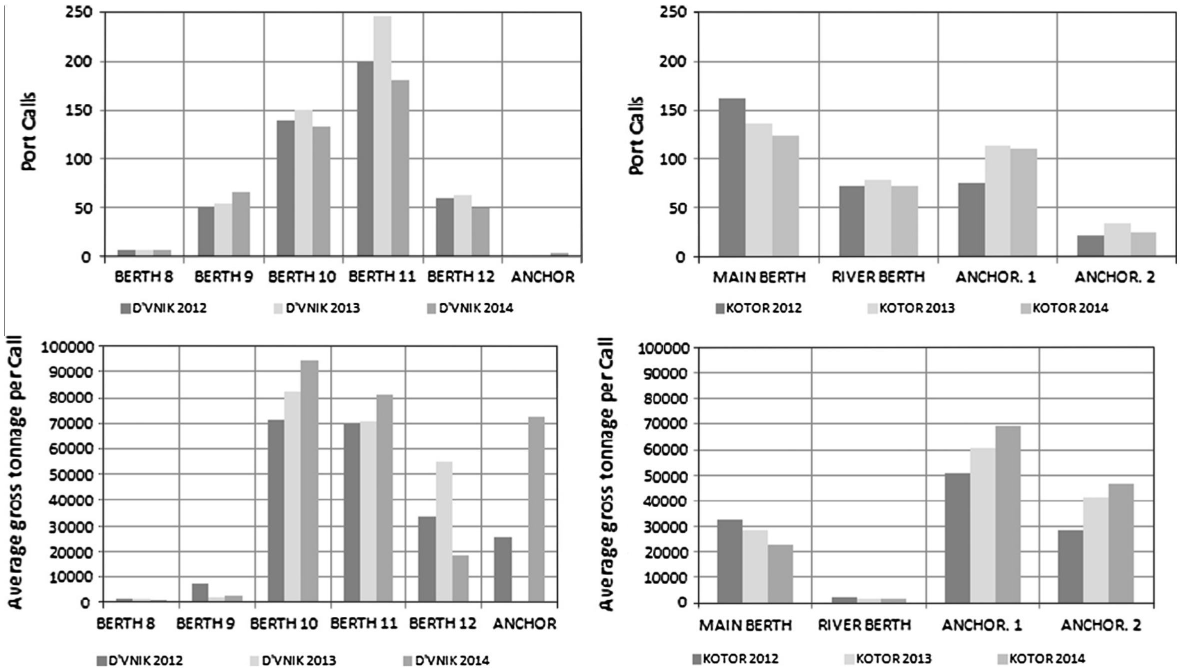

Fig. 4. Berth and anchorage utilization in terms of number of port calls and average gross tonnage per call.

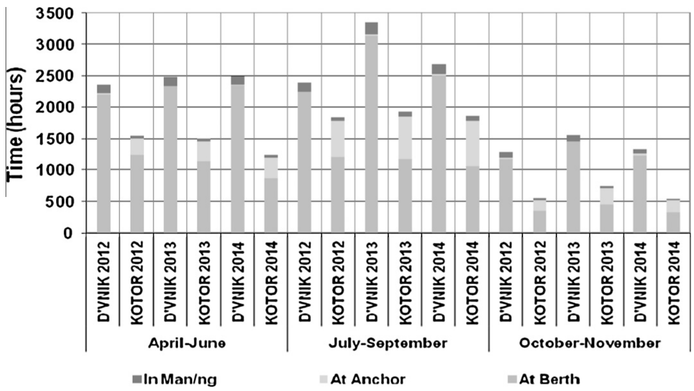

Fig. 5. Seasonal distribution of ship activity times at port.

an activity-based emissions inventory for ships, emissions are estimated as a function of energy consumption during each activity (expressed in terms of engine power usage and time) multiplied by an emission factor expressed in terms of grams per kilowatt-hour (g/kW h). The ship emission inventory is composed of the NO_X, SO_2 and PM emissions produced during each call i at the ports of Dubrovnik and Kotor in the period from 1st April to 30th November, whereas the emissions produced during each port call is the sum of the emissions in each ship activity phase (of maneuvering, E_{MAN} and at berth or at anchorage, $E_{A/B}$), according to the expression:

$$E_i = E_{MAN} + E_{A/B} \quad \text{(tons)} \tag{4.1}$$

where

$$E_{MAN} = \left[T_{MAN} \cdot \left[\left(P_{ME} \cdot \mathrm{LF}_{ME} \cdot \sum \mathrm{EF}_{ME_e}\right) + \left(P_{AE} \cdot \mathrm{LF}_{AE} \cdot \sum \mathrm{EF}_{AE_e}\right)\right]_{MAN}\right] \cdot 10^{-6} \tag{4.2}$$

and

$$E_{A/B} = \left[T_{A/B} \cdot \left[\left(P_{ME} \cdot \mathrm{LF}_{ME} \cdot \sum \mathrm{EF}_{ME_e}\right) + \left(P_{AE} \cdot \mathrm{LF}_{AE} \cdot \sum \mathrm{EF}_{AE_e}\right)\right]_{A/B}\right] \cdot 10^{-6} \tag{4.3}$$

Table 2
Engine load and emission factors.

Load factors (LF)					
ME in Man/ring	AE in Man/ring	ME at Berth	AE at Berth	ME at Anchor	AE at Anchor
0.25	0.80	0.00	0.60	0.25	0.80

	Emission Factors (EF)		
	NO_X (g/kW h)	SO_2 (g/kW h)	PM (g/kW h)
In Maneuvering	12.8	6.18	0.67
At Berth or Anchor	12.4	0.45	0.18

where

T_{MAN} and $T_{A/B}$ = time spent in maneuvering and at berth or anchorage (h),
P_{ME} and P_{AE} = ship's main engine (ME) and auxiliary engine (AE) allocation of power (kW),
LF_{ME} and LF_{AE} = load factors of main and auxiliary engines and
EF_{ME} and EF_{AE} = emission factors of emission e for the main and auxiliary engines (g/kW h).

Although the definition of the main and auxiliary engine load factors during the various ship activity phases as shown in Table 2 took account of the existing research literature on this issue (Tzannatos, 2010a,b; ICF, 2009), the particularities of cruise shipping in both regions dictated the need to refine and average their values according to location specific information (as provided by local port pilots). Engine load factors at anchorages include the additional auxiliary power for supporting the stand-by operation of propulsion motors and the main power for their intermittent operation during the ship's dynamic position adjustment/correction.

Toward the selection of the NO_X, SO_2 and PM emission factors, in view of the dominance of medium speed diesel engines in the powering of the cruise ships, it was considered appropriate to assume that the ships employ Medium Speed Diesel (MSD) engines (whether for mechanical or electric power generation) which on average correspond to Tier I (i.e. post-2000) NO_X specification and burn fuel oil of 1.5% sulfur during sailing (incl. maneuvering) and 0.1% sulfur MDO/MGO at anchorage or at berth. The average NO_X, SO_2 and PM emission factors according to the ship's activity phase shown in Table 2 were based on the guidelines for the preparation of port-related emission inventories (ICF, 2009).

The evaluation of the damage produced by the air pollution from ships can be achieved through several methods, such as NETCEN, Clean Air for Europe (CAFE) and New Energy Externalities Development for Sustainability (NEEDS). According to Maragkogianni and Papaefthimiou (2015), NEEDS is the most updated methodology, which is covering all major pollutants in EU member states. NEEDS quantifies health effects as well as side effects of emissions on materials, biodiversity and crops. Values are expressed as damages per ton of emission of PM, SO_2 and NO_X. Although it includes all European sea territories, it does not address external costs in relation to ports.

According to Korzhenevych et al. (2014), the damage cost of PM emissions is dependent on the type of area where the pollutant is emitted, being distinguished between rural (less than 150 inhabitants/km^2), suburban (between 150 and 900 inhabitants/km^2) and urban (over 900 inhabitants/km^2). Dubrovnik has a population density of 2000 inhabitants per square kilometer, thus representing an urban area. The above researchers quote the damage costs of NO_X, SO_2 and urban PM for Croatia as being equal to 15,149, 12,317 and 208,779 euros per emitted ton, respectively. In the case of Montenegro, since no reports on damage costs are available in the literature, it was considered appropriate to utilize the GDP per capita equivalence (Preiss and Klotz, 2008) of another reported country. Korzhenevych et al. (2014) reports damage costs of NO_X, SO_2 and the rural PM for Bulgaria which can be considered also applicable to Montenegro and are equal to 14,454, 12,598 and 34,862 euro/ton, respectively, assuming a rural population density of 68 inhabitants/km^2 for the port city of Kotor.

In general, a ship activity-based (or "bottom-up") approach for the estimation of ship emission inventories is considered to provide the most reliable modeling, although it involves uncertainties mainly relating to the accuracy of the parametric values to be used. Beyond the ability to retrieve reliably the technical specification of installed engine power of all the ships, the power developed during each ship activity while in port is depended upon the engine load factors which could not be accessed on an individual ship or call basis and identical average values were used relying on the experience and the expertise of local port pilots. Similar uncertainty is involved in the assignment of averaged engine emission factors which rely on the assumption that the employed factors represent all ships and calls, and have constant values irrespective of engine loading. Taking into account that electric propulsion was involved on average in 89.9% of all port calls in both ports, the engagement of individual generator units (out of a "genset bank") in order to cover the demand for varying power alleviates the need to vary the engine load factors accordingly. Therefore, the assumption of varying partial load operation of the main and auxiliary engines in the modeling of the various ship activities does not imply the true partial load of individual engines and therefore the engine emission factors can be considered to be the same for all engine load values. In any case, it should be mentioned that for the purpose of a comparative assessment of ship emissions and their damage between the two ports, the use of the same parametric values of engine load and emission factors for both ports is limiting the influence of their uncertainty. The information regarding the time spent in each activity (i.e. in maneuvering and at berth or at anchor) during each port call is considered to be accurate as it is based on the reliable records of the port authorities. Finally for the evaluation of the air pollution damage, the unit costs have been found to vary significantly according to the applied methodology which in the current case (as already mentioned) is the most updated and hence mostly used by recent research in this area. Tichavska and Tovar (2015a) offer a concise assessment of available external cost methodologies which has been taken into account in this work in order to select the NEEDS methodology as proposed by Korzhenevych et al. (2014).

Results and discussion

Emission inventories

The analysis of the port emission inventories for Dubrovnik and Kotor during the period of 2012–2014 is presented in Table 3. In terms of total emissions, the ships calling at the port of Dubrovnik have produced higher emission levels than the ships calling at Kotor. NO_X emissions are the highest and PM emissions are the lowest in both ports throughout the period 2012–2014, reflecting the influence of the corresponding emission factors. The higher emission levels at Dubrovnik are partly due to the influence of the higher number of port calls, although other parameters such as ship size, port time and ship activity can also affect the level of produced emissions. As shown in Fig. 6, the clearer seasonality of emissions at the port of Kotor observed through their rapid increase from July to September and particularly during 2014 is consistent with the intensified use of the anchorages at this port over this period (as shown in Figs. 3 and 5).

Furthermore, the influence of the ship activity phases on the level of port emissions is shown in Fig. 7. Anchored ships at the port of Kotor produce 65–75% of the total emissions. This reflects the generally higher energy consumption of anchored ships, in conjunction with the significant time spent at the anchorages and their frequent use by larger vessels due to the lower berth availability of Kotor compared to Dubrovnik, as presented through the comparison of the port layouts in Figs. 1 and 2. In the case of the port of Dubrovnik, the contribution of the maneuvering phase is found to be significant (around 30%) because of the navigational complexity of this activity (i.e. astern maneuver for berthing) and steadily proportional to the port calling demand throughout 2012–2014. The maneuvering emissions in the port of Kotor are equally steady and proportional to the ship calling frequency, although they constitute less than 50% of those produced at Dubrovnik. The seasonal influence of the anchorage use at Kotor on emissions is also shown in Fig. 8, in which the emissions of anchored calls from July to September (and particularly in 2014) are profound.

Finally, as shown in Fig. 9, the emissions per call and hour spent at the port of Kotor, as well as the emissions per gross tonnage called at this port, are higher than in Dubrovnik which provides additional indication that the ship operations in Kotor have a higher weighted pardon on the local air quality mainly due to the impact of the anchorage phase.

With regard to the port of Kotor, it is important to note that the use of anchorages is related to the low availability of berths mainly due to the limited infrastructure rather than the frequency of port calls which in any case is lower than that of Dubrovnik. Despite the influence of port congestion, it should be noted that the port calling schedules are determined by

Table 3
Analysis of emission inventories.

	Kotor			Dubrovnik		
	2012	2013	2014	2012	2013	2014
Total emission (tons)	185.6	246.6	306.7	363.7	452.4	414.7
Total NO_X (tons)	168.6	224.9	279.8	315.1	392.0	355.6
Total SO_2 (tons)	13.8	17.7	21.9	41.5	51.6	46.9
Total PM (tons)	3.2	4.0	5.0	7.1	8.8	12.2

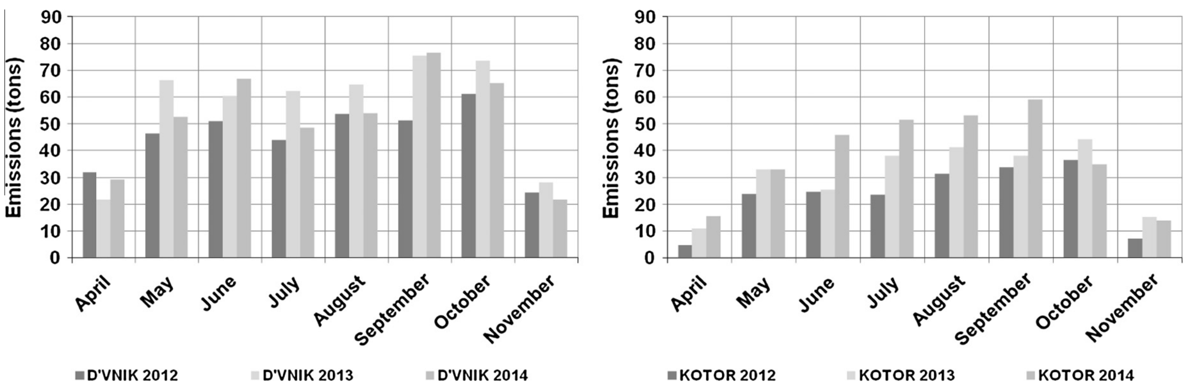

Fig. 6. Monthly distribution of emissions.

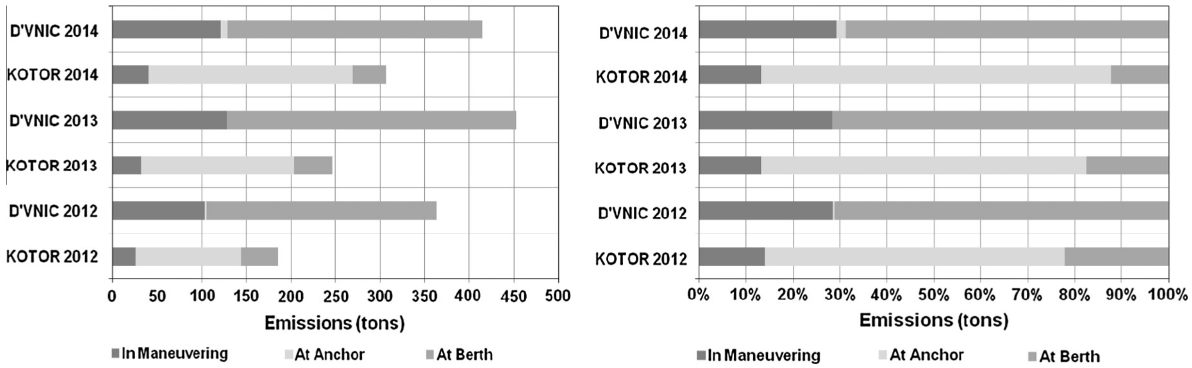

Fig. 7. Distribution of emissions relative to ship activity phase.

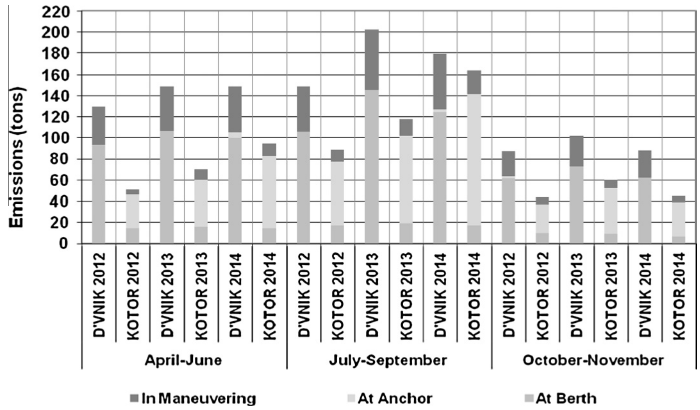

Fig. 8. Seasonal distribution of emissions relative to ship activity phase.

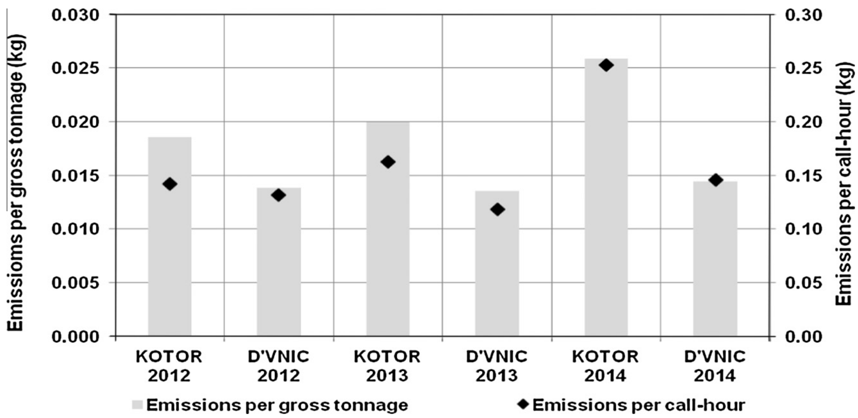

Fig. 9. Comparison of gross tonnage and call-hour weighted emissions.

the cruise operator and therefore, for a given port calling demand the provision of improved (i.e. extended) berth facilities becomes the only realistic option for reducing the need for anchorage and hence the achievement of lower emission levels.

Externality results

The analysis of the damage costs of the air pollution produced by the ships calling at the port of Dubrovnik and Kotor is presented in Fig. 10. Damage costs were generally found to be in proportion to the emissions produced in each port, i.e. they

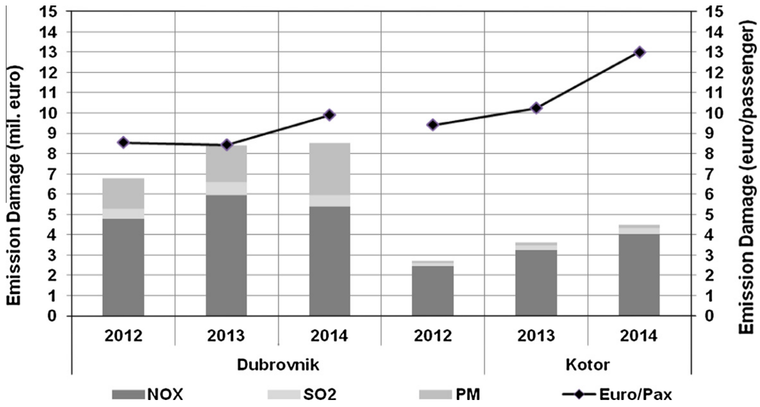

Fig. 10. Analysis of damage costs of air pollutants.

Table 4
Analysis of air pollution damage costs.

	2012		2013		2014	
	Kotor	Dubrovnik	Kotor	Dubrovnik	Kotor	Dubrovnik
Damage costs (mil. euro)	2.7	6.8	3.6	8.4	4.5	8.5
Damage costs (euro) per call	8125	14,751	9931	16,163	13,464	19,282
Damage costs (euro) per GT	0.27	0.25	0.29	0.25	0.38	0.29
Damage costs (euro) per hour	692	1131	868	1146	1230	1325
Damage costs (euro) per call-hour	2.06	2.46	2.37	2.20	3.71	2.99

are higher in Dubrovnik than those in Kotor. In this study, the pollution of NO_X is the most damaging primarily due to its higher emitted quantities, as its unit costs are generally significantly lower than those of PM emissions. The share of PM damage is significantly higher for Dubrovnik because of its urban characteristics as opposed to the rural population density of Kotor, thus following the general pattern as noted by McArthur and Osland (2013).

The air pollution damage at the port of Kotor was found to be higher in terms of the port calling cruise passengers, ranging between 9 and 13 euro per passenger for the port of Kotor as opposed to 8.5 to around 10 euro per passenger for the port of Dubrovnik.

Furthermore, the port of Dubrovnik was generally found to bear higher damage costs per call and per hour spent in port, whilst in contrast to the observed higher emission levels per GT at Kotor, the damage per GT was found to be generally comparable between the two ports because of the lower impact of PM unit cost at Kotor in comparison to that at Dubrovnik (Table 4). However, with the exemption of 2012, the air pollution damage per call-hour at the port of Dubrovnik was higher than that at Kotor, following the trend observed for the corresponding emission parameter.

In an attempt to recover the damage costs of air pollution from ships, port management should consider the enforcement of port dues which incorporate the associated costs. The aforementioned analysis offers the ability to choose from a range of port pricing policies amongst which the damage cost per port calling passenger appears to be the most appropriate, as cruise passengers are the ultimate users of the shipping services.

Alternative scenarios for port of Kotor

In this section, two scenarios are considered in order to assess the influence of limiting the use of anchorage in the port of Kotor for 2014, upon the damage costs of air pollution. The first scenario assumes moving all calls from anchorage 1 to berth and the second scenario assumes that there is no use of anchorages and all ships are served at berth. As shown in Table 5, the total damage costs during 2014 in Kotor for Scenario 1 are reduced by 39.7%, i.e. from the initial damage of 4.5 (of Table 4) down to 2.71 million euro, whilst a reduction of 47.3% is observed for Scenario 2, i.e. a reduction from 4.5 to 2.4 million euro. This indicates that amongst the two anchorage operations the most harmful is that of anchorage 1, having the most frequent use. Both scenarios reduce the damage costs per call, GT, time in port and passenger, with most of the reduction offered through the application of Scenario 1.

In any case, it should be taken into account that the realization of these benefits relies on infrastructure which is not currently available. However, the port of Kotor has been seeking ways to resolve port congestion through the provision of additional berthing facilities either through quay extensions or installation of floating docks aiming at improving the operation of the port with apparent positive influence upon its commercial and environmental performance. It is encouraging to note that with regard to this issue there is an alignment between cruise port commercial competitiveness and environmental

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Table 5
Air pollution damage costs for the port of Kotor during 2014 under different anchorage scenarios.

	Scenario 1 (without the use of anchorage 1)	Scenario 2 (without the use of anchorages)
Damage costs (mil. euro)	2.7 (reduction of 39.7%)	2.4 (reduction of 47.3%)
Damage costs (euro) per call	8113	7096
Damage costs (euro) per GT	0.228	0.199
Damage costs (euro) per hour	747.2	653.4
Damage costs (euro) per PAX	7.84	6.86

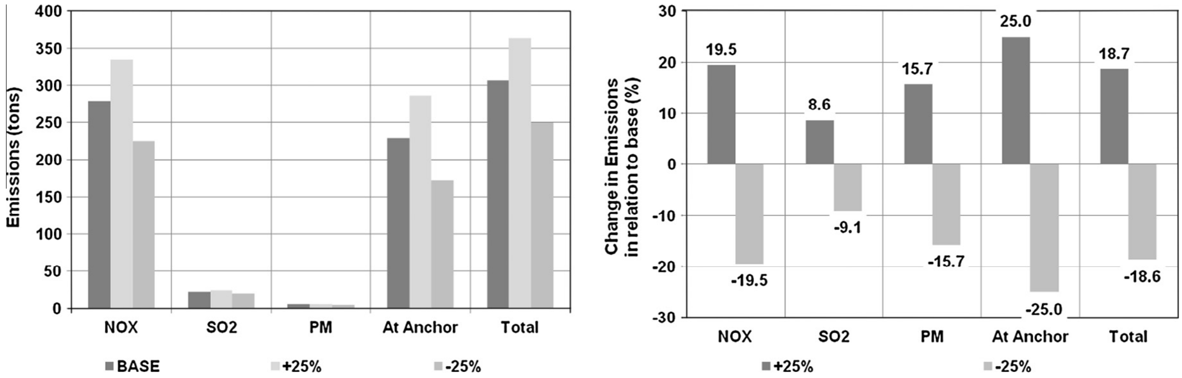

Fig. 11. Sensitivity of engine load factor variation (±25%) at anchorage on emissions at the port of Kotor in 2014.

friendliness. This has been demonstrated through the findings of the recent MedCruise Fact Finding Report (Pallis et al., 2015), in which infrastructure expansion vis-as-vis increasing size of ships were included in the top ten priorities amongst 70 challenges which were presented to all MedCruise members.

In relation to other ship emission control measures, it should be mentioned that further de-sulfurization of the marine fuel oils used by ships whilst in port would incur a substantial increase in bunkering costs. The same applies for the onboard installation of scrubbers or the provision of "cold ironing" which involves shore-side and ship-side investments. Although the introduction of these environmental measures would improve the air quality in the port of Kotor at additional costs which can be recovered through the increase of cruise package prices, they do not offer the added commercial advantages of extended berthing. Amongst them, the ability to provide easy access to Kotor by cruise passengers by removing the need to embark or disembark using tender services is bound to make this destination more attractive. Therefore, the roadmap for the overall improvement of the cruise services at the port of Kotor involves coordinated interventions i.e. the provision of adequate berth facilities (and the minimization of anchorage use), as well as the "cleaning" of the energy used by the cruise ships whilst in port.

Finally with regard to the influence of the introduced uncertainties upon the overall results of this work, it should be stated that the comparative assessment of emissions and associated damages between the two ports cannot be greatly altered, neither can the comparison of emissions between the various ship activities within each port as it is adequately distinct to enable their relative assessment. For example, with reference to the use of anchorages which is profound at the port of Kotor, the application of a sensitivity exercise involving the variation of the main and auxiliary engine load factors by ±25% during the use of anchorages at the port of Kotor in 2014 revealed that the overall emission change in relation to the base (or original) scenario was almost ±19%, respectively (Fig. 11).

Furthermore, according to the base scenario the contribution of the anchorages was found to be equal to 74.6%, whereas the increase and decrease of the engine load factors at the anchorages by 25% would make their contribution equal to 78.6% and 68.8% respectively. Therefore, although this engine load factor variation alters the contribution of anchorages to the overall emission level, it does not greatly alter the comparative picture of emissions during the various ship activity phases, amongst which the emissions at the Kotor's anchorages maintain their dominance.

Conclusions

The analysis of emission levels and associated damages in the cruise ports of Kotor and Dubrovnik indicates that for a given regulatory framework for the control of air pollution from ships and for a given port calling demand, the available port infrastructure in terms of its complexity and adequacy constitutes a decisive factor.

The port of Kotor was found to suffer under the influence of the low availability of berth space which dictates the use of the anchorages especially during the busy summer season, whilst the port of Dubrovnik imposes upon ship operators a complex maneuvering procedure which inevitably leads to increased emissions and even higher air pollution damages due to its urban characteristics.

The provision of port facilities for the improvement of the local air quality requires investments which can be realized through the internalization of the damage costs associated with the in-port ship emissions. According to the "polluter pays principle", it is proposed that pricing policies for the provision of cruise port services should incorporate the damage of air pollution from ships for facilitating the financing of appropriate remedial projects, such as the supply of adequate and easily accessible berths.

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