Air pollution and port operations: a case study and strategies to clean up

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Abstract

As in almost all the major maritime cities, Ancona harbour is very close to the urban area and hosts a multi-purpose port receiving cruise boats, passenger ferries, commercial liners, and fishing boats. A consistent part of the related airborne pollutants is due to the vessels stationing while the main contribution comes from the consequent road traffic and other anthropic activities. To reduce air pollution without penalizing local economy, understanding and quantifying the very true sources of pollution has become a major concern. Here we present a set of studies we carried out to understand the respective weight of pollutant sources. The results are a complete airborne pollutant emission inventory for Ancona city, province and harbour and the related assessment for pollutant concentration and deposition within the area. The study pointed out that most of fine particulate-matter emissions (PM10) in the harbour, namely up to 70 percent, arises from ship "hotelling" i.e. ship operations during the stop within the port area. Therefore, solutions to reduce the emission of pollutants from diesel engines for ships, mainly by providing alternative sources of energy during the hotelling, shall be found. A significant reduction of pollutants can be achieved by applying a ground electrification of the docks in order to provide the electricity usually produced by the polluting engines of the ships.
Keywords: ship hotelling emissions, PM10, urban air pollution, cold ironing.

1 Introduction

PM10 (Particulate Matter smaller than 10 microns in diameter) is the term used for a potentially toxic mixture of solid particles and liquid droplets suspended in the air. The EU daily mean limit value set for the protection of human health is

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50 μg/m^3, not be exceeded more than 35 days a calendar year. Furthermore, the annual mean must not exceed 40 μg/m^3. In 2011, PM10 concentrations recorded at the monitoring station of Ancona-Port, located very close to the wharf, exceeded 97 times this legal limit and, in previous years, the number of exceedings has always been above the legal limits. These data can be compared with those of another environmental monitoring unit, located less than 1 km far and known as "Ancona-Cittadella". PM10 values of this unit are dissimilar, both for the annual mean and for the number of exceedings.

To evaluate emissions strictly due to maritime sources, we applied several methodologies but the cornerstone is represented by a report developed for Methodologies for Estimating air pollutant Emissions from Transport" (MEET), namely a set of models to estimate pollutant emissions produced by vessel traffic, through specific emission factors specialised for various types of ships [1, 2]. We evaluated ship movements during a typical week in the whole harbouring area of Ancona. From these data, we got an estimate of the weakly emissions of particulate produced by vessel traffic, so that we can highlight the impact of this activity on the city and on the whole region. We confronted our results with comparable data, obtained by a branch of Italian National Environmental Agency, ISPRA, using a top-down methodology, i.e. starting from the fuel national consumption and using the percentage of docking in this port among the national total as a disaggregation proxy variable.

Table 1: PM10 concentrations at Ancona port and city center.

	Ancona Port			Ancona Cittadella		
	Annual average (μg/m^3)	Exceedences	% On	Annual average (μg/m^3)	Exceedences	% On
2006	45	101	> 75	-	-	-
2007	48	127	88	34	52	91
2008	39	58	> 75	31	36	92
2009	46	119	> 75	32	24	92
2010	48	139	94	32	31	77
2011	45	97	85	33	29	83

2 Marpol VI and EU directives

Pollutant emissions can be reduced according to two approaches: ad-hoc management of combustion, combined with exhaust gas treatment and improvement of fuel quality. Several studies relate PM emissions produced by ship engines with the sulfur content in fuels. Emissions of SO_2 and PM are primarily linked to the quality of fuel being used. Liquid fuels, used for maritime transport, contain sulfur which is released upon combustion in gaseous form, predominantly as SO_2. Following its release into the atmosphere, SO_2 reacts with other pollutants and forms PM which is referred to as secondary PM (SO_2 is a precursor of PM). For this reason we can consider this type of fuel as the predominant factor in the variations of PM emissions in the port of Ancona.

Air pollution due to international maritime navigation is regulated by an International Convention for the Prevention of Pollution from Ships or

MARPOL Annex VI (short for Marine Pollution). In October 2008 the International Marine Organisation's (IMO's) Marine Environment Protection Committee has approved amendments to MARPOL Annex VI in order to strengthen the emission standards for NOx and the sulphur contents of heavy fuel oil used by ship engines. These changes led to a reduction from 4.50% by weight of the sulphur content of all marine fuels used globally to 3.50% from 1 January 2012 and to 0.50% and from 1 January 2020 (the latter subject to a fuel availability review in 2018) and a reduction from 1.50% by weight of the sulphur content of all marine fuels used in SECAs to 1.00% from 1 July 2010 and to 0.10% from 1 January 2015.

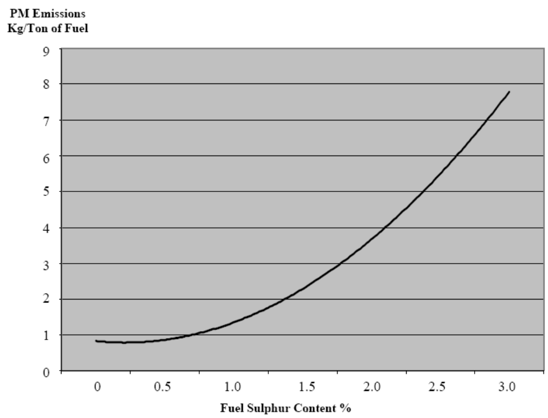

Figure 1: Relationship between fuel sulphur content and total PM emissions according to Lloyd's register Marine Exhaust emissions research programme [5].

The European Union issued several directives. The last one is the 2005/33/EC, which extends the scope of Directive 1999/32/EC to include all liquid fuels derived from petroleum and used by ships operating in territorial waters of Member States. Between all, 2005/33/EC limits the Sulphur content of marine fuels as follows: Max 1.5% mass content, from 11 August 2006, for fuels used by passenger vessels on regular services to or from any port in the Union; Max 0.1% mass content, from 1 January 2010, for fuels used by ships on inland waterways and at berth (implemented in Italy by D.Lgs 55/2011), Max 1.5% mass content for marine diesel fuel sold in the European Union; Max 0.1% mass content for marine gas fuel sold in the European Union.

3 EMEP methodologies for estimating air pollutant emissions from ships

EMEP/EEA Air Pollutant Emission Inventory Guidebook, within Navigation Chapter 1.A.3.d, shows three emission estimates methods. The Tier 1 method is very simple and applies default emission factors only. These emission factors assume a linear relationship between the intensity of the processes and the resulting emissions. Tier 2 is similar to Tier 1 but the default emission factors are replaced by country-specific ones or technology-specific ones. Tier 1 and Tier 2 approaches use fuel sales as the primary activity indicator and assume average vessel emission characteristics to calculate the emission estimates. The Tier 3 ship movement methodology is based upon ship actual activities for individual ships [1, 4].

Table 2: Current legislation in relation to marine fuel quality.

Legislation	Region	Heavy fuel oil		Marine diesel	
		Sulphur % weight	Implem. date	Sulphur % weight	Implem. date
EU-Directive 1993/12	Mediterranean	None		0.2 (*)	1994
EU-Directive 1999/32	Mediterranean	None		0.2	2000
EU-Directive 2005/33	Mediterranean	1.5 (*)		0.1	2008
Marpol Annex VI	Mediterranean	4.5	2006		
Marpol Annex VI amendments	Mediterranean	3.5	2012		
		0.5	2020		
D.Lgs 55/2011 (Italy)	Italy	1.5 (**)	2010	0.1 (**)	2010

(*) Sulphur content limit for fuel sold inside EU.
(**) Sulphur content limit for fuel sold inside Italy.

We chose Tier 3 method since the detailed methodology allows separating and analyzing the contributions to ship emissions due to the different stages (i.e. cruising, maneuvering and hotelling). Tier 1 and Tier 2 are more suitable for national inventories being based on fuel sales but are unsuitable for local analysis.

Tier 3 methodology is the most detailed but requires a much more detailed input. Several input data are usually unavailable and must be obtained from other info. For instance the power of the main engine can be evaluated from the Gross Tonnage, the power of the auxiliary engine might be derived from that of the main engine, and the percentage load of the main engine is a function of the "phase" of a ship. Entec evaluated much info from statistical analysis of Lloyd's database for years 1997 and 2010. Lloyd's Register provides details of ships having "Gross Tonnage" greater than 100, thus for all ships loading more than $387m^3$. We also gathered additional specific data from databases of local administrations (Ancona Port Authorities, Marche Region, Etc.). For instance we collected data about number of dockings, ship characteristics, hotelling times, and engine powers. Tier 3 emission factors for PM and Specific Fuel Consumption for different engine types, fuel combinations, and vessel trip phases (cruising, maneuvering, and hotelling) in g/kWh are reported in Table 3.

4 Ancona Port situation

The Ancona Port Authority supplied data regarding hotelling time and auxiliary engine power for ships moored in the week from March 11th to 16th, 2011. We combined such data with gross-tonnage values and main-engine powers obtained

Table 3: Emission factors in Entec Tier 3 methodology for bunker fuel oil, marine diesel oil, and marine gas oil.

<table>
<tr><th>Engine</th><th>Phase</th><th>Engine type</th><th>Fuel type</th><th>TSP
PM10
PM2,5
(g/kWh)</th><th>Specific fuel consumption (g fuel/kWh)</th></tr>
<tr><td rowspan="10">Main</td><td rowspan="10">Manoeuvring
Hotelling</td><td rowspan="2">Gas turbine</td><td>BFO</td><td>1.5</td><td>336.0</td></tr>
<tr><td>MDO/MGO</td><td>0.5</td><td>319.0</td></tr>
<tr><td rowspan="2">High-speed diesel</td><td>BFO</td><td>2.4</td><td>234.0</td></tr>
<tr><td>MDO/MGO</td><td>0.9</td><td>223.0</td></tr>
<tr><td rowspan="2">Medium-speed diesel</td><td>BFO</td><td>2.4</td><td>234.0</td></tr>
<tr><td>MDO/MGO</td><td>0.9</td><td>223.0</td></tr>
<tr><td rowspan="2">Slow-speed diesel</td><td>BFO</td><td>2.4</td><td>215.0</td></tr>
<tr><td>MDO/MGO</td><td>0.9</td><td>204.0</td></tr>
<tr><td rowspan="2">Steam turbine</td><td>BFO</td><td>2.4</td><td>336.0</td></tr>
<tr><td>MDO/MGO</td><td>0.9</td><td>319.0</td></tr>
<tr><td rowspan="4">Auxiliary</td><td rowspan="4">Manoeuvring
Hotelling</td><td rowspan="2">High-speed diesel</td><td>BFO</td><td>0.8</td><td>227.0</td></tr>
<tr><td>MDO/MGO</td><td>0.3</td><td>217.0</td></tr>
<tr><td rowspan="2">Medium-speed diesel</td><td>BFO</td><td>0.8</td><td>227.0</td></tr>
<tr><td>MDO/MGO</td><td>0.3</td><td>217.0</td></tr>
</table>

for each ship. The main business of the Ancona port is represented by passenger and freight traffic (Ro-Ro Passenger) towards the eastern coast of Adriatic Sea (especially Greece, but also Croatia and Albania). Thus, the timetables of all shipping companies were used to obtain the hotelling time of each ship as difference between arrival times and next-departure times. We introduced two seasons: a high season (a kind of extended summer), characterized by frequent dockings, and a low season characterized by lower traffic. We used the timetables of 2012, which are readily available, also to ease future emission estimates in different scenarios of decreasing traffic mainly due to the Greece economical crisis, particularly concentrated on freight traffic (Table 4).

Table 4: Number of dockings at Ancona main port.

Year	2006	2007	2008	2009	2010
N. of dockings	2,852	2,726	2,643	2,586	2,348

4.1 Passenger and Ro-Ro

The Tier 3 methodology correlates the gross tonnage with the total main engine power through empirical formulas obtained by interpolation for each ship family. Ancona port also hosts hybrid ships (passengers + freight), so we checked equations for Passengers and for Ro-Ro and we compared the results with known data regarding main engine power. In table 5, the first two columns show actual Gross Tonnage and actual power of ships performing both passengers and freight transportation service (Ro-Ro) from Ancona to the east coast of Adriatic Sea (Greece, Croatia, and Albania). The third and forth column show values of engine power (in kW) obtained through the Tier 3 methodology as a function of Gross Tonnage according to two equations provided by Entec in 2007 for 2006

Mediterranean Sea fleet. Table 5 and Fig 2 show that, for at least 5 ships in service towards Greece and all with GT>30,000, the Entec value of main engine installed power is far from the actual one, both when we apply the Passenger equation and when we apply the Ro-Ro cargo equation.

Table 5: Gross tonnage, actual main engine power and the main engine values obtainable applying formulas made available by Entec for ferries.

	Name of ship	Gross Tonnage	Main Engine Power [kW]	Passenger (Entec)	Ro-Ro (Entec)
Greece	"Superfast VI"	32,728	42,837	22,797	10,577
	"Superfast XI"	30,902	48,679	22,021	10,264
	"Olimpic Champion"	32,694	50,400	22,783	10,572
	"Cruise Europa"	54,919	55,440	31,156	13,871
	"Cruise Olympia"	54,919	55,440	31,156	13,871
Croatia and Albania	"Marko Polo"	10,154	15,000	11,249	5,730
	"Zadar"	9,487	7,000	10,797	5,530
	"Dalmatia"	12,087	12,600	12,497	6,278
	"Regina della Pace"	16,405	17,664	15,027	7,367
	"Riviera del Conero"	8,975	10,297	10,442	5,372

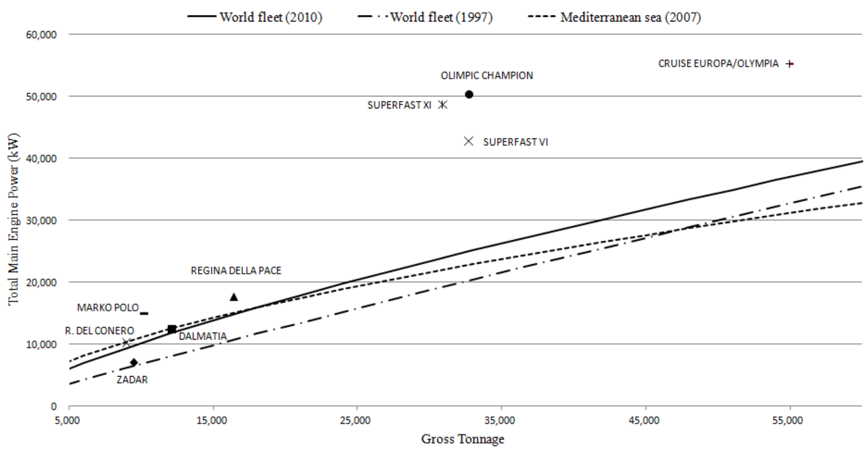

Figure 2: Passenger equation (Entec) vs. actual main engine power.

For several other ships the Passenger equation estimates much better the actual engine power than the Ro-Ro equation. We can conclude that the Passenger equation is apparently deficient for large tonnage ships. This is evident also when we apply the equations to two cruise boats that usually dock at the port of Ancona as reported in Table 6.

In the first phase we applied all Tier 3 methodology only to ships that are well interpolated by the Entec equation. For the passenger category of the Mediterranean Sea fleet the recommended average power ratio between auxiliary and main engine is 0.27.

Table 6: Gross Tonnage, actual main engine power and the main engine values obtainable from formulas made available by Entec for cruise.

	Gross Tonnage	Main Engine Power [kW]	Engine Power through Entec Passenger formula [kW]
"Costa Victoria"	75,166	50,700	37,653
"MSC Armonia"	58,174	31,680	32,258

Table 7: Estimated percentage load of main and auxiliary engine (Entec).

	% load Main Engine	% time Main Engine	% load Auxiliary Engine
Cruise	80%	100%	30%
Manoeuvring	20%	100%	50%
Hotelling	20%	5%	40%

For this study we analyzed only maneuvering and hotelling phases. For the maneuvering time we conjectured an average of 30 minutes for each ship. Entec suggests a 0.8 hours for passenger ships, but this value seems too high for this harbor. From the 2012 timetables we extracted the number of dockings and the average hotelling time. The formula to evaluate emissions in a certain phase according to Tier 3 is

$$E_{Phase} = Time_{Phase} * \begin{bmatrix} IMEP * LFME_{Phase} * TME * EF\ ME_{PM10} \\ +IAEP * LFAE_{Phase} * EF\ AE_{PM10} \end{bmatrix}$$

where Time is the overall considered period [h], IMEP is the Installed Main Engine Power [kW], LFME is the Load Factor of Main Engine [%], TME is the percentage Time of Main Engine on [%], EFME is a proper emission factor for the main engine (0.9 [g/kWh]), IAEP is the Installed Auxiliary Engine Power [(kW], LFAE is the Load Factor of Auxiliary Engine [%], and EFAE is a proper emission factor for the auxiliary engine (0.3 [g/kWh]).

The overall PM10 emissions from ferries towards non-Greek destinations (namely 748 total arrivals) are 1.01 tons due to maneuvering and 7.16 tons due to hotelling. Thus, every docking ship emits, on average, 1.34 kg of PM10 during maneuvering phase and 9.58 kg of PM10 during hotelling phase.

For the ships cruising to Greece, the Main Engine Power is not well interpolated by the gross-tonnage vs. main-engine-power curve so we checked two different approaches. In the first one, Tier 3 methodology has been applied for passengers' ships, considering the actual auxiliary engine power installed (Table 12) in hotelling phase. This value is multiplied by load of auxiliary engine. In the second one, average active values of auxiliary engine power provided by Ancona Port Authority have been applied.

This means that every ship destined to Greece, on average, emits 4.64 kg of PM10 during maneuvering phase and 5.93 kg of PM10 during hotelling phase for each docking. Individual emissions during hotelling phase of these ships (bigger in tonnage and installed power) are less than those of the ships cruising to other destinations, in particular Croatia and Albania (5.93 kg instead of 9.58 kg). The second approach is not applicable to the majority of boats hosted at Ancona Port due to the lack of data regarding auxiliary motors, thus we opted for Tier 3 methodology applied to the main and auxiliary engines installed power (Tables 10 and 11), instead of the average provided by the Port Authority (Table 12).

Table 8: Emissions from ferries to Croatia and Albania in low season.

Low season		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
"Marko Polo"	132	0.5	163.7	14	1,321.7
"Zadar"	117	0.5	139.3	15	1,124.5
"Dalmatia"	100	0.5	137.8	14	1,112.4
"Regina della Pace"	110	0.5	182.2	14	1,471.3
"Riviera del Conero"	156	0.5	179.6	5	1,449.9

Table 9: Emissions from ferries to Croatia and Albania in high season.

High season (summer)		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
"Marko Polo"	29	0.5	36.0	10.25	138.4
"Zadar"	46	0.5	54.8	5.5	113.1
"Dalmatia"	19	0.5	26.2	11	108.1
"Regina della Pace"	19	0.5	31.5	11	130.0

Table 10: Emissions from ships (route Ancona-Greece) – low season.

Low season		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
"Superfast VI"	81	0.5	341.4	21.5	1,674.5
"Superfast XI"	81	0.5	384.0	21.5	1,766.1
"Olimpic Champion"	81	0.5	394.8	21.5	1,730.4
"Cruise Europa"	138	0.5	989.7	3	1,652.3
"Cruise Olympia"	138	0.5	989.7	3	1,652.3

Table 11: Emissions from ships (route Ancona-Greece) – high season.

High season (summer)		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
"Superfast VI"	82	0.5	345.7	3	236.5
"Superfast XI"	82	0.5	388.8	3	249.5
"Olimpic Champion"	82	0.5	399.6	3	244.4
"Cruise Europa"	20	0.5	143.4	3	239.5
"Cruise Olympia"	20	0.5	143.4	3	239.5

Table 12: Auxiliary engine power (source: Ancona port authority).

	Auxiliary engine power installed [kW]	Average active value of auxiliary engine power [kW]	
		Low season	High season
"Superfast VI"	4,800	600	1000
"Superfast XI"	4,800	600	1000
"Olimpic Champion"	4,500	550	900
"Cruise Europa"	29,100	2,200	2,400
"Cruise Olympia"	29,100	2,200	2,400

Using the first approach, the overall PM10 emissions from ferries towards Greek destinations (namely 805 total arrivals) are 4.52 tons due to maneuvering and 9.68 tons due to hotelling. This means that every ship of this kind emits, on average at each docking, 5.614 kg of PM10 during maneuvering phase and 12.03 kg of PM10 during hotelling.

If we apply the second approach and we consider the actual power of auxiliary engines, according to Port Authority data (Table 12), we obtain 3.74 tons of PM10 due to maneuvering and 4.77 tons of PM10 due to hotelling.

For the cruise ships, the Port Authority registered 52 dockings during 2010, with an average maneuvering time of about 30 minutes and an average hotelling time of about 6 hours. Applying the same methodology used for the passenger traffic towards Greece we obtain 191.6 kg and 772.1 kg of PM10 respectively due to maneuvering and hotelling of "Costa Victoria" and 135.9 kg and 637.5 kg of PM10 respectively due to maneuvering and hotelling of "MSC Armonia".

4.2 Freight ships

The same methodology can be used for non-passengers ships. In this case we do not have specific data from Port Authority, besides the names of the ship moored in the week of 2011 we are considering. Moreover, while ferry service is usually performed by the same ships, freight traffic implies a greater variability of tonnages, installed powers and hotelling times. So we decided to use all the Tier 3 methodology for this type of ships. To apply Tier 3 is necessary to have at least the Gross Tonnage data. This has been obtained as an average over ships docked in the port in the week from March 11th to 16th, 2011.

Since the values are rather uniform, Tier 3 methodology with Entec equation has been applied as the main engine power registered in a sole week could not be used as a general sample. The powers of auxiliary engines have been obtained through the values in Table 13, and emissions have been calculated based on the total dockings provided by Ancona Port Authority for each typology of ship in the year 2010. Also in this case, two different approaches have been followed: in the first one we considered the average hotelling time in the week of March 2011 (results in Table 14), while in the second one (Table 15) we considered the hotelling time provided by Entec (although it does not consider the differences between ports of different countries and with different intended use, i.e. mainly touristic ports, commercial hubs, and so on). The estimate of emissions for the maneuvering phase is the same for both methodologies while, for the hotelling time, in the second case time periods increase and so emissions do (6.38 tons/year instead of 3.54 tons/year). We decided to consider the mean time of the typical week and not the time span provided by the Entec to use a more realistic value for Ancona port.

Table 13: Gross tonnage, actual main engine power and the main engine values obtainable from formulas made available by Entec for each type of freight traffic.

	Gross Tonnage mean value	Main Engine Power [kW], mean value	Equation for Mediterranean Sea fleet (Entec)	Ratio Auxiliary vs. Main Engine power (Entec)
Liquid bulk ships	15,069	4,873	5,129	0.35
Dry bulk carriers	2,937	1,485	2,426	0.39
Container	12,646	10,078	10,999	0.27

Table 14: Emissions from freight ships (hotelling time is the average value of the week).

		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
Liquid bulk ships	355	0.5	211.7	8.5	789.3
Dry bulk carriers	52	0.5	15.0	25.5	179.5
Container	390	0.5	472.9	14.5	2,575.0

Table 15: Emissions from freight ships (hotelling time suggested by Entec).

		Manoeuvring		Hotelling	
	Total arrivals	Length (hours)	kg/PM10	Length (hours)	kg/PM10
Liquid bulk ships	355	0.5	211.7	38	3,528.8
Dry bulk carriers	52	0.5	15.0	52	366.1
Container	390	0.5	472.9	14	2,486.2

4.3 Fishing boats

For fishing fleet we applied Tier 1 instead of Tier 3. This choice is due to the lack of data about engine powers while the tonnage of these ships is too small to require registration in Lloyd's register and detailed information on moorings are missing. In the regional plan for ports prepared by Marche Authority in 2010 a fleet of 134 fishing boats (constantly decreasing in number) is estimated. The average gross tonnage of Marche fleet is 20. Individual tonnage is very variable according to the type of fishing and to the specific activity (e.g. the average for trawling is 100). For this reason we decided to use the fuel consumption and apply an emission factor for PM10 (1.5 g PM10/kg fuel). The more recent datum on fuel consumption is given by the Piano Energetico Ambientale Regionale (Marche Environmental Energetic Plan, 2002) and is 35,000 tons of gas oil per year in the whole Ancona Province. Considering that the incidence of Ancona fishing fleet is 65% of the total of Province, the total emission from the fishing sector in the 3 phases (cruising, manoeuvring, and hotelling) is 34,125 kg/year. In 2005 the Italian Institute for Environmental Protection and Research (ISPRA), carried out the provincial disaggregation of the national emission inventory. For to the fishery activity, data supplied by ISPRA give similar results compared with data obtained by Tier 1 since both methods are based on fuel consumption.

5 Cold ironing

A significant reduction of pollutants can be achieved by applying a ground electrification of the docks. When the ships are docked all generators are on to supply electricity to vital devices, as on board lights and air conditioning. The so-called "Cold Ironing" lets ships to connect their on-board electricity systems to an ad-hoc electricity grid on-shore and to shut down the on-board auxiliary engines. The Port of Los Angeles was the first in the world to implement cold ironing for container ships in 2004. The first project in the Mediterranean Area has been planned for Civitavecchia port (nearby Rome) and it concerns the electrification of one pier. Only cruise ships with gross tonnage up to 130,000 and stationary electrical power consumptions up to 16 MW can moor in this wharf. However, to reach a true development of the technology, either important advantage for the shipping company shall occur or a proper set of rules shall force port authorities to implement and enforce cold ironing.

Another key point about cold ironing is the possibility to produce locally electricity in the so-called distributed co-generation mode so to obtain both electricity and heat. This allows an overall efficiency much higher than usual for small scale generators and, since ports are usually within or nearby populated areas, heat can be delivered to houses, offices, and commercial activities for heating and cooling through absorption refrigerators. This means that we reduce local pollution in three ways: by switching from oil to methane as primary fuel, by enhancing efficiency of conversion, and by reducing the emissions due to residential heating. We are now performing an overall evaluation on such scenarios to calculate the total amount of PM10 saved for Ancona port and neighbouring area.

6 Results and discussion

The total emissions of PM10, evaluated for passenger ships, are 24.11 tons/year. All the estimates were done considering low-sulfur fuel (0.1%) while emission factors [g/kWh] are the same for PM10 and TSP. We experienced difficulties in calculating the emissions of ships performing service towards Greece since the power value both of the main engine and of the auxiliary engine is not well estimated by the Entec equation. To improve the accuracy of our estimation, a survey on the actual power used by these ships during the hotelling phase is crucial. Comparing our results with the 2005 ISPRA data for the activity 080402, National Sea Traffic Within EMEP Area, we noticed that particulate matter emissions are similar, namely 34.84 tons. ISPRA values were obtained considering the fuel national consumptions and using the number of ships arrived

Table 16: Quantification of emissions from ships.

	Total arrivals	Manoeuvring (tonn PM10)	Hotelling (tonn PM10)
Croatia and Albania	748	1.01	7.16
Greece	805	4.52	9.68
Total ferry	**1553**	**5.53**	**16.84**
Cruise	62	0.33	1.41
Total (ferry+cruise)	**1615**	**5.86**	**18.25**
Bulk + container	797	0.70	3.54
Total	**2412**	**6.56**	**21.79**

in all the ports of the Province as a proxy variable. ISPRA values are higher also because they consider all the phases of cruising, manoeuvring, and hotelling.

The emissions inventory of Marche Region estimates for Ancona a quantity of PM10 coming from all the other activities of about 150 tons. This means that the port accounts for about the 14% of total PM10 emissions.

Regarding cold-ironing, in the short period is not possible to intervene on freights terminal to do not discourage the activities. Any decision on this sector must be taken by mutual agreement with other ports and also encouraging the ship owners, because of the high cost for the tuning of the ships. Thus, we support the electrification of the docks destined to cruise and passengers sectors as port authorities of the main Italian ports (Civitavecchia, Venice) currently do. In general this sector requires high installed powers, namely several MW, so cold ironing is functional in case of high percentage of passenger ships. This is true in Ancona port where most dockings are related to ferry services to the Adriatic East coast countries. Cold ironing applied to this type of ships could save 16.84 ton/of PM10 due to the hotelling phase. The cost for this type of traffic is easily amortizable, since these ships carry line service and only the few ones that moor more frequently in the port must be modified (Table 5).

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