A Case Study on the Environmental Impact of Harbour Activities: Analysis and Solutions

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Abstract

The problem of environmental pollution from marine activity is more and more relevant, particularly in zones where several ships with high electric energy production are frequently at berth. For these reasons, it is deemed very important to study the effect of simultaneous presence in port of ships that release big quantities of potentially noxious substances in the atmosphere.

In the Deptartments of Electric Engineering and Naval Architecture of the University of Naples "Federico II" (Italy) a common research program has been carried out with the aim of studying the impact of the operations of ships in port with particular regard to the effects of the exhaust gases when large amounts of electric energy is produced at bollard. Thus, the goal of the present study is to quantify the amount of noxious elements released in the atmosphere close to ports (and the consequent overall impact on the community living around the area) and figure out possible and sustainable solutions.

In this work we present the most recent aspects of this activity: acting rules, real effects on the human health, available data for the simulation of the environmental impact, reasonable scenarios for this simulation, alternative solutions to reduce the emissions of exhaust gases and the concentration of noxious elements in areas close to ships.

Keywords: Marine Engineering, All Electric Ships, Environment, Marine Pollution

1. Introduction

Since the Sixties, the consequences of the industrialization in the Western countries (and other) introduced a new item depending on the decadence of the natural environment where human beings, animals and the whole vegetal world live.

Many steps have been taken, many rules adopted and adapted to cope with this new "global" problem; but it's clear that a war like this cannot be easily won and the new levels of the environmental pollution are not always predictable and manageable because in most cases it involves huge establishments, political decisions, industrial trends and so forth.

Although the reaction against the increase in the environmental pollution has been strong and visible, some particular technological and logistic situations may still create relevant problems to people; indeed, sometimes new organizations of the social life can unintentionally lead to new (and important) sources of pollution that, in some cases, have not been taken into consideration at the start.

This is the case of many commercial passenger harbours located very close to highly inhabited zones; the exhaust emissions from many ships berthed close to each other at the same time, may reach such a level of air pollution that the atmosphere deteriorates unbearably.

Ports where a large access of cruise ships is allowed are certainly the most exposed to this risk and the zones close to sites where such ships berth are to be accurately studied from the point of view of the sustainability for human life: indeed, since during stays in ports many electric users must be on, this kind of ship requires a much larger amount of energy in comparison to others and this may lead to a relevant pollution of the surroundings.

This is the reason why the first steps of our work are focused on this kind of ships, disregarding – for the moment – other sources of pollution in port like cargo and other ships, vehicles operating in port areas, industrial activities, etc. Thus, in this paper, the existing (and future) rules managing the exhaust emissions from ships are stated, the effect of noxious substances on human health coming from that exhausts are described; thus, after a brief profile of the reference database we are using to study the behavior of ships in the field of emissions, an easy simulation of the case of the harbour of Naples is carried out in order to give some figures capable to represent the level of the problem we are facing.

1.1. Rules on the exhaust emissions from ships in ports

The attention of the legislator on this matter focused, most of all, on reducing emissions of sulphur oxides (SOx) and nitrogen oxides (NOx) in the atmosphere. Currently, in many European ports, rules control the emissions of SOx through the limitation of the content of sulphur in the fuel; in so called ECA areas, the maximum content of sulphur admissible in the fuel is 0.1%.

Alternatively, it is possible to burn fuels with higher concentration of sulphur if a retrofit capable to reduce the contents of SOx to less than 6.0 g/kWh is installed.

As regards NOx, there has been a progressive definition of the levels of emissions (tiers) progressively imposed, depending on the engines and their rpm.

Table 1 shows the way this limitation is arranged.

Table 1. Definitions of TIERs and limitation in NOx (g/kWh)

ENGINE SPEED	TIER II (< 1/1/2016)	TIER III (> 1/1/2016)
rpm < 130	14.4	3.4
130 < rpm < 2000	$44 / rpm^{0.23}$	$9 / rpm^{0.2}$
2000 > rpm	7.7	2.0

Deeper discussions on this matter can be found in (Coppola, and Quaranta, 2010), (Battistelli et al., 2011).

1.2. The effect of the noxious emissions on the human health

On this matter the WHO (World Health Organization) often supported studies on the impact of the environmental pollution on human health, stated its results on this item, suggested limitation in the various branches of human activity; in tables 2 and 3 the indications of WHO about the impact of SOx and NOx on the organism are given.

Table 2. WHO indications on the SOx impact on the human health

Sulphur oxides	
Concentration	*Effects on the health*
Exposure with limited injury	
0,06 mg/m^3	possible bronchitis episodes and chest infections
0,3 mg/m^3	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m^3	olfactory sensing of the substance (stimulates search for gas mask and refuge)
Exposure with serious injury	
0,06 mg/m^3	possible bronchitis episodes and chest infections
0,3 mg/m^3	possible damages to the respiratory system (especially for children and elderly)
0,8-2,6 mg/m^3	olfactory sensing of the substance (stimulates search for gas mask and refuge)

Table 3. WHO indications on the NOx impact on the human health

Nitrogen oxides	
Concentration	*Effects on the health*
50-150 mg/m^3	(for short periods of time) possible harm to lungs
100 mg/m^3	serious damages to the breathing apparatus
300-400 mg/m^3	lethal

Other indication about the influence of the noxious emissions on the health in (Coppola and Quaranta, 2010; Battistelli et al., 2011).

2. Possible solutions

There are no easy solutions to such a major problem. Moreover, a final solution for the limitation of emissions close to the big harbours can be achieved only by means of a strong cooperation among politicians, technicians and operators in the marine sector.

From a technical point of view, table 4 summarises the main causes of the air pollution in port areas together with a list of possible remedies.

Table 4. Main causes of air pollution and possible remedies

Air pollutants	Main pollution causes	Possible solutions
- particulate matter PM (PM10 in particular); - VOCs (Volatile Organic Compounds – benzene, formaldehyde, toluene and others); - nitrogen compounds (NOx); - sulphur oxides (SOx); - carbon monoxide (CO); - carbon dioxide (CO_2).	- propulsion and auxiliaries diesel engines onboard ships; - diesel engines onboard the vehicles destined to the handling of merchandise inside harbours.	- low sulphured, ecologic fuels; - use of new engines with lower SFOC and capable to use cleaner fuels; - retrofit (NOx and SOx); - cold ironing; - restrictions to the access in ports for old pollutant vehicles; - restrictions to the speed of ships and road vehicles in port areas; - electric energy supply to berthed ships from shore mobile systems fed by ecologic fuels.

3. The contribution of the electrical technologies to the port environmental sustainability: the cold ironing

Nowadays, technologies such as renewable energy sources and ICT (Information & Communication) offer, potentially a very high potential of environmental sustainability with the aim of containing pollution in harbour areas.

In the field of renewable sources sun, wind, biomasses, production of electric energy with fuel cells, innovative systems of energy storage, just to name a few, are more and more considered for the application in the harbour areas.

These systems should be integrated by microgrids or smart microgrids configured as a local active electrical systems able to supply all the electric loads normally in connection with the electric distribution utility (Battistelli and Fantauzzi, 2011).

In this context cold ironing surely represents the first step of any road map of eco-sustainable processes involving electric technologies.

Cold ironing (or "shore connection") means to supply ships at berth with feeding points close to the mooring sites so that the diesel electric generators onboard can be switched off and no exhausts are delivered during the ship stay. In these conditions, the shore electric system can feed the ship in "plug-in" mode.

This technique is not an absolute innovation. Applications of electrified banks have been known for many years and, since the 80s, even ferries could use such a technology because, as they have a stable mooring point, the connection with an electric network is very easy.

Anyway, this approach is nowadays particularly appreciated in the case of larger ships – first of all, cruise ships – in order to lower air pollution in ports.

Indeed, the electrified docks have a considerable success today, especially in North America and Europe; the following tables 5 and 6 report the European and American installations in use up to 2008 together with the main electric characteristics(Ericsson and Fazlagic, 2008)..

Many other applications are in progress; the most interesting are in Northern Europe and North America but remarkable installations regard China and Japan. In Italy, the ports of Civitavecchia, La Spezia and Venice have already shown their interest in cold ironing applications. A standard solution for cold ironing is not available yet; actually, the kind of installation depends on the specific environmental and commercial vocation of the port as well as on the kinds of ship to be fed.

This means that the solution to be adopted is to be evaluated on the basis of the maritime traffic and of environmental pollution of a particular port area, preferably in a mid-to-long-term scene.

Table 5 – 6. European and American installations in use up to 2008

European Ports	**Connection Voltage [kV]**	**Frequency [Hz]**
Göteborg (Sweden)	0.4	50
	6.6	
	10	
Stockholm (Sweden)	0.4	50
	0.69	
Helsingborg (Sweden)	0.4	50
	0.44	
Piteå (Sweden)	6	50
Anversa (Belgium)	6.6	50/60
Zeebrugge (Belgium)	6.6	50
Lubecca (Germany)	6	50
Kotka (Finland)	6.6	50
Oulu (Finland	6.6	50
Kemi (Finland)	6.6	50

USA Ports	**Connection Voltage [kV]**	**Frequency [Hz]**
Los Angeles (California)	0.44	60
	6.6	
Long Beach (California)	6.6	60
Seattle (Washington)	6.6	60
	11	
Pittsburg (California)	0.44	60
Juneau (Alaska)	6.6	60
	11	

Furthermore, the actual plant will depend both on the particular layout of the port (with constraints deriving from the arrangement of the existing electric connections), and on the particular electric power plant onboard the ships (Khersonsky et al., 2007), (Islam et al., 2007), (Islam et al., 2009), (Dev and Vahik, 2009).

Nevertheless, for practical, economic and dimensional problems, there are some invariants in present installations among which the most important, doubtless, the MV flexible cables (6÷20kV), even if the inner electric distribution net of the ship is at low voltage.

Other elements almost always present in a terrestrial plant are:

- the availability of an easy connection of the port medium voltage box dedicated to the cold ironing with an adequate power;
- the installation of such a box close to the mooring area.

In Figure 1 (see ref. Kohli, P.) a cold ironing system type is reported schematically. The connection is granted by a mid voltage flexible cable. A medium voltage socket and transformers are fitted onboard of those ship with a low voltage internal electric distribution system.

In some cases, the shore side connection is made by flexible cables unrolled from the ship and plugged to the berth.

Clearly, for a correct cold ironing installation, it is very important to evaluate the need of electric power and energy required by ships mooring in the given port.

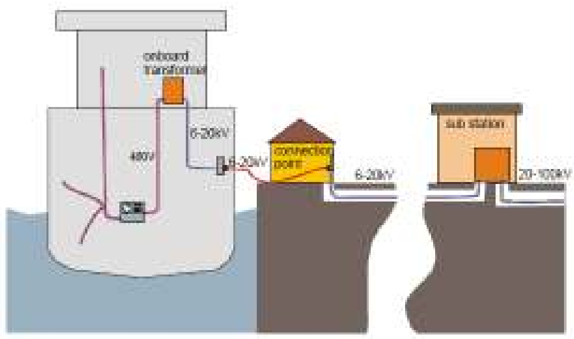


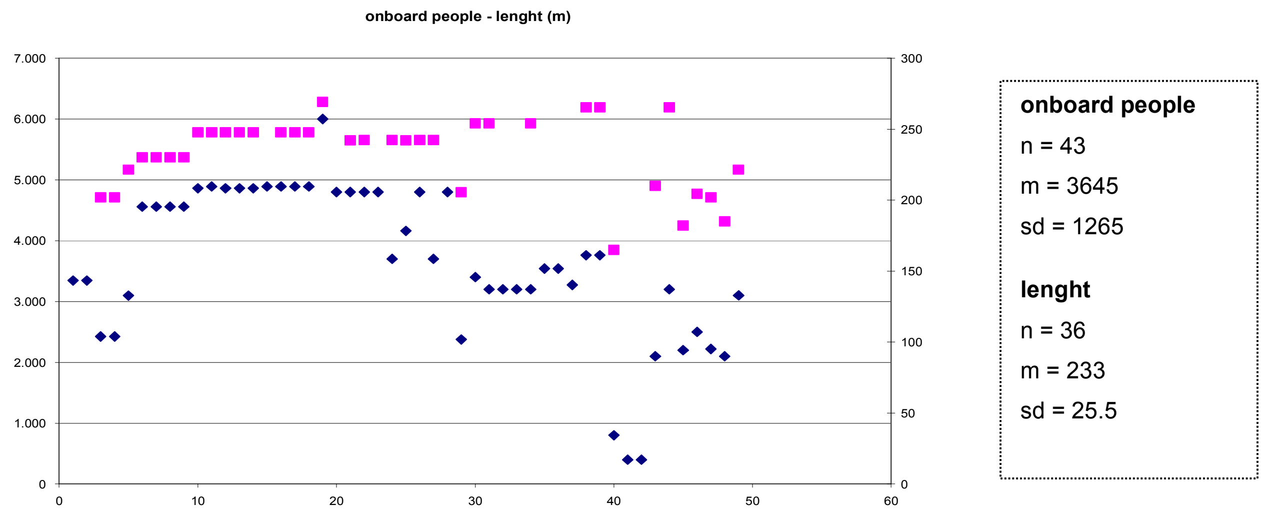
Fig. 1. Scheme of cold ironing connection

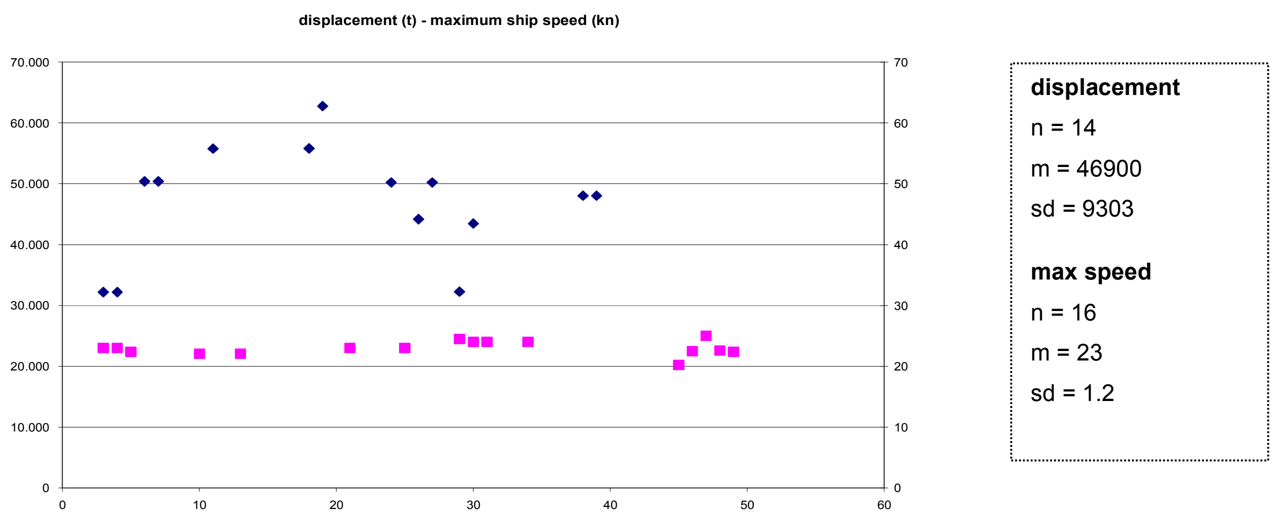
4. The reference database

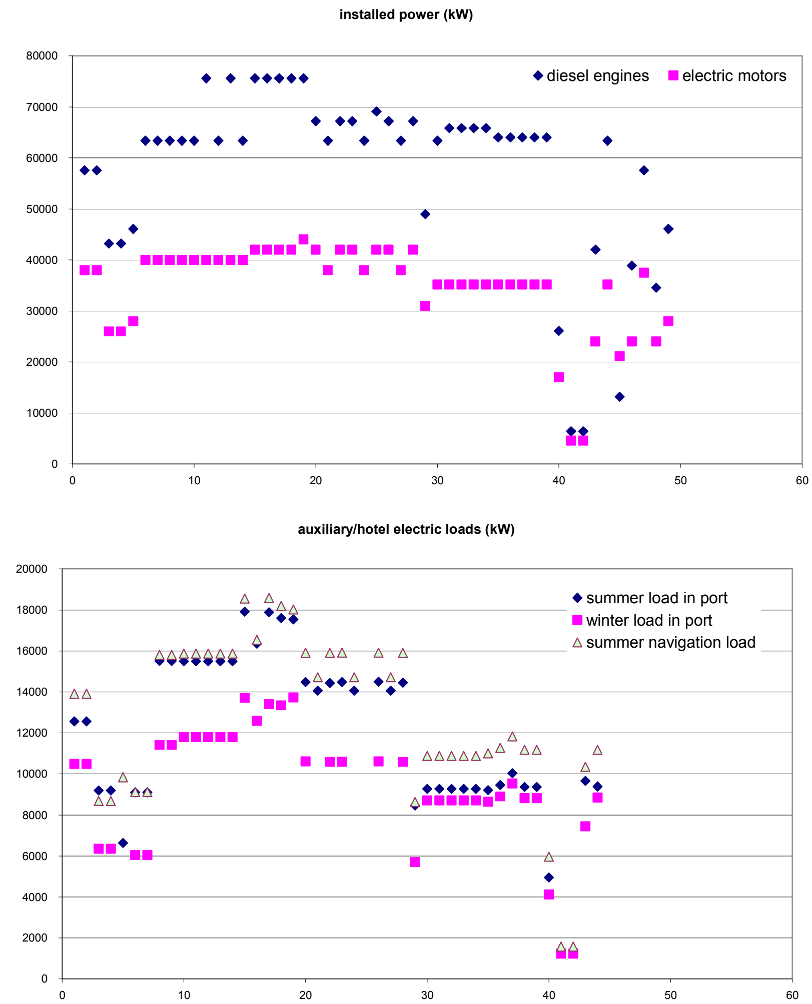
In order to develop the item we are talking about, we deemed it very useful to carry out the first realistic simulations on the possible pollution scene in a case study regarding a port whose major characteristics (number and size of ships simultaneously at berth, emissions from auxiliary engines, other pollution sources etc.) are known.

To do so, we could use a very interesting database that Fincantieri SpA gave us to help our study; it includes approx. 60 among the most recent cruise ships built in Fincantieri yards and gave us the possibility of a correct evaluation of the main parameters involved in the problem of pollution close to the harbour areas.

Following graphics summarize the used database by showing the main characteristics of the ship reported (for each graph, n = number of samples, m = mean value, sd = standard deviation).







diesel engines
n = 49
m = 58100
sd = 16700

electric motors
n = 49
m = 34700
sd = 9000

summer load
n = 43
m = 11800
sd = 4126

winter load
n = 39
m = 9340
sd = 3030

navigation load
n = 43
m = 12750
sd = 4050

Fig. 2. Main characteristics of the cruise ships used for the exhaust emissions simulation

5. A case study on the environmental pollution in port

Maybe, the size of the problem regarding the air pollution in ports where many cruise ship stay simultaneously can be better grasped with an easy but reliable application. Thus, we used the available database and simulated the contemporaneous presence of five cruise in the Port of Naples (which is possible - and probable - from May to October).

5.1. The Port of Naples

Since the fifth century BC, we have evidence of port activity in Naples; as the city expanded eastwards, the maritime traffic increased and the structures of the port were progressively renewed and extended.

Times and again the Port of Naples was rearranged and refurbished; during the XVth century, fortifications and operative structures like warehouses, depository and factories were built. In the XVIIIth

century, the harbour grew to become one of the most complete and active port structures including even a real yard where the first steam vessel of the Mediterranean area was launched.
Nowadays, the Port of Naples occupies a large part of the town coast, more than 5 km, from the San Giovanni area to berths in the centre of the city, and extends westbound where small structures destined to the local maritime traffic are located. The total length of its banks – useful for berthing ships – is more than 11 km, with 75 landing points; in the port there is a street network more than 3 km long and a rail system (more than 2 km) connected with the national railways.

5.2. Traffics in the harbour

From the point of view of the developed activities, the Port of Naples is one of the busiest harbours all over the world: all kinds of freight, goods, general loads, products, service liquids and all possible payloads are managed and transported by general cargos, container ships, oil and product carriers and any kind of known ships. In table 7, last available statistics (referred to 2009 – 2010 years) are reported with the aim of showing which the level of traffics in the Port of Naples.

Table 7. Traffics in the Port of Naples

Traffic	2009	2010
Cargo traffic (t)	19.419.192	22.064.180
Container traffic (TEU)	515.868	532.432
Passenger traffic (cruise + local)	8.618.000	8.000.000

More details about the Port of Naples, logistics, statistics, history, rules etc. in (Web 4).

5.3. Simulation of the emissions profile of cruise ship at berth

In order to give some significant figures about the possible pollution generated by the simultaneous presence of many ships close to inhabited zones, a simple simulation was carried out: starting from the layout of the harbour of Naples, a situation was imagined where five cruise ships in service are in the same time at bollard in a sector called “Molo Beverello” (as it is very usual to see) with diesel engines on for the production of electric energy.

The five ships were chosen from the Fincantieri cruise ship database; their characteristics are synthetically reported in table 8.

Table 8. Main characteristics of ships used for the simulation

n	mp	Lbp	Δ	v	PBme	PBce	PBmp	Psum
		(m)	(t)	(kn)	(kW)	(kW)	(kW)	(kW)
3	2425	202	32200	23	26000	43200	22300	**9200**
7	4560	230	50400	nd	40000	63360	34325	**9100**
19	6000	269	62800	nd	44000	75600	37800	**17500**
29	2375	206	32300	24,5	31000	49000	26600	**8500**
30	3400	254	43500	24	35200	63400	30000	**9300**

Legend:

n	number of ship (in the datasheet)
mp	maximum allowable number of persons onboard
Lbp	lenght between perpendiculars
Δ	full load displacement
v	maximum ship speed
PBme	installed propulsion electric motor power
PBce	installed diesel engines brake power
PBmp	diesel engine brake power for propulsion
Psum	aux/hotel electric load in port (summer)
nd	not declared

In order to have an idea of the overall emissions from these ships, supposed contemporaneously at bollard in the berthing point closest to the very centre of the town, we appreciated the values of the main emissions (SOx and NOx) simply by applying the present rules and the limitation involved in them.

So, as regards the SOx emissions, since a maximum emission of 6.0 g/kWh is admissible, we supposed this level for all the ships; NOx emissions were set to the maximum acceptable value in obedience to the abovementioned rules (rpm of diesel engines and alternators = 600).

The exhaust emission scene coming from this simulation is resumed in table 9.

Table 9. Exhaust emissions from five ships supposed at berth in the Port of Naples

n	Psum	SOx emission	NOx emission
unit	**(kW)**	**t/h**	**t/h**
3	9200	0,0552	0,0930
7	9100	0,0546	0,0919
19	17500	0,1050	0,1768
29	8500	0,0510	0,0859
30	9300	0,0558	0,0940
Total	**53600**	**0,3216**	**0,5416**

Thus, the point is to spill one third of ton of SOx and half ton of NOx per hour in the environment close to this crowded wharf; it is very easy to understand how heavy is the impact of such quantities of noxious elements released in a relatively short space and how easily microareas where the air is very toxic can be created.

6. Conclusions

It's time to react to the extension of pollution due to marine operations in some areas where the quality of the air risks of becoming unbearable. Apart from the technical solutions (described above), it is necessary for those who have the responsibility of the health of citizens to get engaged; it seems to be clear that the problem must be first studied deeply in order to highlight all its aspects and suggest the right countermeasures. The next steps of this study should be the prediction of pollution levels by ships in given conditions and, when possible, the measurement in site of these levels of concentration of noxious elements in the observed zones. As it frequently happens, a real (and dynamic) cooperation among the parts involved in this question should be established with the aim of concentrating the efforts for the quickest possible solution.

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References

Coppola, T., Quaranta, F., 2010. Il caso del Porto di Napoli: valutazione dell'impatto sull'ambiente cittadino generato dal traffico marittimo; The future Boat & Yacht 2010 Venice Convention – Venice (Italy), November 2010; Convention Proceedings (it - ISBN 978-88-900567-4-1).

Battistelli, L., Coppola, T., Fantauzzi, M., Quaranta, F., 2011. Evaluation of the environmental impact of harbour activities: problem analisys and possible solutions; IMAM 2011 Conference, Genoa (Italy), September 2011.

Battistelli, L., Fantauzzi, M., 2011. "Smart Microgrid in ports" Economic Perspectives and Industrial Strategies National Conference of AEIT Federazione Italiana di Elettrotecnica, Elettronica, Automazione, Informatica e Telecomunicazioni- 27-29 june 2011.

P. Ericsson, I. Fazlagic, 2008. "Shore side power supply" Master of Science Thesis – Chalmers University of technology – Goteborg Sweden 2008

Y. Khersonsky, M. Islam, K. Peterson, 2007. "Challenges of Connecting Shipboard Marine Systems to Medium Voltage Shoreside Electrical Power", IEEE Transactions On Industry Applications, Vol. 43, No. 3, May/June 2007, pagg.838-844.

M. Islam, K. Peterson, P. Chavdarian, C. Cayanan, 2007. "State of shore power standards for ships", IEEE PCIC '07 - Petroleum and Chemical Industry Technical Conference – Calgary 17-19 sept 2007

M. Islam, K. Peterson, P. Chavdarian, C. Cayanan, 2009. “Tackling ship pollution from the shore”, IEEE Industry Applications Magazine – Jan/Feb 2009, pagg.56-60.

P. Dev, H. Vahik, 2009. “Shore-to-ship Power Supply System for a cruise ship”, IEEE Industry Applications Society Annual Meeting, 2009 - Houston 4-8 Oct.2009.

Pawanexh Kohli, Cold ironing, An overview, CrossTree techno-visors presentation available at http://crosstree.info/Documents/ColdIroning.pdf

Web 1, http://www.ipta.org.uk/review_of_marpol_annex_vi.htm

Web 2, http://www.severnesnow.com/html/emissions.php

Web 3, http://www.imo.org/conventions/contents.asp?doc_id=678&topic_id=258

Web 4, http://www.porto.napoli.it/en/