SHORE-SIDE POWER SUPPLY OF SHIPS AS A POSSIBLE SOLUTION TO THE ENVIRONMENTAL POLLUTION IN THE HARBOURS

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ABSTRACT

The environmental problem in land activity created a big alarm especially close to very inhabited zones; in the marine field, after a very long period of stand by, the problem is felt mainly in the big water cities where, close to the harbours, a heavy microclimate exposes people who live nearby to risks of serious damages for their health.

As well known, one of the main causes of air pollution in the harbours is the contemporaneous presence of many ships producing large amounts of noxious substances.

In this paper, therefore, after a concise analysis of the electric power demand of ships while at berth, a particular attention is paid to the problem of the environmental impact of marine engines with considerations on the present rules and on evaluations about the air pollution in port areas also by means of experimental data drawn out during a full scale test campaign carried out in the harbour of Naples in the period March – April 2012.

Then some aspects of the shore-side power supply of these ships (also called "cold ironing") are presented.

Cold ironing claims to be an efficient solution to the reduction of air pollution in port areas since the on board diesel electric generators can be switched off and no exhausts are delivered during ship stay.

Anyway, as a real industrial standard solution for cold ironing is not available yet, it seemed appropriate to focus on some technical and economic aspects which are at the basis of any cold ironing project, and also on a series of possible interventions in port areas, all feasible at the present stage of the technology, able to match objectives of both energy savings and air pollution reduction.

1. INTRODUCTION

The economic importance of the sea and the development of maritime transportation has increased the territorial role and the socio-economic relevance of harbours, especially in a country, like Italy, that has become a big logistic platform at the centre of both inter-Mediterranean trades and of the routes between the Far East and Northern Europe.

As a consequence, problems regarding the operative capability of maritime logistic terminals together with a need for the economic management of equipped harbour areas, logistic board-shore

transfer processes and ship berthing have arisen.
The harbour is an integral part of a territory with a specific mission in the field of logistics and transportation; it has however some peculiarities that is worth noting in the perspective of problem analysis and operative solutions like the one examined in the paper:

- the harbour is an important territorial component with a definite location occupying large, properly distributed and equipped areas, with a wide structural impact on the morphology and geophysical aspects of the territory and on the ecosystem, on both land and sea;
- unless it is a pure industrial terminal, the harbour represents a significant part of the urban and/or suburban texture where the physical context is included;
- the activities developed in an harbour involve infrastructural and service networks with the territory;
- the development of the port activity is related to productive, commercial and service activities of organized external bodies varying in market sectors, geographic distribution, operative strategies;
- the development of the port activity is connected to the presence and interaction of several internal operators organized in a sort of condominium, with a complex and variously connected organization, both on the level of at infrastructures and of services.

Since port activities are both infrastructural and productive, they are a leading component of the economic and social development of the context, integrating and interrelating its activities with the surrounding territory. Nevertheless, the productive and infrastructural development often involves a contradiction with the principle of environmental preservation.
From the environmental point of view, the problem is particularly felt in the big water cities where, close to the harbours, a heavy microclimate may expose people who live nearby to risks of serious damages for their health; as a consequence, the objectives of reduction of noxious elements in the air and water, of energy efficiency, reduction of times and costs of activities in port areas and of interface with the surrounding urban context, have become very important, for both maritime operators and territorial bodies.

2. ELECTRIC POWER DEMAND FROM SHIPS WHILE AT BERTH

Passing through a big harbour it is possible to count “in activity” many ships at berth at the same time.
These ships are used to generate electric energy onboard for many applications, from simply feeding lights and air conditioners to more sophisticated systems of control and steering. In order to grant a correct ship management, other systems require electric power such as hull systems (bilge, ballast, balancing, etc.) safety systems, engine room devices, and all tools for the movement of loads and/or the management of passengers.
As well known, to produce the electric power needed to end users on board, dedicated diesel electric groups are used in conventional ships, while common diesel electric groups are used both for feeding auxiliary services and propulsion systems in the case, nowadays typical for cruise ships, of AES (All Electric Ships).
As typical for power system users, the power demand on board is variable in time and load curves during the berthing time may represent the power required for different kind of ships correctly.
Unfortunately, there is a lack of information on such data (electric measurement on board are missing) and the only way to evaluate the electric power absorbed onboard while a ship is at berth, is by means of some selected data base and the so called “load factors”.
Load factor is a coefficient which gives the average power used onboard (during berthing) with the maximum power demand as a reference.
Sometimes “load duties” are used instead; in this case, the same average power is referred to the overall electric power installed onboard for auxiliary services.

These factors obviously may vary greatly from ship to ship.
Load duties are sometimes difficult to obtain, especially when they have to be fixed from a data base; in the case of conventional ships the overall power installed with auxiliary diesel engines is a datum not always available even in Lloyd's Register of Ships (see, for inst. Browning and Bailey, 2006), while it is meaningless for an all electric ships.
Table 1 gives an idea of the on board power demand for different types of ships. The table has been built in Ericsson & Fazlagic (2008) and, although it only considers some type of vessels, it is particularly relevant as a guidance for dimensioning shore-side power installations.

Table 1. Power demand of different vessels type at berth

Vessel type	**Average Power Demand [kW]**	**Peak Power Demand [kW]**	**Peak Power Demand for 95% of the vessels [kW]**
Container (<140 m)	170	1000	800
Container (>140 m)	1200	8000	5000
Ro/Ro & vehicle	1500	2000	1800
Oil & Product Tankers	1400	2700	2500
Cruise	7500	11000	9500

The table clearly shows that cruises are the vessels that use major rates of electric power while at berth, followed by deep see containers and tankers.

3. ENVIRONMENTAL IMPACT OF ON-BOARD AUXILIARY ENGINES

As well known, the operation of the on board auxiliary diesel engines is one of the main causes of air pollution in a port area.
In particular diesel engines emit noxious gases, the most important being:
a) nitrogen oxides NO_x and sulphur oxides SO_x;
b) carbon monoxide (CO) and carbon dioxide (CO_2);
c) particulate matters PM (in particular PM_{10});
d) the volatile organic compounds (VOCs - benzene, formaldehyde, toluene, etc.).
Apart from the presence of these substances, their combinations may create further noxious elements. For example, the interaction between VOCs, NO_x and the sunlight produces ozone; sulphur oxides, combined with water steam, generate the so called "acid rain" which can cause serious damages even in zones far away from the pollution source.

3. 1 Rules

The awareness of the problem of the environmental pollution dates back to some decades ago: thus, the famous ANNEX VI of the MARPOL 73/78 (and its amendments) created the so called SECA (Sulphur Emission Control Area) where the use of fuels with a controlled level of sulphur was introduced.
The first SECA entered into force in 2006 and involved the English Channel and the Baltic Area.
Sometime later, in order to meet the dramatic conditions of ports located close to big towns, the ECA (Emission Control Area) were introduced as zones where more stringent fuel sulphur and engine NO_x limits were imposed. In all European ports, for example, the maximum sulphur contents in the fuels was fixed in the 0.1% (since 2008/1/1).
As regards the air pollution, in particular, the production of NO_x, SO_x, PM (depending on the sulphur

oxides) and CO_2 are under observation in order to contain the noxious effects of these substances on the environment.
The ways to handle NO_x and SO_x in order to clean the exhausts are considerably different: the limitation in SO_x is achieved by a reduction of the sulphur in the fuel. The synthesis of present and future limits is given in table 2.

Table 2. Maximum admissible content of sulphur allowed in the fuel (%)

TERMS	NON SECA AREAS	SECA AREAS
> 1/1/2012	3.5	
> 1/1/2020	0.5	
< 1/1/2015		1.0
> 1/1/2015		0.1

In addition to these limits, the "EU DIRECTIVE 2005/33/EC", emending "MARPOL Annex VI Air Pollution", limits the sulphur contents of marine fuel in many areas (including all European ports) to 0.1 % (see for inst, Revised MARPOL Annex VI – 1997, Directive 2005/33/EC of the European Parliament).
If low sulphured fuels are not available onboard, the Annex VI permits the use of retrofits that must reduce the maximum value of SO_x to 6 g/kWh.
The emission of NO_x depends on the temperature of combustion and the only way to contain it in the exhaust emissions is to set the engine (pumps, turbochargers, ignition timing etc.).
Table 3 presents limits in NO_x contents in the exhausts from marine engines; in the field between 130 and 2000 rpm (practically, all the engines destined to the production of electric energy onboard), the limitation are fixed as a function of the engine rpm.

Table 3. Maximum admissible emissions of NO_x (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

3. 2 Evaluation of the emissions from ships

To give an idea of the environmental impact of ships while at the berth let's consider the case of four large cruise ships berthed together in a same mooring area (many European ports have a similar situation).
For an average power demand of 7.5 MW for each engine powering these 4 ships (see table 1), 30 MW will be required; even if all engines fully respect the present limits for NOx and SOx, an easy calculation permits to determine the amount of emission of NOx released in a small area close to the berthing point. Since for engines working @ ~ 900 rpm the maximum allowable emission of NOx is 9.20 g/kWh, the total emission from the four ship is about 0.27 t/h.
A different question regards the SO_x emission: the use of low – sulphur fuels drastically lowered that emission. Using "clean" fuels a reasonable figure for the specific emission of SO_2 is about 0.5 g/kWh (see the following table 4). With these numbers, a possible value of the hourly emission of SO_2 is 15 kg/h. But, in case low – sulphur fuels are not available onboard during the stay of the ship in port, a major emission is permitted (for inst. using scrubber or other retrofits) up to 6 g/kWh. With this level of emission, the total release of SO_2 in the air may raise up to 0.18 t/h.

3. 3 Evaluation of the pollution in ports

A reliable determination of the level of pollution connected with the ship operations is very hard to do and it is almost impossible without the support of full scale tests aiming at revealing the real concentration of the noxious substances in the air close to the harbour. Indeed, an analytic prediction of this parameter, apart from the exact emission rate from all engines present in port, should consider many factors connected with the diffusion of substances in the air (thermal gradient, direction and intensity of winds, even humidity of the air and so on).

In Battistelli et alii (2012) the first results of a series of full scale tests carried out in the port of Naples are given; tests were performed in March-April 2012, in the area close to the berths normally occupied by cruise ships.

Although only few ships where at bollard in that period, some pollution problem was clearly detectable and the maximum allowable limits suggested by the WHO for NO_x and SO_x concentration in the air were approached.

In order to give a synopsis of these results, Table 4 shows the present limits for NO_x and SO_2 according to the rule n. 155/10 accomplishment of the DIRECTIVE 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

Table 4. Admissible levels for the concentration of NO_x and SO_2 in the air

Substance	***Kind of average***	***Maximum acceptable limit***
NO_x	1h	200 μg/m^3
	civil year	40 μg/m^3
SO_2	24 h	125 μg/m^3
	1 h	350 μg/m^3

The abovementioned tests showed levels of NO_x of about 100 μg/m^3 practically for all the period when only one cruise ship was at bollard, about 120 μg/m^3 with 3 or 4 ships in port; much less was the detected content in SO_2, due maybe to the correct use of low sulphur fuels when ships were in the port area. For more detail see the reference above; but, anyway, the situation is clearly critical since the maximum limits are approached even if the port is not full like it is in other periods of the year.

4. SHORE SIDE POWER SUPPLY OF SHIPS

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

This technique is not to be considered an absolute innovation since applications of electrified banks for military ships date back in the 80s.

Anyway, during the last years, the electrified docks have had a considerable success, especially in North America and North Europe, with a significant number of installations under the thrust of the environmental driving force partly summarized in Table 5 where the comparison of average emission factors for the electricity production in Europe and onboard generation of electricity with 0.1% sulphur fuel, as stated by ENTEC (2005), is reported.

News of remarkable installations - in progress and/or planned – are coming from China and Japan while in Italy, the ports of Civitavecchia, La Spezia, Genoa and Venice have shown their interest for cold ironing applications.

Table 5. Comparison of average emission factors for the electricity production in Europe and onboard generation of electricity with 0.1% sulphur fuel.

	NO_x [g/kWh]	**SO_2** [g/kWh]	**VOC** [g/kWh]	**PM** [g/kWh]
Average emission factors for electricity production in Europe	0.35	0.46	0.02	0.03
Emission factors from auxiliary engines using 0.1% sulphur fuel (EU 2010 limit)	11.8	0.46	0.40	0.30

Referring to a cold ironing power system project it is worth pointing out this is not a straightforward task. A real industrial standard solution does not exist; every port, where a cold ironing project is under consideration, must have its own solution evaluated on the base of many different considerations that may be grouped as allows:

a) *ships to be fed;*
b) *maritime traffic;*
c) *port limitations or constraint.*

For the item a), particular attention has to be given to the onboard electric power system and its compatibility with the terrestrial system; differences can arise depending upon the country the ships were manufactured. Moreover ships modifications are normally required for the shore side power supply and the cost associated must be properly taken into account. Detailed inventory of pollution emissions must be necessary developed.

A detailed maritime traffic - better if in a mid long-term scene – must be usually available; docking intervals and frequency of their calls at the specific port are essential data to know.

Port limitations or constraints can occur in layout, unavailable staff for maintenance and operation of shore power handling, limitations in making provisions for available shore power supply or in a power utility interface inadequate for power delivery.

An economic analysis is usually required to derive the cost effectiveness factor (CEF) based upon the net present cost v/s total emissions reduced for all pollutants over the projected life of the project; the aim of such analysis is to identify the most convenient ships to be shore side supplied.

5. ROAD MAP OF ECO-SUSTAINABLE ACTIONS IN PORT AREAS

Cold ironing must represents only the first step in the implementation of a road map of eco-sustainable actions in port areas.

With the aim of reducing noxious elements in the air, a set of ecosustainable interventions in both internal and external port's areas, better if integrated with the metropolitan area environment, are nowadays possible and must be considered for their accomplishment.

All the interventions comply the environmental objective also through energy efficiency improvements and reduction of times and costs of activities in port areas and make use – as common element – of modern electric and ICT (Information & Communication) technologies including for example:

- renewable sources as sun, wind and biomasses, production of electric energy with fuel cells, electric energy storage systems;
- high efficiency lighting systems;
- electric vehicles (EVs), hybrid electric vehicles (HEVs) and electric charging points for the internal and external mobility of the port's area;
- microgrids or smart microgrids able to integrate all the electric subsystems and implement a two-

way communication system with the possibility of a direct participation to the electric energy market. In the near future, with a well-defined intervention program, port's areas are expected to become "smart", integrating the environmental monitoring with the intelligent distributed energy resources, including shore to ship facilities managed according to the technological "smart grid" paradigms.

6.CONCLUSIONS

The development of maritime transportations if on one hand has increased the territorial role and the socio-economic relevance of harbours on the other hand highlighted some important problems that haven't been solved yet.
Among them, the environmental pollution related to the maritime activity in harbours is certainly into close-up; in particular, the simultaneous presence of many ships at berth – with engines working – generates large amounts of toxic substances in limited zones. Air pollution due to the emission of noxious gases in the atmosphere by many diesel engines operating in ports is now under observation by all the Bodies in charge of the safety in such areas.
One of the most attractive way to face this problem is through shore side power supply of ships while at berth. Anyway, for every specific port where a cold ironing is planned, an economic analysis with many technical considerations involved, is usually required to identify the most convenient ships to be shore side supplied.
In view of an environmental strategy linked to harbour activities it is advisable not to limit the interest to cold ironing installations only; a set of eco-sustainable interventions in both internal and external port's areas are nowadays not only feasible but desirable.
Apart from technical solutions, it is necessary for those who have the responsibility of the health of citizens to get engaged; a real (and dynamic) cooperation among the parts involved in this question is unavoidable in order to give definite answers on the subject.

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