# Emission reduction in port with Cold Ironing: Italy national case study

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## Abstract

The paper reports the large scale three years feasibility study carried out in Italy at the national level with the aim to evaluate initiatives to reduce emissions of pollutants (particularly sulfur oxides and nitrogen oxides) from ships at berth by connecting them to the national grid.

## Introduction

A specific Recommendation of the Commission of the European Communities on this subject was published in 2006 (Commission of the European Communities, 2006) deals with connecting ships to national electric grid when berthed in port. In particular, it is possible to reduce emissions from ships during their stay in port by connection to the land based electricity network (cold ironing) allowing ships to turn off their auxiliary engines in such a way that all the engines of the ship can be switched off in port. The technology reduces net emissions, because land-based electricity generation complies with emission standards more stringent than those for ship engines.

The feasibility study involves four national ports (Livorno, Ravenna, Gioia Tauro, Taranto) and a cruise line with three cruise terminals (Palermo, Napoli, Livorno) in the Tyrrhenian Sea.

The port of Livorno, classified as big regional (first level) in the Tyrrhenian Corridor, by the Freight Leaders Club, is a multi-purpose port, that is equipped with infrastructure that can accommodate any kind of ship and handle any kind of goods and all types of traffic (LO-LO, RO-RO, liquid and dry bulk, new cars, cruises, ferries, forest products, machinery, etc.). The Port of Ravenna, a major 'canal' port extending for more than 14 km, is an Italian leader in commercial trade with the East Mediterranean and the Black Sea (about 30% of the national total excluding petroleum products), and plays an important role in trade with the Middle and Far East. Gioia Tauro is a terminal for the transhipment of containers, transported both by large transoceanic ships and by small ships for the distribution in the short range (Feeder) with over 3 million Teus/year handled. The port of Taranto is the second in Italy for goods traffic, handling raw materials and products of the major European steel plant, liquid bulk and containers. The Napoli cruise terminal has 7 boarding berths, which are 1,100 meters long with over 500 calls for year. The Livorno cruise terminal also has over 500 calls for year while the Palermo cruise terminal has over 250 calls for year.

## Consumptions and emissions estimate

For every berth at each port date and time of arrival and departure of each ship have been collected for a period of one to five years depending on the port. Each ship has been associated with the specific fuel consumption (*Lloyd's Register of ships* and direct census on national ships fleet) and total fuel consumptions at berth have been computed.

The fuel consumption was calculated according to the following formula:

$$C_{ij} = P_j \cdot t \cdot FC_{ij}$$

where: i, fuel (Bunker Fuel Oil, Marine Gas Oil); j, type of engine (main, auxiliary); $C_{ij}$, total consumption of the fuel i for the engine type j, $P_j$, power of engine j used in port (kW); $FC_{ij}$, specific fuel consumption (g/kWh) of the fuel i and engine type j; t duration of stay (hours).

With regard to the engines power, the Lloyd's database was used for information relating to the total power of the main (ME) and auxiliary (AE) engines. The power output of the engines at berth was calculated by taking the percentage of load from previous study (Entec, 2005) and data survey (Table 1). Specific fuel consumptions derive from previous Concawe study (Entec, 2007) on Mediterranean Sea (Table 2).

Table 1: Engine operation parameters for the different activities

| | % load of MCR* for ME operation | % of time all MEs operating | % of electric power from shaft generators | % load of MCR* for AE operation |
|---|---|---|---|---|
| At sea | 80 | 100 | 50-100*** | 0***-30 |
| In port (tankers-using pumps) | 20 | 100 | 0 | 60 |
| In port (no tankers) | 20 | 5 | 0 | 0***-30**-40 |
| Manoeuvring in port | 20 | 100 | 0 | 0***-50 |

** Data from survey in this study, Entec, 2005 otherwise
*** Turbine electric propulsion, Diesel propulsion otherwise

Table 2: Specific fuel consumptions

| Engine type | Specific fuel consumptions (g/kWh) | |
|---|---|---|
| | *Bunker Fuel Oil (BFO)* | *Marine Gas Oil (MGO* |
| High-speed diesel | 234 | 223 |
| Medium-speed diesel | 234 | 223 |
| Slow-speed diesel | 215 | 204 |
| Gas Turbine | 336 | 319 |
| Steam turbine | 336 | 319 |

The emissions are obtained using the formula:

$$E_{ijk} = P_j \cdot t \cdot F_{ijk}$$

where: i, fuel (Bunker Fuel Oil, Marine Gas Oil); j, type of engine (main, auxiliary); k, pollutant; $E_{ijk}$, emission factor of pollutant k, from the use of the fuel i in engines of type j $P_j$, power of engine j used in port (kW); $F_{ijk}$, emission factor of pollutant k, from the use of the fuel i in engines of type j.

Using emission factors (Table 3) from the EMEP/EEA Guidebook (EMEP/EEA, 2009), emissions have been finally evaluated for each berth of each port (Table 4).

Table 3: Emission factors at berth

| Fuel | Bunker Fuel Oil (BFO) | | | Marine Gas Oil (MGO) | | |
|---|---|---|---|---|---|---|
| Engine type | $NO_x$ (g/kWh) | $PM_{10}$ (g/kWh) | NMVOC (g/kWh) | $NO_x$ (g/kWh) | $PM_{10}$ (g/kWh) | NMVOC (g/kWh) |
| Main engines | | | | | | |
| High-speed diesel | 9,30 | 2,40 | 0,60 | 9,90 | 0,90 | 0,60 |
| Medium-speed diesel | 10,80 | 2,40 | 1,50 | 10,20 | 0,90 | 1,50 |
| Slow-speed diesel | 14,00 | 2,40 | 1,80 | 13,10 | 0,90 | 1,80 |
| Gas Turbine | 3,00 | 1,50 | 0,50 | 2,80 | 0,50 | 0,50 |
| Steam turbine | 1,60 | 2,40 | 0,30 | 1,60 | 0,90 | 0,30 |
| Auxiliary engines | | | | | | |
| Medium-speed diesel | 14,20 | 0,80 | 0,40 | 13,50 | 0,30 | 0,40 |

## Potential for emissions reduction

Potential for emissions reduction with the electrification of all the docks are evaluated, in a very conservative approach, comparing emissions from ships with emissions from land based electricity productions from fossil fuels computed with average national emission factors. In this evaluation only ships stops whose duration is greater than a threshold value (2 hours), chosen

in a conservative way based on technical times of connection and disconnection, have been taken into consideration. Potential for $NO_x$ emissions reduction (Table 4) is in the range of 80%-95%, for $SO_x$ reductions are about 35% (respect to 0.1% sulfur content marine fuel oil), for $PM_{10}$ are in the range 68%-95% and for NMVOC are in the range 78%-95%.

Table 4: Potential for $NO_x$ emissions reduction with the electrification of all the docks

| $NO_x$ Emissions (Mg) | Livorno | Ravenna | Gioia Tauro | Taranto | Napoli cruise terminal | Palermo cruise terminal |
|---|---|---|---|---|---|---|
| Total port (t) | 2873 | 1269 | 667 | 1163 | 528 | 148 |
| Berth longer 2h only | 2600 | 1169 | 667 | 1064 | 528 | 148 |
| Berth longer 2h with "*cold ironing*" | 228 | 55 | 28 | 41 | 108 | 34 |
| Avoided emissions - "*cold ironing*" (t) | 2372 | 1114 | 639 | 1023 | 414 | 114 |
| Reduction on selected berths % | 91% | 95% | 96% | 95% | 79% | 77% |
| Reduction on all berths % | 83% | 88% | 96% | 88% | 79% | 77% |

## Techno-economic aspects of grid connection

No major technical or economic issue, which may constitute obstacles to the development of actions at individual docks, has been detected. The electrical loads required for each dock and globally for the whole port have been evaluated as reported in Table 5.

Table 5: Estimated electrical loads for the selected ports

| Port | Average power (kW) | Maximum power (kW) | 95° percentile (kW) (°) | 90° percentile (kW) (°°) |
|---|---|---|---|---|
| Ravenna | 10.157 | 21.747 | 15.711 | 14.318 |
| Taranto | 10.758 | 24.669 | 17.081 | 15.391 |
| Livorno | 21.739 | 86.243 | 40.850 | 33.830 |
| Palermo cruise terminal (°°°) | 11.049 | 49.522 | 32.690 | 28.385 |
| Napoli cruise terminal (°°°°) | 15.533 | 36.190 | 34.613 | 30.160 |

(°) 95 % hours/year maximum total power requirements less than the reported value
(°°) 90 % hours/year maximum total power requirements less than the reported value

A land-based power source, transmission system, and related infrastructures are required to provide electricity to a hotelling marine ship. An electrical cable system is required to bring shore-side power to the ship during hotelling. A preliminary analysis of port costs is reported in Table 6 comparing solutions with centralized and decentralized dock systems (transformer and frequency converter) and fixed or mobile alternative maritime power (AMP) supply. Finally the docks on which to assess the details of connection have been selected.

Table 6: Example of cost evaluation for different dock configuration (Napoli cruise terminal)

| | Description | Costs (€) with Fixed AMP system | Costs (€) with Mobile AMP system |
|---|---|---|---|
| Solution 1: decentralized dock systems | dock 9-10-11 | 5.700 | 6.700 |
| | dock 6-7 | 5.700 | 6.700 |
| | dock 5 | 4.000 | 4.900 |
| | **Total** | **15.400** | **18.300** |
| Solution 2: centralized system | **All docks** | **12.738** | **15.043** |

A detailed assessment of the cost of electricity and fuels has been carried out taking into account the broad variability of fuel prices (Figure 1) and electricity prices for different levels of consumption including or excluding taxes. Finally the money saving vs. oil prices for different electricity prices (Figure 2) has been evaluated. In the cost/benefit analysis it is used the forecast of 344€/t for MGO (1% sulfur content) in 2020 (Concawe, 2009) evaluating the impact of taxes.

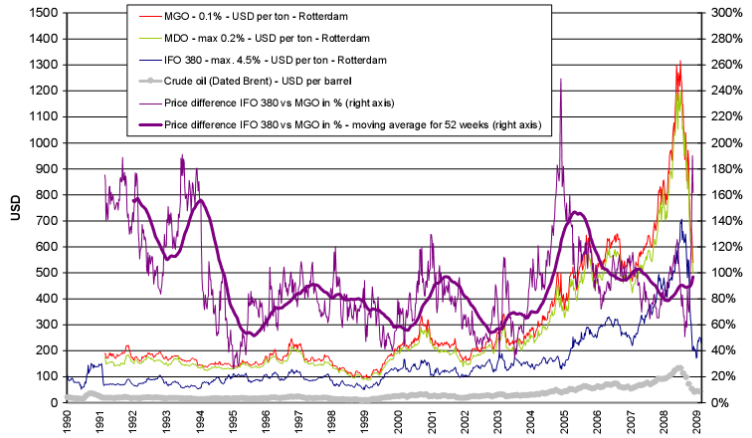


Figure 1: IFO 380 (BFO), MDO, MGO and crude oil prices (Rotterdam)

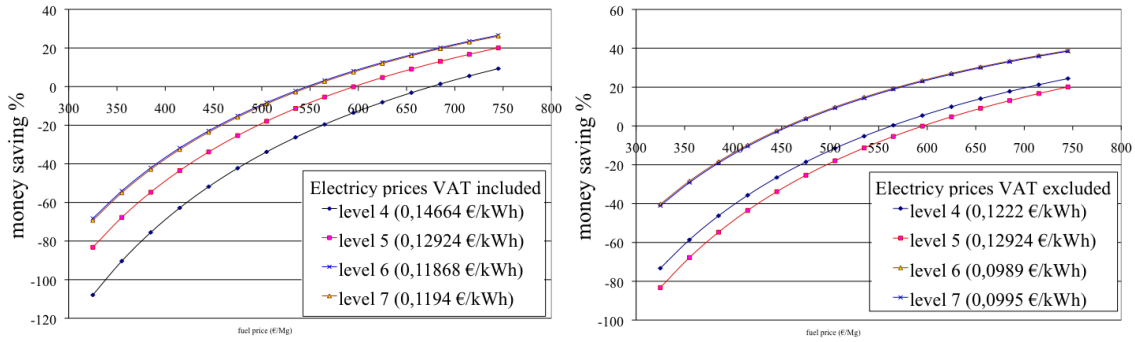


Figure 2: Cold ironing money saving vs. oil prices for different electricity prices (VAT included or excluded)

## Cost estimates

Costs of the port for connection to the national electricity transmission network and for the implementation of the connection system (Table 7) as well as costs for ship-owners for adjusting the electrical systems on board and their management (Table 8) have been evaluated.

Table 7: Cost evaluation for port infrastructures (whole port)

| Porto | Livorno | Ravenna | Gioia Tauro | Taranto | Napoli cruise terminal | Palermo cruise terminal |
|---|---|---|---|---|---|---|
| Investment costs (k€) | 89.166 | 58.698 | 36.364 | 48.231 | 15.400 | 22.500 |
| Time of life (years) | 20 | 20 | 20 | 20 | 20 | 20 |
| Annual total costs (k€/anno) | **5,102** | **3,168** | **2,064** | **2,451** | **896** | **1,309** |

Ships participating in a shore-power electrification program will require the installation of shore-power cable receptacles and an associated electrical management system. For ships already in service without shore-power capabilities, retrofitting of the current system is necessary. In-service retrofit of the existing on-board electrical system is possible. For new builds, the ship owner can request an on-board shore-power ready system be included as part of the ship's electrical system design. In the evaluation of costs for ships owners the investment costs are

assigned for 50% to the port (assuming another 50% assigned to the port of origin/destination). The investment costs calculated in such a way are reported in Table 8.

Table 8: Investment and installation costs for ships owners (all ships)

| Porto | Livorno | Ravenna | Gioia Tauro | Taranto | Napoli (^) | Palermo (^) |
|---|---|---|---|---|---|---|
| On-board transformers (k€) | 43.150 | 18.210 | 28.238 | 20.053 | - | - |
| Winder systems (k€) | 59.292 | 81.775 | 28.500 | 58.917 | - | - |
| *Total (k€) (°)* | 102.442 | 99.985 | 56.738 | 78.970 | | - |
| Time of life (years) | 10 | 10 | 10 | 10 | - | - |
| *Annualized costs (k€)* | 11.102 | 10.836 | 6.149 | 8.558 | **-** | **-** |

(°) include winder systems, if required by law, and are valued at 50% to account for the operations of the vessels of at least two ports and the resulting distribution of costs on different sites
(^) on board transformer already in use on cruise ships

Operating costs have been evaluated as the difference between electricity costs and reduced costs for saved fuel (Table 9).

Table 9: Operating costs for ships owners (all ships)

| Porto | Livorno | Ravenna | Gioia Tauro | Taranto | Napoli | Palermo |
|---|---|---|---|---|---|---|
| Fuel saved (Mg/year) | 39.371 | 14.647 | 22.207 | 21.521 | 8.610 | 2.534 |
| Money savings (k€/years) | 15.945 | 5.932 | 8.994 | 8.716 | 3.487 | 1.026 |
| Electricity purchased (MWh/year) | 157.968 | 58.636 | 88.815 | 86.608 | 36.452 | 10.781 |
| Electricity with VAT (k€/year) | 18.861 | 7.578 | 10.541 | 10.279 | 4.711 | 1.581 |
| Electricity without VAT (k€/year) | 15.718 | 6.315 | 8.784 | 8.566 | 3.926 | 1.317 |
| Total VAT included (k€/year) | 2.916 | 1.646 | 1.547 | 1.563 | 1.224 | 555 |
| Total VAT excluded (k€/year) | -227 | 383 | -210 | -150 | 439 | 291 |

## Effective emissions reduction and cost/benefit analysis

The reduction of emissions that can be achieved with cold ironing was evaluated as reported on Table 10 only on pier with a significant number of calls (greater than 50 for year).

Table 10: Reduction of emissions that can be achieved with cold ironing

| Porto | Emissions reductions (Mg/years) | | | | % emissions reduction on selected piers | | | | % emissions reduction on overall port | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $NO_x$ | $SO_x$ | NMVOC | PM | $NO_x$ | $SO_x$ | NMVOC | PM | $NO_x$ | $SO_x$ | NMVOC | PM |
| Livorno | 1937 | 28 | 124 | 80 | 91 | 38 | 90 | 90 | 68 | 28 | 63 | 62 |
| Ravenna | 757 | 10 | 37 | 25 | 95 | 39 | 95 | 95 | 61 | 25 | 55 | 54 |
| Gioia Tauro | 1167 | 15 | 50 | 33 | 96 | 39 | 95 | 95 | 86 | 35 | 70 | 75 |
| Taranto | 1143 | 15 | 54 | 36 | 96 | 40 | 95 | 96 | 84 | 34 | 71 | 75 |
| Napoli | 386 | 7 | 45 | 28 | 79 | 34 | 80 | 80 | 73 | 31 | 74 | 74 |
| Palermo | 114 | 2 | 14 | 8 | 77 | 33 | 78 | 78 | 76 | 33 | 77 | 77 |

Finally a cost benefit analysis was carried out (Table 11) with and without VAT. The calculation of cost effectiveness shall be based on the following formula:

$$CE_i = C / ER_i$$

where: i, pollutant; $CE_i$ cost effective for the reduction of emissions of pollutant i (€ / tonne); C total cost (€ / year); $ER_i$ reduced emissions of pollutant i (tons / year).

Table 11: Cold ironing cost benefit analysis

| Port | Cost effective (€/Mg) VAT not included | | Cost effective (€/Mg) VAT not included | |
|---|---|---|---|---|
| | $NO_x$ | Sum of $NO_x$, $SO_x$, NMVOC, PM | $NO_x$ | Sum of $NO_x$, $SO_x$, NMVOC, PM |
| Livorno | 7.04 | 6.26 | 5.42 | 4.82 |
| Ravenna | 13.53 | 12.26 | 11.86 | 10.75 |
| Gioia Tauro | 5.74 | 5.26 | 4.23 | 3.88 |
| Taranto | 7.44 | 6.76 | 5.94 | 5.39 |
| Napoli | 5.94 | 4.87 | 3.91 | 3.20 |
| Palermo | 16.51 | 13.60 | 14.2 | 10.00 |

## Conclusions

The work has highlighted the great potential for reducing emissions but also the constraints and limitations.

The reductions that can be achieved for nitrogen oxides in the ports examined are between 750 to 2000 tons per year, while in the case of the largest cruise terminal in the study, located in centre of city, reductions are nearly 400 tons.

From the point of view of realization of the implementation at individual docks there are no major technical or economic problems, which may constitute obstacles to the development of actions.

The major constraint to the success of interventions is the cost that ship-owners will have to face for the adaptation of onboard systems. In this regard, a coordinated European approach to carry out initiatives that allow owners to use the service of "cold ironing" in different ports is a priority. To apply a reduced rate of electricity tax to electricity directly provided to vessels at berth in a port can give an economic incentive to the use of shore-side electricity (EC 2011).

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