

# Renewable energy supply to ships at port

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**Abstract.** *Maritime industry requires the environmentally friendly operation of ships. This fact has significant importance when the ships call at port and especially in those cities whose basins are near to urban centres. This work presents a study about supplying electrical energy from renewable sources when the ships call. This approach is called Onshore Power Supply. Then, an empirical application for the Cartagena Port is presented. In this particular case, the facility has dual character, with both solar and wind energy farms. The facility is sized basing on port traffic data of three years. Furthermore, the greenhouse gases reduction obtained with the application of this approach on the basins of the Cartagena Port is estimated.*

**Keywords** - Onshore power supply, ports, renewable energies.

## 1 INTRODUCTION

The maritime transport constitutes the main pillar of worldwide commerce and the main impulse of globalization. Ports around the world manage approximately the 80 % of worldwide commerce and 70 % in value terms. There are more than 2,000 ports around worldwide geography, which are the main focus of economic and pollution growth in the cost areas [1].

Different sources have to be considered to value the atmospheric pollution in the harbour areas. It can be identified the ships, lorries, port services, trains or another equipment dedicated to transport the cargo. Most of them use diesel engines to move. Thus, these vehicles cause an important impact on quality air by greenhouse gases (GHG) and particulate matter or soot (PM) from exhaust gases. It can be noticed some strategies to reduce or remove the atmospheric pollution in cost areas, basins or terminal ports. For instance, there are time restrictions of engine idle of lorries, the use of alternative fuels, low sulphur fuel oils, ecologic designs of new port terminals, GHG emissions on port areas or shore-side power supply [2].

Focusing on atmospheric pollution caused by shipping on port areas, it can be remarked the relevance on European and International schedule of environmental protection. It can be found in a literature survey numerous works related to atmospheric pollution from different point of views. Hall [3] investigated the impact that shore-side power supply could have on the pollutants emissions from ships at berth if the electricity is drawn from national grids. Other authors [4] analysed the current regulations providing sustainable solutions to deal with the problem of pollution on port areas due to naval activities. It is also possible to find papers [5] where the impact of European directives related to GHG emission reduction on vessels are evaluated. Other many works examined the pollution caused by ships at berth in

many ports, for instance, Bergen (Norway) [6], Kaohsiung (Taiwan) [7], Victoria (Canada) [8] or Piraeus (Greece) [9]. They also exposed new strategies to reduce or remove the exhaust gases from ships.

Recent studies estimate that around 15 % the global emission contribution of NO<sub>x</sub> is caused by ships. On the other hand, SO<sub>2</sub> emissions range is between 4-9% [10]. Dalsøren et al. [11] concluded that 6% of fuel consumption of vessels takes place during hostelling stages. This value comprises around 11 millions of tonnes per year.

Today, it is required a considerable energy consumption while vessels are berthed, mainly generated from auxiliary engines. This consumption is required to load and unload cargo, heating system, lighting system, as well as, other activities necessary to maintain the ship operations at port. However, energy generation on-board causes pollution, mainly by exhaust gases of diesel generators, noise or machinery vibrations. As it has exposed, these auxiliary machineries, which remain in operation during hostelling cause the main environmental problem on cities located near to port terminals or harbour basins. The atmospheric pollution affects mainly port workers or people who live near to port area [2]. So, shore-side supply from local grid or other sources can be established as suitable alternative of electricity generation on-board. Following this way, vessels may operate avoiding or minimizing the pollution effects at port terminals during hostelling stage. Therefore, this solution allows to reduce the GHG emission from the ships while they are berthed.

The main goal of this work is to apply the OPS concept to Cartagena Port (Spain), by means of analysing data port traffic. The combination with renewable energy sources leads to total emission reduction. The power generation is also described as improvement of OPS strategy. The orographic and environmental conditions on Cartagena Port basins are analysed. Solar and wind farms capable to supply the power demand from ships at port are estimated. Finally, an analysis of environmental impact on quality air on Cartagena Port area is carried out.

## 2 ONSHORE POWER SUPPLY CONCEPT

The OPS concept is based on replacing the energy generation on-board using diesel generator engines by shore-side supply electricity [3]. Therefore, it can be defined as strategy focused on improving the air quality on port areas and cities through emission reduction of pollutants from exhaust gases of ships, mainly CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub>. Sometimes this strategy is included into Green Shipping Practices (GSP). It is obvious, if renewable energy are the

source of electricity, it is possible to achieve total emission reduction, as it is exposed on the present work.

It is important to remark that the assessment of cost and benefits according to specific port are required before its implementation. Not all ports are suitable to include the OPS facilities, so the local characteristics must be analysed from environmental and economic point of views. The main benefits of this technology vary according with several factors [12]. The usability factor of port terminals can be considered in a previous design, for instance. In this line, the higher use of the installation and power consumption gives the higher the environmental benefits. Frequent-calling vessels with long port stays and high consumptions offer the greatest emission reduction potential. Therefore, ferries were the first type of vessel, which implemented the OPS technology. These vessels always berth in same position making easy the supply of electricity from shore-side.

It is important to take into account the variations in the power, voltage and frequency levels in the design of OPS facilities. The main obstacle comes from the difference in electrical frequency between the North American continent/parts of Japan and the rest of the world. It is also a factor that needs to be accounted. Furthermore, the ship electric system rated voltage can be different depending on a vessel type, the size and the regional operating conditions. For instance, the ship electric system voltage frequency of 60 Hz (about 70%) prevails in the world merchant navy, whereas there are at least five voltage levels below 1 kV and three exceeding 1 kV [13]. The low-voltage systems (typically 400-480 V) require numerous connection cables, while today high-voltage systems (6.6 -11 kV) are easier to handle. Other key aspect of the OPS installation is the synchronization between shore and on-board installations to avoid failures on electric system of the vessel or power cuts.

## 2.1 OPS in the World

Today the ports, which have OPS installations in their quays, are located on North American East coast and Northern Europe [2, 9] due to community pressure or the strong environmental legislation, for instance. The port of Gothenburg (Sweden) was the pioneer in the world using low-voltage to supply ships with electricity from shore in 1989 [14]. These vessels were ferry ships, which cover the regular line between Gothenburg and Kiel. In 2010, this port got the first High Voltage Shore Connection. Then, this port gave a new step in sustainable operation of vessels in port with starting new OPS installation focused on Stena Line vessels ([www.stenaline.com](http://www.stenaline.com)), which cover the regular line between Gothenburg and Germany. Today there are 21 ports with OPS installations. The application of shore-side supply technology in cruise terminal in the port of Juneau (EE.UU.) to provide vessels of Princess Cruise shipping company ([www.princess.com](http://www.princess.com)) with electricity was other landmark in this field in 2001.

As can be noted, today the OPS installations are focused on frequency – calling vessel, highlighting cruise vessel. Therefore, 10 of the 21 ports with OPS technology are capable to supply of electricity to cruise vessel.

The OPS application in other types of vessels is minor. Container and bulk cargo ships can be outlined, for instance. The port of Pittsburgh (EE.UU.) and Pohang Iron and Steel Company ([www.posco.com](http://www.posco.com)) developed the OPS facilities to bulk cargo ships in 1991 [15]. According with this line, Angeles port (EE.UU) was the first terminal with shore-side supply installation to provide power to container ships of shipping company China Shipping Container Line in 2004 [15]. The Long Beach (EE.UU) port together with British Petroleum ([www.bp.com](http://www.bp.com)) started to provide electricity oil tanker ship in 2009 [14].

Taking into account data port traffic of year 2011, most of important ports in the world have implemented OPS facilities: Rotterdam (Holland) with 32,738 calls, Antwerp (Belgium) with 15,240 calls, Gothenburg (Sweden) with 10,000 calls, Zeebrugge (Belgium) with 8,351 calls Long Beach with 5,364 calls, for instance.

It can be emphasized that other numerous ports in the world try to implement the OPS technology: Amsterdam, Barcelona, Bergen, Civitavecchia, Genoa, Helsinki, Le Havre, Livorno, Marseille, Tallinn, or Riga in Europe; the ports of Oakland, Richmond, Houston, South Carolina or Tacoma in North America; or the ports of Hong Kong, Tokyo, Yokohama, Kaohsiung or Nagoya in Asia, for instance.

So, the OPS strategy can become a suitable solution to reduce or remove the pollutions on costs areas and cities near to ports.

## 2.2 Towards Cero Emission at Port. OPS 2.0

The reduction of pollutant emissions can be achieved with the OPS strategy, as exposed. Thus, the combination of the OPS with other solutions can allow to remove the pollutants from vessels, while they are berthed. For this reason, the combination with renewable energy sources is presented as an improvement of the OPS solution. The aim of the idea is to remove the GHG emissions on ports and cities with harbour basins located near the town centre.

It is obvious that the air quality of port areas improves if the electricity comes from traditional energy sources as nuclear or thermal power, but the emissions are moved from ports terminal to other areas, where power installations are placed. Therefore, the pollutants from exhaust gases of vessels will be remove if the power comes from renewable energy sources.

The use of renewable energy sources in OPS facilities depends of the port locations, the economic or the legal factors. The wind power may be the main renewable energy source in ports located on North Europe. Conversely, the solar power may be the main source on Mediterranean ports. Algeciras port can be an example of this idea. The location allows to install wind and solar farm to supply vessels at port with electricity.

In the same line, this work develops an application of this idea on Cartagena basins, which are located on South Spain. A complete study of data port traffic, renewable energy source estimation to supply ships with power, is exposed.

### 3 EMPIRICAL APPLICATION TO THE PORT OF CARTAGENA

#### 3.1 Features of the port of Cartagena

The Port of Cartagena, bathed by the Mediterranean Sea, is located in the southeast of the Iberian Peninsula. This is the unique port of General Interest belonging to the Spanish Government ports network located in the Murcia Region. According to the Landlord Port configuration of the Spanish Port System, receives the name of Autoridad Portuaria de Cartagena.

The port is made up for two basins called Cartagena and Escombreras. They have particular characteristics that differentiate them from other Spanish ports. Both basins are located in a natural bay. In particular, Cartagena basin is flanked by mountain massifs, with a mouth of 250 m. width [16]. This basin registers traffics of general cargo, containers and cruise passengers. Escombreras basin is partially also flanked by mountain massifs in the northern part. This basin is focused on liquefied natural gas and solid and liquid bulks traffics. In this case, the distance from these berths to the closest residential area is 3.5 km.

Another aspect to take into account in order to know the feasibility of the development of OPS facility with renewable energy is related to the climatological aspects of Cartagena. In this sense, the potential installation of electric power generation would have a dual character. On the one hand, this area gets a high solar irradiation energy registered, with an average value of 5.13 kWh/m<sup>2</sup>·per day [17], as well as, a high number of sunshine hours per year, with an average value of 2,971 hours (fifth Spanish region with more hours of sunshine). On the other hand, the mountain massifs that surround both basins constitute a suitable place for the installation of wind turbines.

The following sections are structured as follow. First, the power requirements of the ships when they are at port are determined. Second, the facility estimation to supply power generation from renewable energy sources is exposed. Finally, the emission reductions associated with the implementation of the OPS 2.0 technology in the port of Cartagena are calculated. The power requirement estimation is performed by data analysis of the calls registered during last three years. This data analysis leads to obtain a consumption pattern of ships. The calculation of power provided with renewable energies, requires to determine wind and solar resources available in the geographical area. Finally, the electricity consumption of vessel at port allows to estimate a greenhouse gases emission of the gensets.

#### 3.2 Vessel's energy needs at port

The power demand required by ships at port of Cartagena were analysed the calls during three years (2010, 2011, and 2012) in order to avoid distortions on the results associated with an isolated year. For each call the ship type, the gross tonnage and the day and hour of the beginning and the end of the call are known. Nine types of vessels are the most representative of the traffic described above: reefers, general

cargo, gas tankers, product/chemical tankers, bulk carriers, cement carrier, cruise ships, crude oil tankers and container ships. The procedure applied consists on defining for each type of ship, the power of genset installed according to the size, as well as, distributing the power consumption of each vessel daily by adjusting the duration of the call at the minute.

In 2011, 1,325 of 1,414 total calls correspond to the nine type of ships, which represent a total hours in port of 58,318. Distribution by basins was 8,047 hours for Cartagena, and 50,270 hours for Escombreras. In 2012, the total hours of ships at port was a value of 82,058 hours. The pattern was similar to obtained in 2011, with 13,198 hours in Cartagena and 68,860 hours in Escombreras.

The average daily consumption became at 23.80, 34.52 and 48.93 MWh/day in 2010, 2011 and 2012, respectively. It is also necessary to take into account the peak values of power demand, especially from the point of view of the sizing of the installation. Thus, in 2010 the peak power consumption was registered on September 6 with 47.57 MWh/day, related to 34 calls. In 2011, the peak consumption was higher than registered in 2010 with 81.88 MWh/day on December 12 with 18 calls. Finally, in 2012 the peak consumption was slightly higher than in 2011 with 86.36 MWh/day on February 28, registering 21 calls this day.

#### 3.3 Sizing of wind-solar installation

This section describes the estimation of the renewable energy resource available in the geographic area of the basins of Cartagena and Escombreras. It is necessary to note that both basins have suitable characteristics for the installation of panels for the use of solar energy, while the nearby mountains to Escombreras can accommodate the installation for wind turbines, reducing the visual impact on the city, combining the wind and solar power supply. In particular, in the case of the available wind resource, disruption would be minimal because the absence of architectural elements. Another aspect to take into account resides in the proximity between the generating installation and potential consumers, so that reduces the losses associated with the distribution network.

The estimation of the installation of solar panels is related with the use of the available area to reduce the visual impact. This work suggest that the roofs and ceilings of buildings and other constructions available in both basins may be available to install photovoltaic panels. To carry out the estimation of the solar resource the available area of ceilings and roofs in both basins were analysed. The available area are 51,395 m<sup>2</sup>. Along with the above, the average solar radiation in this area is 5.582 kWh/m<sup>2</sup> for a panel at an angle of 30° and an azimuth angle of 0°. The production of solar energy can be estimated considering modules of 2 m<sup>2</sup> of surface, with a peak power of 280 Watts and installation performance of 0.75 [18]. Then, solar plant may give a power of 31.05 MWh per day. Analysing the wind resource in the area, an average wind speed of around 6 m/s is obtained [19]. In this case, to estimate the production of wind energy has been used a Weibull distribution [20].

Considering the installation of wind turbines of 850 kW of unitary power, it is possible to obtain a daily production of 2.6 MWh. Thus, the wind farm is formed by 30 wind turbines; these could provide 76.9 MWh per day. Taking into account the aforementioned average monthly production for wind and solar farms is obtained an average monthly production of 108 MWh, enough to cover average daily power demand and associated power peaks. Therefore, in this sense the demand would be around 45% of the maximum capacity of the facility.

### 3.4 Reduction of Pollutant Emissions

Analysing data from emissions corresponding to the three years of study, each year on average were generated 242,133 tonnes of CO<sub>2</sub>, 3,871 tons of NO<sub>x</sub>, 759 tonnes of SO<sub>2</sub> and 562 tonnes of CO. Focusing on CO<sub>2</sub> emissions, it is interesting to compare their equivalence with other sources of pollution in urban areas such as emissions from road traffic. Taking as reference CO<sub>2</sub> emissions in 2012, the implementation of OPS technology in all the docks of the port of Cartagena it would be equivalent to remove emissions of approximately 178,000 cars from the streets of the city.

## 4 CONCLUSION

Onshore Power Supply technology is an appropriate way to reduce air pollution from ships. However, this technology can be applied with renewable energy in order to remove the GHG emissions and other pollutant gases. Although it should be noted that the level of implementation of this technology is very low at present. To achieve a greater level of implementation is necessary to develop two important keys. On the one hand, the design of power generation facilities from renewable sources. On the other hand, the adaptation of the installation necessary on the ship to receive electric power from shore. Also, it can highlight that the experience of those ports that currently have OPS has been satisfactory.

Related to particular case discussed, the geographic and orographic environment of the Port of Cartagena allow to install the OPS system entirely from renewable sources. In addition, the port traffic features lead to implement this strategy progressively, guiding the first implementation phase to those ships in which the state of the technology is fully developed. The implementation would be a significant environmental benefit both to port workers and to the population of Cartagena and adjoining areas, even in the immediate phase with a reduction of 10% of emissions generated by fossil fuels. So that the most immediate challenges ahead for the reduction of GHG from ships in port keep a strong relationship with the adoption of the OPS 2.0 technology.

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