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Article

Influence of the Implantation of the Onshore Power Supply (OPS) System in Spanish Medium-Sized Ports on the Reduction in CO_2 Emissions: The Case of the Port of Santander (Spain)

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Abstract: Society and its leaders are increasingly aware of the need to fight climate change and CO_2 emissions in the search for sustainability. Maritime transport and ports are important sources of pollution and, while industry and the rest of the large-scale emitters have achieved considerable reductions in this area, "shipping" is still not advancing at the same rate, falling behind in this race. The aim of this article is to underline the importance of an early implementation of On-Shore Power Supply (OPS), Cold Ironing (CI) or Alternative Marine Power (AMP) by making a study of potentially avoidable CO_2 emissions from vessels docked (on the basis of the EPA [Environmental Protection Agency] and ENTEC [Environmental Engineering Consultancy, an environmental and engineering consultancy in UK] methods) close to urban areas in the Port of Santander (Spain). It is the first time potential reductions have been calculated for the last 11 years (2011–2021), distinguishing yearly emissions per type of vessel and providing real information to port authorities to prioritize the installation of this technological basis for the operation of piers/terminals to optimize investments and outcomes. In this case study, results demonstrate the outcomes of ROROs, ferries, and cruises being the first target of OPS implementation (reaching total of 37.95% of total emitted tons of CO_2 during the period of study). As a clear conclusion to this paper, the reader can understand the enormous and growing potential of this technology multiplied by the continuous development, increase and implementation of green energies.

Keywords: cold ironing; sustainability; green ports; OPS; CO_2 emissions

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1. Introduction

Since the industrial revolution, technological development and process optimization have been constants in the pursuit of companies to achieve improvements in their performance and profits. In recent years another goal has emerged, just as important as these previous ones: sustainability.

It can be stated that the first time this concept appeared as we know it today was in 1987 [1] in what is known as the Brundtland report. In it, the concept of sustainable development is defined as the process of "satisfying the needs of present generations without compromising the possibilities of those of the future to meet their own needs". In this sense, through both private and public initiative, for more than 30 years now a great effort has been made in researching and developing technologies capable of combining these objectives: the optimization of processes and the reduction of emissions.

Today there is extensive legislation, both nationally and internationally, that commits countries to the common goals of reducing emissions of polluting agents into the atmosphere. The EU has set medium- and long-term objectives [2,3] that seek to implement measures that lead member countries to respect the environment by reducing the emission of greenhouse gases: a "European Green Deal" [4]. The goal is, by 2050, to have reduced these emissions to at least 80% below 1990 levels. To do this, taking the same reference values, two milestones must be achieved: a 40% cut in emissions by 2030 and 60% by 2040.

According to Mikova [5], in addition to the legislation and efforts carried out by each country individually, collaborations between counties are essential. Similarly, synergies between the public and the private spheres are important; finally, another key factor in achieving success is the role of renewable energies and their application.

Unfortunately, despite all of the efforts made, the indicators of the European Environment Agency (EEA) [6] show that the desired results will not be achieved. According to the same source, thanks to the efforts of all parties, the EU in recent years has overseen a significant reduction in emissions. Unfortunately, however, the evidence for the transport sector shows that it has not been following this downward trend, its relative contribution to the total tons of CO_2 having increased.

"On Shore Power Supply" (OPS) consists of satisfying the energy demand of a ship from the port during its stay in dock. It is a combination of technologies that are already well-developed and mature, but which are not being fully exploited and are not yet implemented today in most of the world's ports. Most of the on-board equipment is in operation when the ship is in motion (navigating or maneuvering), while it is switched off when it is docked. At that time, the auxiliary engines of the ship itself are responsible for supplying the energy [7]. The idea of the OPS is simple: connect the ship to the land network so that it can be supplied with the necessary electrical energy while it is in port. This will allow it to stop its auxiliary engines, which are the ones that feed all the necessary services of the ship through the combustion of MGO (Marine Gas Oil), significantly reducing emissions during this period [8]. The objective is "zero emissions in port" and, in this way, by not burning diesel during the period of loading/unloading operations, emissions will be suppressed, while the noise and vibrations they produce will be eliminated.

Therefore, the reduction in emissions will depend on the origin of the energy supplied to the vessel from land. The ideal situation would be to supply energy from a renewable and clean source, minimizing that which comes from fossil fuels and optimizing the ecological performance of the installation. However, the most common situation is a mixture in which there is also a part of a fossil fuel source. It is important to control the percentages supplied. If this exceeds 80% from fossil sources, the opposite result to that pursued might be obtained and this may lead to even greater damage than that caused by the ship's engines [9]. Hence, the percentage of energy supplied from renewable sources will ultimately be responsible for optimizing emission reductions. Another advantage of the system is that emissions are relocated and moved away from urban centers and ports, emitting in already established production areas where the impact to population is marginal [9].

According to Chang [10], adopting an OPS system could reduce CO_2 emissions by 57.16% in port areas. According to Hall [11], it is estimated that the implementation of this technique in the ports of the UK could reduce CO_2, SO_2, CO and NOx emissions by around 25%, 46%, 76%, and 92% compared to what would have been emitted when using the ships' diesel auxiliary engines.

"On Shore Power Supply" (OPS) is also known as "Cold Ironing" (CI), a term which comes from the practice of steamships cooling their coal engines while moored in port. It is common practice for docked warships [12], port tugs or vessels in shipyards, but is not yet for merchant ships operating in commercial docks. The EU has established as an objective the implementation of these facilities in all European ports [13–15] by the year 2025 [16]. Government aid is essential for achieving the implementation of this initiative [17]. Without this, the ports will not invest until the ships have the technology to exploit it and vice versa.

This is the so-called 'chicken and egg dilemma' [9]. Where and how is it encouraged? That is the question that needs to be answered to achieve the objective of promoting the system both in ports and among shipowners so that, after the initial aid, the rest of the community continues along the same path [18]. The more ports that have this technology, the greater the number of vessels that will install the OPS option, achieving the desired benefits. Thus, ports such as Los Angeles or Long Beach are in the process of making the use of the OPS mandatory, leading to an optimization of the system since, if it is not used, other types of investments such as machinery renovation, incentives for voluntary speed reduction, etc., might well be found to be more convenient alternatives.

It should be noted that, in addition to the environmental, mechanical and maintenance benefits of reducing engine wear, diesel consumption, vibrations, noise, etc., the OPS has significant economic advantages [19]. Despite the large initial investment required, these advantages are more significant the higher the price of fossil fuel and the lower the price of the KWh of electricity from the supply network [16].

In view of the obvious advantages that OPS potentially offers, shown by previous investigations from other researchers, this work focuses on the maritime industry and the emissions it produces because of port activity. In it, a study is carried out to quantify the CO_2 emissions released by ships at berth and the emissions which might potentially be avoided through the implementation of the OPS system are evaluated in order, based on the results, to obtain conclusions on the importance of prompt implementation of this technology, and on objectives and priorities which can determine investments in the search for maximum optimization. This paper will calculate emissions depending on the kind of vessel and bearing in mind time alongside fuel consumed. In this paper, vessels have been classified as: Ferry, Cruise, Tanker, Chemical Tanker, Bulkcarrier, General Cargo and RORO, always counting time only while berthed and always bigger than 500 GT (Gross Tonnage). Neither time at the shipyard nor at anchorage have been considered, since objective of this paper is to classify priorities of installation of this technology on the basis of the occupation of piers/terminals, seeking to optimize investments and outcomes at the commercial port of Santander.

To achieve the proposed objective, the CO_2 emissions produced by the auxiliary engines of the ships in the port chosen for the study are calculated. Due to its volume of traffic according to yearly vessel calls, this port is a medium-sized port amongst Spanish ports [20], receiving 7 different types of vessels on a regular basis. Next, the emissions that ideally would have been produced if both the ships and the port had the necessary facilities to use the OPS system are calculated. Finally, the work concludes with the comparative analysis of the results obtained, thus quantifying the potential of the application of this measure.

2. Literature Review

There are many technologies that are currently in the process of development and numerous studies, projects and articles focused on reducing emissions in all areas of industry and, especially, in port logistics and movements [21]. These include private and industrial vehicles, freight-handling equipment, operations assistance equipment [22], barges and ocean-going vessels, etc. The maritime industry, although it is on a par with aviation and about five times lower than land transport, is one of the main sources of pollution of the atmosphere [9]. This is due to the large volume of goods transported by this mode (in 2019, despite the slowdown due to COVID-19 [23], 11.08 billion tons). For this reason, both ocean-going vessels and ports are among the main sources of gas emissions into the atmosphere, making them a key target in this fight to respect the environment and the health of all beings on the planet.

The activity of research and development of new techniques is another important field to assess. The objective is to achieve a "shipping" that respects the environment, and to achieve 'zero emissions' through technology. A great deal of research is being conducted in the field of ports in a search for the sustainable port, including initiatives, projects, and the investment of European funds (https://portosproject.eu/ (accessed on 17 August 2022)). This technological field can be divided into two: on the one hand, there are alternative energies which, although their potential is very high and promising, are still in the experimental phase. They have not been sufficiently developed for reliable exploitation: wave energy [24–29], tidal energy [30,31], and thermal gradient, etc. On the other hand, there are wind and solar energies which can be said to be mature technologies.

This manuscript focuses on the great advantages offered using OPS, but its scarce implementation is significant. According to Krämer and Czermanski [32], in 2019 only 574 ships were equipped on board with this technology, with 81% of these being container ships (466). Among other factors, it must be considered that, as Schwartz [33] points out, to install this technology on a ship it should not be more than 10 years old, since it must be considered an important investment in "retrofitting". It varies significantly depending on the type of ship. In general, installing it in an already built ship is more expensive than installing it in a newly built one. According to Yu [34], in the case of a 5000 GT (gross tonnage) ship, the final bill could amount to between 50,000 USD and 350,000 USD, while a container ship, chemical tanker or a cruise ship of about 100,000 GT may require an investment of 750,000 USD. At the same time, the port authorities must consider that they will need an estimated investment per dock of 1.5 to 2 million USD (as reported in the current IEC/ISO standard 80005), but these data could vary greatly depending on the terminal to be electrified and its requirements [16]: number of berths, distance, power to be supplied, type of vessel, etc.

The cited articles deal with the OPS, its advantages, disadvantages, and health benefits, but they are always based on the origin of the energy. This means that it must be carefully studied case by case depending on the energy supply of each port/country. As has been said before, this article will focus on the port of Santander based on the Spanish energy supply, providing real results and concrete estimations of CO_2 tons emitted from the more than 22,000 vessels' calls studied. It also opens the door to future studies, the calculation process being repeatable for other ports.

Health Background, Data and Policies

Various studies demonstrate the health risks to which populations near ports are exposed: asthma, lung cancer, heart attacks, respiratory infections, etc. [35–38]. It should be remembered that a high percentage of the world's urban centers are located in coastal areas directly affected by all these gases from the combustion of ship engines.

The emissions of greenhouse gases directly related with the maritime industry have increased from the 977 million tons in 2012 to the 1.076 million tons in 2018, an increase of 9.6%. [39] From all the gases released by engines mentioned above, this work focuses on CO_2. According to Smith [40] during the period 2007/2012, an average of 33 billion tons per year were emitted into the atmosphere. Of these, it is estimated that 3% correspond to shipping and, with respect to 2050, an increase of 250% is predicted.

As Acomi demonstrates in his study [41], there are many variables that influence these emissions from vessels (state of the engines, age, conditions, etc.), but the fuel used to power the engines will be a decisive factor both for the calculation of the tons discharged into the atmosphere and for operating costs. According to Corbett [36], the imposition of limits to reduce the speed of ships and thus emissions near ports could save 8300 lives annually and alleviate the respiratory diseases of 3 million people in the US. In fact, the port of Long Beach already in 2006 imposed a "Reduced Speed Zone (RSZ)" of 20 miles around the port, later doubling this range in 2010. In this case, governments and shipowners share the objective of reducing fuel consumption, given the significant impact on the ship's operating costs. Speed and route optimization is a major goal for emissions control [42–44].

This situation requires action to be taken by the authorities. The European Commission strongly recommends the reduction of emissions from all transport by 60%, including a reduction of between 40–50% from the maritime industry by 2050 compared to the 2005 figures. It must be stressed that in the maritime area, these measures cannot be imposed unilaterally by any of the governments or even by the European Union, since they would also affect vessels that sail under the flag of other countries over which they do not have jurisdiction outside their territorial waters [45]. It should be the IMO (International Maritime Organization) that regulates at the international level, as for example it has already done through MARPOL (International Convention for Prevention of Pollution from ships—MARitime POLlution) Annex VI, where it establishes use of fuel of a maximum of sulfur level in certain areas [14,46,47]. At the port of study, this limit insists on levels being less than 0.1% if berthed or anchored for more than 2 h. Although the European Union has shown interest in expanding these areas, it must progressively seek support and undertake measures to avoid a confrontation with the United Nations or break the Law of the Sea 1982 (UNCLOS) to which the EU is a signatory [48].

3. Methodology

3.1. Framework of Calculation

1. Scenario and reasons.
2. Authors classified vessels by type per each year.
3. Calculate (via EPA and ENTEC method) CO_2 emitted. Basis is the number of hours burning fuel and auxiliary engine power of each ship.
4. Basis is the electricity production of the grid, as authors apply % of renewable energy per each year to the total CO_2 yearly emitted, so total CO_2 tons which could have been avoided if using OPS is calculated.

3.2. Scenario—Port of Santander

The main reasons that make the Port of Santander such an interesting object of study are, on the one hand, the variety of vessels that operate there (size, types of cargo, purpose, etc.) and, on the other, the proximity to the city and population. Both factors will be considered in the conclusions to determine the docks and types of ships in which a greater benefit can be obtained after the installation of this technology.

A priori, a dock of special interest is the so-called "Muelle del Almirante" (Admiral's Dock) which welcomes cruise ships and ferries at less than 150 m from residential buildings in the city center. Given the great activity and regularity of the ships that make use of these facilities, it can be judged to be a clear candidate for the use of the OPS. The greater the number of calls and frequency of the vessels of a shipping company, the greater the return on investment and the faster the amortization will be. This recurrence will allow the implementation of a system that is 100% compatible with the regular vessels that operate in it, achieving an easy and rapid implementation, avoiding risks, reducing time, increasing safety, etc. This will be just the same way as it has been developed in other European ports such us Marseille in which is OPS fitted and which confirms, from practice, how fast and effective the repetition and specialization are, connecting and disconnecting the vessel from land easily and simply in about 15′.

On the other hand, one must not lose sight of the fact that, precisely, ferries and cruise ships are (as a rule) large vessels dedicated to the transport of people and vehicles whose great needs during periods in dock require a significant capacity to satisfy all their requirements [49]. Therefore, they always need their powerful auxiliary engines. This requirement leads to a large emission of gases from the combustion of these engines, which produces significant pollution in areas very close to the city, as well as causing high noise pollution that has already led to some port–city disputes.

3.3. Analysis of the Used Models

There are two models used for the quantification of the CO_2 emissions of vessels. [50] The first is 'Top-Down', used for the calculation of global emissions and full fleets based on their fuel consumption. The second is 'Bottom-up', based on activity and used for the calculation of specific emissions based on operating hours, installed power, etc.

This article focuses on the bottom-up model with which CO_2 emissions per year are calculated from the sum of the estimate of each of the vessels that dock and carry out operations in the dock. In this case, emissions are calculated using the EPA and ENTEC system and the results obtained are compared to evaluate possible deviations depending on the chosen method.

Both the ENTEC and EPA methods have been published by the Lloyds Register Engineering Services Data using their databases to generate the emission factors and to make these as realistic as possible in their predictions [51]. The method is based on ENTEC 2002, 2007 publications and MEPC (Marine Environment Protection Committee of the IMO) resolution 212/(63). Therefore, they are regularly used to calculate CO_2 emissions of marine origin [52].

For the study carried out in this article, a database has been generated where the port calls in the Port of Santander of ships of more than 499 GT have been registered. The sample, of 22,714 entries, only considers the hours spent in dock (18,071 calls totaling 558,626.77 h in dock) since, as seen above, the OPS can only be applied when the ship is docked. Ship emissions during navigation, anchoring, approaching port or maneuvering have not been considered in this study, the object of study is therefore the auxiliary engines.

As stated in the previous paragraph, for all the calculations carried out, the fuel used will be the MGO, whose Conversion Factor (CF) is dimensionless, according to MEPC 212/63 of 2 March [53] and the Fourth IMO GHG Study 2020 [39], which for diesel and petrol is 3206 tons of CO2 for each ton of fuel consumed. They have a standard carbon content of 0.875.

The fourth study published in July 2020 [39] introduced modifications (with respect to the third study) which are of interest and must be considered. Thus, in the case of specific fuel consumption, (SFC) (g/kWh) the emissions of the auxiliary engines go from being dependent on their power to being dependent on the age of the engine (which, as will be seen below, is also of importance in the calculation). For MGO engines built from 1984 up to 2000, SFC will be 190 g/kWh and from 2001 onwards will be 185 g/kWh.

In this sample, it is not possible to verify the year of construction of the auxiliary engines of the 18,071 vessels (min 499 GT) which, from January 2011 to December 2021, docked in the port and are part of the database. Therefore, it is the calculation of the least and most polluting situation in terms of CO2 emissions that will be analyzed and compared. For this reason, on the one hand, all the auxiliary engines will be counted as being built before the year 2000 and on the other, all with be counted as having a later date, so that the deviation of emissions between the 2 extremes will be quantified.

Considering the specific consumption of an engine (SFC) and the conversion factor (CF) of the fossil fuel used, it is possible to obtain the CO2 pollutant emission factor of an engine in g/kWh.

The pollutant emission factor (EF) is defined as the product of the specific consumption of an engine multiplied by the conversion factor of the fossil fuel used:

$$(\mathrm{EF}) = \mathrm{CF} \cdot \mathrm{SFC} \tag{1}$$

The ENTEC Method is the model used by the European Commission. The formula used [54] is as follows:

$$\mathrm{E} = \mathrm{t} \cdot [\mathrm{ME} \cdot \mathrm{LFME} \cdot \mathrm{EF} + \mathrm{AE} \cdot \mathrm{LFAE} \cdot \mathrm{EF}] \tag{2}$$

In the case of our study, the emissions generated by the combustion of the main engine (ME) are not of interest, leaving the Formula (2) as follows:

$$\mathrm{E} = \mathrm{t} \cdot [\mathrm{AE} \cdot \mathrm{LFAE} \cdot \mathrm{CF} \cdot \mathrm{SFC}] \tag{3}$$

where:

t(h) $\rightarrow$ engine working time

AE (kW) → Auxiliary engine power

LFAE (%) → engine load—it is considered that the auxiliary engine is working at 50% of its capacity when moored

EF (g/kWh) → Emission Factor depending on fuel and engine

The EPA Method, [55] is the one accepted in the USA and is obtained in mathematical form from the tons of CO_2 emitted into the atmosphere using the following data:

1. Time that the vessel employs in the operation that is to be calculated
2. Consumption of the vessel during this period
3. A calculation of the emissions is obtained based on the fuel used

The formula used corresponds to the following equation:

$$E = EF \cdot MCR \cdot P \cdot t \quad (4)$$

where:

EF (g/kWh) → Emission Factor depending on fuel and engine

MCR (%) → Engine Work Regime. In the case of the auxiliary engines, it is considered that they are working at 100%

P (kW) → Power of auxiliary engines

t (h) → Time considered for the calculation.

Therefore, on this situation, if the methods for measuring and calculating port emissions are carefully studied, considering only those of the auxiliary engines, it can be concluded that the American and European (EPA and ENTEC) methods differ only in the percentage/load of work considered for the auxiliary engines. (EPA 100% vs. ENTEC 50%).

To apply the EPA and ENTEC methods, it is necessary to obtain the time spent in dock for each of the calls (A) and to know the power of the auxiliary engines (B) of each of the vessels.

A. The hours of stay of each call have been calculated using the registry data of the Santander Port Authority [56]. Thanks to these data, it is possible to know the exact time from which any ship docks until the time it leaves port.
B. The power of the auxiliary engines is a fundamental value. However, given the volume of the data sample used in this article, it has been decided to proceed differently depending on the type of vessel and based on information obtained from Seaweb [57]. On the one hand, due to the power needed to maintain cruise ships and ferries and to the proximity of these docks to urban centers, the values have been carefully entered scale by scale and vessel by vessel for the 2346 entries. However, for the rest of the vessels (chemical, oil, RORO (roll on-roll off), general cargo or bulk carrier), these values have been assigned by the authors based on the study of a sample. In the bibliography consulted, the question of the difficulty of assigning these values is raised due to the usual lack of information and the complicated relationship with GT, length, or other characteristics, leading some articles/authors to consider this value constant [49].

On the other hand, some dry cargo ships are fitted with cranes. It must be taken into account that, in ports such as Santander, the ships' cranes are rarely used for the loading and unloading of merchandise, since it is much faster and safer to proceed with land-based means. For this reason, it is understood as an error to consider the power of the auxiliary engines for vessels with cranes as a reference for the calculations since this really is a power that would not be used and, therefore, it would be oversizing and falsifying the result which is the object of this article. Hence, the applied values are as per Table 1.

Table 1. Auxiliary engine power values. Source: Authors.

	Chemical Tanker	Tanker	Bulkcarrier	General Cargo	RORO
GT	**Pot Aux (kW)**	**Pot Aux (kW)**	**Pot Aux (kW)**	**Pot Aux (kW)**	**Pot Aux (kW)**
<2000	325	350	129.13		
2001/4000	424.08	417.76	272.41	207.37	300
4001/6000	527.53	567.14	343.12	317.95	
6001/8000	541.05	704.77		370.37	
8001/10,000	544.47		384.12	395.31	354.71
10,001/12,000	709.06			451.34	
>12,000	850	1049.72			
10,001/15,000			419.2	476.73	
15,001/25,000			450.58	538.53	
25,001/35,000			563.54	735.51	
>35,001			654.16	800	
10,001/20,000					544.38
20,001/30,000					1022.96
30,001/40,000					1054.51
40,001/50,000					1224.69
50,001/60,000					1524.57
>60,001					1620.03

4. Results

The Table 2 summarizes the data obtained per group of years and type of vessel, including number of studied ships and total tons of CO_2 emitted (both via EPA and ENTEC).

Table 2. Results per type of vessel and total period of study. Source: Authors.

		2011–2013	2014–2016	2017–2019	2020–2021	TOTAL
FERRY	Number of ships	576	597	740	336	2249
	Hours alongside	2736	3817	5422	3864	15,840
Total tons of CO_2	EPA-1984/2000	3134.250	4133.770	5822.540	3880.030	16,970.590
	EPA-2000+	3051.770	4024.990	5669.310	3777.930	16,524.000
	ENTEC-1984/2000	1567.125	2066.885	2911.270	1940.015	8485.295
	ENTEC-2000+	1525.885	2012.495	2834.655	1888.965	8262.000
CRUISE	Number of ships	29	25	40	3	97
	Hours alongside	278	229	399	29	936
Total tons of CO_2	EPA-1984/2000	377.290	251.700	522.970	49.160	1201.120
	EPA-2000+	367.360	245.080	509.220	47.870	1169.530
	ENTEC-1984/2000	188.645	125.850	261.485	24.580	600.560
	ENTEC-2000+	183.680	122.540	254.610	23.935	584.765
TANKER	Number of ships	16	27	52	37	132
	Hours alongside	544	817	1965	1258	4587
Total tons of CO_2	EPA-1984/2000	178.930	216.200	739.560	464.970	1599.660
	EPA-2000+	174.220	210.510	720.100	452.730	1557.560
	ENTEC-1984/2000	89.4650	108.100	369.780	232.485	799.830
	ENTEC-2000+	87.110	105.255	360.050	226.365	778.780
CHEMICAL TANKER	Number of ships	220	148	190	86	644
	Hours alongside	4783	3677	5363	2395	16,219
Total tons of CO_2	EPA-1984/2000	1480.110	1179.100	1757.860	763.170	5180.240
	EPA-2000+	1441.150	1148.080	1711.610	743.080	5043.920
	ENTEC-1984/2000	740.055	589.550	878.930	381.585	2590.120
	ENTEC-2000+	720.575	574.040	855.805	371.540	2521.960
BULKCARRIER	Number of ships	1784	1824	1749	1235	6592
	Hours alongside	9108	81,276	92,446	62,238	32,7042
Total tons of CO_2	EPA-1984/2000	18,087.770	17,118.850	20,398.200	13,457.820	69,062.640
	EPA-2000+	17,611.780	16,668.350	19,861.400	13,103.680	67,245.210
	ENTEC-1984/2000	9043.885	8559.425	10,199.100	6728.910	34,531.320
	ENTEC-2000+	8805.890	8334.175	9930.700	6551.840	33,622.605

After calculating the CO_2 emissions of all the studied vessels that have called over the last 11 years (18,071), it is found that, despite being a small to medium-sized port in the

EU, the vessels docked have been emitting into the atmosphere for a total of 558,626.77 h in areas very close to urban centers. In addition to the constant noise caused by the operation of the auxiliary engines, it has been determined, by the EPA method, that these vessels have emitted a total of 158,227 tons into the atmosphere if considering auxiliary engines being built before the year 2000, and 154,112 tons if built at a later date. On the other hand, by the ENTEC method, 79,139 tons were emitted if considering engines being built between before the year 2000, and 77,056 tons with a later date.

In view of the results obtained, the difference in emissions between tons of CO_2 (based on the year of construction of the auxiliary engines: 1984/2000 or 2000+) is approximately 2.62%. Therefore, from now on for the rest of the operations and, given that the aim is to obtain the tons emitted, the greenest condition will continue to be accepted: all engines will be considered as being built after the year 2000.

As can be seen in the Figure 1, the evolution of the percentage of energy from renewable sources (including hydraulic, hydro-wind, wind, solar photovoltaic, solar thermal, other renewables, and renewable waste) compared to those from non-renewable sources, we arrive at the conclusion that, even in the worst scenario (year 2012), it would have been possible to reduce CO_2 emissions into the atmosphere by 30%. Moreover, the evolution and increase in renewable energies has gained pace in recent years, with this percentage becoming more and more significant (with renewable energies being even higher at certain times of the year compared to non-renewables).

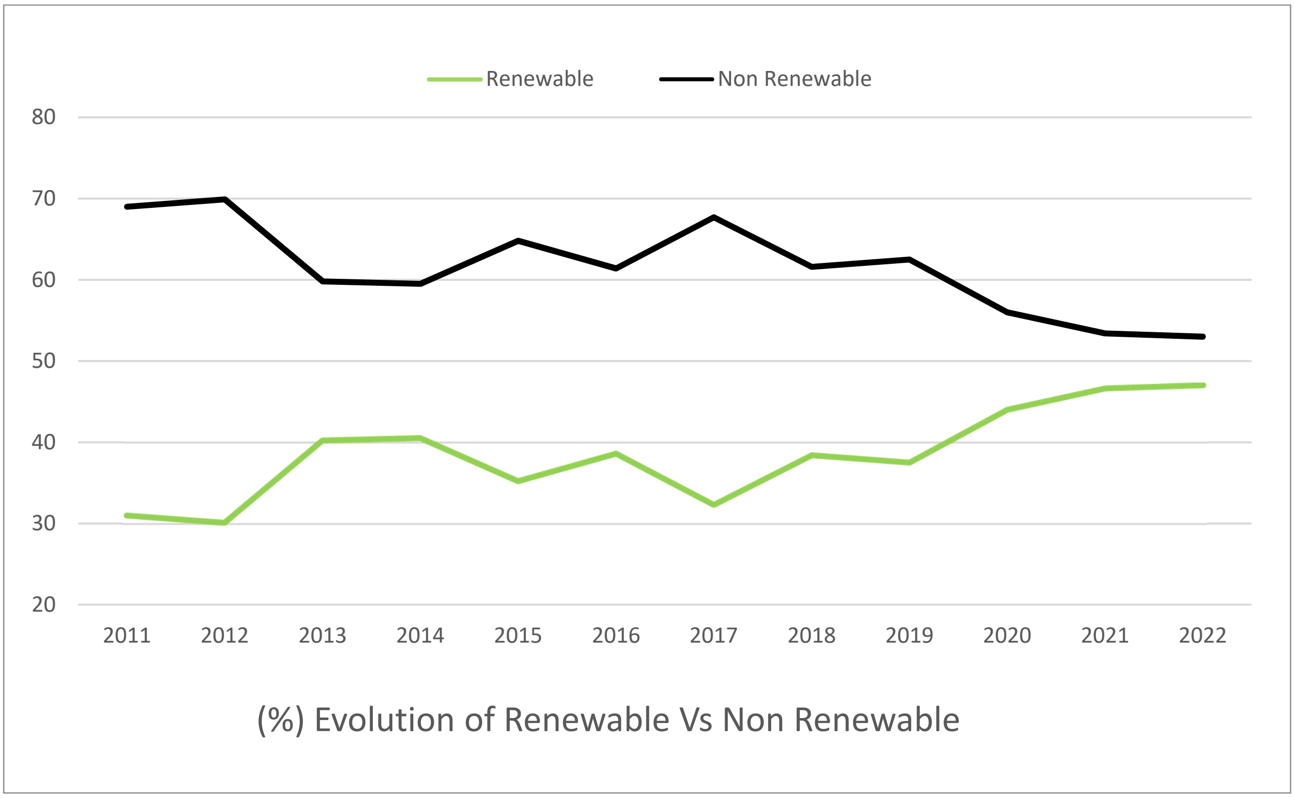

Figure 1. Graphic of the Evolution of Renewable versus Non-Renewable energies. Source: www.ree.es [58] https://www.ree.es/en/datos/generation/evolution-renewable-non-renewable (accessed on 6 January 2022).

If a direct reduction is applied in the percentage of clean energy from the Figure 1 on the tons of emitted CO_2 calculated per year on Table 2, the result will be tons that would have been avoided through the application of the OPS in the Port of Santander.

Formula as per below:

Emitted tons (Table 2) × Percentage of Renewable Energy origin (Table 3) → Potential Save of CO_2 tons (Table 4).

Table 3. Evolution of Renewable versus Non-Renewable energies. Source: www.ree.es [58] https://www.ree.es/en/datos/generation/evolution-renewable-non-renewable (accessed on 6 January 2022).

%	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Renewable	31	30.1	40.2	40.5	35.2	38.6	32.3	38.4	37.5	44	46.6	47
Non-Renewable	69	69.9	59.8	59.5	64.8	61.4	67.7	61.6	62.5	56	53.4	53

Table 4. Potential saves of CO_2 per year/type of vessel/method. Source: Authors. Calculation of emissions per type of vessel and per year that could have been avoided taking the auxiliary engines to have a manufacturing date after the year 2000 (least contaminating situation) and considering the percentage of green energy produced per year.

		2011–2013	2014–2016	2017–2019	2020–2021	TOTAL
FERRY		576	597	740	336	2249
Potential save of CO_2 tons	EPA ENTEC	1021.874 510.937	1.542.659 771.3293	2083.966 1041.983	1691.343 845.6715	6339.842 3169.921
CRUISE		29	25	40	3	97
Potential save of CO_2 tons	EPA ENTEC	125.3275 62.66374	92.83066 46.41533	181.2379 90.61894	22.30742 11.15371	421.7034 210.8517
TANKER		16	27	52	37	132
Potential save of CO_2 tons	EPA ENTEC	61.34269 30.67135	79.32283 39.66142	264.673 132.3365	205.7943 102.8971	611.1328 305.5664
CHEMICAL TANKER		220	148	190	86	644
Potential save of CO_2 tons	EPA ENTEC	486.0212 243.0106	437.1079 218.5539	618.5519 309.2759	338.0673 169.0337	1879.748 939.8741
BULKCARRIER		1784	1824	1749	1235	6592
Potential save of CO_2 tons	EPA ENTEC	5992.793 2996.396	6350.675 3175.337	7171.244 3585.622	5950.531 2975.266	25,465.24 12,732.62
GENERAL CARGO		752	696	681	488	2617
Potential save of CO_2 tons	EPA ENTEC	1935.544 967.7719	2528.522 1264.261	2017.093 1008.546	1868.55 934.275	8349.708 4174.854
RORO		1243	1507	1799	1191	5740
Potential save of CO_2 tons	EPA ENTEC	2294.555 1147.278	3662.479 1831.239	4384.614 2192.307	5548.578 2774.289	15,890.23 7945.114

Therefore, it can be inferred that if the OPS had been used in the Port of Santander to supply energy to the vessels docked over the last 11 years, potentially the CO_2 emission of 589,857.604 tons into the atmosphere would have been avoided as per EPA method and 29,478.802 tons as per ENTEC method. Moreover, it should be noted that the reduction in emissions would have grown proportionally with the percentage of clean energy, leading to an increase in the optimization of this resource.

5. Discussion

If energy sources in Spain are analyzed, according to the report prepared by the consulting firm Deloitte for the Wind Energy Business Association in which the benefits provided by clean energy [59] are quantified, in 2020 wind energy accounted for 22% of the energy generated in Spain, with an upward progression which is expected to reach 50,333 MW of installed power by 2030. According to the same study, between 2011 and 2020 the emission of 260 million tons of CO_2 into the atmosphere was avoided. All these efforts, however, are still far from enough. Among other potential objectives, it is necessary to increase this capacity and produce green energy that is supplied to ships in port, increasing the differential and the advantages of using the OPS compared to conventional auxiliary engines. Even though a small percentage of energy from fossil sources must be used, through this system it is possible to reduce emissions while delocalizing pollution. These emissions, as they occur in areas far from urban centers, will have less harmful effects on the population than in the case of being emitted in ports and urban areas. Thus, through a combination of technology and mature renewable energies such as wind, solar energy etc., it is possible to supply the necessary electrical energy so that ships in port can turn off their auxiliary engines, reducing local emissions to 0.

Another factor to bear in mind is the option of producing electrical energy from nuclear power. This energy has determined production capacity and important disadvantages such us risks of leaks, wasted nuclear fuel, potential disaster, or others, but according to Eide [60] this could lead to a reduction in emissions of up to 95%.

Knowing that the total number of calls in the port of Santander were 22,714 and considering that ships during their stay in the shipyard and ships smaller than 499 Gt (reduced to 18,071 ships) were discarded from this study, the estimation of CO_2 emissions into the atmosphere can be obtained. Such a high figure for a small-to-medium-sized port suggests the great number of ports of similar or larger sizes, all of this justifying the growing interest in promoting the OPS as an optimal tool for reducing emissions in search of the sustainability proposed as long ago as 1987 but still, in 2022, far from being achieved.

Transferring the data obtained in this study to a graph (Figure 2), obviously, emissions depend fundamentally on the number of vessels docked and time spent alongside burning fuel to produce their needed energy. For the Port of Santander, having mainly RORO and bulk traffic, the result highlights how bulk carriers and RORO vessels are those that emit the most tons in total values.

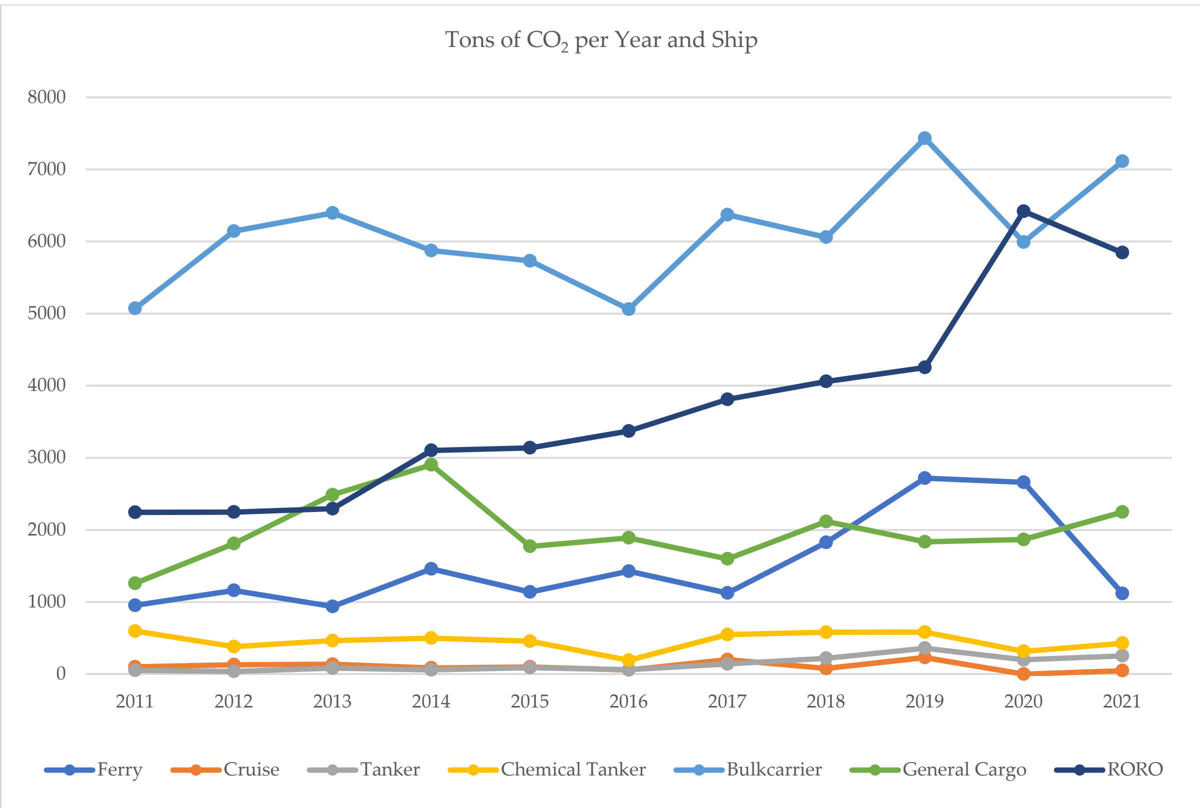

Figure 2. Emissions per year and type of vessel. Source: Authors.

The total percentage of emissions accumulated by each type of vessel over the 11 years of the study is shown in Figure 3.

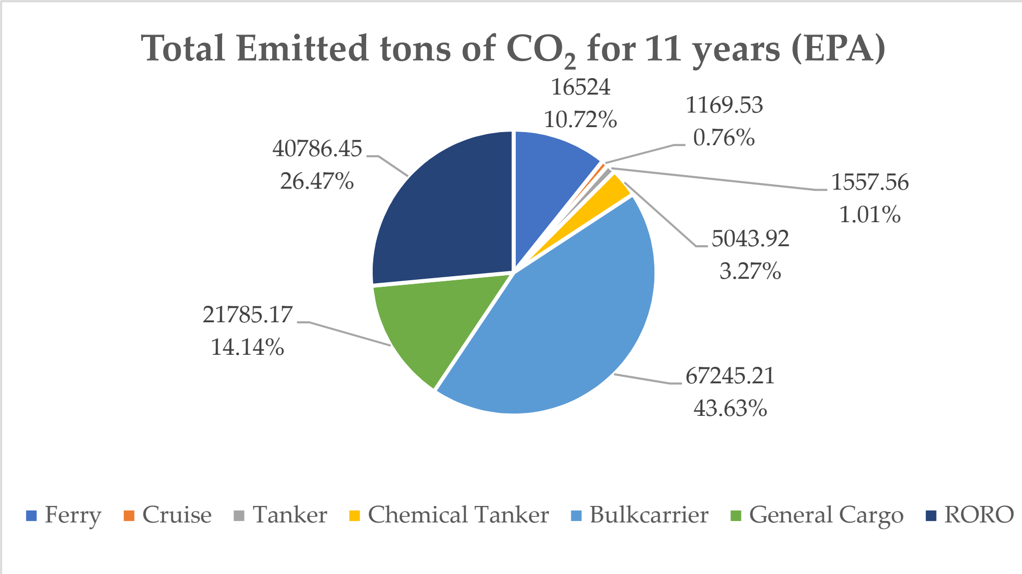

Figure 3. Tons of CO_2 emitted per type of vessel. Source: Authors.

After analyzing the data, and with a view to implementing the OPS system, the feasibility, and the possibility of improving the reduction of emissions must be considered. Ideally, all vessels and docks should be equipped with this system, but due to the costly initial investment required by the ports and shipowners, this implementation must be gradual, and a balance must be found that allows the results to be maximized.

The type of ship that accounts for 43.63% of the accumulated tons is the bulk carrier. Most of these vessels belong to the tramp market. In other words, they do not have any regular or specific routes and, in many cases, call at the port of Santander less than once a year. In addition, these ships belong to too wide a variety of shipowners, without there being any large owners that group together a high percentage of vessels of this style. Therefore, today, in the bulk of docks where these vessels operate, it is not considered feasible to get the most out of the OPS. Hence, a great deal of interest is not to be expected from ports or shipowners who will not be able to receive a return on their investment. The longer the OPS is used, the greater the benefits. It will not be an initial target for the OPS installation.

The case of ROROs, which have emitted slightly over 26.4% of the total accumulated emissions, is radically different. This type of vessel is a clear target, with great potential to be the ideal candidate for the introduction of this technology. The automotive industry is currently making great investments to reduce its carbon footprint and, as is logical, logistics is one of the processes it is looking to improve. In this sense, RORO shipowners are already making large investments in R&D, developing technologies such as rigid sails [61] or alternative fuels [62] among others. In short, these are vessels that emit large amounts of CO_2, are moored between 6 and 12 h, although sometimes for even longer and, more importantly, they are ships with a great regularity that belong to a few shipowners and could obtain a clear benefit in the reduction of consumption. Virtually all of them cover regular lines, calling regularly at the same ports and making numerous annual calls. Both ports and ships will be able to implement this technology, reducing connection/disconnection times, saving fuel, reducing noise, improving the quality of life for the inhabitants, port workers, sailors, etc.: in short, they will be able to optimize the investment.

In view of the above, general cargo vessels (which do not have the necessary regularity) will not be among the initial objectives of the OPS in a port such as Santander, but the group of ferries (which occupies the 4th position of the total accumulated emissions of CO_2) will be. From the data in this study, it can be inferred that during 2021 (still heavily affected by the COVID-19 epidemic) they have called at port 149 times, of which 142 calls have been made by just 2 ships in the continuous rotation of a regular line. Based on the data obtained, in 2021 these two ships emitted, in a total of 832 h, 921.3 tons into the atmosphere according to the EPA method. Therefore, this recurrence would allow the development of a system specifically designed for them that meets their needs and allows them to achieve the desired objectives. In addition, the dock for these operations is literally less than 150 m from inhabited buildings and from the city center, which, from a socio/sanitary point of view, multiplies the interest on the part of the authorities, passengers, and citizens of Santander, while the fuel savings will justify that of the shipowners.

As Bouman [63] points out in his article, the maximum reduction in emissions is not based on one single solution but must be a combination of different technological and operational measures, etc. Therefore, if in addition to achieving improvements and advances in the docked ships, this is combined with other measures aimed at reducing emissions and environmental improvements, such as controlled speed zones, emission limits for vehicles in port (trucks, machinery, cars, cranes . . .), technological improvements for process automation, electric/ecological vehicles [64], energy efficiency improvements in port buildings, installation of solar panels, etc., a significant reduction in CO_2 emissions would be achieved, thus achieving the targets set.

According to the data provided in this study, approximately 38.26% of the tons of the CO_2 emitted by ships docked in the port of Santander could have been avoided. This result goes in the same line as that proposed by WJ Hall [11], who concludes that the impact of the OPS on CO_2 emissions will be −37.8% in Spain. In this manuscript figures are the result for the last 11 years, but this percentage is not linear, since it varies depending on weather conditions (mainly wind and sun) and the resources and generating plants available in the system. Hence, this percentage will be increased significantly in the future as the multiple projects and investments of the green energy generation come into operation, or as new technologies that are currently in the experimental phase are developed and established. Therefore, it can be stated that the OPS will be a far more advantageous technique in the coming years than in the past, as it is logical to assume that if 37.5% of the energy produced in Spain in 2019 were renewable, that figure would be 44% in 2020, 46.6% in 2021 and forecast for 47% in 2022, and the next few years will be the period with the greatest expansion and consolidation of the OPS.

It should be noted that this improvement in the performance of the system does not entail extra investments or costly upgrades or fine-tuning of the facilities, since this optimization is achieved at the energy source, in the production mode. The OPS is simply based on the supply of electricity. Therefore, the sooner this type of facility is installed and put into service, the more years it will serve everyone and the greater the number of tons of CO_2 emissions will be avoided.

On the other hand, in the area of the port, from the point of view of health, the vessels moored where the OPS is a common or even mandatory feature would avoid the emission of 100% of the greenhouse gases (from the combustion of auxiliary engines) harmful to living beings in highly populated areas and urban centers, such as ports. In this way, the prevention of cardiorespiratory diseases, allergies and other diseases related to this type of contamination is promoted, leading to an increase in life expectancy and quality of life, a relief in the pressure on hospitals and health centers and even significant savings for the national health systems so heavily punished in recent years by the aging of populations, various pathologies, or even global epidemics such as COVID-19. It is also true, as a weakness of this technology/this paper, if nergy provided from the grid to the boats has a fuel-burning origin, emissions will only be shifted (delocalized) from the area of the port to the power plant areas (usually settled already far from urban centers where the impact to population is marginal), potentially increasing health problems for living beings in the area.

According to the estimations of Winkel [9] a saving of over 2.94 billion Euros could be made if all European ports were equipped with the OPS, while according to Vaishnav [65] the saving would be between 70 and 150 million dollars if between 1/4 and 2/3 of the vessels that call in US ports had this type of technology. If it is considered that the installation of this technology in an average port can cost 7.4 million Euros [66] and that its amortization is estimated to take 7 years (less if subsidies are received), it can be stated that there is plenty of scope for governments to aid and promote the private investment of port authorities or shipowners in return for a subsequent reduction in health spending. In the case of Spain, with an investment of around 6.2 million Euros of which 1.6 million (26%) come from European funds [67], there is a project called the 'OPS Master plan' [68] through which this type of installations is being promoted with the clear objective that all the general interest ports should be equipped with this technology by the year 2030. Among the ports participating in this project are Algeciras, Barcelona, Valencia, Bilbao, Motril, etc.

The policies of governments and international organizations have for many years been promoting and aiding the installation of green energy sources [69]. The rewards of these policies are now being felt, as there has been a considerable increase in the use of this clean energy over other sources of energy.

Most of the major companies are already aware of the importance of reducing emissions. In addition to the clear goal of reducing costs and optimizing profits, they value very highly and invest heavily in minimizing their carbon footprint, and their logistics play a fundamental role in this regard. Shipping companies, ports, carriers, operators, etc. must comply with these requirements to maintain a fruitful business relationship. The object of this study is the world of maritime transport and port activity. In this area, these initiatives are advancing little by little, timidly making their way, but there is still much to be done. Bearing in mind that the vessels studied in the Port of Santander make up only a small part of the total calls at the national level, and the dependence of countries on the maritime sector for their international trade (74% of imported/exported goods of the EU and 37% of exchanges within the EU are by sea) [70], it can be concluded that there is an enormous potential for reducing emissions that can be achieved without the need to develop new technologies, simply by applying existing ones. Even though the concept of the 'green port' is based on the combination of several different techniques, the OPS stands out as a key part in achieving significant reductions in emissions into the atmosphere (greenhouse gases) based on already developed and mature technologies with a guarantee of success. As Winkel states [9] in his study, if all European ports had these facilities, a potential reduction of 800,000 tons would be obtained. As the introduction of new technologies and mandatory measures must be done progressively, this work justifies that these investments should move forward based on the tons emitted and the regularity of the ships that call at the different ports. The characteristics of each of these vessels must be considered, regularity being a key point in decision-making. Thus, it is concluded that in the port of Santander the initial targets and the focus of attention should be on RORO ships and ferries as well as on the docks where they operate to optimize the initial investments.

Hence, given the great environmental and health benefits underlined in this study, and although there is still a long way to go before it becomes a reality, Spain already has a strategic plan published in December 2021 for a progressive installation of these dock electrification systems [71]. The port of Bilbao has a project that has an investment of 51.8 million Euros for the progressive installation of OPS in 7 docks [72], and the port of Barcelona (through the project Nexigen) will invest 110 million Euros to electrify their facilities [73]. On the other hand, the European Union has not stopped urging its members to encourage and promote the installation and use of the OPS with the hope of a prompt implementation of these systems in all the ports of the area [13,15] and of the world.

6. Conclusions

The following conclusions can be drawn from the data and results of this study:

1. The current measures are not enough to meet the emission reduction targets set by international organizations and governments. Bearing in mind that Santander is a medium-sized port and emissions could have been reduced by 38.26%, the OPS system has great reduction potential if applied to all ports in the area. It is also compatible with the introduction of other preventive measures.
2. From an economic point of view, the greater the fuel/electricity price difference, the more attractive it will be for private entities to undertake the necessary investments.
3. The OPS system is an innovative ship power supply system where its development should focus on the standardization, safety, and speed of the system. Technological advances in electricity production and the increase in green energy generation plants will directly improve the OPS' emission reduction potential without the need for new investments.
4. The reduction in emissions into the atmosphere will be greater the longer this system is in use.
5. Regularity is a key factor in its development, both on ships and in ports. Decision makers need to carefully evaluate pier priorities case by case per each port/traffic. From the results obtained in this work, it is deduced that, for the Port of Santander, the initial objective should be to implement the OPS for RORO, Ferry, and Cruise ships, which account for 37.95% of the total CO_2 emissions during the period studied.
6. OPS environmental performance varies directly depending on the source of the energy supplied.
7. It is inferred that between 2011 and 2021, the reduction in emissions in Santander could have reached an average of 38.26%. Hall [11] already in 2010 estimated potential CO_2 reduction of OPS around 37.8%. Its reducing capacity is not constant, but it is yearly increasing. It is expected that this positive trend will continue multiplying benefits during the next years due to the significant development of green energies in recent times.
8. Regardless of the source of energy, a vessel docked and connected to the OPS reduces auxiliary engines port emissions locally to 0, improving the quality of life of the port community and all those located in its area of influence. (In the case of releasing CO_2 emissions to the atmosphere, these are relocated where energy production facilities are settled).

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