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The Future of Energy in Ships and Harbors

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ABSTRACT: In recent decades, maritime transport, hand in hand with the International Maritime Organization (OMI), has promoted a change in the energetic model in ships and harbors. The main goal of this paper is to show the most useful advances in technologies with respect to reducing gas and particle emissions, and the implementation of technologies based on renewable energies for the propulsion of ships and the energy supply in harbors. Furthermore, new hybrid renewable energy-desalination water technologies which could change the shape of water supply to the ships from near shore zones will be shown. To carry out this study, exhaustive bibliographic research was conducted, including scientific and technical papers.

1 INTRODUCTION

For centuries, maritime transport has been an important exchange link between nations, regions and continents. It is currently a vital sector for the world economy and an essential support for the international market for exports, imports and distribution of goods. Likewise, in recent decades, the transport of goods across the seas has increased considerably, and jointly, emissions, polluting gases and the pollution generated by this sector have also risen notably [1].

That is why the International Maritime Organization (IMO) forecasts a notable increase in emissions within the maritime sector, between 50% and 250% by the year 2050, if limiting measures are not applied [1-2]. For this reason, the IMO has established a series of objectives for maritime transport to reduce greenhouse gas emissions from ships [2-4]. Specifically, one of the objectives is to reduce CO2 emissions generated by ships by 50% compared to 2008 levels. As part of this strategy, the aim is also to reduce the intensity of CO2 emissions from the sector by at least 40% by 2030 compared to 2008 levels [1]. In addition, one of the most recognized shipping companies worldwide, Maersk, has announced the purpose of achieving carbon neutrality by 2050, considering that ships that do not generate harmful emissions can be commercially viable, and that in such a way they can be incorporated to the fleet of companies operating in the maritime transport sector [1-4].

One of the ways to achieve these objectives is to implement regulations at the international level in which increasingly restrictive limits are established on the emissions generated by ships. Halff A. et al. analyses the implications of these IMO regulations in the maritime transport [5]. Psaraftis H. N. makes a wide study of the relation with the market with respect the implementation of these regulation to cope this problem [6]. In legislative terms, the IMO, through regulations such as MARPOL, is focusing its efforts on reducing emissions of polluting gases and particles such as sulfur oxide (SOx), nitrogen oxide

(NOx) and airborne solid particles (PM) and reduce the level of greenhouse gases in the atmosphere, such as carbon dioxide (CO2) and methane (CH4). This agreement was applied to the maritime transport sector to prevent pollution generated by maritime transport, and mainly assigns limitations and controls to the levels of atmospheric pollutants produced by exhaust gases in ships, especially gases such as sulfur oxide (SOx) and nitrogen oxide (NOx), as well as restricting the emissions of substances that affect the ozone layer and also delimiting special areas where emissions are controlled (ECA). Initial efforts have been done by considering lower speeds in the shipping transport [7-8]. However, within the maritime transport sector, shipping companies are expected to begin to consider cleaner fuel and energy options, thus including the use of renewables [9-11].

Within said regulation, one of the most important elements is Annex VI of the MARPOL agreement, which was adopted in 1997 and entered into force in 2005. In it, the different emission levels were set by a series of standards known as Tier I, Tier II and Tier III. The Tier I model is defined in the 1997 version of MARPOL Annex VI, while the Tier II and Tier III standards were introduced in the MARPOL Annex VI amendments adopted in 2008 [1,4].

Given the need to set more restrictive emission levels, on January 1, 2020, a revision was implemented in Annex VI of MARPOL, which requires that the sulfur content in fuel oil for ships be reduced from 3, 5% mass/mass, which was the required requirement since 2012, to 0.5% mass/mass [12-13]. Likewise, the limits of SOx and other polluting particles were reduced in emission control zones (ECA) to 0.10% in 2015 [1-4].

As the requirements for the sulfur content of any fuel used on board ships have changed over the years, with these limits becoming more and more demanding in an effort to achieve the objectives. The IMO suggests a series of changes and measures to have a positive impact on the emissions generated by the sector. Like, for example, making use of compatible fuel oils with low sulfur content (<0.50% mass/mass) [12-13]. And if the sulfur content is exceeded, use a cleaning method, for example, a sulfur scrubber in the exhaust gases. In addition, it seeks to replace the use of fuels with a high sulfur content for alternative fuels such as Liquid Natural Gas (LNG), methanol and others.

Wu Pei-Chi and Lin Cherng-Yuan [13] carried out a comparison between these two approaches to reduce emissions, where the choice of fuel with low sulfur content is a more adequate strategy for longer periods. In addition to the application of these strategies, it is important to remark that the energy supply provided on land during docking periods helps to save fuel burning and reduce greenhouse gas emissions. That is, the electrification of the ports and cold ironing are a key issue in the reduction of greenhouse gas emissions, as discussed in Section 4.

In this way, the IMO, through different regulations, has stipulated mandatory technical and operational measures, which require an efficient use of energy and simultaneously an exhaustive control of emissions. New indicators have been introduced as Energy Efficiency Existing Ship Index (EEXI) or the carbon intensity indicator (CII) with the purpose of measuring and improving the energy efficiency [1,14]. In this line, the IMO Marine Environment Protection Committee has adopted some amendments. These amendments are expected to be established on 1 November 2022, whereas the EEXI and CII certification will take effect from 1 January 2023 [1].

Therefore, shipping companies must take into account the correct choice of cleaner fuels and energies, such as the use of renewables. In addition, rising fossil fuel prices in a highly volatile global market provide an additional reason for shipping to drive alternatives based on renewable sources and technologies. Hence the need to introduce more efficient propulsion systems that are increasingly less dependent on fossil energy sources. Moreover, in recent years new proposals of energy and emission management systems (EEMS) have been devised in the ships [15-16]. These systems contribute to minimize the consumption of fuel, minimize and manage all kind of emissions, minimize all kind of losses into other ways of optimization. Special mention inside the EEMS should be made to the power management systems (PMS) which manage different enery sources or the battery management system (BMS) focused on an adequate use of the batteries [17-18]. All these systems, all acting in a global way, allows optimizing at a high level the available energy of the ship. In fact, new proposals have been put forward by several researchers to optimize the consumption of the different systems in a vessel as desalination plants, seawater cooling systems between others [19-21]. Moreover, these management systems are essential in the new recent projects related with autonomous ships with zero-emissions [16, 22-26].

2 HYBRID PROPULSION SYSTEMS (DIESEL-ELECTRIC)

A viable alternative for the purpose of improving efficiency and reducing emissions is hybrid propulsion, more specifically, diesel-electric. This combination of mechanical power, provided by diesel engines, with electrical power, supplied by electric generators, provides the necessary propulsion power, thus ensuring a wide operational capacity in ships and a precise supply of power to the propeller [27].

Thus, for ships that sail most of the time at a practically constant speed, such as container ships, it would not be as effective to replace a mechanical diesel engine with a hybrid propulsion system, while for tugboats and barges, which require a high degree of maneuverability, the installation of a hybrid system in their propulsion plant would be more appropriate and lead to more efficient results. Notwithstanding, it is also true that the installation of a set of batteries will generally be beneficial for any boat, due to the additional energy that it can provide [28-30].

As an example of the installation of this technology, the MS Color Hybrid ship [31-32] has a plug-in diesel-electric hybrid propulsion system and is therefore considered the largest ship with this type of technology. An attractive feature is that the vessel can be powered for a limited time range purely electrically by a series of additional batteries installed on the vessel.

The battery bank of the ship has a charging capacity of around 5 Megawatt-hours (MWh), weighs a total of 65 tons and can be fully recharged in just one hour via a fast-charging station at Sandefjord pier. The battery system can provide enough energy for about 60 minutes of electric-only navigation at a speed of 12 knots. This electric autonomy is focused on port entry and exit maneuvers. Another essential feature of the electric propulsion system is the reduction in noise and vibration levels in the ship [33]. Similarly, there is also the cruise ship MS Roald Amundsen, which has the option of operating for limited periods of time only with the electrical energy supplied by the batteries, which means that at those moments the ship stops consuming fuel [34].

The diesel-electric hybrid system is an option that is gaining ground because fuel consumption levels are significantly reduced and, therefore, CO2, NOx, SOx and other volatile particle emission levels are also reduced during navigation. Assuming navigation based only on electric power from the batteries, the fuel consumption and emissions during this period will be zero. Furthermore, this system manages to reduce the noise and vibrations of the propulsion system as a whole. Another positive aspect is that the battery operation system is a technology that is developing rapidly. Therefore, it can be applied and offer great potential and enormous benefits to the merchant fleet and the cost of this type of system will be increasingly cheaper. In addition, the diesel-electric hybrid system is also applicable to large ships, which is very attractive for the merchant fleet. Although currently, a purely electric propulsion is a technology unfeasible for large vessels, therefore, this technology will be developed in smaller vessels first.

Like any other powertrain, the diesel-electric hybrid has some drawbacks. One of them is that this system requires large spaces in the ships to house the set of batteries. Additionally, the set of batteries of this type of system must be replaced when its useful life ends, which is determined by the total number of charge and discharge cycles. It should be noted that it is a system in which a fossil fuel such as diesel is used, although it is true that a decrease in polluting emissions is generated, this problem cannot be completely alleviated. For this reason, it is rather a system that serves as a transition to a mode of transport that is increasingly cleaner and more respectful of the natural environment.

3 RENEWABLE AND CLEAN ENERGIES

The contribution of renewable energy to the shipping sector is currently somewhat modest. However, shipping companies are increasingly improving the design of ships with the application of new technologies, where significant savings are shown in relation to fuel consumption and therefore the reduction of emissions.

These solutions range from aspects related to the design of the ship to the use of certain marine technologies, navigation routes or various operational and maintenance factors. Although it is true that there is a wide range of possibilities aimed at minimizing emissions and high fuel consumption in ships, special attention will be paid to new technologies and propulsion systems based on renewable and clean energies [35] that have been applied in the maritime world. Propulsion systems known as hybrids, systems based on wind energy: such as rigid sails, kites, wind turbines or Flettner rotors; systems based on solar energy through photovoltaic panels; and fuels based on hydrogen cells, are some of these alternatives that are beginning to be implemented in the maritime transport sector.

3.1 *Hydrogen propulsion systems*

Putting an emphasis on hydrogen fuel, this is an element that can be harnessed as energy to power propulsion systems. In addition, it offers great potential, is a clean energy and could play a fundamental role in making the transition to an emission-free maritime transport sector a reality.

However, hydrogen is generally found in nature in combination with other elements, hence the need to extract hydrogen from certain substances. Currently, most of its production is made from natural gas since it is the most economically profitable option.

There are two ways to harness the energy of hydrogen. On the one hand, this element is suitable for generating energy through batteries or fuel cells. This is converted through the aforementioned fuel cells into electricity by a chemical process, to later provide energy to electric motors. On the other hand, hydrogen fuel can be used directly to power internal combustion engines or together with other conventional marine fuels to power dual engines [35-39].

The process of converting hydrogen energy to electrical energy through hydrogen fuel cells is highly efficient and occurs without the emission of carbon dioxide and sulfur oxide into the atmosphere, and only negligible amounts of nitrogen dioxide. On the other hand, burning hydrogen in internal combustion engines, which is the other way to take advantage of this energy, is generally somewhat less efficient, and also somewhat more polluting because exhaust gases can be generated, being the most common in this aspect nitrogen oxide (NOx) [35-39].

The MV Viking Lady was one of the first merchant ships to be fitted with a hybrid propulsion system using hydrogen fuel cell technology [40-41]. This ship has a battery system that offers a maximum power of about 500 Kilowatt-hours (kWh) and was built in 2009. The ship currently has a hybrid propulsion plant installed with a dual liquefied natural gas/diesel engine and a set of hydrogen fuel cell batteries that generate electrical power. The vessel also has the option of being reconfigured to operate on methanol fuel. This propulsion system has the capacity to reduce emissions by 100% in SOx levels, by 25% in NOx levels and by 30% in greenhouse gases [41]. In addition, fuel savings 10–15% reduction in fuel are achieved [43].

Another example is the New York Hornblower Hybrid ship, which is a passenger vessel that operates with energy extracted from hydrogen in New York City, making tourist routes to the Statue of Liberty and Ellis Island. Additionally, this ship uses solar energy through photovoltaic panels and wind energy through wind turbines that supply extra energy to the propulsion and auxiliary system of the ship [44]. As a result of the combination of hydrogen, solar energy and wind energy in this boat, it is possible to minimize both the environmental impact of its operations and the savings in fuel consumption, which means a benefit in efficiency and at the same time economic.

This type of propulsion system offers certain advantages. One of them is that hydrogen as a fuel is clean, depending on the extraction method, and efficient. Likewise, with these systems it is possible to significantly reduce the levels of emissions and the consumption of fossil fuels. In addition, no CO_2 or SO_x emissions are generated into the atmosphere. In addition, hydrogen can be used in different types of propulsion systems, both in fuel cells, as well as for internal combustion engines. Additionally, another positive aspect is that it is possible to reduce noise and vibration levels inside the ships.

However, there are certain disadvantages to this type of propulsion system. One of the main ones is that it is a system that has been scarcely applied in the maritime industry. Likewise, based on its physical-chemical characteristics, hydrogen can generate certain safety problems for the crew. In addition, almost all hydrogen production is generated from fossil hydrocarbons, the most common in this regard being liquefied natural gas, which is not the most efficient way to produce said fuel for the purposes of emissions and environmental care [10].

3.2 *Wind-powered propulsion systems*

Another very effective energy is that produced by the wind. Wind energy is a renewable energy with great potential. Taking advantage of the wind to generate propulsion in ships is something that has been done since the beginning of navigation, although it is true that currently the merchant fleet is not giving it practically any use. However, introducing wind systems generates certain very attractive advantages. It is a technology that produces energy without generating polluting emissions and is applicable to practically the entire merchant maritime fleet. Likewise, wind power can be generated from a wide variety of systems and technologies with different characteristics. In addition, they provide additional energy in the propulsion systems of ships, which means significant savings in fuel consumption.

Like other technologies, wind propulsion systems have some drawbacks. Among them, the production of energy through these systems depends on the wind conditions to be effective, such as the intensity or direction of the wind. In addition, another aspect to take into account is that these technologies usually require an adequate control system, and in some cases a crew trained for this type of technology is required. Likewise, normally wind propulsion technologies are focused only on providing partial benefits to the set of propulsion systems [44].

Currently there are three different technologies by which wind energy can be harnessed for ship propulsion purposes, these are kites, Flettner rotors and different types of sails.

In the early 1920s, as an alternative to conventional sails, Anton Flettner invented a propulsion system known as the Flettner rotor, which is a smooth, vertically constructed cylinder. It must be taken into account that Flettner rotors take up space on the deck of ships and will most likely increase the total height of the ship and can generate heeling forces on the ships. Due to such characteristics, possible impediments may arise for installation in certain types of ships or complications may arise for the respective function or operational profile that certain ships are going to perform. In this way, it is observed that all these nuances must be taken into consideration when implementing these systems. A large number of ships belonging to the merchant fleet could introduce Flettner rotor technology to their propulsion systems. However, not all ships are suitable for this technology, due to a series of requirements that fall mainly on the practical and operational profile, and on the space required on deck.

The installation of Flettner rotors is more appropriate for general cargo ships than for container ships, which, unfortunately for this system, require practically all the space on deck and loading and unloading operations that make their installation difficult. Another special feature is that this technology is more suitable for ships that navigate mainly at a constant speed than for ships with a highly maneuverable operating profile, such as tugboats or supply ships [45].

An example of the application of this technology is that of the E-Ship 1 cargo ship belonging to the German company Enercon GmbH dedicated to the wind turbine factory that has used Flettner rotors as an additional propulsion system [45-46]. Said rotors provide the ship with fuel savings between 30% and 40% for a speed of 16 knots with optimal wind conditions. In addition, this also represents a reduction in emissions generated into the atmosphere.

So the Flettner rotor manages to generate emission-free renewable energy. Likewise, it is a very efficient wind propulsion system, it is approximately 10 times more effective than a traditional sail [45], achieving a reduction in fuel consumption and consequently the reduction of emissions generated by the vessel that makes use of this technology. In addition, it is a very efficient system as a way of producing additional propulsion.

However, this technology requires specific wind meteorological conditions to achieve optimal thrust in ships. Also, Flettner rotors have limited maneuverability and take up deck space. In addition, they can affect the stability of boats.

Like the Flettner rotors, the application of kites in ships provides benefits in terms of fuel consumption and reduces harmful emissions. Another positive aspect of the kites is that they can be actively controlled from the bridge of the ship in order to optimize their flying conditions and thus increase the pulling force. In addition, this technology has an automatic control system, which facilitates handling. Also, kites fly at high altitudes where the wind generally blows with greater intensity, thus achieving greater traction. In addition, this system does not take up too much space on deck, hardly causes heeling forces on vessels and is applicable to practically any type of vessel.

However, kites have certain disadvantages to take into account. This system cannot be used in low intensity winds because it is not effective. Also, kites should not be used in areas with heavy marine traffic for safety reasons and cannot be used when sailing against the direction of the wind.

Continuing with wind-related technology, different types of sails can be applied as additional propulsion systems in ships, thus providing a complementary thrust with other propulsion systems and generating fuel savings and a decrease in emissions. Another positive aspect of the sails is that they can be used in different conditions, in both low and high intensity winds - they are versatile, and there are varieties with different characteristics. Furthermore, most sail systems are controlled by a computer from the bridge and, in some cases the controls are fully automated.

Although it is true, there are some negative aspects about sails that should be highlighted. This type of system normally requires high maintenance by the crew. Likewise, the sails must be adapted for each wind condition if they do not have an automated control. Like other wind propulsion systems, they depend on wind conditions to be efficient. In addition, it is a system that requires areas on deck for its installation and operation.

Next, several projects present or in the development phase of wind propulsion systems specialized in sails are presented.

The Neoliner 1360 vessel is a pilot project in the development phase [46]. It will be a ro-ro ship of 136 meters in length and a beam of 24.2 meters. It will be powered primarily by a sail rig system that will have an aerial draft of around 67 meters, and will additionally be equipped with a 4,000kW diesel-electric hybrid propulsion system, for when wind conditions do not offer the necessary potential. The Wind Surf is a cruise ship that harnesses the energy from the wind through a sail system [47]. It is one of the largest sailing cruises in the world. Rigid sails were installed on several Japanese ships in 1980 with the aim of achieving a reduction in fuel consumption. As a result, these Japanese vessels reported great savings in fuel consumption, reaching a savings rate of 30% [48-49].

Bound4Blue is a Spanish company founded in 2006 that has designed and patented a wind propulsion system that serves as an additional complement to the propulsion system as a whole. It is a system of rigid sails capable of offering additional thrust to ships by making optimal use of wind energy. In this way, this technology manages to reduce fuel consumption and cost and, consequently, polluting gas emissions are also reduced [50].

The Bound4Blue system is a rigid sail system that operates 100% autonomously, therefore requiring no additional crew training. The design and structure of this type of sail is light and low in weight, thus avoiding stability problems and minimizing possible heeling of the ship. Likewise, it is a system that requires little maintenance, and its folding sails guarantee greater safety and optimize performance in adverse or unfavorable weather conditions. An attractive aspect of this system is that it can be installed on existing ships or on newly built ships [51].

Dyna-Rig type sails are also a wind propulsion system. They are square sails, of large dimensions with independent and rotating masts. By turning the mast, the sail can be adjusted to the wind direction and when the sails cannot be used, they are furled inside the mast. Also, the sails can be managed electronically through automated controls. This system was developed in the 1960s by the German engineer Wilhelm Prölss. The Maltese Falcon is a luxury yacht that uses Dyna-Rig type sail technology in its propulsion system. The sophisticated automated control system contained in the yacht allows the detection of parameters and wind conditions automatically and displays data and key information for trimming the sails.

As an example of application, the WASP (Ecoliner) is a design prototype of a ship that is still in the development phase. In the design, the Dyna-Rig type sail system has a meteorological routing program with the purpose of optimizing the navigation route and the use of the engine to the maximum. The reduction in fuel consumption would be around 25% and 40% depending on weather conditions and routes [51-52].

The objective of these technologies are aimed at achieving savings or reduction in fuel consumption and therefore a decrease in emissions [53].

3.3 *Solar power propulsion systems*

Similarly, solar energy brings great potential for a cleaner mode of transport. This is an important source of renewable energy and has been used by humans since ancient times through a series of technological systems that have evolved. As a technology, solar panels can be installed flat on the deck or in another way they can be arranged vertically coupled to certain types of sails. The main limitations for this system are mainly the lack of spaces for the deployment of sufficient photovoltaic panels and the lack of spaces for the storage of energy generated by those panels.

However, over the last few years, solar energy storage technologies have been developed that offer greater potential and a better perspective for applying this type of technology to ship propulsion systems. Propulsion based exclusively on solar energy is being directed mainly to develop in relatively small boats, while for larger boats, solar propulsion will serve to offer additional power or supply the energy demand of auxiliary systems [54]. Due to the physical and technical limitations of this system for large ships, solar energy is aimed at supplying auxiliary components, powering the ship in certain port operations or for use on short-term trips.

The Auriga Leader was the first merchant ship to be partially powered by solar energy. It is equipped with a plant of about 328 photovoltaic panels that generate up to 40 kilowatts of electricity, which represents 0.05% for the propulsion power and 1% for the generator systems. On the other hand, when it is moored in port, solar energy reaches up to 10% of what the ship requires. The Emerald Ace propulsion system consists of diesel engines and additionally has a photovoltaic panel plant on the upper deck of the ship. The plant has 768 solar panels that generate a power of 160 kilowatts each one. And by means of a series of a set of lithium batteries, the solar energy captured by the photovoltaic cells is stored [53]. Once the ship docks in port or is anchored, the solar panel system and the set of batteries take over the power supply without the need for the operation of diesel generators, in such a way that this prototype completely reduces the emission of polluting gases during the stay in port or at the anchoring points [55-56].

Solar power can supply some additional power for propulsion systems, but primarily supplies power to the auxiliary systems of the ship.

There are certain advantages to employing solar propulsion systems on ships. This energy does not generate emissions and is a renewable energy, which implies that the system will always be supplied. Also, with the application of this technology it is possible to reduce fuel consumption and thus pollutants. Another interesting aspect is that solar technology can be applied in conjunction with wind or other systems.

However, there are certain disadvantages regarding solar technology. And it is that the efficiency of this technology depends on meteorological parameters as it happens with wind systems. In addition, the percentage levels of energy that they generate for the propulsion systems are usually low, so these systems are aimed at supplying energy to the auxiliary systems. And it is currently an economically expensive technology, although it is true that over the years, with the development and research of this technology, it has become more commercially viable. Besides, an aspect to take into account with these systems is that extensive spaces are required on the main deck of ships; for this reason, they are not applicable to any type of ship.

As an example of these technologies based on renewable energies, it is worth mentioning the Energy Observer vessel, a French experimental vessel which has been the first in the world to achieve completely emission-free hydrogen production on board. [56-57].

Also, the recently built ship MV Yara Birkeland [58-61] is a totally autonomous and electric freighter dedicated to the transport of containers, which does not generate emissions. Its propulsion system consists of fully electric motors and a set of batteries with a capacity of 7 to 9 MWh that will provide the energy supply to said motors.

Likewise, the ZeroCat 120 ship [62-63] is a totally electric ferry of about 80.8 meters in length, about 20.8 meters in beam and has a capacity for 120 vehicles and 360 passengers. Its propulsion system consists of two electric motors of about 450 kilowatts of power, whose energy is supplied through two lithium-ion batteries with a capacity of 1,000 kilowatt-hours that are recharged during the two stops on its route. In this way, the ferry does not use any type of fossil fuel in its operations. And consequently, it does not emit any type of polluting gases or particles into the atmosphere.

4 ENERGY SUPPLY IN THE PORT

The power required by the machinery operating while the ship is berthed (e.g, loading cranes, pumps) is often provided by auxiliary engines running on any type of fossil fuel, which typically has a large content of particulate matter. The greenhouse gas and, importantly, particulate emissions from these auxiliary engines are an important source of pollution. A situation that is arguably the result of the absence of emissions controls for merchant vessels.

In recent years, the emphasis on emissions reduction has promoted alternative ways of providing energy to the machinery of ships, most notably cold ironing.

Cold ironing [18], known also as shore connection or shore to ship power, effectively reduces emissions from auxiliary engines, given these engines are not working at port. Moreover, it allows to incorporate renewable energies generated or received at port directly into the energy supply of the ship. Overall, this is a wide field of research, which can accommodate, in addition to conventional renewable energy sources (hydropower, wind), new marine renewables (offshore wind, wave, tidal energy) [64-65].

The prospects for emissions reductions through cold ironing have been investigated by Zis [22], and case studies considering the integration of renewable energy into cold ironing have been published for a number of ports, including Barcelona [23], Aalborg [66] and Aberdeen [67]. The application of tidal stream energy from the Shannon Estuary (Ireland) to serve the needs of the Shannon Foynes Port, among other uses, was recently proposed by Fouz et al. [68]. The four above-mentioned ports are very different in size, which corroborates the applicability of renewable energy sources to supply ships at berth in both small and large ports. On the other side, it is worth mentioning the combination of a hydrogen-based hybrid energy system and cold ironing, which has been recently investigated by Sifakis et al. [69]

Finally, new ways of obtaining energy near shore based on temperature gradient of the water column and the wave energy [70-75] have emerged in recent years. Because of the increasing industrial activity of the ports, along with the necessity to support electrical energy to the ships the ports show a higher potential energy demand. This fact is promoting the search of new ways of energy supply based on renewable energies. In particular, a great emphasis has been put in the marine energies given the nearness of the sea to the ports. However, all marine energies are not adequate for the ports. Offshore wind needs of wind farms which is not appropriate for a port. Tidal energy is not possible for a port, given high differences are necessary in the tides. Because of that, wave energy is being paid attention in recent years [73]. Different Wave Energy Converter projects are being executed as MAtchUP European project in Valencia port or many others [64,73].

These new approaches can provide additionally desalinated water [71-72] and refrigeration near the coast, i.e., ships could be supplied with energy and water, and refrigerated by these systems. Different initiatives as the prototypes tested by Wave Piston [72] or the prototype Gaia tested by Ocean Oasis [76] are examples of these new wave energy devices focused on the production of desalinated water.

5 CONCLUSIONS

In this paper a global vision of the normative, applied by several organisms with respect to the energy consumed by the ships have been shown. These directives are aimed at reducing contamination and achieving an optimal use of energy in the maritime sector. Different options to provide energy to the ships are shown, and their advantages and drawbacks are discussed. In conclusion detailed knowledge of all these alternatives is necessary in order to choose the best option in each case. In general, a combination of alternatives is the best option in most cases. Moreover, new ways of providing energy from ports have been shown. In this vein, a number of recent studies were reviewed which deal with options to provide energy, water and refrigeration to the ships from renewable natural resources.

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