Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2018.22595

127 (2018) 90–96
September

Shipyards waste and sustainable management in Greece: case study

Georgios Papamanolis, Evangelos Giannakopoulos*, Ioannis K. Kalavrouziotis*

School of Science and Technology, Hellenic Open University, Tsamadou 13-15 & Saint Andrea, 262 22 Patras, Greece, emails: ikalabro@eap.gr (I.K. Kalavrouziotis), v.giann@yahoo.com (E. Giannakopoulos)

Received 31 March 2018; Accepted 5 June 2018

ABSTRACT

The shipbuilding industry and the several building or repair operations carried out on it, are reported as amongst the common sources of waste, which is not possible to extinguish but can only be eliminated through the adoption of the appropriate waste management techniques. This need is enhanced further from the lack of an International regime (with mandatory law requirements) specifying shipyard operations, prevention actions, and waste management techniques, and is immense in countries with a narrower regulatory establishment on shipyard waste management, like Greece, which adopts the general E.U. Law requirements but does not offer a detailed regulatory basis concerning individual shipyard or industrial operations and the management of resulting wastes. This work analyzes the several sources of waste generated from shipbuilding activities and investigates the extent that these wastes can be managed in a sustained manner, for the case of "Neorion Syros" Shipyard (NSS) in Greece. The results show that NSS undertakes almost all possible shipbuilding or repair operations (sandblastings, paintings, use of solvents, etc.) apart from the dissolution of ships, there by producing a broad range of solid and liquid wastes (volatile organic compounds, tributyltin, etc.) and air emissions that spread across Syros and heavily pollute the island and the sea, especially under specific weather conditions, making the need for the elimination of pollution related with the operation of the shipyard, an area of intense interest and importance.

Keywords: Treatment shipyards wastes; Sustainable waste management; Pollution; Shipbuilding repair industry

1. Introduction

The shipbuilding industry (shipbuilding and ship repairing) is considered as one of the oldest and heaviest manufacturing industries in the world. It produces significant amounts of sewage from all the productive activities carried out on it [1]. Today, it is considered a "complex" and large-scale industry that affects the atmosphere, the aquatic and terrestrial environment, producing solid, liquid, and gaseous wastes and therefore affects the life and health of human beings [1–4]. The shipbuilding industry worldwide is not regulated by a specific international law and the obligations regarding the environmental function of each shipyard in Europe are related to the national legislation of each country and European law requirements [5–7]. So there are countries that apply stricter environmental criteria, while in others there are "looser" criteria and fewer measures are taken to protect the environment and human health [4,6,8]. Since it is impossible to avoid pollution caused by a shipyard, it is very important to achieve efficient management of the generated waste by its operation [9,10]. This is an extremely important requirement for the protection of the environment and requires an understanding of the polluting activities of a yard. Knowing as far as possible the quantitative and qualitative characteristics of pollutants, it is easier for them to be addressed appropriately and effectively [9,11]. The proper management of waste is related to the prevention, minimization and, as far as possible, recycling and re-use, where possible before they are finally disposed of [1,9,12]. In some cases, a waste management model is used to assist in the decision-making process. Nowadays these models are applied successfully on municipal waste management. According to Morrissey and

* Corresponding author.

Presented at the 15th International Conference on Environmental Science and Technology (CEST-2017), 31 August–2 September 2017, Rhodes, Greece.
1944-3994/1944-3986

Browne the goal of this model is simple, (to optimize waste collection routes for vehicles), while in others, it is more complex (to evaluate alternative waste management strategies). Many of the models identified are decision support models, using a variety of important methods and tools, such as risk assessment, environmental impact assessment, cost–benefit analysis, multicriteria decision–making, and life cycle analysis, as part of the decision-making process [29].

In Greece several shipbuilding units are active, mainly in the field of ship repair and small shipyards for various productive operations. The shipyards of Skaramanga and Eleusinas, in the wider capital region, along with the shipyard of Neorion in Syros and the one of Aulidas in Halkida are considered to be the bigger and most organized in the country [13] (Fig. 1).

One of the main units that operate is the "Neorion Syros" Shipyard NSS, located on the island of Syros, in the Cyclades of the Aegean Sea, which will be the subject of a study in this work regarding the work carried out on it, the waste generated, measures taken to address and limit the waste generated, and the environmental impacts resulting from its operation [14]. This knowledge as an authoring tool will be used to design a future shipyard waste management model for the case study [29].

2. Shipyard processes

The shipyards carry out various types of work and the production methods applied lead to the production of hazardous wastes and pollutants, with serious impacts on the environment and human health [1–4]. Some of the important basic shipyard processes and waste emissions from these operations are discussed briefly in Fig. 2.

In shipyards, in addition to the basic primary building materials used, a wide variety of processed and more complex materials are produced [16]. The main tasks performed in a yard include in general all ship modifications, scheduled repairs and maintenance, major damage repairs and repairs to their equipment. Most of the time, these work must be completed as soon as possible in order for the ship to be put back into operation. Good planning of the work is therefore required, while at the same time taking all necessary measures to protect the environment. So, a typical maintenance and repair of a ship in a Greek shipyard include:

Fig. 1. The shipyard of ○ Eleusinas, □ Skaramanga, ◇ Aulidas in Halkida, and △ "Neorion Syros" in Syros Island, on the Greece map [14].

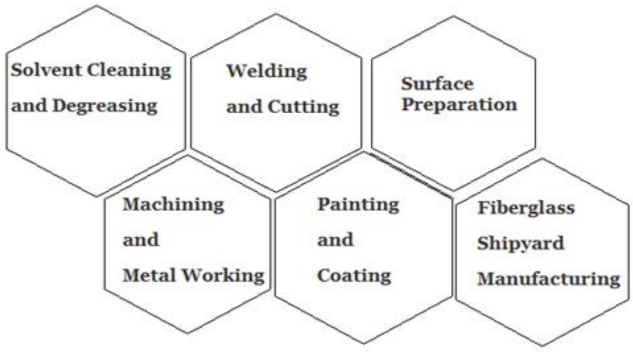

Fig. 2. Basic shipyard processes [15].

- The painting of the ship (boats, frets, superstructures, internal compartments, tanks, workplaces, etc.), which involves the cleaning of the surfaces either by sandblasting, by the watering method or by using some other method of preparation of the surface painting.
- Repair and maintenance of ship machines (machines, turbines, generators, pumps, compressors, refrigerators, etc.).
- Repair and maintenance of the ship's piping facilities.
- Repair and control of rudder, propeller, axial system, system alignments.

2.1. Surface preparation process

Surface preparation is a very important process in the shipbuilding industry. The different processing and preparation techniques of the various surfaces are directly related to the location of the surface. The most widespread are [17]:

- by using various solvents and chemicals,
- by using "Blastings,"
- by mechanical machining,
- the wet sanding and watering process.

The above application techniques for preparing the surfaces are described below.

2.2. Painting process

Paintings are carried out in almost all areas and sections of a shipyard, due to the requirements and the variety of work performed on it. They protect a ship and its entire equipment from erosion, given that the ship operates in the highly corrosive environment of the sea. The biggest "requirements" are on the hulls of the ship, the surfaces below its waterline, which are constantly in contact with the seawater, as well as its various tanks. Consequently, each ship applies paints suitable for the protection of its surfaces, depending on location and corrosive requirements [1]. For example, strong antifouling and quite toxic colors are chosen for the hulls of a ship, with the additional purpose of preventing the attachment of shellfish to them. It is clear, therefore, that the construction and repair of ships requires the use of different types of colors, depending on their needs and conditions of application. Water-based paint qualities that are more environment-friendly can be used, up to high epoxy-friendly colors, depending on the environment to be exposed to each surface [3].

2.3. Solvents cleaning

Solvents for all types of cleaning and degreasing are widely used in the shipbuilding industry, although in the context of environmental protection, aqueous alkaline cleaners have in many cases replaced them [9]. Purification and degreasing are achieved either by cold cleaning or by steam degreasing. Chilled cleaning refers to processes performed in tanks at room temperatures in which the surfaces to be cleaned are either dipped in the solvent or the solvent is sprayed, brushed, wiped, and rinsed off the surface. It is desirable for the use of solvents to be restricted only to closed controlled areas and where the result cannot be achieved by an environment-friendly process. As mentioned earlier, aqueous alkaline cleaners have in many cases replaced the use of solvents. Also mechanical cleaning systems can replace solvents in degreasing and cleaning operations. By using special steam vapor guns and possibly using mild detergents, a similar result can be achieved. The waste resulting from this process is usually oily and edible, and as a result, after proper separation, part can be disposed of in a sewerage system and the remaining, after being collected, sent for recycling. Prevention and reduction at source is preferable and desirable but possible re-use and recycling of solvents may be a viable alternative for the yards. There are techniques that can be used by shipyards to separate solvents from contaminants such as distillation, evaporation, sedimentation, centrifugation, and filtration, which must be applied by shipyards in order to achieve the minimum burden of the environment from these processes [18].

3. Pollutant sources

The Greek shipbuilding industry uses various kinds of raw materials, which result in the entry and expose of any kind of pollutants. Various categories of steel, various other metals, paints and various kinds of solvents, as well as various lubricants and oils for cutting machines, are used in shipbuilding. In addition, a wide variety of chemicals are used for surface preparation and finishing, such as degreasing solvents, acid and alkaline cleaners, as well as various cyanide metals and other metallizing materials. As a result of the above inputs and processes followed as well as the execution of each production activity, it is the production of various pollutants and wastes such as volatile organic compounds (VOCs) (styrene, acetone, methylene chloride, etc.) [19], suspended particles, solvent wastes, oils and resins, sludges containing hazardous metals, waste paint, chip colors and abrasives [20]. The main pollutant sources in a Greek shipyard and the wastes generated are described below [21].

3.1. Preparation of surfaces to be suitable for applying paints

Proper preparation of a metal surface is a very important factor for its longest possible life. The process of removing all foreign bodies and substances such as dusts, rust, and various fats and salts affects the efficiency of the paint system and creates the proper conditions for the proper adhesion of the protective coatings [3].

The materials used and the waste generated during the preparation of the various surfaces depend basically on the specific methods applied. The surface treatment method chosen depends on the state of its metal surface , for example, if the metal surface is coated with old paints or if it has rust and to what extent, the type of metal, its size, its shape, and its location. Metals such as chromium, aluminum, brass, cadmium, copper, iron, lead, nickel, zinc, and many others are used to "finish" metal sheets. In addition, cyanide solutions and various other solvents, which are rinsed with water and combined with various rust inhibitors used, produce waste that is considered to be hazardous and toxic [1,15].

The above operations and materials generate gaseous emissions as described below [16].

3.1.1. Air emissions

Air emissions result from metal fogs, from fumes and gas bubbles, from the vaporization of solvents used to clean the surfaces before coating them. Also, with the lamination preparation, various particles are produced, including color fibers and various other toxic metals, which burden both the space in the shipyard and the surface water around it. Other emissions to air, such as VOCs and various other atmospheric pollutants, arise from the use of cleaning solvents, paints, and corrosive materials [1].

3.1.2. Solid wastes

The main solid wastes produced during the surface preparation process are a mixture of paint chips and used abrasives containing lead as well as hazardous antifouling substances. Although they are particularly toxic substances, due to the presence of significant quantities of used blasting material with a neutral composition, they create a final waste, which may not be dangerous [22].

Irrespective of the hazard and toxicity of this final sand blasting and sludge generated by the water bath, it must be cleaned and collected from all the lagging surfaces and, above all, from the basins of floating tanks prior to precipitation, so as not to diffuse in the aquatic environment. Particular attention should be paid to the purification and removal of waste containing tributyltin (TBT) compounds [23,33], which according to most studies have been shown to be particularly toxic to oysters and other marine organisms [11,23,24].

Solid sand blasting wastes can be effectively detoxified by heat treatment and process efficiency is influenced by temperature and time of treatment [25]. This process removes organotin compounds with high yield, so that the material produced can be re-used as a building material or as a coating material in sanitary landfill [25,26].

3.1.3. Liquid wastewater

Significant quantities of liquid wastewater can be produced during the cleaning of a ship, its cargo tanks, ballast tanks, and shadows before surface preparation and painting. These effluents are often impregnated with cleaning solvents, oil and grease residues, color chips as well as various other surface contaminants created by sandblasting, watering, and various wet abrasives used.

Hull wastewater contains organotin compounds and can be effectively treated by extraction with a suitable solvent [26] Thus, with various leaching experiments that can be carried out, useful conclusions can be drawn for the development of waste treatment of antifouling paints in shipyards [15].

3.2. Paintings and surface coatings

To protect the surface of the ship, simple types of colors can be used with water-based coatings, as well as high epoxy coatings (antifouling paints). They are used to prevent the growth of marine organisms and are very toxic substances such as heavy metals, organometallic compounds, and TBTs [10,23,24,27,33].

In painting operations, for the more effective protection and maintenance of metal surfaces, various colors and solvents are used to transfer the pigment and its binder to the surface to be dyed. The colors used contain various toxic substances, such as chromium dioxide, titanium, lead, copper, as well as tin-containing compounds and significant amounts of VOCs are produced. Organic solvents are used to dilute colors and usually contain very dangerous substances, resulting in the waste produced by dyes being considered as the most dangerous in a yard [1].

3.2.1. Air emissions

When performing any kind of dyeing on ships, significant amounts of VOCs and other gaseous pollutants are emitted, mainly during the process of bleeding the solvents during dye drying. The problem is intensified as solvents are used to clean the equipment used in the process (spray guns, brushes, containers, etc.). With the use of spray guns, amounts of paint, either in spray or over spray, create gaseous emissions, as volatiles and other dry dyestuffs are volatile at high speed, which can be pulled out of the yard to nearby surface [2].

3.2.2. Solid wastes

Solid waste associated with dyestuffs in a shipyard is considered to be the largest category of hazardous waste [11]. They include paint remnants, empty paint containers, rags and other paint materials, spent solvents, and sludges from washing any kind of dyeing components. The most hazardous wastes are those from the use of antifouling, as mentioned, contain particularly toxic metals [10].

Particularly important is the separation of waste according to its risk, since waste associated with the bottom of ships is more dangerous because of its strong antipollution requirements, compared with the less toxic colors used in the ship's interior [8].

3.2.3. Liquid wastewater

Waste contaminated with paints and various kinds of solvents are created during the washing of all the components and equipment used in the dyeing process. Water is mainly used for the purification of water colors, while mixtures of various solvents, such as aromatic hydrocarbons, aliphatic hydrocarbons as well as various halogenated solvents, are used for cleaning and degreasing in "more complex" situations [8].

3.3. Use of solvents and degreasing processes

Solvents are widely used for cleaning and degreasing operations such as cleaning of various components, cleaning of equipment used for other processes (e.g., dyes), and for preparing any type of surface to be protected from corrosion.

The type of solvent used depends on the type of pollutants to be removed, the degree of cleaning required, the properties of the surfaces to be cleaned, the properties of the different solvents, their toxicity, the stability, their flammability, and cost. Thus, both halogenated and nonhalogenated solvents, various other mixtures thereof, as well as aromatic and aliphatic hydrocarbons, ketones, esters, alcohols, phenols, etc. are selected and used. Common cleaning and degreasing processes include cold cleaning and degreasing of vapors [19].

Significant waste is generated by the used solvents, as well as by improper handling and storage. Gaseous emissions consisting of VOCs cause significant release of pollutants into the atmosphere. Additional wastewater is produced during the cleaning or rinsing of the various surfaces [9].

4. Management practice study in a Greek shipyard and wastes generated

Neorion Shipyard is one of the oldest Greek heavy industries, located in Ermoupolis, on the Greek island of Syros. The operation of the Neorion Shipyard started in 1861. Since 1994 when it was privatized, it has underwent a technological evolution, implementing an ambitious investment program of more than 35 million euro [28]. It soon became famous for the quality of its services, provided by some of the most experienced craftsmen in the Mediterranean. NSS is equipped with two floating dry docks, both fitted with hydraulic dock arms and adjustable side blocks. Quay space totaling 1,100 m, is served by 1 × 40, 1 × 20, and 3 × 25-ton traveling jib cranes, enable vessels up to 150,000 d.w.t. to be repaired. They are fitted with fresh water/sea water, compressed air, liquid propane, steam, AC/DC power supplies [28]. The operation of the Neorion Shipyard in Syros is a burden to the environment with all sorts of waste, such as gases, liquids, and solid waste, which are discussed below [1]. So, the effective management of wastewater and other waste streams results in lower costs, reduced liability, and thus improves the public image and achieves environmental compliance [4,9].

4.1. Air emissions from NSS

Air wastes are produced by the work of sandblasting carried out in the open air of floating tanks, from various paintwork, from the use of solvents and corrosion inhibitors, as well as from the operation of various machinery in the yard.

Despite the technological improvements in recent years, the blasting carried out at the shipyard still remains a serious and unhealthy work, with serious consequences for both human health and the environment, mainly due to the abrasive used. The use of abrasive materials creates an airborne dust which, in addition to its impact on the environment and human health, generates large quantities of waste and the need to manage it, as in the case of Neorion Syros, is an inconceivable problem [21]. During the process of the external sandblasting, various particles are emitted which, depending on the intensity, the direction of the wind, the size and the place where the work is carried out, are dispersed in and out of the installation in the air or dropped into the tank. The problem is partially addressed by performing work in enclosed spaces whenever possible. Thus, in the process of internal sandblasting, particulate emissions are relatively limited, because appropriate antifouling systems (mainly bag filters) are used. Most of the processes such as welding, painting, blasting, fiberglass production that have a direct effect on workers' health, that is, exposure to VOCs, fumes resulting from burning through base metal, and from burning the interior and exterior coatings that are often left in place, can cause acute and chronic health problems [20]. In addition, various VOCs are produced and escaped into the atmosphere in the process of performing any kind of dyeing, while various filters are used in the interior, resulting in a significant reduction of these emissions. It is therefore necessary to carry out as much work as it can, indoors, and the limitation to what is absolutely necessary for execution outdoors. The aim is to minimize the environmental nuisance and its consequences for the environment and for humans [14]. From the operation of various machinery in the yard, for example, compressors and electromechanical machines, exhaust gases are emitted, the quantities of which are relatively small and consequently do not greatly affect the atmosphere.

4.2. Solid wastes from NSS

The main solid wastes from the shipyard's production process generate from sandblasting–blasting (blasting by-products). In addition, various ferrous metal polishing and turning products, as well as metal powders and particles from the machine shop and rolling mill, are added to the solid waste generated by the operation of the shipyard.

In addition to the processes carried out in the shipyard, "used" electrode residues, waste from all kinds of sheets, used cloths and tarpaulins, empty paint boxes, used paint process components, and waste wire fragments are produced. Also wooden pallets of transported materials in the yard, papers and boxes and various other municipal waste arise from the operation of the shipyard. Obviously, some of the solid materials are nonhazardous waste, and the simple procedure provided for nonhazardous solid waste is followed by landfilling in landfills, while others are quite dangerous and require special attention in their management (e.g., waste from dye processes and solid waste from blasting). The largest quantities of solid waste produced in the shipyard are generated by the work of the excavation and due to their toxic characteristics, special attention is needed in their management. These waste are concentrated in specially designed open and sheltered spaces in the shipyard [14].

In recent years, there is a huge problem with this kind of waste. In spite of the systematic actions for the promotion of the material in the landfill of the island, it has not been possible, resulting in large quantities of used sand blasting at the yard, due to political reasons and lack of strategy [21].

4.3. Liquid wastewater from NSS

A fairly large percentage of the dust generated from the work of drilling ends up in the marine environment, despite whatever measures are taken, either during or after the work is done. From the data and compounds that end up in the marine environment of the port of Ermoupolis, TBT is the most dangerous, because it is a powerful biocide used in antifouling paint on ships [23,24,27,33].

In addition, for the case of the Neorion Syros, and given that the waterworks that are carried out due to the high cost and the quantities of liquid waste they produce are quite limited, most of the liquid wastes of the plant result from the operation of the Machine Shop and its Power Station. But they do not cause a large environmental burden because they are easier to collect, handle, and dispose of [14]. The unit has a chemical cleaning unit, where the waste is guided and, after appropriate treatment, is taken to the Ermoupolis urban wastewater network and transferred to the biological cleaning plant of the island [14]. The chemical cleaning unit achieves equilibration and pH adjustment, removing floating substances and precipitating solids, resulting in the effluent leading to the biological of the city not containing metals, oils, and various other dangerous solids.

In the shipyard's liquid waste, the desalination discharged brine, which is disposed directly into the sea, can also be included. The elements and compounds contained in the discharged brine according to the relevant analysis are: NH_4, K, Na, Mg, Ca, HCO_3, NO_3, Cl, F, and SO_4. As can be seen from various measurements taken, they do not burden the marine environment, in accordance with the applicable environmental study prepared for the shipyard [21].

Also some quantities of the liquid waste, produced from the waterworks, are collected as much as possible and they are also transferred to the chemical processing unit, where they are processed. Water products have very dangerous characteristics for the environment and therefore also for humans, and therefore their chemical treatment is necessary before they are disposed of to the grid that leads them to biological cleaning [14]. According to the technical characteristics of the unit, the water after the treatment undergoes, limits its toxic characteristics and can now be diverted for further biological treatment at the island's unit.

5. Results and discussion

This work analyzes the several sources of waste generated from shipbuilding activities [1], and investigates the extent that these wastes can be managed in a sustained manner [9], for the case of NSS in Greece. The results show that NSS undertakes almost all possible shipbuilding or repair operations (sandblastings, paintings, use of solvents, etc.) apart from the dismantling of ships, thereby producing a broad range of solid and liquid wastes (VOCs, TBT, etc.) [20,23,33] and air emissions [3] that spread across Syros [21] and heavily pollute the island and the sea, especially under specific weather conditions, making the need for the elimination of pollution related with the operation of the shipyard, an area of intense interest and importance [4]. The main results are that: (1) the shipyard "Neorion Syros" is the oldest shipbuilding industry in Greece and is considered to be one of the most well-equipped repair units in the entire Mediterranean Sea [28]; (2) the yard performs all kinds of work that can be carried out in a yard as it has all the required basic parts, which are properly equipped such as machine shop, steel workshop, pipe workshop, power plant, foundry, and various other support, as well as two large floating tanks and a shiplift, for smaller ships or yachts [28]; (3) at the yard, as is the case with most shipyards around the world, work is being carried out to prepare and clean the various surfaces of a ship, all kinds of dyes, repairs to various ship machinery, tubing, and rolling [1,3,15]; (4) all above work produces all sorts of waste (solids, liquids, and gases) and various hazardous pollutants [1,3,15,16,18]; (5) a major problem arises from the work of sandblasting, especially when the weather conditions are inadequate, so that powders and suspended particles burden the city's environment, while the material used precipitates at the surface of the sea and then sinks to the bottom of the sea [1]; and (6) measures have been taken to manage and minimize waste generated while the unit has a wastewater treatment plant, hazardous waste storage facilities, and sheltered storage facilities for the sand blasting used, and measures have been taken to ensure that the wastewater from the workshop and electrification to be collected and brought for treatment before they are finally disposed of to the sewer system of the island [14]. The knowledge of above elements would enable waste managers at such shipyards, as well as policymakers outside the shipyards, to take concrete steps to achieve more sustainable waste management practices as authoring tools a decision-making model [29].

6. Conclusion

Shipbuilding, like any industrial activity, affects and pollutes the environment and, consequently, human life, especially near the sites of installation and operation of such units. In most yards, work is carried out requiring the consumption of significant quantities of raw materials and energy, and with the processes being carried out, significant quantities of polluting substances are emitted, such as solid and liquid wastes, as well as gaseous emissions containing dangerous pollutants for the atmosphere. The operation of such units is essential to the functioning of the global economy related to shipping, trade and transport, and therefore the environmental burden of this kind of industry is inevitable. With this in mind, it is desirable to minimize and correct the shipbuilding waste, even at a higher economic cost, in order to cause less environmental problems. To this end, it is necessary to identify sources of pollution from all production activities. The characterization of the waste streams produced in a shipyard is therefore necessary because of the significant quantities produced during its operation. Characterization helps to separate waste into hazardous and nonhazardous waste streams. This sets out their sustainable management techniques, which are related to pollution prevention, waste reduction at source, re-use, recycling, and final treatment and disposal.

It is noted that shipyard "Neorion Syros" has taken the necessary pollution control measures, contained in the applicable environmental conditions for the operation of the yard by applying so-called "best practices" for waste management [14], but not always achieving the desired result, which seems to be due to various reasons, either economic or ignorant from the point of view of administration, workers and the state [4]. So, this study would be a quite valuable step, as then decision-makers would be able to compare the relative costs of managing wastes in different ways and identify the least-cost (or most cost-effective) way of achieving any particular sustainable waste management goal [30–33].

Shipyards around the world have to restructure their work to meet the requirements for sustainable development with the most effective protection of the environment. The negative environmental impact seems to undermine in many cases the contribution of the shipbuilding industry to sustainable development, and most studies and waste management models find that radical changes in socio-economic and political structures are necessary to enable environment-friendly practices to be adopted, while preserving employment opportunities for residents of the areas in which yards operate [21].

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