

Conceptual design of shore station for an innovative waste collecting vessel

Niklas K.^{1,*}, Pruszko H.², Reichel M.³, Jaworska J.⁴, Marcinkiewicz E.⁵

ABSTRACT

Marine environment protection legislation in the EU requires ships to return waste they generate on voyages to waste-reception facilities in ports. In many harbors there is a need to expand the port infrastructure to enable the operation of Waste Collecting Vessels (WCVs). In addition, these vessels can perform new functions of cleaning port basins and adjacent waterways. A novelty in the presented research on the conceptual design of the shore station is the inclusion of new requirements for an autonomy and modularization of the vessel. The shore station was designed in the form of a floating pontoon, taking into account the various functional requirements addressed in the ship's conceptual design stage. The pontoon consists of modules corresponding to the ship segments moored in them. The conceptual design was intentionally defined in a generalized form to allow for further development and adaptation to local requirements at individual ports.

KEY WORDS

WCV autonomous; Station; Waste, Environment, Modular.

NOMENCLATURE

MARPOL - International Convention for the Prevention of Pollution from Ships

PRF - Port Reception Facilities

WCV – Waste Collecting Vessel

INTRODUCTION

At the international level, marine environment protection is addressed by the MARPOL Convention, which has been consistently extended to new areas including oil pollution (Annex I), sewage (Annex IV) and garbage (Annex V), air pollution (Annex VI). The most demanding environmental protection rules apply in so-called "special areas" which include the North Sea, the Baltic Sea, the Mediterranean, the Black Sea, the Red Sea and other basins that include a globally significant number of seaports. In European Union countries, the law is implemented on the basis of the relevant directives into national regulations. Recently, a directive was introduced on port reception facilities for the delivery of waste from ships (The European Parliament & Council of the European Union, 2019). The directive is a part of the circular economy policy (European

¹ Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology, Gdansk, Poland; ORCID: 0000-0002-8652-765X

² Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology, Gdansk, Poland; ORCID: 0000-0003-1902-2659

³ Faculty of Mechanical Engineering and Ship Technology, Gdansk University of Technology, Gdansk, Poland; ORCID: 0000-0002-9876-9584

⁴ Seatech Engineering Ltd, Gdansk, Poland; ORCID: 0009-0004-2239-7026

⁵ Seatech Engineering Ltd, Gdansk, Poland; ORCID: 0009-0002-5152-9150

* Corresponding Author: karol.niklas@pg.edu.pl

Commission, 2018) and the plastics strategy (European Commission, 2020) of the European Commission. Under the requirements, ports are required to collect sewage and garbage from ships using land-based Port Reception Facilities (PRF). In practice, these are the most often adapted sections of existing port infrastructure. Garbage collection is particularly problematic, due to the fact that waste is segregated differently in various countries, and the way it is disposed of has not been standardized internationally. Thus, a ship returning garbage at each port can expect different formal rules and different collection methods, as well as different fees.

Port waters are at particular risk of pollution due to their high exposure to the negative effects of various human activities. It is port basins that often have the highest density of ship traffic in relation to water volume. It should be noted that these areas are often characterized by very limited exchange with the waters of the seas and further with the world ocean. Pollution is concentrated in port basins and is a growing challenge that should be addressed for environmental protection. It is worth noting that ships themselves and their traffic may account for only a fraction of a percentage of the various sources of pollution in many ports. In addition to ship traffic, port basins are exposed to impacts from various industrial companies, such as chemicals, heavy industry, ship repair yards, and cargo reloading companies. Particularly the latter in some locations pose a problem of heavy dusting of loose coal cargo, which, blown by the wind, partly ends up in the water and partly in nearby land areas. In many locations, harbor waters also experience pollution from various types of garbage, which, unlike that on land, is much more difficult and costly to remove, mainly because of the difficulties involved in finding, identifying, collecting, separating, transporting and disposing. Water pollution has been identified in many places as the most important environmental problem according to port authorities (Roberts et al., 2023). The survey was conducted among port authorities in 26 countries and city authorities in 13 countries. Air pollution and waste were identified as equally important aspects of environmental protection, where significant improvement measures are planned in the coming years. Currently, about half of the ports surveyed have facilities for re-use and recycling. This creates a lot of room for change with the growing awareness and ability to incorporate ports into circular economy (Roberts et al., 2021). For example, organic waste from ships can be used to produce feed for aquaculture (Strazza, Magrassi, Gallo, & Del Borghi, 2015). With the rapid development of many port cities and their revitalization, there is a need to address the challenge of cleaning port basins through special vessels, which are called Waste Collecting Vessels (WCV). It should be noted that they can have a variety of functionalities and range from picking up trash from commercial vessels, collecting trash from the water surface, to neutralizing small oil spills. The inadequate port infrastructure also poses a significant practical challenge to the operation of such vessels. In most port basins, the need for a systemic solution to the water treatment problem has not yet been addressed. Most port basins do not have a specially designed section dedicated to WCV and other environmental vessels. Garbage collection in ports is generally carried out in adapted portions of wharves, which have significant functional limitations. These are generally makeshift solutions that have been organized by local port authorities to comply with increasingly demanding environmental regulations. It should also be noted that a problem in vast port basins is also the presence of multiple stakeholders who use a common basin but are involved to varying degrees in its proper maintenance. Meanwhile, thinking ahead, in most port basins, since they are owned by a public entity, a systemic solution can be applied in the form of special municipal water services co-financed by all stakeholders. The next chapter presents the design assumptions for the selected conceptual design of a WCV-type vessel. This is followed by a description of the conceptual design of the shore station serving this new type of vessel. The conceptual design was made in the form of a universal modular concept adaptable to a variety of ports.

FUNTIONAL DESIGN ASSUMPTIONS OF THE WASTE COLLECTING VESSEL

The main functional design principles for the next-generation WCV vessel will be presented here. This is a conceptual design for a vessel with autonomous operation capability being developed through a consortium of an ongoing research and development project titled 'Zero Emission Waste Collecting Vessel to Use in Ports and Close-to-Shore Areas' carried out by a Polish-Taiwanese consortium. This description is intended to present a broader context on the various functionalities of the innovative vessel and the resulting requirements for the shore station. Various vessels of this type are currently being developed by design firms as conceptual designs in response to new demand from the niche sector of debris removal from port areas. It should also be added that the vessels currently operating in various ports are mainly the simplest solutions adapted from existing other vessels. A good example would be a towed transport barge with a container on board for collecting or picking up garbage by hand. Admittedly, this can be a quick and cheap temporary solution that works well in some places. At the same time, the large scale of needs and increasing environmental requirements are prompting the design of a dedicated special vessel that can safely and economically realize new functions. Functionally, a WCV vessel is envisioned for both collecting garbage from the water and areas near ports. In some cases, the functionality to pick up garbage directly from ships from the harbor roadstead is also required. An important task of this vessel is also to clean the harbor waters of trash, seaweed and minor oil spills. It is worth noting that statistically, as much as 80% of oil spills occur in ports and involve the normal operation of ships and port operations (Miola, Paccagnan, Massarutto, Perujo, & Turvani, 2009). These are unitary relatively small spills. However, their



negative effects accumulate over time in small volumes of port water. In summary, the following main functions were selected for the designed universal WCV vessel:

- collecting and removal of garbage floating on the surface of port waters,
- picking up of garbage containers from ships and yachts at anchorage,
- removal of minor oil spills from port waters,
- collecting seaweed from the water surface.

Since the required functionality may be different in different ports, the ship project was developed in the form of modules, which are connected according to the needs and tasks performed. The following modules of the WCV ship were defined:

- Module 1 (bow) occurs in different variants depending on the intended functions of collecting small oil spills. In Figure 1 the option of oil skimmer is shown.
- Module 2 (middle) which is the propulsion module of the vessel to which modules 1 and/or 3 are attached as required. The propulsion has been considered in two variants: the azimuth thrusters, or special water jets. This module also has consoles for optional manual control and suitable working conditions for a one-man crew. This module is equipped with tools for collecting trash from the water, a transport belt and containers for collecting waste.
- Module 3 (aft) provides additional transport volume for collected garbage. Optionally, this module can also have a transport belt.

Thanks to the hull's modularization, the ship can operate as a full three-module set or as a set consisting only of two modules, or as just the middle module as an independent unit. Modularization of the unit will ensure that it is multifunctional, allowing it to be used to its fullest potential, with the ability to select multiple modes of operation as needed. The vessel will be able to perform tasks in three operation modes: as a fully autonomous unit with pre-programmed operation mode, as a remotely controlled vessel and as a manned vessel controlled from aboard. In the last case, control will take place from a control panel located in the superstructure of the middle module. The use of Artificial Intelligence (AI) can also be considered in the autonomization of a ship of this type. In particular, to increase the operational energy efficiency and effectivities learned by the algorithms based on site-specific data. The conceptual design of a WCV-type vessel is analogous to that of other ship types and includes the design of the hull, propulsion and other equipment. At the same time, relatively more attention needs to be paid to maneuverability due to the functions performed and the often-tight area of operation. The initial design process shall include the selection of hull type between i.e. monohull and catamaran. The main dimensions are mainly driven by the desired functionalities. A key component of the project is the propulsion. Also in terms of its damage safety and operability in shallow waters. Overall, due to the multifunctionality and the required small hull size, the design process of a WCV-type vessel may be quite complex and demanding. A description of the innovative design approach for the new type of small special vessels like the WCV's is planned as the subject of a separate article. A visualization of the selected conceptual design of the WCV vessel in a catamaran version with an overall hull length of LOA=14 m is shown in Fig.1.

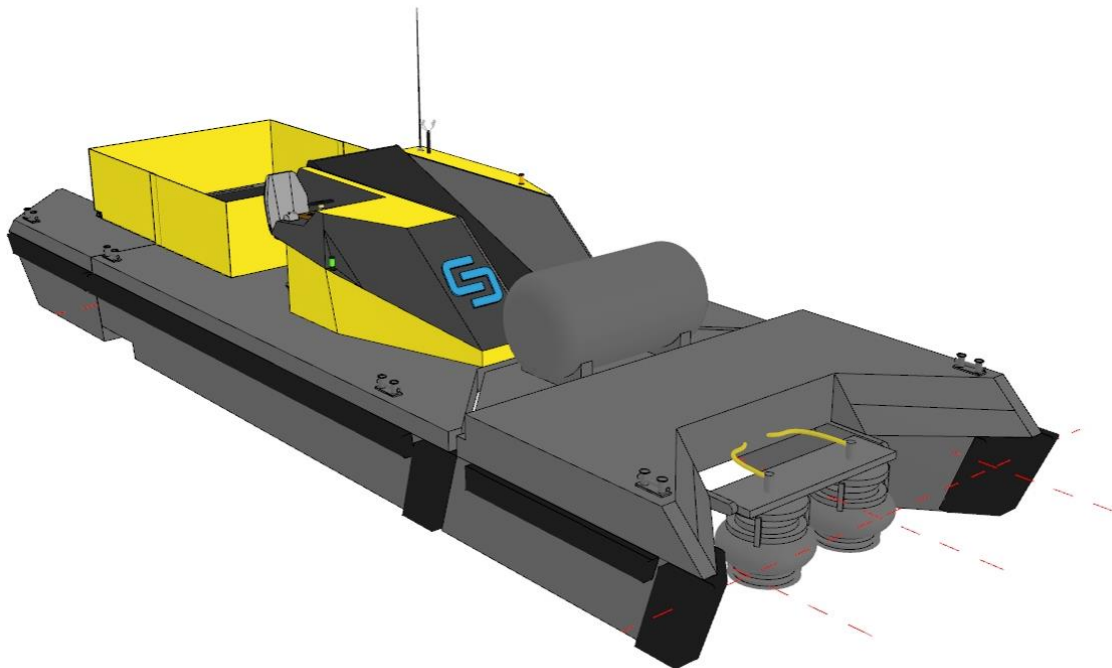


Figure 1: Conceptual design of the modular Waste Collecting Vessel

CONCEPT DESIGN OF THE SHORE STATION

The implementation of legislation on port reception facilities for the delivery of waste from ships assume fulfilling the following general requirements (The European Parliament & Council of the European Union, 2019). The main indication is that the port infrastructure shall be adequate to receive the types and quantities of waste from ships normally using that port. This needs to be done avoiding delays and without charging excessive fees. Also, ship waste needs to be managed in an environmentally appropriate way in accordance with the directive (European Parliament, 2008) and other EU legislation on waste. However, as the study shows, the current waste management at the vast majority of ports is insufficient (Özkaynak & İçemer, 2024). In large part, this may be due to the lack of proper port infrastructure, which was built when current environmental requirements did not apply. Effective logistics and management without a systemic solution of utilities is practically unfeasible. Thus, here the authors propose the modern idea of a shore station for Waste Collecting Vessels. The following functional assumptions are defined for the port quay:

- a) The possibility of mooring a WCV-type vessel, which can operate in different modular configurations: as a single module designated as "2", as module "2" with attached modules "1" and "3". At the same time, module "1" comes in three variants depending on the function performed. In addition, the modularity of the ship and its multifunctionality is tailored to the individual needs of the specific area on which it is to operate and the selection of functionality with which it is to be equipped. No less, there is always at least module "2", which is also the propulsion module of the vessel. All modules should allow mooring in a position suitable for the connection and/or departure of the vessel. That is, bow modules marked "1" should be moored bow to quay, and stern modules marked "3" should be moored stern to quay. Module "2" should be moored with the stern to the quay, due to the easier transfer of containers with collected garbage to land. This positioning of module "2" influences the preferential location of the connection connectors for charging the electric drive batteries on the stern side of module "2". It is possible to use a different configuration of charging connections if there are other reasons for this. The functional diagram of the mooring of the modules of the WCV ship is shown in Fig.2. The arrows in the diagram indicate the direction in which the modules will sail when connected to each other.

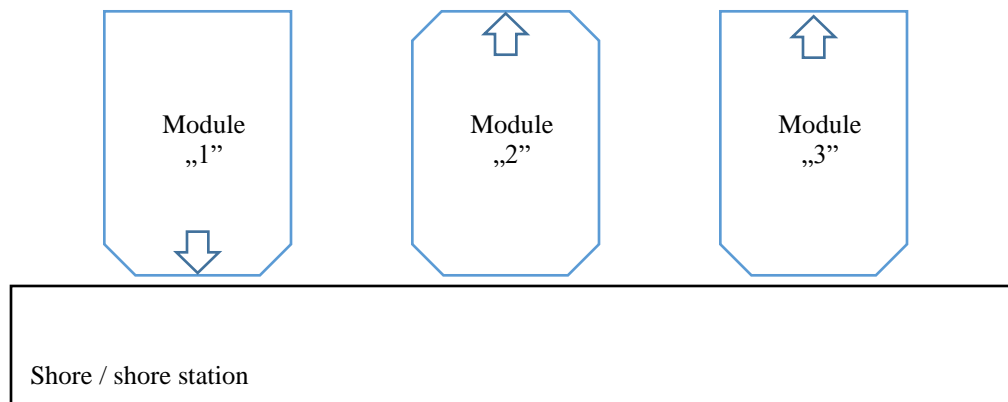


Figure 2: Functional diagram of the mooring of WCV ship modules to the shore

- b) Mooring capability with different levels of autonomy of the WCV vessel. This functionality creates the need for an automatic mooring system. For a small vessel, it is possible to develop an automatic mooring system using suction pads and hydraulic actuator systems. Such solutions have already been developed commercially for larger vessels and their adaptation is relatively easy.
- c) Capability of automated charging of electric propulsion batteries.
- d) Ability to return collected waste to land. Each module is designed to collect waste of a different type. The quay at the docking point of module "1" should allow for the return of oil pollutants to land. This is usually done by pumping out the oily water to a vehicle (tanker) receiving the waste ashore. For this function, it is possible to automate the pump-out process (connecting, pumping, disconnecting). The second module is designed to drive the vessel and collect garbage and plants from the water surface has containers in the rear for collecting them on board the vessel. Again, it is possible to automate the replacement of containers. Replacement of the containers with empty ones, their cleaning is carried out by the city's municipal services. The third module is designed, like module "2", to store garbage and seaweed collected from the water. In addition, this module can receive garbage from ships, and this can be done similarly to module "2" using standardized site-specific containers. In all of the above cases, access to the quay and moored modules should be made available to vehicles dedicated to collecting each of the listed types of waste. Usually there will be special municipal vehicles – i.e. garbage trucks, cisterns, trucks with transport containers.

- e) Ability to moor in defined weather conditions. Safety associated with mooring also in difficult weather conditions (e.g., strong wind, ice).
- f) Ability to moor in tidal areas without restrictions (in practice, it is 15 m). For this purpose, the charging station was designed in the form of a floating modular pontoon. The movement of the station in relation to the quay can be carried out using guides attached to the quay, or by means of piles driven into the bottom of the basin. Depending on the expected loads from sea waves, the tidal guides and piles can have an additional function of stabilizing whole pontoon.
- g) Safety capability. Selective access, the ability to access the modules for inspection.
- h) Ability to disconnect modules and access each module for the purpose of performing maintenance work, and major repair work if needed.

Different variants of possible technical solutions have been analyzed in terms of the design assumptions set above. There are no dedicated design regulations for this type of facility. Therefore, design can take place based on i.e. the individual evaluation of the selected classification society. Design requirements for this type of object strongly depend on the choice of material to be used. For the design of a barge made of steel, the regulatory requirements for standard barges can be used directly. On the other hand, if one would like to use different material, the specific requirements must be agreed with the regulatory body. It should be noted that due to local regulations, in some countries it may be advantageous to classify the docking station as a hydro-engineering structure, and in others as a floating barge. This requires recognition in the country of intended use and is important because of differences in the costs of maintenance. The main design criteria concern structural strength and stability. When it comes to structural strength, the dominant load is dead weight and water hydrostatic pressure. In addition, there is a need to take into account the hydrodynamic pressure from wave action caused by passing ships. Particularly vulnerable elements at that time are the connections between modules and the junction area between the barge and the quay. Consideration needs to be given to both the loads from short waves hitting the side surfaces of the docking station and long waves that can induce additional bending moments on the entire hull of the barge. When designing a new type of docking station, stability requirements shall also be taken into account. This is not obvious, after all, the station is ultimately connected by movement to the guides or piles of the quay. At the same time, the transport of modules separately or combined to the site of use may include towing. The docking station does not have its own drive, which greatly simplifies the design process. On the other hand, the docking station is equipped with electric charging stations which introduces additional requirements specific to electric devices. However, from a practical point of view, the main determinant of the project concept presented below was economic criteria while allowing the design to be used in various ports around the world. Implementation in existing ports precisely for economic reasons is possible almost exclusively through the adaptation of existing port berths. A major challenge in most locations is ensuring the safety of the ship's mooring due to possible high wave loads, i.e. from passing vessels. Therefore, the individual modules of the WCV unit are docked in such a way that they do not protrude beyond the outline of the pontoon. A key aspect that improves the economics and flexibility of the proposed solution is the modularity of the shore station to match the modularity of the WCV. Each module reflects functional requirements of a particular vessel module. This means that the shore station will consist of such modules for which the need for mooring in a particular port is foreseen. Due to the optional different levels of autonomy of the WCV, all modules are suitable for both traditional human-operated mooring and different levels of autonomy. The design assumes applying universal connectors that allow different configurations of shore station modules. A visualization of the shore station conceptual design is shown in Figure 3. The stern and bow modules are to be moored in a way that enables their automatic connection with the middle propulsion module without the need to move or rotate and without human intervention. This means that the stern module will be moored aft, while the bow modules will have the bow facing the quay. Automatic mooring of all modules can be carried out using a dedicated pneumatic mooring system. After mooring, the module needs to be additionally secured by an automatically released mechanical holder. The reason for this is the need to reduce energy consumption during downtime. The charging of the middle module can be realized by dedicated automatic connector from the shore. At this stage of conceptual design technical details both for the pneumatic mooring system and the automatic charging connector were not analyzed. However, a review of the literature indicates that products with the required features could be available on the market very soon, if only they are desired. However, the implementation of the presented project to the technical design phase requires adequate research work for the components and the entire system. This may be the subject of further research work.



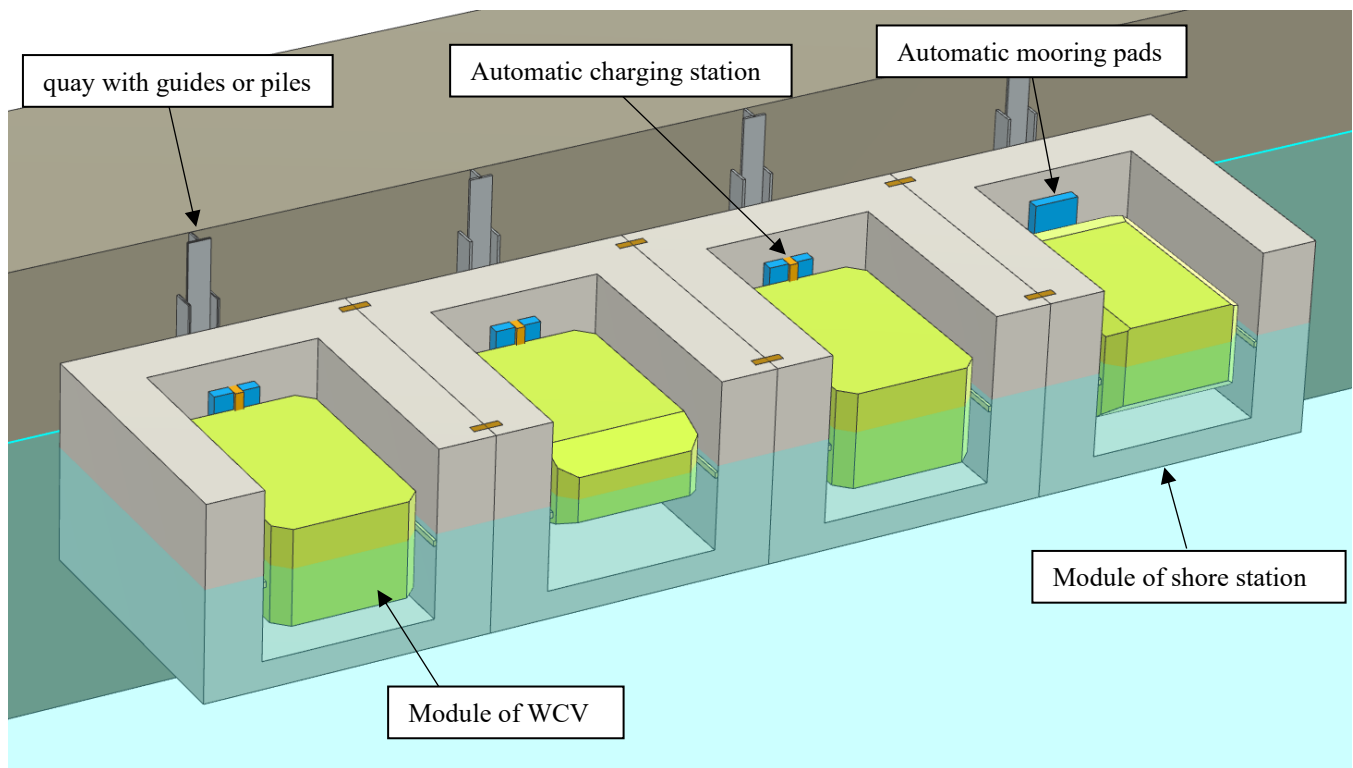


Figure 3: Conceptual design of the shore station for WCV vessel

SUMMARY

Progressive environmental regulations, especially in the port zones of SOLAS special areas, are forcing the development of port infrastructure and vessels related to the collection of waste from ships. On many basins, it is also important to clean port waters of various types of pollution - such as minor oil spills, garbage floating on the water surface and others. The problem, although it affects many ports and various locations, is particularly evident in developing countries where, for various reasons, waste management has not yet been properly addressed. It should be noted that the key challenges are the unification of solutions used in different ports, the application of affordable fees and the time of waste collection from ships.

The proposed conceptual design of shore station can be part of a key infrastructure for receiving waste from ships and pollution collected from the surface of port waters. The project uses a modern design approach based on modularity and versatility of various functionalities that can be tailored to the individual needs of a given port. They can also be changed or expanded relatively easily as the port grows. The presented shore station included new requirements for autonomy and modularization of a Waste Collecting Vessel. Finally, the form of modularized pontoon takes advantage of cost efficiency both for new and existing berths. Mooring the pontoon on piles or guides allows the station to be used in tidal areas. Also crucial for the mooring of small WCV-type vessels is their protection from waves, which has been achieved by the special shape of the station modules matching those of the ship. The presented conceptual design was made intentionally in a generalized form to allow for further development and adaptation to local requirements at individual ports. The project is under development being in line with the circular economy and industry 4.0 trends.

CONTRIBUTION STATEMENT

Author 1: Conceptualization; investigation; methodology; writing – original draft; writing – review and editing. **Author 2:** Conceptualization; investigation; methodology; writing – review and editing; funding acquisition. **Author 3:** Conceptualization; investigation; supervision; methodology; writing – review and editing; funding acquisition; project administration. **Author 4:** Conceptualization; investigation; visualization. **Author 5:** Conceptualization; investigation; visualization; writing – review and editing.

ACKNOWLEDGEMENTS

The research was supported by the National Center for Research and Development (NCRD) within the project ZeroWastePorts: Zero Emission Waste Collecting Vessel to Use in Ports and Close-to-Shore Areas. Agreement no PL-TW/IX/43/ZEROWASTEPORTS/2022. The project visualization was supported by the Academic Computer Centre in Gdansk (CI TASK). All support is highly appreciated by the authors. Authors thank the reviewers for their valuable comments.

REFERENCES

- European Commission. (2018). *Strategy for Plastics in a Circular Economy. COM(2018) 28 final*. Brussels. <https://doi.org/10.4325/seikeikakou.30.577>
- European Commission. (2020). *A new Circular Economy Action - Plan For a cleaner and more competitive Europe. COM(2020) 98 final COMMUNICATION*. Brussels. <https://doi.org/10.7312/columbia/9780231167352.003.0015>
- European Parliament. (2008). DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives. *Official Journal of the European Union*. <https://doi.org/10.5040/9781782258674.0028>
- Miola, A., Paccagnan, V., Massarutto, A., Perujo, A., & Turvani, M. (2009). *External costs of Transportation, Case study : maritime transport. JCR Scientific and Technical Reports*. <https://doi.org/10.2788/18349>
- Özkaynak, Ö. H., & İçemer, G. T. (2024). Based on stakeholder questionnaires of ship-derived waste, waste management re-planning in Ports and determining the need for inspection. *Marine Policy*, 159(March 2023). <https://doi.org/10.1016/j.marpol.2023.105912>
- Roberts, T., Williams, I., Preston, J., Clarke, N., Odum, M., & O’gorman, S. (2021). A virtuous circle? Increasing local benefits from ports by adopting circular economy principles. *Sustainability (Switzerland)*, 13(13), 1–25. <https://doi.org/10.3390/su13137079>
- Roberts, T., Williams, I., Preston, J., Clarke, N., Odum, M., & O’Gorman, S. (2023). Ports in a Storm: Port-City Environmental Challenges and Solutions. *Sustainability (Switzerland)*, 15(12), 1–24. <https://doi.org/10.3390/su15129722>
- Strazza, C., Magrassi, F., Gallo, M., & Del Borghi, A. (2015). Life Cycle Assessment from food to food: A case study of circular economy from cruise ships to aquaculture. *Sustainable Production and Consumption*, 2(February), 40–51. <https://doi.org/10.1016/j.spc.2015.06.004>
- The European Parliament, & Council of the European Union. (2019). Directive (EU) 2019/883 of the European Parliament and of the Council of 17 April 2019 on port reception facilities for the delivery of waste from ships, amending Directive 2010/65/EU and repealing Directive 2000/59/EC. *Official Journal of the European Union*, 2019(November 2000), 116–142. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/LSU/?uri=CELEX%3A32019L0883>

