Creating an Industrial Symbiosis with Ship-Generated Waste

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Abstract: Sustainable practices are becoming more important in many industries as demand grows and resources become limited. Since one answer for establishing sustainable industries is to shift from a linear economy to a circular economy, examples of industrial symbiosis have become more prominent. Industrial symbiosis, a circular economic model that can help decarbonize industries, is one viable remedy for the negative effects on the environment. The maritime industry can have a significant role to play in this approach with all the waste generated on ships. The aim of this study is to theoretically design a model that will evaluate the suitability of the ships participating in an industrial symbiosis with the waste they generate. First, it was determined which of the wastes generated onboard ships could be included in an industrial symbiosis, and then it was calculated how much of these wastes could be supplied in a given time frame. Finally, the areas in which these wastes can be used as raw materials are specified.

Keywords: Industrial symbiosis, Ship-generated waste, Sustainability, Green transition, Decarbonizing

1. Introduction

As widely known that the World must learn new ways of working together in order to solve the challenges of 21st century like water consumption, waste management and use of resources. By 2050, it is estimated that the world will consume three times more resources and produce twice as much waste than today (Kaza et. al., 2018). This will result in intensified climate change effects, ecosystems overload and an increased landfill. Following the same path, and failing to make resources and energy consumption more sustainable could put the world in a vulnerable position. Therefore, more strategies to “close the loop” on resource use and extraction, especially in sectors with high energy intensity and environmental impacts like the process manufacturing need to be implemented.

In The 2030 Agenda for Sustainable Development, the United Nations set 17 global goals for sustainable development which are urgent call for all member countries to act. One of the main goals of this global agenda is Responsible Consumption and Production and with the specified targets of this goal, UN aimed to substantially reduce waste generation by prevention, reduction, recycling, and reuse. Encouraging companies to adopt sustainable practices and achieving environmentally management of wastes in their life cycles to reduce their release to air, water, and soil to minimize their adverse effects to the human and environment were other targets of the UN [URL1].

A possible solution for this problem is industrial symbiosis, a circular business model that can play an important role in decarbonizing of industry (Chertow, 2000). Maritime industry can play an important role in this model. The waste generated on ships can be collected on ports and be used by the industrial symbiosis created in those areas including the ports. The challenging part and the first thing to be sorted out should be identifying which waste can be used again as a resource and then which industries to be included in this symbiosis in an optimized way considering the infrastructures. It is necessary to determine the places that can use each other's waste at close distances and its adequacy should be investigated. Also, it may be necessary to establish new centers for the recycling and reuse of these wastes.

In this study, firstly waste generated on board ships will be defined and classified according to their potential to be a raw material in process manufacturing in different industries. Then, a calculation for a selected port and time period will be done to determine the amount of waste that can be collected. To provide an uninterrupted supply chain and to avoid any shortages, liner ships that call certain ports at certain times will be the focus of this study. It will be followed by determining the suitable industries which can be included in this symbiosis to benefit from using waste generated on board ships.

This partnership will ensure that resources can be shared and reused, thus saving money, and minimizing waste. In this way, the symbiosis created will support the green transition and provide mutual benefits both economically and environmentally (Neves et. al., 2020). Also, this maritime industry-based symbiosis is expected to be a driving force for the green transition of all ports around the world. In addition to the positive effects of the investments made in this field on the environment, the long-term economic positive effects will also convince the industries to take a step in this area. Drawing a roadmap to determine how sustainable cooperation can be developed in this regard will be one of the vital steps to achieve a green future.

2. Examples of Industrial Symbiosis

As demand increases and resources decrease globally, sustainable approaches are gaining importance in many industries. Since the transition from linear economy to circular economy is one solution for creating sustainable industries, examples of industrial symbiosis started to become more visible. The most important of these is the symbiosis in Kalundborg, which has a power station in its center and includes many companies such as factories, farms, production facilities etc. that exchange waste energy or materials (Ehrenfeld and Gertler, 1997). A symbiosis in Barceloneta involves wastewater and chemicals among firms in several industries (Chertow et. al., 2008). Symbiosis in Landskrona consists of organic waste, chemicals, energy, storage places, wastewater and even employees exchange (Mirata and Emtairah, 2005). A large symbiosis in China consists of 31 exchanges of energy and materials between companies (Yu et. al., 2015). Similar examples of symbiosis can be seen at large and small scales. Although a symbiosis involving ships is not seen in the literature, there are symbiosis involving ports. Rotterdam Port was part of a symbiosis program which focused on exchange of waste heat among firms and through households (Baas, 2008). It is seen that there are also smaller-scale symbiosis in some ports of Europe.

3. Regulations Related to Waste Generated on Ships

The International Convention for the Prevention of Pollution from Ships (MARPOL) and Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention) are the main international regulations aimed at preventing ship-borne wastes from polluting the marine environment. There are also international regulations such as the Helsinki Convention, which have a narrower geographical scope, deal with waste sources other than ships and aim to protect the marine environment. However, these regulations do not deal with the specifications of port reception facilities or the processes after the ship generated wastes are delivered to those facilities. MARPOL only requires member states to ensure the provision of adequate reception facilities in ports.

Although the process of delivering the wastes from ships to these organizations is controlled by official documents such as the Garbage Management Record Book, the wastes are only subject to local regulations after they handed over to the land facility. To fill this gap, European Union detailed the requirements of port facilities with the Directive for Port Reception Facilities (2019) and stipulated that there should be predefined plans for waste collection and handling (EU, 2019). In the directive, separate collecting of waste from ships is highlighted not to prevent possible recycling and reuse opportunities by combining the wastes on land which are stored separately on the ships according to MARPOL. However, recycling, reuse and recovery operations must follow the Waste Framework Directive and other relevant EU waste legislation for EU countries and domestic laws of other countries (Arguello, 2020).

4. Management of Waste Onboard Ships

When the handling of wastes produced on land is ordered from the most environmentally friendly to the most harmful, it can be defined as long-term landfilling, recycling, reprocessing, and reusing (Deja and Kaup, 2019) Since most of the waste generated onboard ships are delivered to port facilities, they become part of the waste generated and handled on land. The nature of the operation, which requires ships to be remote from land, makes it difficult to store and handle the garbage and other waste generated on the ship. Moreover, even if ships make frequent port calls, the cost of this process increases as there are no other options other than port facilities to dispose of wastes.

According to MARPOL Annex V, waste generated on ships can be classified as all kinds of food, domestic and operational waste, all plastics, cargo residues, incinerator ashes, cooking oil, fishing gear, and animal carcasses generated during the normal operation of the ship and liable to be disposed of continuously or periodically. There are currently 3 options for the handling of these wastes. Disposal into the sea is one of these options under strict obligations. Comminuted food waste can be disposed into the sea if the distance of the ship from the nearest land is more than 3 nm outside the special areas and more than 12 nm in special areas. Discharge of cargo residues, cleaning agents and additives, animal carcasses can be permitted in some special circumstances. However, discharge of waste such as plastic, synthetic material, cooking oil, paper, glass, metal and similar is prohibited in all waters due to their potential environmental hazard [URL-2]. Especially plastic garbage is very resistant to degradation and generates a variety of environmental hazards linked with waste buildup in nature, since it has hazardous impacts on living beings, soils, and water supplies over time (Meneses et. al., 2022). For these kind of waste, other options must be followed.

Incineration onboard can be an option except for wastes such as garbage containing more than traces of heavy metals, refined petroleum products, and polyvinyl chlorides but it is prohibited to discharge incinerator ashes into the sea in all waters.

Even if the incinerator method is used, ashes must be delivered to a port reception facility which is the third and most common option for handling ship waste. IMO has recognized that provision of reception facilities is essential for effective MARPOL implementation. Marine Environment Protection Committee (MEPC) emphasized the importance of reception facilities and recommended member states to provide reception facilities (PRF) which are sufficient in quantity and quality. PRFs provide services for collecting wastes that cannot disposed into the sea from ships and handling the waste in compliance with related national regulations for a fee. PRFs can play a critical role in a symbiosis because they would be the link between ships and manufacturers on shore. Accurate segregation of the waste and suitable transportation for uninterrupted supply chain are crucial factors for an efficient symbiosis.

5. Case Scenario Calculations for Industrial Symbiosis Involving Ships

To achieve an efficient symbiosis, regular supply of raw materials plays a vital role. Bass (2011) highlighted several symbiosis projects which were rejected because of unpredictable supply of raw materials. Leigh and Li (2015) pointed out the importance of effective supply chain for a sustainable symbiosis. It can be said that it is difficult to include a sector such as shipping into such a symbiosis, where waste is delivered from ships at regular intervals, not continuously, into such a symbiosis. Therefore, the ships that would be most appropriate to include in such a symbiosis are those that operate as liners such as Ro-Ro or container ships. In this study, two major ports in İstanbul region were selected as Step 1 for estimation calculations.

Port 1 is the home port of a Ro-Ro company engaged in international voyages and Port 2 is the most frequented port of a shipping company engaged in liner container shipping. Besides hosting suitable ship types, another reason for choosing these two ports is their proximity to various industries, which is an important criterion for symbiosis.

Step 2 is to determine the number of ships visiting these ports for a period of time. Sailing schedule of the Ro-Ro company in Port 1 indicates that 9 different ships make port calls in a 10-day period and there is always a ship at port [URL-3]. Sailing schedule of container shipping company in Port 2 indicates that 28 different ships dock at the selected port within a one-month period and there is no time when there is no ship in the port [URL-4].

Third step is to determine the amount of each type of waste generated by selected ships. Regardless of how the ships manage the waste they produce; it is mandatory to record the produced and handled quantities in the garbage record book according to MARPOL and present it to the authorities when necessary [URL-5]. However, it can be predicted that these records are questionable since it is impossible to carry out any inspection during the production of wastes. In the report of EMSA, the amount of waste generated onboard different types of ships and different types of waste, amount of waste delivered to port facilities and amount of waste handled onboard the ship has been determined as close to reality with empirical studies [URL-6]. Hence, amounts determined in report were used for the calculations in this study. In addition, the main waste types in this study were determined as plastic, food waste and cooking oil since they are more likely to be used as raw materials in the industry and their intermediate processing requirements are relatively less. Table 1 shows the estimated amount of waste for selected type of ships for one ship in one-month period.

Table 1. Estimated amounts of waste generated onboard selected ships [URL-5]

	Ro-Ro Ship (Port 1)	Container Ship (Port 2)
Plastic	21,75 m^3	2,7 m^3
Food waste	0,95 m^3	0,95 m^3
Cooking oil	30 liters	30 liters

As a result of the calculation made by considering the estimated quantities in Table 1 and the number of ships mentioned before, the amount of waste that can be collected from the ships in a month at the two selected ports is given in Table 2.

Table 2. Estimated amount of collectible waste

	Number of Ships at Port 1	Waste Amount at Port 1	Number of Ships at Port 2	Waste Amount at Port 2
Plastic	27	609 m^3	28	75,6 m^3
Food waste	27	25,65 m^3	28	26,6 m^3
Cooking oil	27	810 liters	28	840 liters

Step 4 is the determination of usage areas of selected wastes. The most common practice in utilization of waste cooking oil is producing biofuels. The perception of waste cooking oil is shifting from harmful waste to viable raw material for industrial use. Especially in developed countries, the use of fuel produced from waste cooking oil collected from land facilities is becoming widespread. In 2021, a transoceanic flight of Air France was powered by a fuel mixture including 16% sustainable aviation fuel produced from waste cooking oil [URL-7]. Also, EU aimed to reach 5% sustainable aviation fuel in jet fuel mixtures by 2030 [URL-8]. According to Zhang et. al. (2003) despite requiring a very complex process, the use of waste cooking oil to produce biodiesel is feasible and it may reduce the cost of raw material. On the other hand, recent studies aim to use waste cooking oil for purposes other than biofuel production. Mannu et. al. (2019) proposed use of waste cooking oil to produce bioplasticizers, chemicals as energy vectors and solvent for pollutant agents. Chemical composition of waste cooking oil makes them valuable in the creation of lubricants but the viability of such applications is linked to effective recycling techniques. Mannu et. al., 2020 and Panadere (2015) pointed out that waste cooking oil can be treated to produce pyrolytic oil, hydrogen gas, power by direct combustion, or as a carbon source if it is purified and sterilized properly.

Food waste is more difficult to handle than other types of waste due to its structure containing many different components and requiring certain storage conditions. However, food waste contains a variety of organic substances and nutrients. In this respect, food waste can be used as raw material in the production of bioethanol, biogas, organic fertilizers (Dong, 2020), various chemicals and fuel if it is supplied at right amounts (Lin et. al., 2013). In particular, vegetable wastes can be used for producing animal feed (San Martin, 2016). After removal of undesired components such as carbon, glass or ceramic production can be possible (Cornejo et. al., 2104).

Plastics are being used widely because of their durable and lightweight structure and have an advantage that can be turned into refurbished and reusable same material after becoming waste. However, the disadvantage is that too much fossil fuel is used for its production and if it is not used in the circular economy, it decomposes very slowly in nature. Hahladakis et. al. (2020) emphasized that plastic is a sustainable alternative over other materials due to its easier recycling requirements and can be considered to have an important role in circular economy. For using as raw material, plastics can be treated mechanical or chemical. Mechanical recycling of plastic trash involves remelting the material to create granules or final commercial goods. Chemical recycling of plastic can be made using a chemical technique such as pyrolisis or catalysis to extract monomers or directly transform it into other valuable materials (Payne and Jones, 2019). Plastic wastes such as polyethylene and polypropylene are utilized as feed to create syngas by steam gasification (Saebea et. al. 2020). Chemical recycling processes are used to transform plastic trash into fuel and other useful items (Salaudeen et. al., 2019). Plastics can also be used as materials to be burned in incineration process and energy recovery can be accomplished by utilizing a boiler to create either thermal or electrical energy (Gu et. al., 2017).

6. Conclusion

The increase in consumption in the world and the decrease in resources require sustainable approaches in many industries and the derivation of new resources. A global transition from linear economy to circular economy that focuses on reusing waste as raw materials is a concept to achieve a more sustainable world. As a subset of the circular economy, the concept of industrial symbiosis allows one firm's waste energy and materials to be used by other firms as raw materials for production or heating.

Management of the waste generated by the ships is done by conventional processes that are disposing into sea under strict regulation, incineration and delivering to port reception facilities. However, waste delivered to port reception facilities are landfilled and generally not included in the recycling process.

In this study, a case scenario was designed to include ship generated wastes in industrial symbiosis. Since uninterrupted and predictable supply of raw material is essential for production, container and Ro-Ro lines which are operated as liner were selected. Because of wider potential use, food waste, cooking oil, and plastic wastes were designated for calculations. Considering the schedules of ship operators, amounts of wastes that can be collected from ships were calculated and are of usage as raw material were identified from literature. It can be considered that certain types of ship generated waste can be used in industrial symbiosis. For the implementation of this concept, it can be advised that usage area of other types of ship wastes, economic feasibility, and role of port reception facilities in this process should be studied in further studies.

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