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Procedia Computer Science 225 (2023) 2654–2663

Procedia Computer Science

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27th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2023)

Sustainable Waste Management for Implementation of a Circular Economy Model in a Port

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Abstrakt

The manuscript presents the management of waste from marine vessels and cargo handling companies in a selected European Union port. The main objective of the paper is to analyse and evaluate the existing waste management model in the port of Szczecin in the context of circular economy. The expert research carried out is aimed, *inter alia*, at identifying which of the solutions currently in use need to be improved from an environmental perspective. These measures could serve as a basis for the development of green logistics chains for waste generated in connection with the organisation of shipping. What is of particular importance in this regard is the information flow, which preferably should be an integral part of an international IT system enabling tracking of waste streams from their place origin to final disposal. In light of the above, it is particularly important to look for solutions which will support the creation and adoption of models providing sufficient control over the entirety of green waste management activities, in line with the circular economy concept.

Type your keywords: waste, sustainability waste management, pollution, ship-generated waste, sustainable transport, protection of the marine environment, circular economy, model.

1. Introduction

Efforts of the European Union to develop maritime economy are currently largely targeted at promoting environmentally friendly solutions [1]. Achievement of the highest environmental standards is crucial not only on seagoing vessels, but also in ports [2]. The increased demand for cargo transport by sea observed in recent years, in particular within the European Union, proves that there is a need for environmental measures focusing on circular

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1877-0509
10.1016/j.procs.2023.10.257

economy [3]. It is therefore particularly important, among other things, to reduce the volume of waste generated directly on ships as well as at seaports. Due to the continuing adoption of increasingly stringent environmental requirements, the maritime industry is obligated to develop the best technological and organisational solutions in this area Accordingly, efforts should be taken across all sectors of the economy to achieve environmental, economic, and social development at the same time [4-7]. Adequate information flow between ships, ports, and waste management companies is essential to develop the best possible waste management model [8]. It is therefore appropriate to encourage shipowners to equip their ships with technical and organisational solutions not only to minimise waste [9], but also to manage that waste in accordance with the principles of circular economy [10].

Most modern ports in the European Union have introduced sustainable solutions centred around the creation of 'green ports' in the recent years and they intend to implement more of them. These measures focus on reducing the negative impact of pollution generated within a port and promoting environmentally friendly solutions [11]. In this context, it is also very important to support managing waste directly in port areas, so as to minimise any further movement of the waste and avoid generating carbon footprint.

2. Research background

2.1. Circular Economy

The concept of circular economy has been the subject of an academic and economic debate for several years. This is due to the need to deliver solutions that will bring this concept to life, most of all in practical terms. It has been particularly important to incorporate the most important principles of circular economy in key documents governing the strategic areas of functioning of the State. These include, without limitation: *Roadmap for Circular Economy Transition* and *National Environmental Policy – 2030*. The documents were approved by the Council of Ministers in 2019 [12]. The concept of circular economy has been present in the literature since the 1960s. In early days, it was promoted in Asia and included some aspects of industrial ecology, focusing mainly on the use of recycled materials (often waste), but most of all, on promoting resource minimisation and clean production [13]. In 2007, Peter et al. presented the circular economy as efforts pursued with the key idea to close the material cycle while reducing inputs [14]. It is particularly important to move towards product reuse (or recycling) in order to offer a better quality of life to the society by reducing the use of resources [15]. In 2011, the OECD (Organization for Economic Cooperation and Development) highlighted the need to improve productivity through sustainable materials management that involves minimising waste management costs and engaging the community in individual measures [16]. From the point of view of the European Commission, a circular economy system should be based on activities that result in maintaining the added value of products for as long as possible, while minimising waste throughout a product's life cycle. A circular economy is the opposite of a linear economy, where a product, after it has been used, most often turns into waste that challenges the ecosystem [5,10,17].

In the port sector, waste is present in many dimensions. It is generated, for instance, in the organisation of shipping, but it should also be noted that ports are an important hub for imports and exports of waste materials [18-19]. An interesting green logistics approach to waste management considerations is presented in a publication by Ulnikovic et al., 2012 [5]. This paper points out the need to build infrastructure and facilities at ports not only to receive, but also to manage waste streams from ships all the way to their final processing and storage destination. Some European Union ports are currently implementing a solution called LOOP-Ports. The concept is designed to facilitate the transition from a linear to circular economy in the port sector. The main objective of the proposed solutions is to maintain products in the economy for as long as possible and, at the same time, minimise production [20]. A circular economy should focus primarily on a rational use of natural resources. These activities should be carried out considering, first and foremost, the successive product life cycle stages in the planning process [21]. The LOOP-Ports project aims to contribute to the adoption of a broad spectrum of circular economy measures in the seaports of the European Union. The project goals include reducing the use of materials with limited reusability in their original or processed form in operations [22].

3. Methodology

The main objective of the research is to analyse and evaluate the existing waste management model in a European port using the example of Szczecin. It was particularly important to evaluate the existing solutions and propose changes in the context of circular economy. The expert method was used in the study.

Figure 1 presents the successive steps of the research carried out to achieve the main objective of the study.

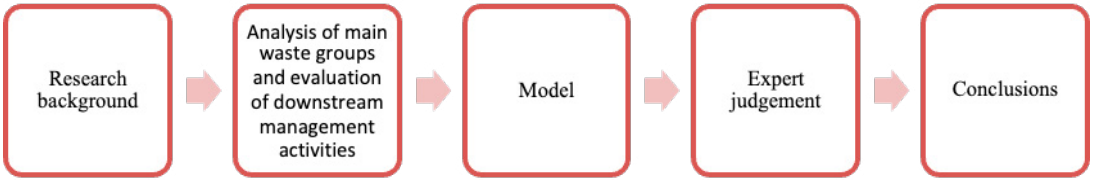

Figure 1 Research framework
Source: Own work

As a first step, the research background was analysed, including the considerations of circular economy in the port sector. The second part of the study analysed the main waste groups and evaluated downstream management activities. The main waste groups generated on ships and delivered at ports are shown in Table 1, while Table 2 shows waste generated by port companies engaged in cargo handling operations. The research was based on information obtained directly from the Port Authority and port companies. It should be noted that accurate identification of waste types is essential for developing the best possible system solutions. The next step presents the existing waste management model at the port, followed by an expert evaluation of current technical and organisational solutions in the context of circular economy. The final conclusions include proposals for measures that would enable the implementation of a sustainable model for shipping waste management aligned with the principles of circular economy.

4. Shipping waste management at a port

The first step towards the development of a concept for the model consisted in exploring the characteristics of shipping waste in detail. In ongoing research on the port system, waste streams have been divided into two main groups: ship-generated waste and solid waste, in view of the organisation of cargo handling processes. In accordance with the guidance of the International Convention MARPOL 73/78, pollution from ships is classified according to six main groups (Annexes) [23,24].

4.1 Ship-generated waste

Table 1 provides a detailed analysis and evaluation of the main groups of pollutants delivered by ships to the port in Szczecin and indicates whether a specific type of waste is managed directly within the port. It should be noted that in the design of a sustainable waste management model, it is crucial to organise the successive steps directly in the port area, to enable – for instance – planning of green logistics chains aligned with the principles of circular economy).

Table 1 Groups of pollutants delivered by ships to the port in Szczecin

Waste categories	Code	Waste type	Waste managed within the port limits
MARPOL Annex I – Oil	13 02 08* 13 05 02* 13 05 07*	– Other engine, gear and lubricating oils – Sludges from oil/water separators – Oily water from oil/water separators	YES Transferred to a reception and treatment facility for petroleum contaminated water – Ostrów Grabowski
MARPOL Annex IV – Sewage	20 03 04	Septic tank sludge	YES Transferred to a mechanical and biological wastewater treatment plant – Ostrów Grabowski
MARPOL Annex V – Garbage	15 01 01 15 01 02 15 01 03 15 01 04 15 01 07 15 01 10* 15 02 02* 16 01 07* 16 02 13 16 02 14 16 06 04 19 01 12 20 01 02 20 01 08 20 01 25 20 03 01 15 02 02*	– Paper and cardboard packaging materials – Plastic packaging – Wood packaging – Light metal packaging – Glass packaging – Packaging containing residues of or contaminated by hazardous substances (e.g., plant protection products of toxicity classes I and II – very toxic and toxic). – Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances (such as PCB) – Oil filters – Discarded equipment containing hazardous components other than those mentioned in 16 02 09 to 16 02 12 – Discarded equipment other than those mentioned in 16 02 09 to 16 02 13 – Alkaline batteries (except 16 06 03) – Bottom ash and slag other than those mentioned in 19 01 11 – Glass – Biodegradable kitchen and canteen waste – Edible oil and fat – Mixed municipal waste – Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances (such as PCB)	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.

Source: Own elaboration based on information obtained from port companies and [23-25]

4.2 Solid waste from port companies providing ship handling services

Table 2 offers a detailed analysis of waste generated by port companies in connection with the organisation of the shipping process. The classification is presented according to the applicable waste codes. The group under review consists mainly of packaging waste, such as wood, plastic, and cardboard. It should be noted that some

waste in this group is classified as hazardous waste. This could be due to the fact that the packaging has been contaminated with a hazardous substance and the downstream management process will be different from that for similar but uncontaminated packaging. Port companies also generate high volumes of iron and steel waste. It should be pointed out that waste generated by port companies is only separated and temporarily stored at the port, and most of management is carried out outside the port by specialist entities.

Table 2. Solid waste generated in the organisation of the shipping process in the operation of port companies

Code	Waste type	Waste management methods	Downstream waste management takes place at the port (YES/NO)
13 01 13* 13 02 07* 13 02 08* 13 08 99* 15 01 10* 15 02 02* 16 02 13* 16 02 15*	– Other hydraulic oils – Mineral-based non-chlorinated insulating and heat transmission oils – Other engine, gear and lubricating oils – Wastes not otherwise specified – Packaging containing residues of or contaminated by hazardous substances (e.g., plant protection products of toxicity classes I and II – very toxic and toxic). – Absorbents, filter materials (including oil filters not otherwise specified), wiping cloths, protective clothing contaminated by hazardous substances (such as PCB). – Discarded equipment containing hazardous components other than those mentioned in 16 02 09 to 16 02 12 – Hazardous components removed from discarded equipment	Stored in sealed drums, receptacles, within metal containers, at a designated location (temporary waste storage facility).	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.
15 01 04 17 04 05 17 04 07	– Light metal packaging – Iron and steel – Mixed metals	Stored in big-bags or metal containers at a designated location.	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.
15 01 01 15 01 02 15 01 06 15 01 07	– Paper and cardboard packaging materials – Plastic packaging – Mixed packaging – Glass packaging	Stored in big-bags or waste bins at a designated location (usually fenced).	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.
16 01 03 17 02 01	– Waste tyres – Wood	Stored separately in warehouses and storage yards (at a specially prepared location).	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.
16 02 11* 16 02 13* 16 02 14	– Discarded equipment containing chlorofluorocarbons, HCFC, HFC – Discarded equipment containing hazardous components other than those mentioned in 16 02 09 to 16 02 12 – Discarded equipment other than	Stored in a properly adapted container at a waste storage facility.	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.

	those mentioned in 16 02 09 to 16 02 13		
16 02 16	– Components removed from discarded equipment other than those mentioned in 16 02 15		
16 06 05	– Other batteries and accumulators		
20 03 01 20 03 03 20 03 99	– Mixed municipal waste – Street-cleaning residues – Municipal wastes not otherwise specified	Stored in a container in a storage yard.	NO Transferred to specialist entities (which hold relevant licenses) for downstream management.

Source: Own elaboration based on information obtained from port administration and [25]

4.3. Existing model for shipping waste management at the port

Figure 1 presents a model that considers the two main waste streams generated in the organisation of the shipping process at the port in Szczecin. It should be noted that the simplified model shows the physical flow of waste as well as the flow of information, which is an integral part of the activities as a whole. It should be pointed out that the current IT solutions for the organisation of this system support it only to a very small extent, thus reducing its efficiency.

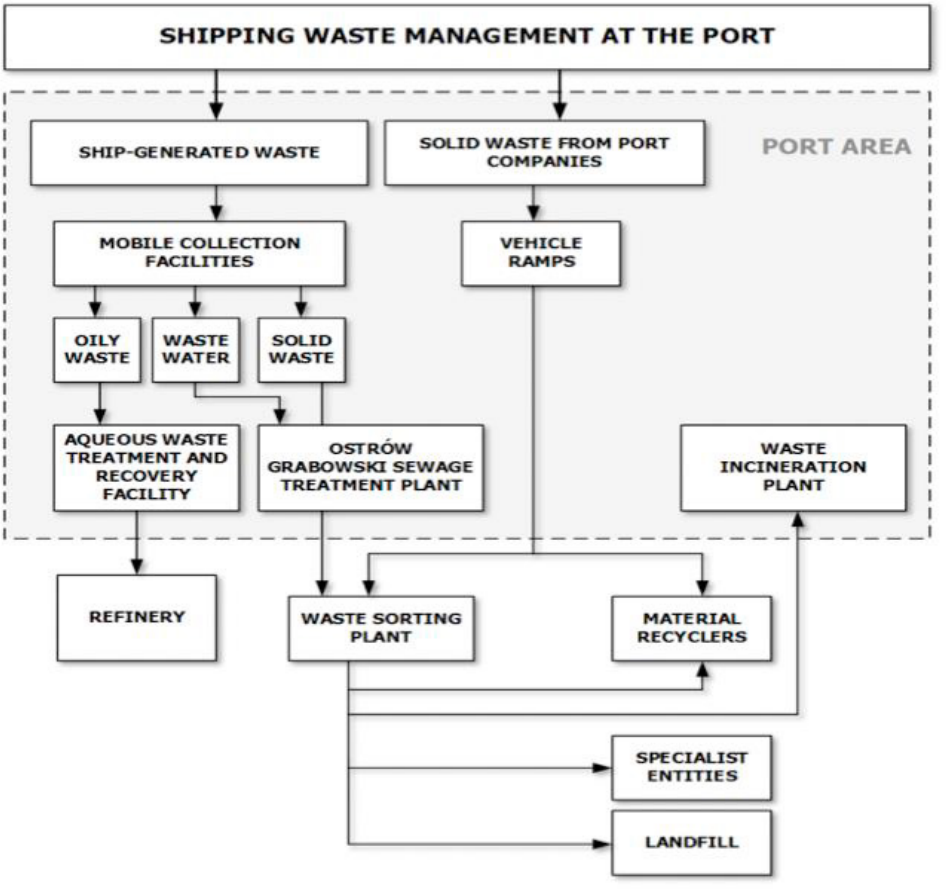

Fig. 1 Model of waste streams generated by maritime transport in the port in Szczecin. Source: Own elaboration

5. Evaluation of the management system for waste from ships and port companies in the context of circular economy

Table No. 3 presents the results of the research, which included an expert judgment on a management system for waste from ships and port companies generated in connection with the organisation of shipping.

Table 3. Expert judgment on waste management at the port

Ship-generated waste management at the port in Szczecin	
Strengths	*Weaknesses*
– Waste collection procedures are clear and understandable. – Round-the-clock access to reception facilities is provided. – Waste collection services are available at	– The ports do not use preferential rates (exemptions) for ships equipped with advanced waste minimisation installations – (systems). – The legislator has imposed certain

most of the quays in operation. – Waste is collected directly from ship to tanker. – Reception facilities are mobile, and their location does not obstruct ship traffic. – Waste can be transferred in various forms (also mixed). – There are special procedures in place for hazardous waste management. – Waste is transferred for downstream recovery. – The Ostrów Grabowski oily water treatment and mineral oil recovery facility is located within the port area. – The approach to the calculation of environmental charges taken by Zarząd Morskich Portów Szczecin and Świnoujście SA strongly reflects the *no-special-fees* concept. – Waste declarations from ships must be submitted to ports using an electronic form integrated into the control and information system. – The integration with PHICS (Polish Harbours Information & Control System) and, in the near future, with PCS (Port Community System) will guarantee effective control of ships with regard to delivered waste. – Sewage is received virtually without any limitations and is collected from a depth up to eight meters, and if the collection company's hoses (2x30 m long) and additional pumps are used and a ship heats the waste to liquify it, the collection capacity ranges from 1.5 m^3/h to 4 m^3/h.	requirements for the collection of waste and cargo residue. – Polish ports are not free to set waste collection and management fees on their own. Tonnage dues are fixed by law. – Waste reception (within a certain limit) is included in tonnage dues, which were not increased upon the introduction of the statutory obligation to collect ship-generated waste. – Ship-generated waste cannot be received from the water side, which limits the possibility of using mobile reception facilities located, for instant, on inland waterway vessels. – Waste (garbage) is transferred for downstream recovery outside the port area. Some of the waste falling into this category is returned as RDF to a waste incineration plant within the area of the port. – Lack of infrastructure for direct delivery (of waste, sewage) to processing installations (use of mobile equipment). – No operational integrated IT systems are currently in place to interconnect the various players in waste logistics.
Management of waste from port companies	
Strengths	*Weaknesses*
– Waste management is carried out in accordance with domestic and European Union law. The activities are aligned with sustainable development goals. – For the most part, waste is properly separated. – Companies cooperate with downstream waste management providers in a manner consistent with the applicable environmental standards, considering the economic dimension.	– No advanced technical solutions for sustainable waste management were observed. – There are no system improvements for waste logistics based on IT systems. – Circular economy solutions are limited. – No operational integrated IT systems are currently in place to interconnect the various players in waste logistics.

Source: Own elaboration based on information obtained from port administration, port companies and [5,26]

6. Conclusion

To streamline the efforts in support of sustainable management of shippi

ng waste, it would be appropriate to apply circular economy solutions. It is crucial to develop models in which a majority of waste processing activities can be carried out directly in port areas.

It would be appropriate from the environmental and economic perspective to take the following measures:

a) Introduce system improvements for waste logistics supported by IT systems that would enable planning and organisation of recovery logistics activities along the entire chain.
b) Ensure that waste is processed directly within the seaport using specialised facilities that are located within the port to eliminate the need to move untreated waste.
c) Shorten the transport routes for waste, which, following a separation process, could be handed over directly to recyclers.
d) Eliminate activities entailing the organisation of additional logistics processes for waste which should be sent directly to thermal recycling at the waste incineration plant (EkoGenerator) located within the port limits.
e) Develop an information system to track waste streams so that they can be routed for downstream management in accordance with the principles of circular economy.

Such solutions could directly contribute to reducing the movement of untreated waste streams both within the urban agglomeration and in maritime areas. These activities would be aligned with the 'green ports' as well as circular economy concepts. As a natural consequence of such improvements, preventive measures will be taken to reduce the risk of adverse events resulting from poor practices in the management of waste from seagoing vessels and port companies.

Funding: This research was funded by the Ministry of Science and Higher Education of Poland

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