The recovery of materials and management at the end-of-life of ships. Models and strategies for a Critical Raw Materials Circular Market in Europe.

**1Francesco Tola, 2Enrico Maria Mosconi, 3Marco Marconi, 4Mattia Gianvincenzi**

1,2,3,4 Università degli Studi della Tuscia

E-mail: 1 francesco.tola@unitus.it, 2 enrico.mosconi@unitus.it, 3 marco.marconi@unitus.it, 4mattia.gianvincenzi@unitus.it

ORCID: 10000-0003-4093-7714, 20000-0001-7065-7313, 30000-0002-5677-1459,

4 0000-0002-5363-3448

Corresponding author: Francesco Tola, francesco.tola1995@gmail.com

**Abstract.** The recovery of end-of-life ship's components and materials requires a complete demolition process as well as the realization processes of reuse that can guarantee the circularity of raw materials in the perspective of economic and environmental sustainability. Since the introduction of the Ship Recycling Regulation, the European Union legislative framework moves toward opening green markets related to the dismantling of ships. The objective is to value the critical materials and to change the design techniques in shipbuilding aiming at the total recyclability of ships. The rationale of the research is to develop a systemic model of the market for the circularity of the materials from the recovery of the medium-large ships. The objective of the study focuses on the potentialities of valorization of the members and the materials of the ships in light of the tightening European legislation. In particular, the research, after a careful analysis of the literature on the subject, focuses on the critical examination of the CBM models that want to make a second commodity exchange system more fluid and circulate in the blue economy. The results take interesting considerations, especially for what concerns recognize opportunities for green business and markets in the field of ship-recycling.

**Keywords.** Ship recycling; circular economy; systemic review; circularity business model

# Introduction

Maritime transport represents the world economy backbone, contributing to nearly 90% of global goods trades, and is physically impossible to replace with another type of transport (Unctad 2019). The current world merchant fleet comprises 99.800 ships (Geneva 2021), of which only 1% - 2% is recycled (Karvelis et al. 2020). Ship recycling refers to the dismantling process of ships with the aim of extracting and recovering materials, in particular steel, which represents around 95% of the material used, hardened steel, hardened copper alloys, titanium, alloys of titanium, aluminum, lead and various electronic equipment that can be reused or disassembled for the recovery of precious materials (Hiremath, Pandey, and Asolekar 2016). About 95% -98% of a ship's LTD weight is made up of recyclable materials (K. P. Jain, Pruyn, and Hopman 2017). Although ship recycling leds to huge economic and environmental benefits from ship recycling, there are some barriers within the current system. The coasts of South Asia bear witness to an industry whose environmental and health balance is urgently in need of a change, such pressures are due to poor quality dismantling techniques and the standards of recycling plants that do not comply with international standards (Devault, Beilvert, and Winterton 2017).

# Literature review

Table 1 shows the most significant regulatory frameworks to overcome the problems introduced previously.

Table 1. End of Life Ship regulatory frameworks

|  |  |  |
| --- | --- | --- |
| **Regulation** | **Year** | **Description** |
| Basel Convention | 1992 | Regulates the Control of Movement of Hazardous Wastes (Moen 2008) Offers guidelines on end-of-life ships that guide their destination, but its full application is difficult to control, as end-of-life ships are considered to be both ships and waste dangerous, so they can legally navigate to non-OECD countries (Gregson, Watkins and Calestani 2013) |
| Hong Kong Convention | 2009 | Regulates the design, construction, operation, and preparation of ships for sustainable recycling. Prohibits the use of some hazardous materials. Waiting to take effect (Glinski, 2022). |
| Regulation (EU) No. 1257/2013 | 2013 | Ship recycling regulation. From 31 December 2018, EU-flagged ships over 500 GT must be recycled in safe and environmentally friendly recycling facilities (Article 2). The list includes structures operating in EU and non-EU territory. 44 suitable EU plants and 9 suitable non-EU plants are recognized. No plant located in Southeast Asia is on the list. |

The political attempt to induce a globalized California effect in the ship recycling industry has not resulted in the raising of the desired environmental and social standards. The ease of circumventing international law through the practice of flag changing is a common practice. The main routes of destination in the recycling centers of these ships took place in the countries of South Asia with the stranded method. The capacity of recycling facilities located in OECD countries is less than 5% of the demand for recycling ships. Data combining analysis of the economic, environmental and social impact of ship recycling is limited. Furthermore, there are many differences for the recycling markets between the different types of ships (Choi et al. 2016). The main studies on quantifying the impacts of ship recycling, mainly focus on handling hazardous materials and ensuring health and safety during ship recycling activities (Zhou et al. 2021a), proposing green supply chains during ships dismantling (Ozturkoglu, Kazancoglu, and Ozkan-Ozen 2019a). The shipbreaking industry is expected to thrive as the number of ships produced around the world continues to increase (Kong et al. 2022).

The circular economy is the main tool in this sector, opening to the secondary raw materials market (Geissdoerfer et al. 2020).

The present study aims to investigate the opportunity, feasibility and potential effects for the creation of a circular business model for ship recycling in order to improve knowledge on the subject and provide a framework that can be used for future research, analyzing the economic feasibility, the environmental impact, the social aspect, the technology and the regulatory aspect.

# Material and methods

A systematic review was conducted to summarize the investigations and key topics in this area, to report and reflect on the trends and themes of the existing literature for all the clusters under observation. The method applied in this document consists of three stages (Figure 1):

1. The research was conducted on Scopus and Sciencedirect base using "ship recycling" as keywords. 25298 articles were collected. Studies concerning maritime power generation, international trade, ship navigation waste, ship sinking, marine biology etc, and studies prior to 2014 have been eliminated in the skimming phase. 582 articles were valid.
2. The articles are imported into the Mendeley database and revised, through an analysis of the content of the definitions, a coding scheme has been developed and applied to obtain an overview of the types of studies and dimensions. The most cited and useful keywords for further research were extracted from the analysis.
3. (3) The articles included were deepened, summarized, addressed in the various research themes and inserted in a matrix.

Figure 1. Concept map of systematic literature search and selection method

The limitation of the research lies in the low number of studies reviewed; however it can be considered as the first systematic review of ship recycling combined with sustainable development.

* 1. **Results and discussion**

Table 2 is the summary matrix of the systematic review in which the reviewed articles are placed in the reference clusters:

Table 2. Summary matrix

|  |  |  |
| --- | --- | --- |
| **n°** | **Study** | **Sustainability** |
| **Economic** | **Social** | **Environment** | **Technology** | **Regulatory** |
| 1 | Ozturkoglu et al., 2019 | ✓ | ✓ | ✓ | ✓ |  |
| 2 | Jain et al., 2018 | ✓ |  |  | ✓ |  |
| 3 | Du et al., 2018 | ✓ | ✓ | ✓ | ✓ |  |
| 4 | Ocampo et al., 2019 | ✓ |  |  | ✓ | ✓ |
| 5 | Senavirathna et al., 2022 | ✓ |  | ✓ | ✓ |  |
| 6 | Yujuico, 2014 | ✓ |  |  |  | ✓ |
| 7 | Kong et al., 2022 | ✓ |  |  | ✓ |  |
| 8 | Schøyen et al., 2017 | ✓ | ✓ | ✓ | ✓ |  |
| 9 | Devaux, 2020 | ✓ |  |  |  | ✓ |
| 10 | Gregson et al., 2014 |  | ✓ |  |  |  |
| 11 | Solakivi et al., 2021 |  |  |  |  | ✓ |
| 12 | Zhou et al., 2021 | ✓ |  | ✓ | ✓ |  |
| 13 | Mizanur and Mayer, 2015 | ✓ | ✓ |  |  |  |
| 14 | Steuer et al., 2021 | ✓ | ✓ | ✓ |  | ✓ |
| 15 | Sujauddin et al., 2017 | ✓ | ✓ |  |  |  |
| 16 | Yan et al., 2022 | ✓ |  |  | ✓ |  |
| 17 | Argüello, 2016 |  |  |  |  | ✓ |
| 18 | Hossain et al., 2016 | ✓ |  | ✓ |  |  |
| 19 | Jain et al., 2016 | ✓ |  |  | ✓ |  |
| 20 | Fachry Indianto, 2020 | ✓ |  |  | ✓ |  |
| 21 | Rizkytama et al., 2020 | ✓ |  |  |  |  |
| 22 | Jain et al., 2017 | ✓ |  | ✓ | ✓ |  |
| 23 | Rahman et al., 2016 | ✓ | ✓ | ✓ |  | ✓ |
| 24 | Handler et al., 2016 | ✓ | ✓ | ✓ |  |  |

The review opens to new ideas for a ship recycling industry capable of making the economic, environmental, and social spheres interact, through the use of new technologies and top-down policies. Table 3 shows conclusions per each cluster.

Table 3. Clusters analysis

|  |  |
| --- | --- |
| **Cluster** | **Description** |
| Economic cluster | Studies agree that there is an inverse correlation between economic growth and ships sent for scrapping (Kong et al. 2022; Steuer et al., 2021). Studies by (Yujuico 2014) analyze the demand and price of steel, showing that South Asian wreckers offer higher figures for end-of-life ships due to high domestic prices for steel scrap. Material Flow Analysis (MFA) is an important tool for improving the management of materials and waste during the recycling phase, enabling the optimization of resources (such as labor, machinery and equipment) to obtain maximum income (K. P. Jain, Pruyn, and Hopman 2017b). According to (Devaux and Nicolaï 2020b) a possible recycling license for ships flying the European flag could trigger an improvement in the trend in the EU territory. Innovation and investment in demolition plants are difficult to implement (Schøyen, Burki, and Kurian 2017). |
| Social cluster | Ship recycling in Europe is a low-frequency activity. Analyzes of the work situation state that in European construction sites, work fails to attract local labor and instead relies on migrant workers (Gregson et al. 2014). The establishment of industrial networks in a community can establish advanced development conditions aimed at continuous improvement (Mizanur Rahman and Mayer 2015). The license strategy would make it possible to internalize the social costs of ship dismantling (Devaux and Nicolaï 2020). The guidelines for safety on construction sites proposed by (Hossain et al. 2016) can be followed to mitigate the impact that demolition yards have on the environment, as well as to promote sustainable practices for demolition activities. |
| Environment cluster | Current end-of-life management problems exist mainly due to the lack of ecological integration in the design and production processes (Senavirathna et al., 2022). The implementation of a holistic framework for risk management could lead Southeast Asian shipyards to be regulated according to environmental standards, as well as technical (i.e. type of ships) and economic standards (i.e. currency exchange)(Ozturkoglu et al., 2019b). From the LCA on steel recovered from ships conducted by (Rahman and Mayer 2016) emerges that there is a substantial environmental advantage in recycling steel compared to virgin raw material. The outcomes of the green supply chain can help from the point of view of organization, on-site management, technology and equipment, use of clean energy etc. (Zhou et al. 2021b) |
| Technology cluster | The ship is not designed for disassembly and recycling (Du et al. 2018). The high demand for the materials extracted from the ship add value to this activity (Ocampo et al., 2019). Revenues can be increased through a heat treatment plant on construction sites for the transformation of waste into secondary raw materials (Kanu Priya Jain et al., 2018). The installation of facilities such as floating piers, wastewater treatment plants, storage facilities and asbestos pre-treatment, can improve the technical conditions of recycling (Steuer et al., 2021). The quantification of materials to facilitate disassembly through the ship's stability manual and the WBS classification system was found to be a feasible and practicable technique (K. P. Jain et al., 2016) |
| Regulatory cluster | Future global and European demand for ship dismantling has been politically underestimated (Solakivi et al. 2021). International treaties usually do not represent the interests of developing countries and there is a lack of a harmonized definition of naval waste (Rahman, Handler, and Mayer 2016). Local policy makers need to improve local ship recycling rules from the point of view of environmental protection structures and plans, ecological environmental protection etc. (Zhou et al. 2021b). Currently, until the dispute between the waste regime and ship recycling has been resolved, the ships at the end of their operational life will continue to land on the coasts of South Asia (Argüello Moncayo 2016). |

* 1. **Conclusions**

The economic value of a ship's materials at its end of life can be a crucial sector for the creation of secondary markets for critical raw materials. From an eco-neutral perspective, a green ship must have all aspects related to sustainability under control at the end of its life. It would be the result of a circular design, made with advanced methods of using materials and energy, in which all components are designed to be continuously reused in future projects, reducing waste. An incessant disassembly, recovery, and reassembly system, made up of the development of cross-sector green markets and related supply chains, to originate an industry made up of circular flows of resources. In order to guide all the actors towards the path of a system strategy, not only is an extensive network of consultation of the parties involved on the common field of the resources necessary resource value, but it is also necessary to validate their real economic, financial and environmental feasibility, so as to be able to realize a safe new business for the maritime industry.

**Bibliography**

Argüello Moncayo, Gabriela. 2016. “International Law on Ship Recycling and Its Interface with EU Law.” *Marine Pollution Bulletin* 109 (1): 301–9. https://doi.org/10.1016/J.MARPOLBUL.2016.05.065.

Choi, Jun Ki, Daniel Kelley, Sean Murphy, and Dillip Thangamani. 2016. “Economic and Environmental Perspectives of End-of-Life Ship Management.” *Resources, Conservation and Recycling* 107 (February): 82–91. https://doi.org/10.1016/J.RESCONREC.2015.12.007.

Commission, European. 2016. “Financial Instrument to Facilitate Safe and Sound Ship Recycling Final Report.”

Demaria, Federico. 2010. “Shipbreaking at Alang–Sosiya (India): An Ecological Distribution Conflict.” *Ecological Economics* 70 (2): 250–60. https://doi.org/10.1016/J.ECOLECON.2010.09.006.

Devault, Damien A., Briac Beilvert, and Peter Winterton. 2017. “Ship Breaking or Scuttling? A Review of Environmental, Economic and Forensic Issues for Decision Support.” *Environmental Science and Pollution Research International* 24 (33): 25741–74. https://doi.org/10.1007/S11356-016-6925-5.

Devaux, Caroline, and Jean Philippe Nicolaï. 2020. “Designing an EU Ship Recycling Licence: A Roadmap.” *Marine Policy* 117 (July): 103826. https://doi.org/10.1016/J.MARPOL.2020.103826.

Du, Zunfeng, Sen Zhang, Qingji Zhou, Kum Fai Yuen, and Yiik Diew Wong. 2018. “Hazardous Materials Analysis and Disposal Procedures during Ship Recycling.” *Resources, Conservation and Recycling* 131 (April): 158–71. https://doi.org/10.1016/J.RESCONREC.2018.01.006.

Du, Zunfeng, Haiming Zhu, Qingji Zhou, and Yiik Diew Wong. 2017. “Challenges and Solutions for Ship Recycling in China.” *Ocean Engineering* 137: 429–39. https://doi.org/10.1016/J.OCEANENG.2017.04.004.

Geissdoerfer, Martin, Marina P.P. Pieroni, Daniela C.A. Pigosso, and Khaled Soufani. 2020. “Circular Business Models: A Review.” *Journal of Cleaner Production* 277 (December): 123741. https://doi.org/10.1016/J.JCLEPRO.2020.123741.

Geneva. 2021. “Review of Maritime Transport 2021.” https://shop.un.org.

Glinski, Carola. 2022. “The Public–Private Governance Regime on Sustainable Ship Recycling: An in-Depth Analysis.” *Review of European, Comparative & International Environmental Law*, June. https://doi.org/10.1111/REEL.12449.

Gregson, Nicky, Mike Crang, Julie Botticello, Melania Calestani, and Anna Krzywoszynska. 2014. “Doing the ‘Dirty Work’ of the Green Economy: Resource Recovery and Migrant Labour in the EU:” *Http://Dx.Doi.Org/10.1177/0969776414554489* 23 (4): 541–55. https://doi.org/10.1177/0969776414554489.

Gregson, Nicky, Helen Watkins, and Melania Calestani. 2013. “Political Markets: Recycling, Economization and Marketization.” *Http://Dx.Doi.Org/10.1080/03085147.2012.661625* 42 (1): 1–25. https://doi.org/10.1080/03085147.2012.661625.

Hiremath, Anand M., Sachin Kumar Pandey, and Shyam R. Asolekar. 2016. “Development of Ship-Specific Recycling Plan to Improve Health Safety and Environment in Ship Recycling Yards.” *Journal of Cleaner Production* C (116): 279–98. https://doi.org/10.1016/J.JCLEPRO.2016.01.006.

Hossain, Md Shakhaoat, Abu Naieum Muhammad Fakhruddin, Muhammed Alamgir Zaman Chowdhury, and Siew Hua Gan. 2016. “Impact of Ship-Breaking Activities on the Coastal Environment of Bangladesh and a Management System for Its Sustainability.” *Environmental Science & Policy* 60 (June): 84–94. https://doi.org/10.1016/J.ENVSCI.2016.03.005.

Jain, K. P., J. F.J. Pruyn, and J. J. Hopman. 2016. “Quantitative Assessment of Material Composition of End-of-Life Ships Using Onboard Documentation.” *Resources, Conservation and Recycling* 107 (February): 1–9. https://doi.org/10.1016/J.RESCONREC.2015.11.017.

———. 2017. “Material Flow Analysis (MFA) as a Tool to Improve Ship Recycling.” *Ocean Engineering* 130 (January): 674–83. https://doi.org/10.1016/J.OCEANENG.2016.11.036.

Jain, Kanu Priya, Jeroen Pruyn, and Hans Hopman. 2018. “Strategic Guidance Based on the Concept of Cleaner Production to Improve the Ship Recycling Industry.” *Environment Systems and Decisions* 38 (2): 250–60. https://doi.org/10.1007/S10669-017-9654-5/TABLES/1.

Karvelis, Petros, George Georgoulas, Vassilios Kappatos, and Chrysostomos Stylios. 2020. “Deep Machine Learning for Structural Health Monitoring on Ship Hulls Using Acoustic Emission Method.” *Https://Doi.Org/10.1080/17445302.2020.1735844* 16 (4): 440–48. https://doi.org/10.1080/17445302.2020.1735844.

Kong, Xianghui, Kuishuang Feng, Peng Wang, Zheng Wan, Lin Lin, Ning Zhang, and Jiashuo Li. 2022. “Steel Stocks and Flows of Global Merchant Fleets as Material Base of International Trade from 1980 to 2050.” *Global Environmental Change* 73 (March): 102493. https://doi.org/10.1016/J.GLOENVCHA.2022.102493.

Mizanur Rahman, S. M., and Audrey L. Mayer. 2015. “How Social Ties Influence Metal Resource Flows in the Bangladesh Ship Recycling Industry.” *Resources, Conservation and Recycling* 104 (November): 254–64. https://doi.org/10.1016/J.RESCONREC.2015.07.022.

Moen, Amy E. 2008. “Breaking Basel: The Elements of the Basel Convention and Its Application to Toxic Ships.” *Marine Policy* 32 (6): 1053–62. https://doi.org/10.1016/J.MARPOL.2008.03.002.

Ocampo, Euler Sánchez, and Newton Narciso Pereira. 2019. “Can Ship Recycling Be a Sustainable Activity Practiced in Brazil?” *Journal of Cleaner Production* 224 (July): 981–93. https://doi.org/10.1016/J.JCLEPRO.2019.03.173.

Ozturkoglu, Y., Y. Kazancoglu, and Yesim Deniz Ozkan-Ozen. 2019a. “A Sustainable and Preventative Risk Management Model for Ship Recycling Industry.” *Journal of Cleaner Production* 238 (November). https://doi.org/10.1016/J.JCLEPRO.2019.117907.

———. 2019b. “A Sustainable and Preventative Risk Management Model for Ship Recycling Industry.” *Journal of Cleaner Production* 238 (November): 117907. https://doi.org/10.1016/J.JCLEPRO.2019.117907.

Rahman, S. M.Mizanur, Robert M. Handler, and Audrey L. Mayer. 2016. “Life Cycle Assessment of Steel in the Ship Recycling Industry in Bangladesh.” *Journal of Cleaner Production* 135 (November): 963–71. https://doi.org/10.1016/J.JCLEPRO.2016.07.014.

Rahman, S. M.Mizanur, and Audrey L. Mayer. 2016. “Policy Compliance Recommendations for International Shipbreaking Treaties for Bangladesh.” *Marine Policy* 73 (November): 122–29. https://doi.org/10.1016/J.MARPOL.2016.07.012.

Senavirathna, G. R.U., U. I.K. Galappaththi, and M. T.T. Ranjan. 2022. “A Review of End-Life Management Options for Marine Structures: State of the Art, Industrial Voids, Research Gaps and Strategies for Sustainability.” *Cleaner Engineering and Technology* 8 (June): 100489. https://doi.org/10.1016/J.CLET.2022.100489.

Solakivi, Tomi, Tuomas Kiiski, Tuulia Kuusinen, and Lauri Ojala. 2021. “The European Ship Recycling Regulation and Its Market Implications: Ship-Recycling Capacity and Market Potential.” *Journal of Cleaner Production* 294 (April): 126235. https://doi.org/10.1016/J.JCLEPRO.2021.126235.

Steuer, Benjamin, Margarethe Staudner, and Roland Ramusch. 2021. “Role and Potential of the Circular Economy in Managing End-of-Life Ships in China.” *Resources, Conservation and Recycling* 164 (January): 105039. https://doi.org/10.1016/J.RESCONREC.2020.105039.

Unctad. 2019. “Review of Maritime Transport 2019.”

Zhou, Qingji, Zunfeng Du, Jiayue Liu, Jing Liang, and Yueqin Jiao. 2021a. “Factors Influencing Green Ship Recycling: A Conceptual Framework and Modeling.” *Journal of Cleaner Production* 322 (November): 129155. https://doi.org/10.1016/J.JCLEPRO.2021.129155.

———. 2021b. “Factors Influencing Green Ship Recycling: A Conceptual Framework and Modeling.” *Journal of Cleaner Production* 322 (November): 129155. https://doi.org/10.1016/J.JCLEPRO.2021.129155.