Journal of Circular Economy
https://doi.org/10.55845/FJTP4757 Volume 2, Issue 3

**Research paper**

# Navigating the EU Ship Recycling Market: Economic and Environmental Perspectives

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Handling Editor: Roberto Minunno

Received:12.01.2024/ Accepted: 13.10.24


## Abstract

Ship recycling refers to the process of dismantling ships to extract and recover materials and it is typically seen as the best method to dispose of a ship when its service life is coming to an end. Exploring the European Union's aspiration to enhance competitiveness and boost ship recycling near its shipyards, this study delves into the European ship recycling market's environmental, economic, and regulatory facets. It focuses on factors influencing recycling activities in the EU, set against global market trends and stringent regulations. Employing a multiple linear regression model, the study analyzes variables like shipyard capacity, Light Displacement Tonnage (LDT) price, ship age, shipbuilding rates, maritime trade volumes, and material circularity, drawing data from 2016 to 2022 from various open-source databases. The research uncovers correlations between shipyard capacity and demolition rates, and the impact of LDT prices on demolitions. The study also notes the interplay between shipbuilding activities and demolition rates. This paper contributes crucial insights to the European ship recycling market, aiding sustainable development in a changing operational environment.

**Keywords:** Ship Recycling · Ship Dismantling · Regression Model · Ship Recycling Market

## 1. INTRODUCTION

Ship recycling represents an inherently sustainable and highly profitable business (Kong et al., 2022). It is a crucial element in ensuring the proper disposal of dismantling ships and the recovery of materials and resources contained within them (Hiremath et al., 2016). This process offers a dual advantage: on one hand, it contributes to the renewal of the global fleet of ships, maintaining a balance between the demand and supply of ships and promoting circular resource supply; on the other hand, ship recycling aims to recycle and reuse materials from decommissioned ships, thus reducing the amount of waste destined for landfills (Dey et al., 2021). This dual nature of ship recycling makes it an important component of the circular economy, as it enables the recovery of valuable materials and the reduction of environmental impact associated with ship demolition (Sant' Ana et al., 2023). However, it should be noted that the ship recycling industry employs various techniques, each with varying costs and environmental and social impacts (Sujauddin et al., 2017).

Among the main ship dismantling methods, find beaching, landing, alongside, and dry-docking. Each of these approaches has its characteristics and implications. Beaching is widely used in countries like Bangladesh, India, and Pakistan (Lin, Feng, Wang, et al., 2022). This method involves dragging the ship onto the beach to be dismantled. However, it raises serious concerns about worker safety and environmental pollution, making it a controversial practice (Zhou et al., 2021). Landing, mostly used in Turkey, involves the ship running aground on a shore or a concrete slipway to facilitate dismantling operations. This method is less risky for workers compared to

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beaching but can still pose safety issues. Alongside, commonly used in China, the European Union, and the United States, involves piece-by-piece dismantling of the immobilized ship on a dock. This method is considered safer than beaching and landing but requires specific port facilities. Finally, dry-docking is the safest and most efficient method and is carried out in enclosed dry docks. However, the costs associated with this method limit its use. The choice of dismantling method often depends on economic considerations but increasingly includes concerns related to worker safety and environmental impact (Samsudin et al., 2022).

The selection of a dismantling location is principally influenced by the monetary value a facility offers for the metal, as perceived by shipowner or the "cash-buyer" intermediary (Hsuan & Parisi, 2020). This value is influenced by the demand for recycled steel in the area concerned and the costs of recycling operations. The market demand and the scrap prices offered by the shipyards are closely linked to the price of steel and the costs of the recycling activity (Yujuico, 2014) . Until the 1980s, Europe was the primary center of the ship recycling market (Kodungallur et al., 2012). However, it later shifted to Asia, with Bangladesh, China, India, and Pakistan accounting for most global demolitions (K. A. Hossain, 2015). Turkey is also a significant player, making a substantial contribution to the industry. This geographic shift in the market was primarily driven by economic considerations. Asian countries offered lower labor costs and a strong demand for recycled steel, making ship recycling more cost-effective in these regions (Barua et al., 2018; M. S. Hossain et al., 2016; Ko & Gantner, 2016) However, this geographical dispersion has also led to greater diversity in dismantling methods and safety practices.

Considering the economics advantages, there are serious environmental and health dangers associated with the ship recycling sector. Hazardous compounds found aboard ships can poison crew members and contaminate the soil and coastal seas, having negative environmental effects (K. P. Jain et al., 2016). Regulations have not yet completely taken effect, despite efforts to raise the industry's health and environmental standards. Therefore, the industry and the scientific community are becoming increasingly interested in the topic of ship recycling as they look for ways to lessen these adverse effects (Ignacio Alcaide et al., 2017) . In recent years, there have been significant transformations in the ship recycling landscape, both in terms of regulations and economics.

Despite regulatory progress, such as the 2009 Hong Kong Convention, the management of end-of-life ships and the recycling of their materials still pose a global issue characterized by persistent difficulties (IMO, 2009). Policymakers have sought to develop more effective regulatory frameworks to prevent the sale of ships to unsafe and environmentally unfriendly demolition facilities (Lin, Feng, Wan, et al., 2022). However, despite efforts, the situation remains critical and requires further actions to promote more sustainable and environmentally friendly recycling practices. The management of EOL in the EU has moved from the regulation on the export of waste Reg.1013/2006 to a specific regulation, Reg.1257/2013 (SRR), which promotes the requirements of international standards for the ship recycling activity in the European area. The SRR aims to be an early implementation of the HKC. The objective of the SRR is to limit the sending of European ships to non-compliant yards. Article 2 of the SRR obliges that all ships flying the flag of the EU with a tonnage of over 500 GT must be recycled in facilities authorized by the European Commission. Article 16 of the SRR establishes the list of yards authorized for ship dismantling, which can be updated. The first publication was in 2016 and included 16 yards with an authorized annual recycling capacity of 0.3 MLTD and a theoretical capacity of 1.1 MLTD. The eleventh edition published in mid-2023 authorizes 48 facilities, located both in Europe and in a third country, the authorized capacity is 1.05MLTD and the theoretical capacity is 3 MLTD (European Commission, 2023). However, the SRR is the subject of controversy, the main ones being the insufficiency of the recycling capacity of the facilities located in OECD countries, the ease of circumventing the regulation, and the lack of an adequate financing mechanism.

The European Union, through the adoption of the Green Deal, aims to focus its policies on a low-resource consumption economy. An integral part of the European Green Deal is the Circular Economy Action Plan (CEAP2), which represents an industrial policy approach aimed at accelerating not only circularity but also the dematerialization of the economy (European Commission, 2020). Ship recycling is perfectly aligned with European policies for industrial recovery and the promotion of the circular economy. The production of steel through ship recycling is not only more ecological but also more economical. Traditional methods for steel production, such as mining, smelting, and rolling, not only consume considerable amounts of energy but are also in sharp contrast with global efforts to adopt more environmentally friendly technologies (Dey et al., 2021). On the other hand, the virtuous recycling of steel allows for the renewal of the world's ship fleet and the maintenance of a balance between supply and demand, while simultaneously facilitating the recycling of millions of tons of waste materials. This not only contributes to the efficiency of the process but also supports the creation of a circular flow for the supply of resources, thus promoting more sustainable management of materials and reducing the overall environmental impact. However, according to studies by Tola et al., 2024 the number of European ships destined for demolition is expected to increase in the coming decades and, if not properly planned, could cause significant problems in terms of recycling capacity and waste management. To address this growing demand, it is essential to improve recycling infrastructures and technologies. Currently, the process of improving the regulation of the Ship Recycling Regulation (SRR) is underway. This review involves assessing the effectiveness of the regulation's implementation and its impact to date, evaluating the extent to which it contributes to the overall objectives of the European Green Deal, and identifying gaps in its application.

Recent studies suggest the need to further research to identify significant factors that can trigger increased competitiveness of ship recycling in the European Union. According to studies Tola et al., 2023, it is appropriate to advance research into the identification of significant factors that can influence ship recycling in the European Union. The study focuses at several of economic, environmental, and regulatory aspects in an effort to examine the ship recycling business in the European Union. Employing a multiple linear regression model, the study evaluates variables such as shipyard capacity, LDT prices, ship age, shipbuilding rates, maritime trade volumes, and material circularity. Data for this analysis were collected from multiple open-source databases spanning from 2016 to 2022. Increased shipyard capacity correlates with more demolitions, necessitating targeted investment policies for enhanced capacity and efficiency. Higher LDT prices also boost demolition activities, emphasizing the need for financial mechanisms to support competitive pricing. Older ships are more likely to be demolished, pointing to the importance of predictive models for effective demolition planning. Shipbuilding activities and maritime trade volumes also influence demolition rates, showing the interconnectedness of these factors. Promoting material circularity supports sustainable practices, linking circular economy principles to increased ship demolition. These insights guide policy development and resource management in the European ship recycling industry.

### 1.1 Economic Overview of Ship Recycling

Annually, between 700 and 1000 ships are demolished around global coasts. The ship recycling market is a constantly evolving sector that adapts to changing global dynamics (Rahman & Kim, 2020). In recent years, there have been significant transformations in the ship recycling landscape, both in terms of regulations and economics. Numerous factors determine the market for ships to be scrapped. The economics of ship recycling are primarily driven by market factors such as freight rates, the price of steel scrap, the costs of maintaining an aging fleet, the price offered by shipyards for the purchase of LDT, the cost of demolition, and the demand for recycled steel (K. A. Hossain, 2017). The light weight of a ship, which includes the weight of the hull, machinery, and equipment, is a crucial parameter. Additionally, the dimensions of the ship, such as length, breadth, depth, and displacement, are fundamental for the purchase and sale of an out-of-service ship.

However, the decision to scrap a ship is also influenced by other factors, such as technological development, new global market needs, regulatory standards, and the entry of new ships into the fleet. The choice of demolition location depends on the demand for steel scrap and the costs of demolition activities (A. Jain et al., 2013). Countries like Turkey, China, India, Pakistan, and Bangladesh have a strong demand for recycled steel, while Europe and North America have a lower demand. This is reflected in the geographical distribution of ship demolition yards (OECD, 2019).

Furthermore, the ship recycling industry plays a crucial role in the economy of South Asia, providing a source of livelihood for many people in the region (Ahasan et al., 2021). This industry not only provides a significant amount of recycled steel but also contributes to the development of the local shipbuilding industry. In general, there have been few recent inferential statistical studies on the ship recycling market. Studies by (Knapp et al., 2008) suggest that further efforts are needed to understand the dynamics of the ship recycling sector. The study focuses on understanding which variables can drive the increase in ship demolition in the European Union, in view of the future changes that this sector will have to face.

## 2. METHODOLOGY

The aim of this study is to examine the variables that may have an impact on the European ship recycling market. Using a multiple linear regression model (MLR), the research issues were addressed. The MLR model is a basic linear regression model extension that enables an analysis of the interactions between independent factors and the dependent variable. MLR analysis is frequently used to explore ideas in a variety of research domains. The literature has already used regression analysis to look at important variables that might have an impact on the ship recycling market (Knapp et al., 2007, 2008; Reddy et al., 2005). The research methodology is structured into four steps, as illustrated in Figure 1.

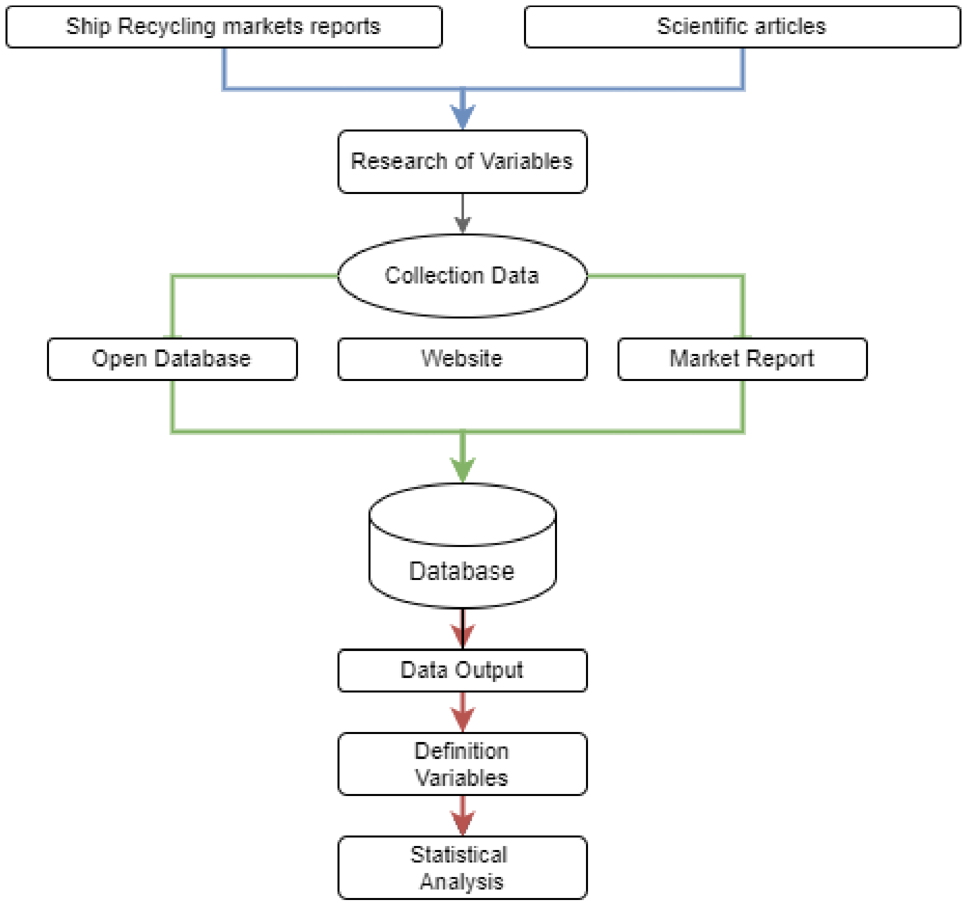


*Figure 1. Methodology of Research*

As a first step, a comprehensive literature review was conducted on studies that have explored the dynamics of the ship recycling market. Scientific articles and industrial reports were analyzed to identify and document the most appropriate variables for advancing the research. Once the key variables capable of addressing the research questions were identified, they were collected through consultation of open-source databases and websites, ensuring the creation of a dataset.

The dataset comprises three main groups of data:

- Economic Data: This includes building prices, demolition cost, and steel recycling rates.
- Shipyard Data: annual recycling capacity.
- Vessel Data: includes the number of demolished ships and the age of the vessels.

The number of recycled ships in the European Union has been chosen as the dependent variable. The dataset covers the period from 2016 to 2022. The year 2016 was chosen as the starting point since it was the year of publication of the lists of approved shipyards by the European Commission. Data sources were obtained from various open-source databases, including Eurostat, UNCATstat, GMS, BIMCO, Clackrson Research, and the NGO ShipBreaking Platform database.

Following the collection of the independent variables, the dataset was constructed. Subsequently, a quantitative approach was adopted to analyze the collected dataset. Statistical techniques and data analysis were utilized to identify relationships and trends among the variables. Descriptive data analysis was conducted to examine the distribution of variables and calculate measures of central tendency and dispersion. The variables considered and their rationales are visible in Table1.

*Table 1. Literature References for the Variables*

| Variable | Source |
|---|---|
| Ship Recycling in Europe | NGO Shipbreaking Platform; Clarskson Research |
| Capacity of recycling shipyard | European Commission |
| Price LTD | GMS; Hellenic Shipping; London Stock Exchange |
| Age of ships | NGO Shipbreaking platform |
| Shipbuilding | UNCTAD-stat |
| Maritime Trade | UNCTAD-stat |
| Circularity Material | Eurostat |

The adopted model is based on standard econometric techniques used to analyze historical series in order to understand the inference associated with one or more variables. This allows for predicting how these variables may influence, either positively or negatively, the impact on the dependent variable (y), which in this case represents the number of ships dismantled in European shipyards from 2016 to 2022. The holistic approach employed, based on the extension of data by (Knapp et al., 2008)mixed various datasets to provide a comprehensive and robust picture of the ships and their relevance to the recycling market. The construction of the dataset was made possible through the integration of observations derived from an extension of primary quantitative data found in open-source databases. These observations highlight events of interest that intuitively affect the dynamics of the European ship demolition market.

The data were collected from various open-source sources and catalogued in an Excel file. A preliminary data cleaning analysis was then conducted. Finally, the MLR analysis was executed using R-Studio software. Multiple combinations of variables were examined to understand the impact of specific variables on the ship recycling market. The regression model formula is as follows:

$$Y_{Eu\ Ship\ recycling} = \beta_0 + \beta_{capacity\ of\ recycling\ shipyard} * X_1 + \beta_{LDT\ price} * X_2 + \beta_{age} * X_3 + \beta_{Shipbuilding} * X_4 + \beta_{Maritime\ trade} * X_5 + \beta_{Circularity\ material} * X_6 + \varepsilon$$

Regression equation describes the impact of several explanatory variables on the number of ships recycled in European facility. The equation can be explained as follows:

$Y_{Eu\ Ship\ recycling}$ represents the number of ships recycled in European shipyards and is the main focus of the analysis. $\beta_0$ is the constant of the model, representing the starting point or intercept, that is, the expected value of $Y_{Eu\ Ship\ recycling}$when all explanatory variables are set to zero. The first explanatory variable, $X_1$, represents the capacity of European recycling shipyards. Its inclusion in the model is justified because shipyard capacity directly affects the number of ships that can be demolished. We can infer that the higher the capacity, the greater the likelihood that more ships will be recycled. $X_2$, the LDT price, is a key parameter. The LDT price significantly impacts the profitability and location of recycling. The age of ships, represented by $X_3$, is included because older ships are generally more likely to be demolished.

$X_4$, which represents the level of production in the shipbuilding sector, is included because an increase in new ship construction may accelerate the scrapping process of older ships. Maritime trade, represented by $X_5$, influences the dynamics of ship recycling. The trend of maritime trade in a given year can affect the decision to demolish a vessel. $X_6$reflects the material circularity capacity in the European Union, which refers to the ability to recover and process waste materials without the need for export to other countries. This variable reflects the European Union's intention to retain its waste within European borders to secure material supply. **ε** represents the stochastic error, capturing the variations in the dependent variable that are not explained by the model. It accounts for all influences not explicitly included in the set of variables in the model.

The equation was chosen to model the behavior of the ship recycling market, considering the key variables that influence the number of ships demolished. The selected variables are based on theoretical and empirical analysis from economic literature and the shipbreaking sector. Each independent variable has a strong theoretical justification for inclusion in the model, as they directly influence the supply of ships for demolition and the behavior of recycling yards. This specific regression equation has been used to capture the linear relationships between the independent variables and the dependent variable.

## 3. RESULT AND DISCUSSION

The results of the multiple linear regression are shown in Table 2 and apply different simulations of comparison between variables to understand significance.

*Table 2. Multiple Linear Regression*

| | Ship Recycling in EU | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Capacity of shipyards | 0.0012488*** | 0.00523988-05 ** | 0.1484005 *** | 0.197805*** | 0.2247804*** | 0.2506805 *** |
| Price_LDT | | 0.523894*** | 1.35946** | 1.30486** | 1,14465*** | 1.16668*** |
| Age ships | | | -0.2483+00* | -2.60232* | -1.1749** | -1,6943* |
| Ship building | | | | 0.872482*** | 1,18209* | 1.12855*** |
| Maritime Trade | | | | | 0.0729107* | 0.0556368** |
| Circularity Material | | | | | | 0.0540312*** |
| $R^2$ | 0.426 | 0.6128 | 0.7349 | 0.8152 | 0.876 | 0.793 |
| Adjusted $R^2$ | 0.3113 | 0.5486 | 0.6198 | 0.8056 | 0.813 | 0.74027 |
| Residual Std. Error | 45.8 | 17.52 | 19.91 | 24.33 | 11.31 | 2.204 |
| F-statistic | 3.712 | 27.76 | 14.36 | 7.217 | 28.37 | 752 |
| p-value | 0.112 | 0.004516 | 0.02765 | 0.1254 | 0.1416 | 0.02768 |

*p<0.1; **p<0.05; ***p<0.01

The variable "Capacity of Shipyards" has a significant impact on the number of ships recycling in Europe, as highlighted by the estimated coefficients in various regression models. In all the models analyzed, the coefficient associated with shipyard capacity is statistically significant with very low p-values, suggesting a strong correlation between shipyard capacity and the number of ships demolished in Europe. Specifically, the positive coefficients in all models indicate that an increase in shipyard capacity is associated with a higher number of ship demolitions in Europe. This may reflect the additional capacity to dispose of ships efficiently and in an environmentally sustainable manner, as well as the increased demand for ship demolition services.

It is essential to note that these results can have significant implications for industrial policy and resource management in the European maritime sector. This evidence is particularly important in a broader context, where the implications of the results can have a significant impact on industrial policy and resource management in the European maritime sector. However, a significant controversy arises regarding the capacity and size of authorized demolition facilities. The European Commission, before the introduction of the regulation, estimated that the demolition capacity in the EU and other OECD countries was just sufficient (European Commission, 2000;

European Commission DG Environment, 2009), but more recent studies highlight a deficit considered unacceptable for the near future (Rahman et al., 2021; Solakivi et al., 2021; Tola et al., 2024). The increase in shipyard capacity can be influenced by investment policies, both public and private, as well as initiatives that promote efficiency and sustainability in ship demolition. Furthermore, to enhance competition in the European ship demolition industry and prevent "structural dumping" by East Asian countries, it may be necessary to establish regulations regarding subsidies and the use of public funding. These regulations should encourage investments with a high European value-added in the ship demolition sector.

The "Price_LDT" variable demonstrates a significant impact on the number of ships demolished in Europe. The coefficient associated with "Price_LDT" is statistically significant with a very low p-value, indicating a strong association between LTD prices and the number of ship demolitions. Specifically, the positive coefficient suggests that an increase in LDT prices is correlated with an increase in ship demolitions in Europe. These results highlight the importance of developing targeted investment policies to address this challenge and reduce the price gap between regions. One possible strategy could include implementing investment policies to bridge the price gap, involving public interventions aimed at promoting higher prices offered by shipyards for the purchase of ships to be demolition (Yang et al., 2019). These policies may include establishing robust financial mechanisms that incentivize the competitiveness of the European ship demolition industry. Furthermore, encouraging on-site ship demolition could contribute to the development of the ship demolition market, making it more stimulating and competitive. This approach could be an integral part of a broader investment policy aimed at promoting sustainability and efficiency in the European ship demolition industry while simultaneously closing the price gap with Asia and maintaining global competitiveness.

The "Age_ship" variable reveals a significant relationship with the number of ships demolished in Europe, highlighting that as the age of ships increases, the number of demolitions tends to rise. This result suggests that older ships are more susceptible to being demolished, likely due to obsolescence or difficulty in complying with newer environmental and safety regulations. Given this relationship, it is important to emphasize the need to intensify research and the development of ship demolition prediction models. Such models could be instrumental in identifying at-risk ships in advance, allowing for more efficient demolition planning and sustainable resource management. The studies of Milios et al., (2019)suggest that improved communication between shipyards and shipowners can contribute to establishing a circular materials supply chain. Additionally, a high level of collaboration among stakeholders is deemed essential (Chhetri et al., 2022). Furthermore, to manage this dynamic more effectively, it may be appropriate to establish platforms for information exchange between shipyards and shipowners. These platforms would facilitate the sharing of details about the condition of ships and future demolition plans by shipowners. Such information sharing could assist shipyards in better planning their operations and offering competitive prices, thus helping to streamline the ship demolition process transparently and efficiently in the European ship demolition industry.

The "Ship building" variable reveals a significant relationship with the number of ships demolished in Europe, as indicated by the estimated coefficients in the regression models. Specifically, it is observed that as shipbuilding activities increase, the number of demolitions tends to rise. This result can be interpreted as an indicator of a dynamic shipbuilding market, where the expansion of construction activities may be correlated with a ship lifecycle that requires more frequent replacement or demolition. Careful monitoring of the ship order portfolio can offer insights into the future of the ship fleet and predict when demolitions may be needed. A significant increase in the order portfolio could signal an imminent uptick in demolitions, as newly ordered ships may drive the replacement of older vessels. Additionally, it can help prevent market overcrowding with new ships, facilitating a smoother transition to a more modern and efficient fleet. This approach underscores the importance of proactive, data-driven analysis to support decision-making in the ship demolition industry.

The "Trade Maritime" variable shows a positive regression coefficient, indicating a clear relationship between the volume of maritime trade and the number of ships demolished. This result suggests a significant connection between European maritime traffic and the ship demolition industry. The positive coefficient implies that maritime trade could serve as a reliable indicator for predicting future trends in the ship demolition market. It is essential to emphasize that constant and adequate monitoring of this variable is crucial to ensuring accurate and timely analysis of industry dynamics. To gain a deeper understanding of future trends in ship demolition in the European Union, it will be necessary to carefully consider several maritime traffic indicators, such as the Baltic Dry Index, the Baltic

Wet Index, and freight rates. These indicators provide a comprehensive view of global shipping dynamics, a sector closely linked to decisions regarding ship scrapping. It is known that fluctuations in revenue, as measured through the Baltic Dry Index, can significantly influence shipowners' decisions regarding the decommissioning of ships, as demonstrated by Açık & Başer, 2017. This is consistent with our results, which show that in periods of crisis or declines in maritime transport revenue, there is a tendency to increase demolition activities. A recent example of this dynamic was observed during the pandemic crisis when border closures and the suspension of cruises led to a significant increase in the number of passenger ships sent for scrapping. This phenomenon demonstrates how vulnerable the demolition market is to global economic fluctuations and the demand for maritime transport. To ensure efficient planning and comprehensive monitoring of the evolution of the ship demolition market, it will be necessary to develop predictive tools based on maritime traffic indicators. Such tools could include advanced forecasting models that consider not only global market indices but also local and regional factors, such as shipyard demolition capacity, environmental regulations in force, and the age of the operating fleet.

The "circularity material" variable shows a significant positive coefficient in all model specifications ($p < 0.01$), indicating that an increase in the circularity rate of materials within the European economic system is associated with an increase in the number of ships being demolished. This is a scientifically relevant result and consistent with circular economy theories. The efforts of the European Union’s industrial policies to retain waste within its borders may incentivize companies to raise recycling and recovery standards. This phenomenon requires further investigation, especially in relation to regulations and directives that promote material circularity. From the results of this variable, it can be inferred that the raising of recycling standards, promoted by public authorities, along with companies’ investments in more efficient recycling technologies, can contribute to increasing the number of ships sent for demolition at authorized European shipyards. However, it is still premature to make long-term considerations. The commitment and regulations aimed at retaining waste within Europe, to ensure material supply, will push shipowners to reassess their internal recycling policies. This could encourage the adoption of new materials and designs aimed at safer and more efficient demolition processes. It will also be important to consider that technological advancements in the ship recycling sector will play a crucial role in improving the efficiency and sustainability of the process. Investing in advanced technologies, such as automation of demolition operations and improving material separation techniques, could not only reduce operating costs but also increase the recovery rates of valuable materials, contributing to greater profitability for sector operators. Another aspect that should not be overlooked is the role of demand for recycled materials. The growing demand for sustainable materials from the manufacturing and construction industries could amplify the demand for ships to be dismantled. This dynamic, combined with stricter environmental regulations, could accelerate the transition toward a more circular economy. Companies operating in the ship demolition sector may thus find themselves in an advantageous position to benefit from an economic cycle centred on resource recovery.

The results obtained contribute to a better understanding of some economic perspectives regarding shipbreaking activities in the European Union, and they can enhance future analysis of how this trend might evolve. The study highlights the existence of a relationship between shipyard capacity and the number of ships recycled in Europe. The hypothesis of an increase in capacity could attract ships nearing the end of their lifecycle, improving European competitiveness. It is crucial to invest in expanding the capacity of European shipyards through both public and private investment initiatives. However, future research should investigate which coastal areas in Europe are most suitable for capacity expansion or potentially the establishment of new facilities. Another aspect to consider is that the European Union has a significant number of shipyards specializing in activities such as shipbuilding and ship repair. To fully identify the latent potential of these yards, a careful assessment of the technological and regulatory levels required to adapt and potentially convert these yards for ship recycling will be necessary. Increasing shipyard capacity would not only improve the efficiency and profitability of the recycling process but also ensure compliance with environmental standards, as the EU is at the forefront of promoting ambitious environmental and social standards globally.

Among the results obtained, one aspect to consider when evaluating the ship recycling market in the EU is the use of a set of macroeconomic and microeconomic indicators that can improve the analysis and understanding of the topic, as well as the various conditions surrounding shipbreaking. Future research should verify which of the wide set of maritime indicators have a strong correlation with the ship demolition market. The study reveals that the order book of new ships is a parameter closely tied to this activity, and academic research should explore in more detail how this indicator, depending on ship type, can provide reliable forecasts for the sector's evolution. Furthermore, it will be important to investigate additional maritime port indicators.

The significant impact of LDT prices on ship recycling activities underscores the need to develop financial mechanisms that support advantageous pricing policies for purchasing end-of-life ships. Public interventions aimed at promoting more competitive prices in European shipyards could reduce the price gap between different regions, making European shipyards more attractive to shipowners compared to non-European alternatives. This type of policy would help strengthen the position of European shipyards in the global ship recycling market, encouraging shipowners to choose local solutions. The implementation of financial and regulatory incentives to support higher LDT prices could significantly enhance the competitiveness of the European ship recycling industry. A possible strategy could be the introduction of eco-incentives for shipyards that adopt sustainable technologies and low environmental impact demolition processes. These incentives could be granted based on sustainability criteria, such as adherence to high environmental standards, reduction of emissions, and the adoption of advanced material recycling technologies. Furthermore, a portion of these incentives could be linked to the shipyards' capacity for circular material recovery, promoting a circular economy model that maximizes the reuse of materials derived from shipbreaking.

Given the relationship between ship age and the likelihood of demolition, it is necessary to develop predictive models to identify at-risk ships in advance. These models could aid in efficient planning and resource management, ensuring that shipyards are prepared for future demolition activities while complying with regulatory limits. Effective communication and collaboration between shipyards and shipowners could further support this planning process.

The positive correlation between material circularity and the number of ships demolished underscores the importance of integrating circular economy principles into the ship recycling sector. Raising recycling standards and promoting the use of sustainable technologies can enhance material circularity. This approach not only supports environmental goals but also creates a growing demand for ship recycling services, stimulating technological innovation and efficiency in the sector. Adopting circular economy practices could contribute to the creation of a supply chain for secondary raw materials. Collaboration among stakeholders, including shipowners, shipyards, regulatory bodies, and the scientific community, is essential for the progress of the ship recycling sector. The establishment of platforms for information exchange and collaboration can facilitate better planning, compliance, and innovation in shipbreaking practices. Furthermore, in the future, it will be beneficial to create synergies among public and private actors, academia, and industry associations to facilitate knowledge exchange and the development of standards aimed at promoting best demolition practices and enhancing knowledge in the demolition sector.

The main limitations of this study include the lack of a long-term historical market analysis and the failure to consider additional market indicators useful for understanding, such as the demand for recycled steel and fuel prices. Other limitations involve the aggregation of ships without distinguishing between different types and the failure to consider the impact of new environmental regulations. Lastly, the study focused exclusively on the European area, leaving room for future research that could expand the analysis to a global level.

## 4. CONCLUSION

The regression analysis has revealed that the selected variables can significantly influence the ship recycling market in Europe, providing important insights for industrial policy. Shipyard capacity has emerged as a key factor, with a correlation between an increase in recycling capacity and an increase in ships demolished in the European Union, indicating the need for targeted investment policies to support this growth or potentially expand the customer base of demolition yards to other non-European countries. Similarly, the analysis of LTD prices has highlighted the importance of public interventions to bridge the price gap between regions and promote the competitiveness of the European ship demolition industry. Furthermore, the age of ships has emerged as another significant factor, suggesting the need to develop prediction models to identify at-risk ships in advance and improve demolition management. Monitoring the new ship order portfolio and maritime trade traffic are two fundamental parameters for capturing market developments, representing essential metrics for forecasting and analysis tools. The correlation between shipbuilding activity and the demolition rate has emphasized the importance of closely monitoring the ship order portfolio to anticipate future trends. At the same time, maritime trade has established itself as a reliable indicator to reflect industry dynamics, underscoring the essential need to carefully monitor this variable. The new ship order portfolio and maritime trade traffic are intricately intertwined, as variations in ship construction and demolition volumes directly impact maritime transport capacity and, consequently, the entire global economic landscape. The result of the "circularity material" variable has highlighted how the adoption of circular economy principles and the promotion of stricter recycling standards can further favor ship demolition activity, creating a growing demand for ship recycling services and stimulating technological innovation throughout the process. The research results offer significant theoretical contributions to the field of ship recycling in Europe. For academic researchers, this work highlights the importance of adopting a regional perspective in the analysis of the ship recycling market. By utilizing econometric metrics, future research on the subject can deepen the understanding of local dynamics and sector-specific characteristics. Additionally, it is recommended to gather data through surveys or interviews with various supply chain actors to obtain detailed and contextualized information. This approach also helps to build a completer and more specific picture of the dynamics influencing the ship recycling market in the EU. Regarding industrial implications, the awareness of the importance of shipyard capacity may encourage private or public operators to invest in expanding the capacity of existing shipyards or potentially building new facilities. The study can also assist in making strategic decisions for the future; by continuously monitoring maritime trade trends and the order book for new ships, it is possible to anticipate market developments. LDT prices offered by shipyards and the fleet's age are key indicators that allow for identifying which ships will be subject to demolition and assessing their actual economic value. Finally, future research should examine the technological advances needed to improve the efficiency of the recycling process, potential policy changes that could impact the sector, funding opportunities for infrastructure investments, and the need for more robust data collection and analysis. These aspects will not only enrich the academic debate but also provide practical insights to enhance operational practices in the ship recycling sector.

## ACKNOWLEDGEMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for profit sectors.


## AUTHOR CONTRIBUTIONS

**Francesco Tola:** conceptualization, methodology, investigation, writing— original draft preparation, visualization, writing— review and editing.
**Enrico Maria Mosconi:** conceptualization, validation, resources, writing— review and editing, supervision.
**Marco Marconi:** methodology, validation, writing— review and editing, supervision.
**Mattia Gianvincenzi:** formal analysis, investigation, writing— original draft preparation.

## DECLARATIONS

**Competing interests** The authors declare no competing interests.

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