Development and Research Directions in Ship Recycling: A Systematic Literature Review with Bibliometric Analysis

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Abstract

Ship recycling has gained significant importance in recent years due to the growing awareness of environmental concerns and the need for sustainable practices within the maritime industry. As vessels reach the end of their operational life, proper recycling methods are crucial to mitigate environmental impacts and promote resource conservation. With an increasing number of ships being decommissioned annually, there has been a growing interest and emphasis on developing efficient and eco-friendly ship recycling practices worldwide.

This article presents a systematic literature review and bibliometric analysis of 228 studies on ship recycling indexed in Scopus. Employing the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology for its robustness in comprehensive literature analysis, this review uncovers key insights into prominent countries, authors, journals, collaborations, topics, and historical trends in ship recycling research, thereby extending the scope of previous reviews. Notably, major contributions from Turkey, India, Bangladesh, the USA, and China focus on environmental impact studies, reflecting urgent global sustainability concerns.

The review discusses commonly adopted methodologies such as Life Cycle Assessment and Elemental Analysis, shedding light on their application in this field. Through thematic analysis across 8 categories, future research pathways are identified, highlighting crucial areas such as continuous environmental monitoring, innovative renewable energy extraction from end-of-life vessels, and the need for human factors in ship recycling. This comprehensive synthesis of existing knowledge and identification of emergent research needs and opportunities serve as a foundational resource for impactful future research and informed policymaking, particularly in aligning with global environmental and sustainability goals. Researchers, policymakers and other stakeholders in maritime safety and environmental sustainability may find the knowledge gained from this systematic literature review insightful.

Keywords: Maritime Safety; Ship Recycling; PRISMA; Bibliometric Analysis; Sustainability, ship dismantling, ship breaking

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1. Introduction

Ship recycling stands as a crucial industry for some developing economies, playing a significant role in generating income, employment, and supplying raw materials (Sujauddin et al., 2017). The waste produced by ship recycling yards holds the potential to produce 90 million KJ/hr of energy and 5.28 MW of electric power (Reddy et al., 2004). Alang, recognised as the world's largest ship-recycling zone, provides direct employment to 30,000–40,000 migrant workers (Misra, 2008). In Bangladesh, the industry contributes a total profit of 921,300 USD through substandard recycling methods (Choi et al., 2016). These facts highlight the multifaceted benefits of ship recycling, showcasing its positive influence on various sectors.

Despite these advantages, the industry is plagued by severe issues that detrimentally affect the environment, ecosystems, and human health and safety. The process of ship dismantling releases toxic wastes and materials, posing threats to surrounding ecosystems. Furthermore, ship recycling is recognised as one of the most hazardous professions, with workers facing a high risk of accidents, including death (91%) and pollution exposure (79%) (Mitra et al., 2020). Over 60% of workers report suffering from injuries or physical ailments such as blurred vision, abdominal pain, and skin problems, attributed to unsafe working conditions and exposure to hazardous materials. The combination of labour-intensive and precarious work, limited access to medical services, inadequate housing and sanitation, and a lack of basic safety measures further compounds the challenges faced by workers in this industry (Ahamad et al., 2021).

Ship recycling has indeed garnered substantial attention in academic circles, resulting in a plethora of literature reviews and research studies. Shahid (2005) delved into the ship recycling industry (SRI) in Pakistan, providing a comprehensive overview of its history, processes, and current status. Knapp et al. (2008) conducted market studies for SRI, exploring the relationships between earnings and costs. Sunaryo et al. (2020) proposed two innovative business models for implementation in SRI, complemented by a feasibility study. Misra (2007) scrutinised the working conditions at the Alang ship-breaking yard, shedding light on the challenges faced by the workforce. Merlo et al. (2018) investigated the incidence and causes of deaths related to asbestos exposure at the Genoa shipyard, alongside associated diseases. Cairns (2014) presented a critical perspective on the social status of workers in the Bangladeshi ship-recycling industry, conceptualising their position at the "bottom of the pyramid". Sunaryo et al. (2019) offered a holistic overview of SRI in Indonesia, aiming to facilitate the development of sustainable practices. S. Rahman (2017) conducted a comparative review of SRI in Bangladesh and the rest of the world, focusing on ship recycling activities. Reddy et al. (2005) employed multiple regression analysis to develop predictive models for the energy content of combustible ship-scrapping solid wastes, correlating energy content with variables derived from material composition, proximate, and ultimate analyses. Jain et al. (2016) proposed a novel format for lightweight distribution to store information about materials used in ship construction, aiding the recycling process. Okay et al. (2016) assessed metal pollution in shipyard and shipbreaking sites, determining the concentration of eight metals in sediments and mussels. Alam et al. (2019) evaluated concentrations and seasonal variations of potentially toxic elements in soils affected by ship recycling activities. Rahman et al. (2021) explored the negative impacts of COVID-19 on SRI, particularly the disruption in global supply chains. Alcaidea et al. (2016) discussed the roles of key actors in SRI, including shipping companies, ship-owners, ship registries, brokers, and ship-recycling yards, with a focus on developing a new global ship recycling policy and addressing the issue of mirror flags. Fariya et al. (2022) proposed a framework for ship recycling yards, aiming to optimise resources and bridge the gap between current regulations and existing practices. Sunaryo & Aidane (2022) recommended strategies for developing a sustainable and environmentally friendly ship recycling industrial. Zhao & Chang (2014) examined the Chinese legal framework concerning SRI. Dey et al. (2021) conducted a systematic review of studies to synthesise six sustainability dimensions in SRI, categorising them into challenges (environmental, social, and economic) and enablers (law and policy, technology, and management), and exploring their interconnections.

The body of research on ship recycling has provided a comprehensive understanding of its operations, highlighting the detrimental effects on worker health and safety, and the extensive environmental degradation through various pollution forms. Additionally, these studies have shed light on the legal dimensions, showcasing the role of conventions, policies, and legal frameworks in mandating obligations and state laws to mitigate these adverse impacts. They also explore into the financial aspects, aiming to ensure the continuity of benefits for all stakeholders involved in this industry.

Furthermore, the research has explored the potential for energy generation and the availability of raw materials within this industry, alongside the implementation of sustainability practices. Despite this extensive coverage, there is a noticeable gap in the literature: a comprehensive bibliometric analysis of the research studies published on ship recycling is yet to be conducted. There is a need for a review that concisely summarises the progress made in this growing field, providing a clear overview of the current state of knowledge, summarising the findings from various research papers, and highlighting potential avenues for future research and the methodological approaches employed. This would consolidate understanding and drive future improvements in SRI practices.

The aim of this review is, therefore, address three pivotal Research Questions (RQs) pertaining to the domain of ship recycling, which have hitherto remained unanswered:

- **RQ1**: What are the predominant countries, authors, journals, top-cited papers, and thematic clusters associated with ship recycling, as observed through a bibliometric analysis of scientific publications?
- **RQ2**: What are the prevalent themes, historical research trends, and the array of scientific methodologies employed in studies on ship recycling?
- **RQ3**: What avenues for future research are available for both novice and seasoned researchers in this field?

The study distinguishes itself through a comprehensive analysis of a substantial set of conference papers and journal articles, employing a systematic literature review methodology as delineated (Kitchenham, 2007). This approach ensures an unbiased, rigorous, and transparent evaluation of the extant literature. The findings, derived exclusively from peer-reviewed publications indexed in Scopus, are poised to offer important insights for policy evaluation, foster academic collaboration, and propel innovative research endeavours. The paper is meticulously structured, commencing with the methodology, followed by a detailed exploration of the research questions, potential limitations, and concluding with a synthesis of the main findings in the conclusions section.

2. Methodology

The methodology employed in this review is based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), a methodological framework esteemed for its structured approach to conducting systematic literature searches (Liberati et al., 2009). PRISMA was selected for its widespread acceptance, systematic nature, and straightforward implementation (Moher et al., 2009). In this context, the PRISMA methodology has been meticulously adapted to address the research questions delineated in the introduction. The ensuing paragraphs provide a comprehensive breakdown of the steps involved in this process, and the information flow as per the PRISMA methodology is illustrated in Figure 1.

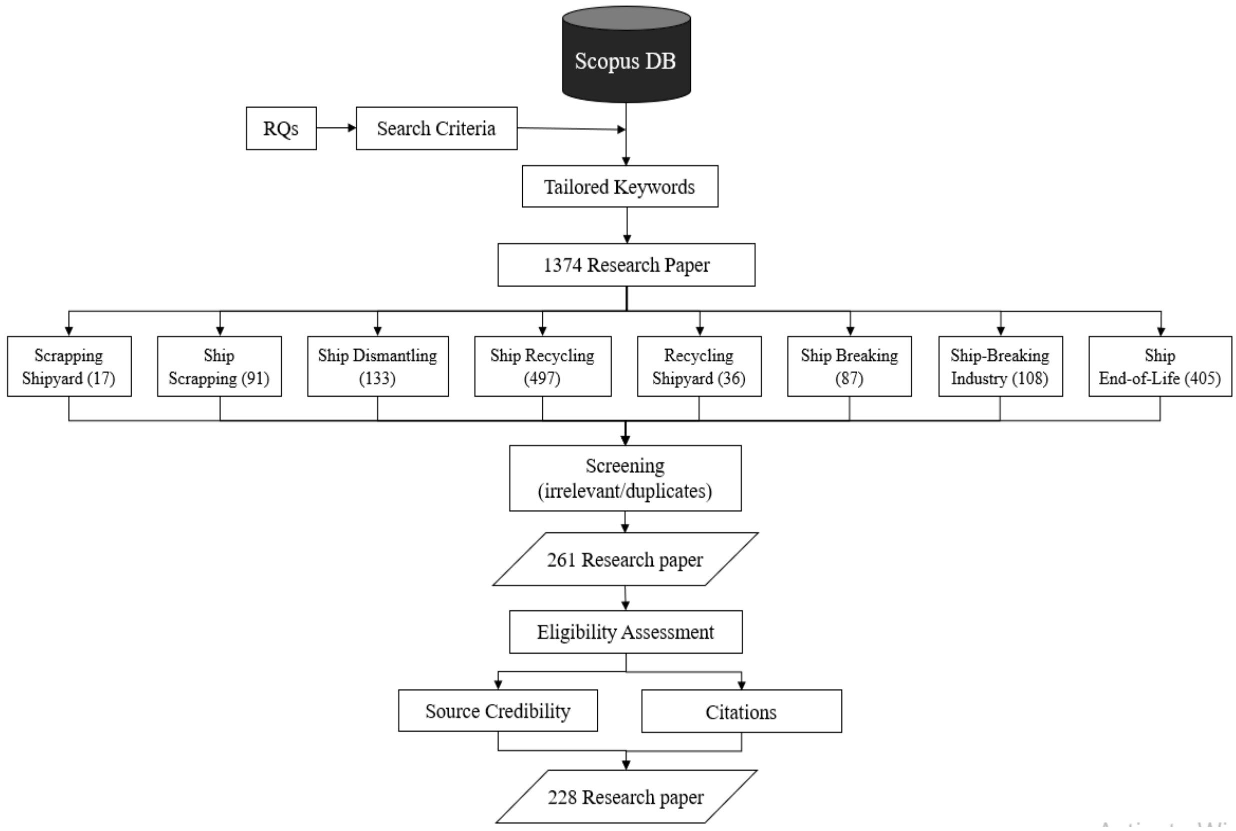

Figure 1: Systematic literature review flow of data (numbers as of Aug-2023).

Step 1: Identification of research studies

To identify relevant research studies, we employed Scopus as our primary search engine, excluding Google Scholar due to its inclusion of non-peer-reviewed and general audience publications. We also decided against searching through individual journal publishers directly, as this approach yielded an overwhelming number of results, many of which were irrelevant. Notably, most journals from major publishers like Elsevier and Taylor & Francis are indexed in Scopus, ensuring comprehensive coverage when using similar search terms. Although it is challenging to definitively compare Scopus and the Web of Science, evidence suggests that Scopus provides broader coverage in key fields (IFERP, 2022). Therefore, we chose Scopus for its comprehensive coverage. Using eight tailored keywords, we identified 1374 papers, narrowing our search to English language publications and focusing on journal and conference papers, including articles, reviews, conference papers, and conference reviews, while excluding books to maintain relevance and specificity.

Step 2: Screening of research studies

To refine our dataset, we conducted a screening process, focusing on the titles, abstracts, and, when necessary, the content of the publications to ascertain their relevance to ship recycling. This step also involved removing duplicate references. As a result, the number of publications was significantly reduced, with a retention rate of 19% (261 out of 1374 papers).

Step 3: Eligibility assessment of research studies

Next, we assessed the eligibility of the screened studies based on specific criteria, including the publication source. We aimed to ensure the inclusion of high-quality research by considering the journal classification proposed by Scimago (SCImago, 2021) excluding Q4 journals. This resulted in a further reduction of the dataset, with an 87% retention rate (228 out of 261 papers), ensuring a comprehensive and quality-focused collection of studies for analysis. The basic information about the selected studies is detailed in Table 4 In Appendix A.

Step 4: Included research studies analysis

In the final step, we conducted an in-depth analysis of the eligible studies, utilising them exclusively to address the research questions. The subsequent sections of this paper present the analysis process and findings in detail.

RQ1: Bibliometric Analysis of Ship Recycling Publications

To address the first research question, we conducted a comprehensive bibliometric analysis focusing on the leading countries, authors, journals, top-cited papers, and cluster topics related to ship recycling.

Country and Author Analysis:

We analysed the contributions of different countries and authors across the 228 included papers. For each paper, we considered:

- The total occurrences of all authors and their affiliated countries.
- The total occurrences of first authors and their affiliated countries.

Journal Analysis:

We identified the most prominent journals publishing ship recycling-related articles, focusing on the number of articles published rather than citation counts to mitigate the influence of publication year. The analysis included only Scopus-indexed journals, with eligibility determined using the Scimago ranking.

Top-Cited Papers:

We extracted the top-cited papers in the field from Scopus, providing insights into the most influential works in ship recycling research.

Bibliometric Network Analysis:

Utilising VOSviewer, we conducted co-authorship and term analyses to uncover cooperation networks among authors and countries and identify prevalent research topics (VOSviewer, 2023). We opted for the fractional counting method in co-authorship analysis to minimise the impact of large author groups on the network, providing a more balanced view of collaborations. For term analysis, we used the full counting method to highlight the most frequently mentioned keywords, ensuring a comprehensive understanding of the research landscape.

The subsequent sections will present the findings from this bibliometric analysis, shedding light on the leading contributors, journals, and topics in ship recycling research.

RQ2: Identifying Themes, Trends, and Methodologies in Ship Recycling Research

To interpret the common themes, historical research trends, and methodologies employed in ship recycling studies, we embarked on a meticulous analysis.

Theme Categorisation and Methodological Identification:

Initially, we examined abstracts and author keywords to categorise the research papers, paying close attention to the methodologies applied. This process revealed instances where papers spanned multiple categories, prompting a second, more precise categorisation attempt. As a result, shared themes among the papers were identified, ensuring a comprehensive classification.

Historical Trend Analysis:

To unveil the historical attention given to various ship recycling topics, we conducted a trend analysis. This involved classifying the studies based on the themes identified in RQ2 and tracking the publication frequency of each research topic over time. This historical perspective provided insights into the evolving focus of ship recycling research.

RQ3: What future research directions would novel and experienced researchers work on?

With a keen eye on the future, we revisited the selected studies, concentrating on the discussion, conclusions, limitations, and future research sections of each document. The categorisation derived from RQ2 served as a guide, helping us to systematically identify and list future research directions, grouped by categories for ease of reference. This approach ensured a thorough and organised presentation of potential avenues for both novel and experienced researchers in the field of ship recycling.

3. Results and discussion

This section delves into the findings of the study, providing a thorough discussion and insightful analysis in response to the posed research questions. The structure of this section is methodically arranged to address each research question, incorporating relevant discussions and insights.

3.1. RQ1: Leading Contributors in Ship Recycling Research

Countries' Contribution: Figure 2 showcase the leading research countries, with metrics including the total number of authors and the number of first authors from the selected papers. Given the extensive list of identified countries (44 in total, with 38 having first authors), the legends in Figure 2 are limited to the top 11 countries. The data reveals that Turkey, India, Bangladesh, the USA, and China predominant contributors in ship recycling research, according to both metrics. A slight variation in rankings is observed between the two metrics. The top seven countries, constituting 16% and 18% of the total number of countries for each respective metric, have made substantial contributions, accounting for 81% of the research output in selected Scopus-indexed publications. This distribution aligns closely with the Pareto principle, suggesting that a significant portion of the output is generated by a smaller fraction of the input (Wicksteed & Pareto, 1906). The consistency in results across both metrics reinforces the credibility of these findings. Furthermore, it is noteworthy that countries leading in academic contributions are also the ones with major ship recycling activities and prominent shipyards, such as India (Alang, Gujarat), Bangladesh (Chittagong), China, and Turkey (Aliaga).

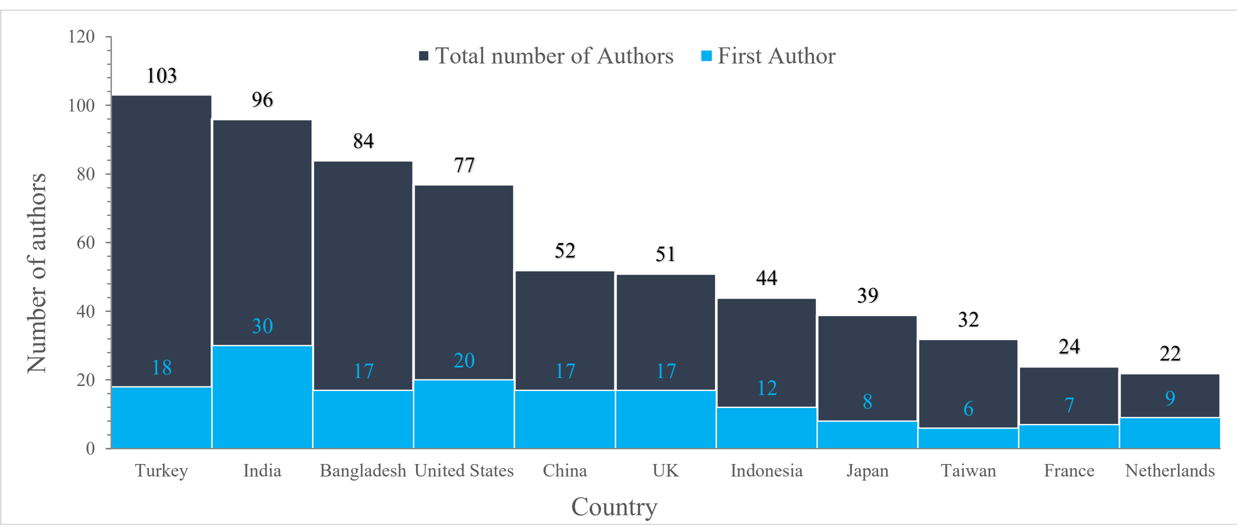

Figure 2: Top contributing countries to ship recycling research by a number of authors

The subsequent sections will continue to unravel the findings related to top authors, journals, highly cited studies, and prevalent cluster topics in ship recycling research, providing a holistic view of the current academic landscape in this field.

Journals' Contribution: Figure 3presents the most influential journals in ship recycling research based on the number of selected Scopus-indexed publications. The Marine Pollution Bulletin stands out as the leading journal, hosting 15 articles from this review. It is closely followed by the Journal of Cleaner Production, with other notable contributions from journals and conferences such as RINA (Royal Institution of Naval Architects), Ocean Engineering, Marine Policy, and Environmental Monitoring and Assessment. The diversity in publication outlets suggests a need for more specialized journals dedicated to ship recycling, reflecting the interdisciplinary nature of the field. The preference for environmental and pollution-related journals underscores the thematic focus of the research, aligning with the common themes identified in ship recycling studies.

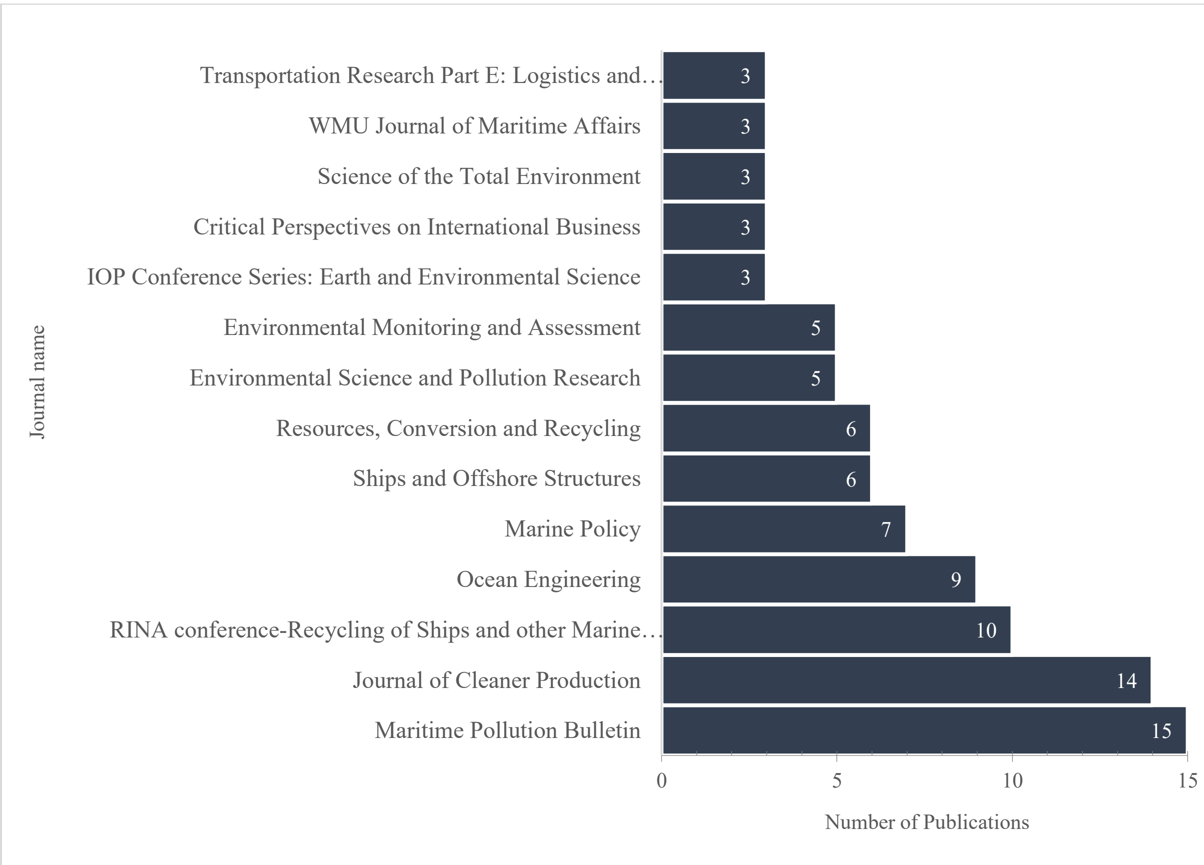

Figure 3: Top journal ranked by the number of publications relevant to Ship Recycling

Authors' Contribution:

The most prolific authors in ship recycling research are categorized based on their overall contributions (total number of authors in all studies) and their role as first authors.

Total Author Contributions: Sixteen authors emerge as the most active in ship recycling research. They are divided into four tiers based on their publication count. Kurt R.E leads with eight publications, followed by Hossain M.M with seven, four authors with six publications each in the third tier, and ten authors with five publications each in the fourth tier. Notably, the University of Strathclyde in the UK and Dokuz Eylül Üniversitesi in Turkey are prominent affiliations, reflecting their commitment to ship recycling research. All results are summarised in Table 1.

Table 1: Top contributed authors based on the first metric (total number of authors in all papers)

Author	Affiliation	Publications
Kurt R.E.	Department of Naval Architecture, Ocean & Marine Engineering (NAOME), University of Strathclyde, United Kingdom	8
Hossain M.M.	University of Chittagong, Chittagong, Bangladesh	7
Asolekar S.R.	Environmental Science and Engineering Department, Mumbai, India	6
Gunbeyaz S.A.	NAOME, University of Strathclyde, United Kingdom	6
Jain K.P.	Delft University of Technology, Delft, Netherlands	6
Joshi H.V.	Central Salt and Marine Chemicals Research Institute India, Bhavnagar, India	6
Turan O.	NAOME, University of Strathclyde, United Kingdom	5
Basha S.	National Environmental Engineering Research Institute CSIR, India	5
Bayram A.	Dokuz Eylül Üniversitesi, Izmir, Turkey	5
Elbir T.	Dokuz Eylül Üniversitesi, Izmir, Turkey	5
Kara M.	Dokuz Eylül Üniversitesi, Izmir, Turkey	5
Neşer G.	Dokuz Eylül Üniversitesi, Izmir, Turkey	5
Odabasi M.	Dokuz Eylül Üniversitesi, Izmir, Turkey	5
Rahman S.M.M.	Arts et Metiers Institute of Technology, Paris, France	5
Sunaryo	Universitas Indonesia, Depok, Indonesia	5
Titah H.S.	Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia	5

First Author Contributions: Table 2 showcases the top first authors, with ten authors leading the way in ship recycling publications. Jain K.P. from Delft University of Technology in the Netherlands tops the list with six papers, followed by Rahman S.M.M. with five, Sunaryo and Titah H.S. with four each in the third tier, and six authors with three publications each in the fourth tier. The presence of common authors across both metrics highlights their significant engagement and expertise in ship recycling research.

Table 2: Top contributed first Author based on the second metric (total number of first authors)

Author	Affiliation	Publications
Jain K.P.	Delft University of Technology, Delft, Netherlands	6
Rahman S.M.M.	Arts et Metiers Institute of Technology, Paris, France	5
Sunaryo	Universitas Indonesia, Depok, Indonesia	4
Titah H.S.	Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia	4
Ahluwalia R.S.	West Virginia University, Morgantown, United States	3
Gunbeyaz S.A.	NAOME, University of Strathclyde, United Kingdom	3
Jones J.E.	ENERGYNTECH, INC., United States	3
Neşer G.	Dokuz Eylül Üniversitesi, Izmir, Turkey	3
Reddy M.S.	University of Ulsan, Ulsan, South Korea	3
Wu W. T.	National Health Research Institutes Taiwan, Zhunan, Taiwan	3

This analysis provides valuable insights for corporations and organizations aiming to establish research collaborations, as it identifies key scholars and institutions actively contributing to ship recycling research.

The analysis of the bibliometric data using VOSviewer has revealed significant insights into the collaborative networks and geographical distribution of ship recycling research. The co-authorship network depicted in Figure 4 illustrates the interconnectedness of research groups, with prominent clusters indicating active collaboration within certain institutions and regions. The central cluster, featuring researchers like Kurt R.E., Turan O., and Sunaryo S., signifies a strong research nexus at the University of Strathclyde and the University of Indonesia.

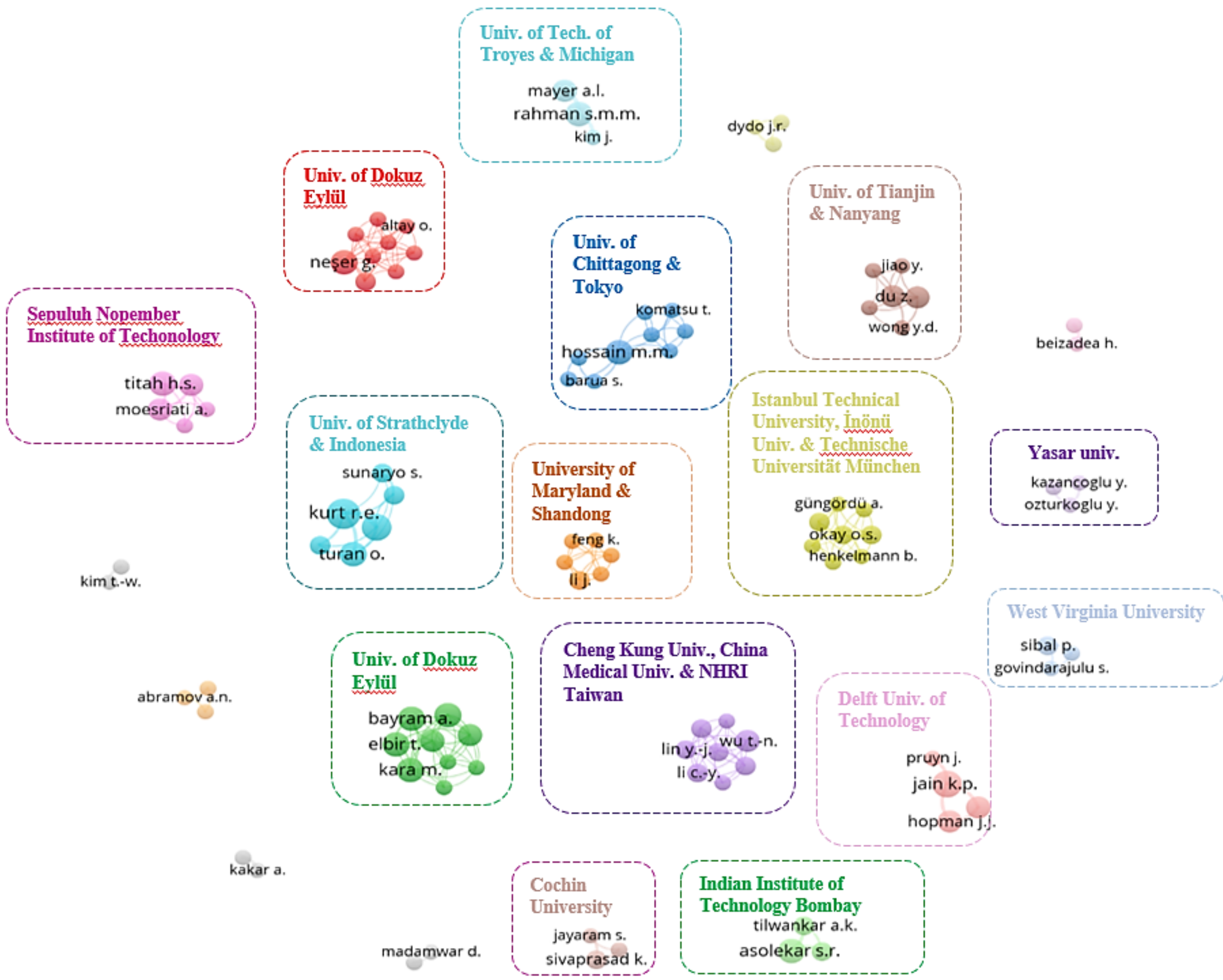

Figure 4: Co-authorship analysis using fractional counting method by the research institute.

Figure 5 further reveals the international collaboration patterns, highlighting robust partnerships between the UK and Indonesia, as well as between Bangladesh and Japan. These connections are emblematic of the global nature of ship recycling research, though it is notable that certain regions, such as Africa, are underrepresented.

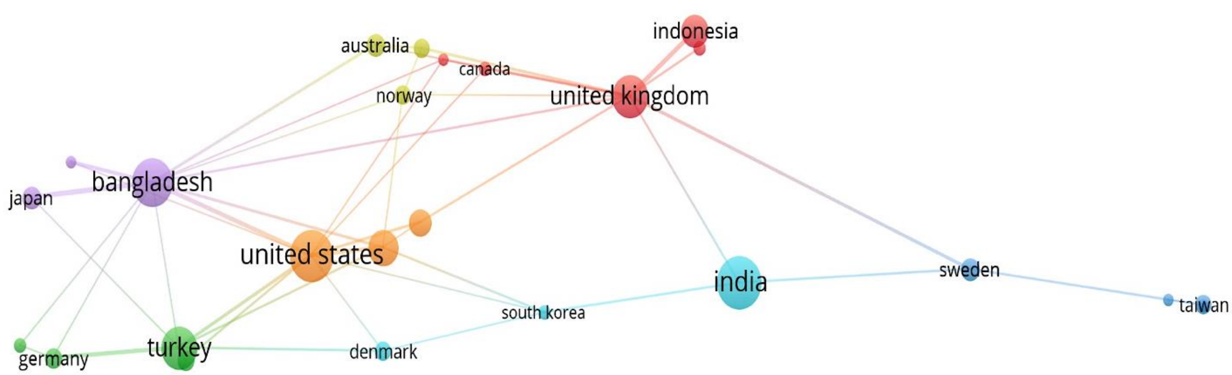

Figure 5: cooperation network between countries based on affiliations.

The presence of multiple research groups within Turkey, as evidenced by the affiliations with Istanbul Technical University, Yasar University, and Dokuz Eylul University, underscores the country's vested interest in ship recycling. This is further corroborated by the presence of two distinct research groups within Dokuz Eylul University, indicating a concentrated effort to advance knowledge in this domain.

The bibliometric analysis serves not only as a testament to the current state of ship recycling research but also as a beacon for future collaborations. It identifies key players and potential gaps in the research landscape, offering a roadmap for emerging scholars and institutions to navigate the field. The absence of African research, in particular, suggests an opportunity for growth and inclusion in future studies.

The term co-occurrence analysis in Figure 6, conducted using the full counting method, provides a nuanced understanding of the thematic focus areas within the ship recycling research domain. By selecting terms with a minimum occurrence of three, the analysis has distilled a network of 87 key terms from an initial set of 928, offering a concentrated view of the research landscape.

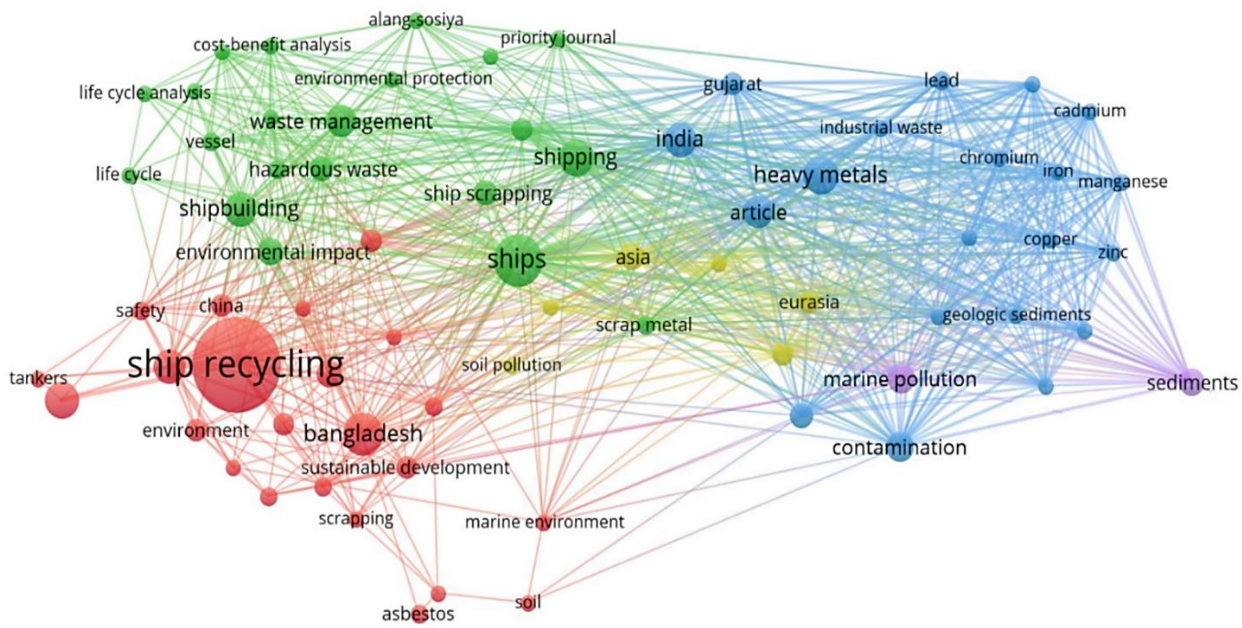

Figure 6:. Term analysis map using full counting method including 87 out of 928 Keywords

The blue cluster's emphasis on pollutants and contaminants, particularly heavy metals in Gujarat, India, reflects a geographical and environmental specificity in the research. This suggests that studies are not only addressing the broader issues of pollution but are also exploring into region-specific environmental challenges posed by ship recycling activities.

The red cluster's focus on health and safety, with a particular emphasis on asbestos, underscores the human impact of ship recycling practices. The frequent occurrence of terms related to asbestos in Bangladesh and China indicates a significant concern for the well-being of workers in these regions, aligning with global health and safety priorities.

The green cluster's discussion on methodologies, including life cycle analysis and cost-benefit analysis, points to a dual focus on environmental and economic aspects of ship recycling. This indicates a research trend towards evaluating the sustainability of ship scrapping operations and exploring how these practices can be reformed to align with green industry standards.

Overall, the term analysis reveals a multi-layered research environment where environmental impact, worker health and safety, and sustainable practices are interlinked themes. The emphasis on specific pollutants, health risks, and methodological approaches to environmental and economic studies indicates a comprehensive approach to understanding and improving the ship recycling industry. This analysis not only maps the current research focus but also potentially guides future studies towards areas that require further exploration, such as the development of sustainable recycling practices and the mitigation of health risks.

3.2. RQ2: Common Themes, Methodological Approaches and Historical Trends

The categorisation of research studies into eight main themes and eight combinatory themes provides a comprehensive framework for understanding the multidisciplined nature of ship recycling research. This classification is instrumental in guiding scholars and researchers to focus their efforts and streamline their search for studies pertinent to specific aspects of ship recycling. Each theme captures a distinct area of focus:

1. **Environmental Studies**: These studies concentrate on the ecological impact of ship recycling, including water, air, and soil pollution, as well as the handling of contaminants, wastes, and hazardous materials.
2. **Technical Studies:** This theme covers operational aspects, design, new approaches, software, data management, logistics, disposal techniques, sustainability, risk assessment and management, and cutting technologies.
3. **Health and Safety Studies:** Focused on the well-being of workers in the ship recycling sector, these studies address health risks and safety concerns related to hazardous processes.
4. **Economic Studies:** These studies delve into the financial dimensions of ship recycling, including market demand and supply, market studies and analysis, and stakeholder interests.
5. **Overview Studies:** Providing a general perspective, these studies offer insights into the history, background, and special activities of ship recycling, including country-specific experiences.
6. **Legal Studies:** Concentrating on the legal frameworks, regulations, policies, and decision-making processes, these studies aim to legalise and regulate ship recycling activities.
7. **Resources Studies:** Focused on the energy potential of the industry, these studies explore energy extraction, material flow analysis, and the utilization of scrap materials.
8. **Social Studies:** Addressing the human element, these studies explore social issues, syndicates, unions, social ties, and debates surrounding workers' rights in the ship recycling industry.

Eight other combinatory themes are found in research studies that discuss two aspects together.

1. Environment, Health & Safety studies
2. Legal and Economic Studies
3. Environment and Economic studies
4. Environment and Technical studies
5. Environment and Legal studies
6. Environment and Resources studies
7. Technical and Resources studies
8. Social, Health and safety studies

The eight combinatory themes, representing intersections of the main themes, underscore the interconnectedness and complexity of the issues surrounding ship recycling. This nuanced approach to categorization not only facilitates targeted research but also emphasizes the need for integrated, multidisciplinary strategies to tackle the multifaceted challenges and opportunities in the ship recycling sector. This section effectively conveys the scope and diversity of research in this field, providing a valuable roadmap for future studies and collaborations.

Error! Reference source not found. offers an analytical representation of the main themes in ship recycling research, highlighting the proportion of papers focused on each theme out of the total 228 studies. It also provides a graphical representation of the interplay and overlap between themes. Environmental aspects are predominant, with 63 of the 228 papers dedicated solely to this topic. Technical studies and Health & Safety studies follow in importance, reflecting over 55% of the total papers in this study. Additionally, the combinatory analysis reveals environmental studies' common overlap with other themes, indicating its central role in ship recycling research.

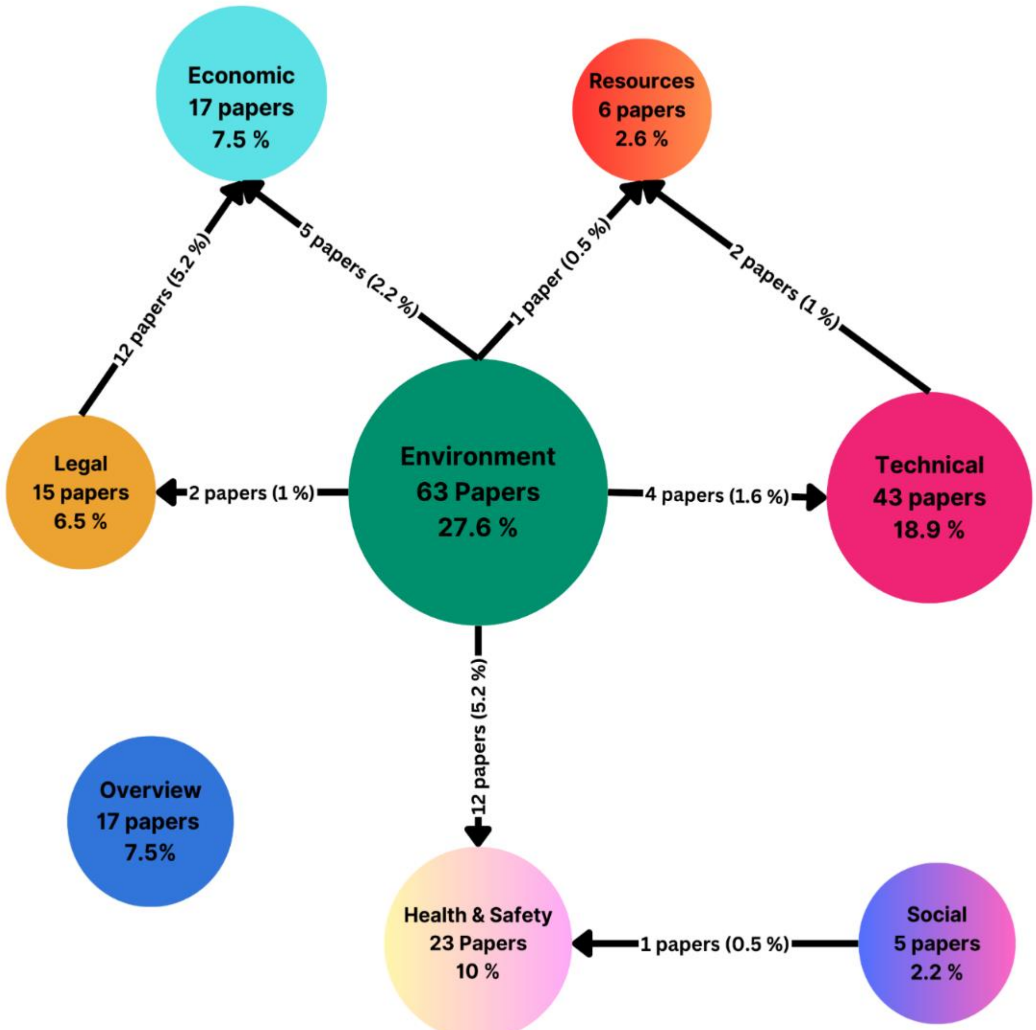

Figure 7: Main research themes, as presented in Table 4.

The dominance of Environmental studies can be attributed to several factors:

- The devastating ecological impact of the ship recycling and scrapping industry on marine, soil, and air environments in industrial zones and their vicinities.
- Support and funding from governmental and non-governmental organizations for global environmental protection initiatives.
- Data accessibility, as most studies involve sampling, analysis, and comparison with accepted thresholds in affected areas.

Technical studies, ranking second, concentrate on process enhancements to improve earnings, reduce costs, and make the industry more sustainable. This involves advancements in shipyard or ship design, management processes, risk assessment techniques, disposal methods, and new cutting technologies. The direct industrial impact of these advancements explains the research emphasis on technical aspects.

Health and Safety studies, in third place, focus on a critical component of the industry: the workforce. The future of ship recycling heavily relies on worker occupational safety and health. These studies often refer to frameworks and conventions that mandate worker rights, offering a benchmark for comparing current industry practices against safety standards.

Despite these trends, there is a noticeable lack of research in areas such as Resource and Social Aspects. Studies exploring the ship recycling industry as a resource beneficiary for various stakeholders are limited. Only two studies discuss the feasibility of using end-of-life vessels for energy extraction from waves as an alternative to scrapping. Mukherjee & Mansour (2010) and Mansour et al. (2013) proposed this innovative concept, yet a decade later, it remains largely unexplored. This idea's implementation could significantly impact the ship recycling industry, potentially reducing its scale, or transforming its practices.

Social studies focusing on worker rights and social security are the least represented in academic research, with only five papers addressing these issues. Despite the poor working conditions in major shipbreaking yards in South Asia, there is minimal academic attention to workers' plight. Contributing factors include:

- Low education and qualification levels among workers, with only 10% having tertiary or higher education (Misra, 2008).
- Major countries overlooking these practices for their trade interests, as highlighted by Paul (2004) in quoting World Bank chief economist Lawrence Summers' controversial statement on toxic waste dumping.

The majority of workers are unaware of their rights and safe working standards, leading them to accept hazardous conditions (Ahamad et al., 2021). Moreover, the low livelihood index in these areas compels them to work under any conditions. Wu et al. (2013) examined mortality among shipbreaking workers over a 24-year follow-up period from 1985 to 2008. A total of 4,962 shipbreaking workers were recruited from the database of the Kaohsiung Shipbreaking Workers Union and then linked to the Taiwan National Death Registry. The results showed that Standardized Mortality Ratios for age (SMRs) among men workers significantly increased for all causes, the study concluded that workers employed in shipbreaking industries experienced an increase in mortality from all causes. The increased SMR for lung cancer was probably related to asbestos, metals, and welding fume exposure. Wu et al. (2015) examined the relationship between cancer incidence and asbestos exposure among former Taiwan shipbreaking workers. Mesothelioma cases were found in the high asbestos exposure group. This study presented the elevated trend of asbestos exposure with cancer incidence for overall cancer, esophagus cancer, and trachea, bronchus, and lung cancer among shipbreaking workers. Those workers previously exposed to asbestos should receive persistent monitoring in order to early detect adverse health outcomes. Merlo et al. (2018) conducted a study included 3984 shipyard workers employed at the shipyard of Genoa, Italy, between 1960 and 1981 and followed up to December 2014. Overall deaths recorded were 3331 (83.6%). The findings support the urgent need for the prevention of asbestos related diseases through the implementation of asbestos ban worldwide, including those countries where asbestos is still mined, manufactured and used.

Figure 7 also reveals interconnections between different themes, such as strong links between legal and economic aspects, and between environmental and health & safety aspects. These connections indicate overlapping factors and mutual topics, suggesting that studies should consider multiple perspectives for a more comprehensive impact.

Figure 8's trend analysis indicates a dynamic evolution in ship recycling research, with initial studies up to the year 2000 focusing on health & safety, environmental, and economic aspects. With the turn of the century, attention expanded into technical realms, paralleling growing environmental considerations. The period from 2006 to 2010, marked by the Hong Kong Convention, catalysed the inception of legal research, reflecting the sector's regulatory shift. Concurrently, economic research intensified, signalling the burgeoning complexity of balancing profit with compliance. The five years leading up to 2020 showed a peak in research, with legal and economic topics at the forefront, suggesting a reaction to increasing industry regulation.

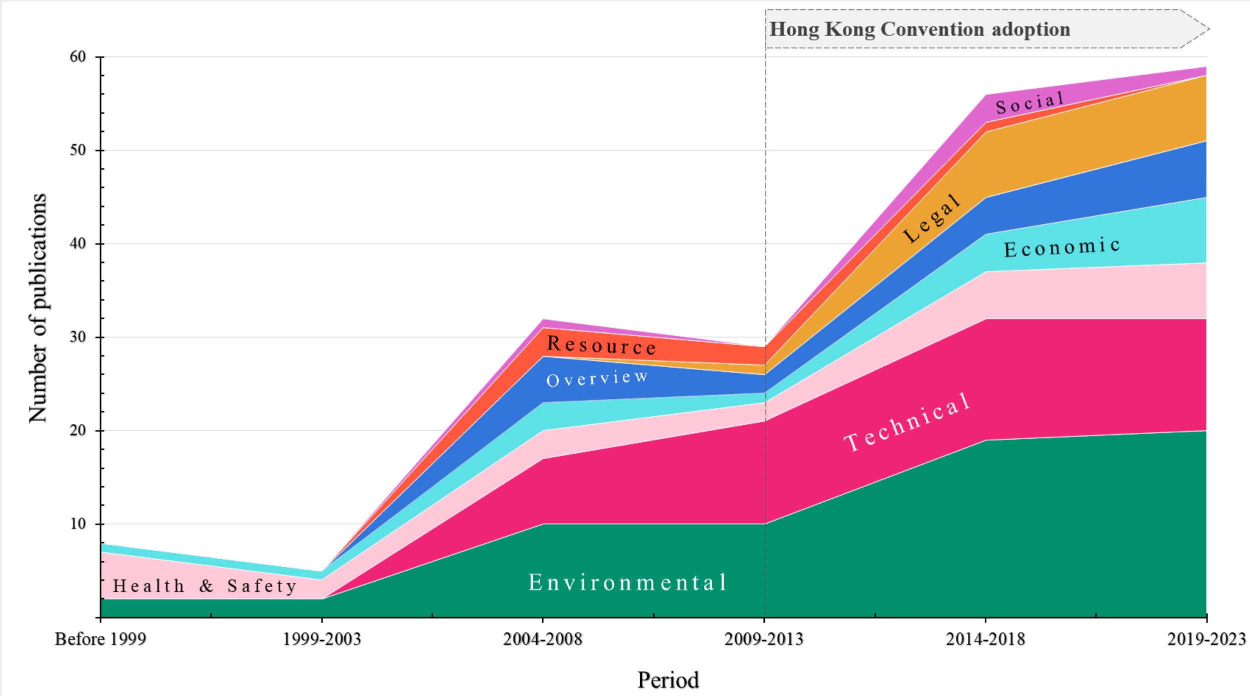

Figure 8: Historical trends based on research themes from publication.

The categorisation used in this study aligns well with the key terms identified and illustrated in Figure 6. This correlation highlights the dominance of certain themes and research directions within the field of ship recycling. Terms such as 'environment', 'environmental impact', 'marine pollution', 'contamination', and 'heavy metals' prominently feature, underscoring the predominance of Environmental studies. These terms are recurrent in the literature, indicating a strong academic focus on the ecological aspects of ship recycling.

Additionally, terms like 'waste management' and 'sustainable development' are frequently associated with Resources and Technical studies. This reflects a growing interest in exploring how ship recycling can contribute to sustainable practices and resource management. The presence of these terms suggests a research trend towards finding more efficient and eco-friendly ways of managing ship recycling by-products and processes.

Furthermore, terms such as "safety" and "cost-benefit analysis" are closely linked to themes of Health and Safety, and Economic studies. These terms indicate a significant research emphasis on assessing the financial implications and safety considerations within the ship recycling industry. This includes evaluating the economic viability of various recycling processes and ensuring the health and safety of workers involved in these operations.

Overall, the correlation between the employed categorisation and the terms in Figure 6Figure 6 provides a coherent understanding of the current focus areas in ship recycling research. It highlights the need for a balanced approach that considers environmental impacts, resource management, technical advancements, economic feasibility, and worker safety.

4. Evaluating Methodological Approaches in Ship Recycling Across Diverse Thematic Domains

Ship recycling research employs various methodologies based on their ability to effectively address the challenges posed by the industry. The employed approaches are tailored to investigate different aspects, with the aim of unravelling the complexities and driving developments in sustainable practices and policy. The studies summarised in Table 3 exemplify a diverse range of approaches, each with its own strengths and limitations.

Notably, methods like Life Cycle Assessment (LCA), as demonstrated by Mountaneas et al. (2015) and Elemental Analysis by Kara et al. (2014), have been employed to provide environmental assessments, crucial for understanding and mitigating the industry's ecological impacts. These methods are particularly favoured for their thoroughness but are also noted for their intensive data requirements.

Technical methodologies, including Fuzzy Logic and Mixed Integer Linear Programming (MILP) that have been devoted by Chhetri et al. (2022) and Ozturkoglu et al. (2022), reflect a growing focus on optimising processes within ship recycling. These approaches are indicative of the industry's aim to shift towards more sustainable and efficient practices. However, they often involve complex calculations and may require substantial computational resources, highlighting a trade-off between depth of analysis and practical applicability.

Legal and economic frameworks explored through Grounded Theory and Econometric Modelling reveal the intricate dynamics between policy, market forces, and operational practices. These studies are instrumental in shaping industry standards and identifying areas where policy interventions are needed. However, they also point to a gap in the application of these methodologies, particularly in addressing the interaction of global economic trends with local operational realities.

An important observation from this review is the evident gap in Human Factors (HF) studies. Despite the crucial role that HF plays in ship recycling operations, there is lack of research efforts even in the most immediate areas such as accident investigation, safety learning, risk modelling, and emergency response. The role of human in these kinds of critical operations have never been properly investigated and researched. As the automation levels increase in ship recycling facilities to comply with upcoming rules further research gaps in human factors field will become urgent such as ergonomics in design, cognitive workload, and human-system interaction. Omitting these fields of research will create uncertainties in the safety of future ship recycling operations, which will in turn allow unaccounted risks to be integrated in operations, cause accidents and result in catastrophic accidents.

The absence of HF-focused research in ship recycling is significant, considering the industry's reliance on manual labour and the complex interaction of human decisions, technology, and safety protocols coupled with highly hazardous environments. In short-term, Human Factors principles could provide valuable insights into designing safer and more efficient work environments, understanding human capabilities during safety critical operations and tailoring training to improve operational performance and safety. Having said this, it needs to be noted that there is even lack of evidence in literature describing the role of human from an overall system safety perspective during ship recycling operations.

Once these initial assessments are made and human factors focussed hazard identifications and observations are done, depending on the level of human assurance required in the operation furthermore advanced human factor studies can be conducted. However, in the lack of prior, former analysis is not possible.

There is plenty of proof in literature that more endeavours are needed in ship recycling yards to ensure better ergonomics principles are employed, health and safety of workers are protected, and safety learning is facilitated. Reluctance of the industry to address these issues is a known problem and happens due to the lack of global enforcement of ship recycling standards. Before these fundamental issues resolved and safety culture amongst ship recycling yards is promoted, it will be unrealistic to expect that better HF principles, whether it is at organisational, individual or design stage, will be implemented soon.

Given that aforementioned fundamental issues are addressed and barriers against HF improvement removed, in the medium to longer term, the gap in HF research could be broadened to include examining the impact of organisational culture and communication patterns on safety and efficiency. Understanding these aspects is crucial in an industry where teamwork and coordination should play vital roles.

Table 3 provides a comprehensive overview of these methodologies, their application in various studies, and the key findings and implications derived from each. It serves as a detailed reference point for understanding the methodological landscape of ship recycling research and offers insights into potential avenues for future studies.

Table 3: Common methods identified in the collected data, their strengths, and limitations.

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
Environment	**Life Cycle Assessment (LCA)** Evaluate the potential environmental impacts of a product, process, or service throughout its entire life cycle (Finkbeiner et al., 2006).	Comprehensive environmental assessment. Evaluate environmental impacts throughout a product's life cycle.	Resource-intensive due to data requirements.	Mountaneas et al., 2015 Kara et al., 2014 Eronat et al., 2019 Deshpande et al., 2012	Comprehensive model for life cycle analysis of ships, capturing all relevant pollutants and linking them to various environmental phenomena.	Provides a thorough understanding of environmental impacts across a ship's life cycle.	Useful in Environmental Impact Assessment, particularly in understanding and mitigating the environmental impacts of products or processes.
	Elemental Analysis Quantify trace elements in samples using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).	Precise analysis of trace elements.	Requires strong solvents posing safety risks.	Kara M. et al., 2014	Identification of significant soil contaminating elements in a heavily industrialised region in Turkey.	Highlights the need for soil remediation and pollution management.	Applicable in Pollution Monitoring, especially in identifying and quantifying trace elements in various samples.
	Spatiotemporal analysis Analyse data collected across both space and time, describing phenomena in specific locations over time (Longley et al., 2015)	Reveals spatial and temporal trends.	Complex integration of spatial and temporal dimensions.	Eronat et al., 2019	Identified spatial characteristics and dynamics of oil spills in Çandarlı Bay, Turkey, over a three-year period.	Advocates for regular monitoring and intervention strategies to manage oil pollution in the bay.	Suitable for Environmental Monitoring, particularly in understanding and managing spatial and temporal trends in environmental phenomena.
	Mathematical modelling Develop mathematical models to represent and predict environmental phenomena (Barbosa, 2003).	Simplifies complex systems. Enables predictions and understanding.	May oversimplify real-world complexities.	Deshpande et al., 2012	Estimation of the zone of influence and cumulative maximum concentration of heavy metals in shipyard environments.	Indicates potential for exceeding national air quality standards, necessitating mitigation strategies.	Useful for predicting environmental phenomena and assessing potential impacts in varied scenarios, especially where direct measurement is challenging.

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
Technical	**Confirmatory Factor Analysis** Validates measurement models by analysing relationships between observed and latent variables (Brown, 2006).	Ensures items measure intended constructs. Assesses model fit.	May yield inconsistent solutions with initial theory. Applicability limited to measurement models.	Sant' Ana J.F. et al., 2023	Identified and validated the structure of sustainable practices in the ship recycling supply chain.	Emphasizes the pivotal role of management practices in establishing a ship recycling supply chain.	Applicable in validating measurement models and ensuring that identified factors are representative of underlying constructs, especially in sustainability and management practices research.
	Exploratory Factor Analysis Discovers underlying constructs within data by analysing interrelationships between variables (Tabachnick & Fidell, 2007).	Identifies latent factors. Measure's internal reliability.	Solutions may not align with initial theory. Applicability limited to uncovering latent variables	Sant' Ana et al., 2023	Sustainable practices in the ship recycling supply chain were identified and their relationships analyzed.	The identification of sustainable practices is crucial for the development of the ship recycling supply chain in Brazil.	Suitable for uncovering underlying constructs within data, particularly when investigating latent variables in sustainability practices.
	Fuzzy Logic A computational paradigm that models human reasoning, allowing for approximate values and inferences, as opposed to traditional (Klir, 2001).	Capable of handling imprecise and vague data. Mimics human decision-making.	Multiple approaches may lead to ambiguity. Lack of systematic problem-solving approaches.	Ozturkoglu et al., 2022	Utilized fuzzy Total Interpretive Structural Modelling (TISM) to discern causal relationships between ship design criteria and impacts on human, environmental, and business sustainability dimensions.	Provides insights into the interconnectedness of ship design criteria and various sustainability dimensions, enabling informed design decision-making.	Applicable in decision-making and system modelling, especially when dealing with uncertainties and vagueness in data and relationships.
	Mixed Integer Linear Programming (MILP) A mathematical optimization approach that allows linear programming with additional	Applicable for solving linear optimization problems. Efficient with available solvers.	Incapable of addressing nonlinear effects. Risk of high dimensionality for complex problems.	Chhetri et al., 2022	MILP optimized the total logistics costs of a closed-loop supply network and ascertained optimal numbers and locations for	Demonstrates the capability of MILP in optimizing logistics and decision-making in a closed-loop supply chain network, providing a viable approach for	Applicable in logistics and supply chain optimization, particularly where decision variables should be integers, and the objective function and

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
	integer constraints (Baker & Ayechew, 2003).				remanufacturing end-of-life (EoL) ships.	minimizing logistics costs in ship recycling.	constraints are linear.
	Discrete Event Simulation A method that models the operation of a system as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system (Cassandras & Lafortune, 2008).	Provides insights into system evolution. Evaluates trade-offs and scenarios. Effective in modelling complex systems.	Requires accurate model development. Resource-intensive, both computationally and in terms of data requirements.	Gunbeyaz et al., 2022	The study demonstrated that alternative cutting technologies, like plasma cutting, could enhance production performance and reduce operating costs in ship recycling yards.	The findings underscore the utility of discrete event simulation in evaluating alternative technologies and strategies in a controlled, risk-free virtual environment, thereby aiding decision-making in operational management.	Applicable in operational research and process optimization, especially in contexts like manufacturing, logistics, and healthcare, where systems are subject to sudden, discrete changes.
Legal	**Grounded Theory Approach** A research method that operates inductively, data is collected, and theories are formulated progressively in light of the data, rather than testing existing theories. (Charmaz, 2006)	Enables the development of new theories grounded in data. Flexible and adaptive to the data as it emerges.	Can be time-consuming. Requires rigorous and systematic data coding and analysis.	Rahman & Mayer, 2016	The study identified a gap between national policies in Bangladesh and international shipbreaking conventions, revealing a lack of capacity for regulatory enforcement and monitoring in the nation.	The findings illuminate the necessity for international policy regimes to consider the capacity disparities in developing nations and to implement mechanisms, such as a deposit-refund system, to ensure compliance with regulations.	Applicable in qualitative research across various disciplines where the aim is to generate theory from data, such as in sociology, nursing, and education, especially when exploring new areas where existing theories may not apply.
Economic	**Econometric Modelling** A method that applies statistical approaches to test hypotheses and forecast future trends in economic data. (Greene, 2012)	Enables testing of hypotheses and forecasting. Can handle large datasets and multiple variables.	Requires robust data. Model misspecification can lead to inaccurate results.	(Knapp et al., 2008	The analysis confirmed various relationships in the ship recycling market, such as a negative relationship with earnings and a positive relationship with scrap prices,	The findings provide insights into the dynamics of the ship recycling market, revealing the influence of various economic factors on	Applicable in economic research and analyses where the objective is to understand economic patterns, test theories, and forecast trends, especially in studies involving

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
					with variations across scrapping locations.	scrapping probabilities and decisions.	financial markets, macroeconomic phenomena, and policy impacts.
	Logit regression A statistical method that predicts the probability of a binary outcome based on one or more predictor variables. (Hosmer et al., 2013)	Capable of handling binary outcome variables. Can manage multiple predictor variables.	Assumes linearity of independent variables and log odds. Requires a large sample size for validity.	Alizadeh et al., 2016	The study found that the probability of scrapping increases with age and varies across different vessel sizes and segments. Additionally, the relationship between earnings and the probability of scrapping ships is negative, while scrapping probability increases with an increase in interest rates, freight market volatility, and scrap steel prices.	The findings elucidate the factors influencing the scrapping decision of dry bulk ships, providing insights that could inform stakeholders in the shipping industry about the potential economic variables affecting ship scrapping.	Suitable for research aiming to predict the probability of a binary outcome by examining the relationship between the outcome and independent variables, especially in studies related to economics, epidemiology, and social sciences where understanding the impact of various factors on a binary outcome is crucial.
	Cost Benefit Analysis A systematic approach for estimating the strengths and weaknesses of alternatives used to determine options which provide the best approach to achieving benefits while preserving savings (E. Boardman et al., 2018)	Provides a systematic way of thinking about choice. Facilitates comparability across diverse types of costs and benefits.	Challenges in quantifying and monetizing costs and benefits. May overlook non-monetary social and environmental impacts.	Choi et al., 2016	Evaluated economic and environmental impacts of three ship end-of-life management options, identifying various influencing economic parameters.	The findings underscore the complexity and multifaceted nature of evaluating end-of-life management options for ships, highlighting the need to balance economic, environmental, and potentially social considerations in decision-making processes.	Applicable in studies where a systematic evaluation of the economic aspects of various alternatives is crucial. Particularly relevant in policymaking, project management, and environmental studies where decision-makers need to evaluate various options and consider both their financial and non-financial impacts.

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
	Vector Autoregressive model A statistical model used to capture the linear interdependencies among multiple time series and generalize the univariate autoregressive model (AR model) (Lütkepohl, 2005)	Captures linear interdependencies among multiple time series. Useful for forecasting systems of interrelated time series.	Requires large datasets for accurate predictions. May not capture non-linear relationships effectively.	Kagkarakis et al., 2016	Identified that international steel-scrap prices significantly influence price discovery in the ship-demolition industry.	Emphasizes the importance of international steel-scrap prices in predicting ship-demolition market trends.	Suitable for studies involving multiple time series data, especially in economic and financial research, to analyse the dynamic impact of shocks to the system and to forecast the future values of the series.
Health & Safety	**Qualitative exploratory case study approach** An approach that involves an in-depth, multi-faceted exploration of a complex issue in its real-life context. It is valuable for exploring new or unclear phenomena (Yin, 2018).	Provides in-depth insights. Allows exploration of context.	Cannot be relied upon solely for decision-making. Potential outdated data sources.	Schøyen et al., 2017	Identified varied demolition practices among Norwegian shipping companies and highlighted the necessity of standardizing recycling yards in subcontinents.	Advocates for increased investments in training, welfare, and infrastructure in recycling yards to enhance sustainability.	Applicable in exploratory phases of research where understanding and context of the issue are prioritized, especially when the issue is not clearly understood or is broad.
	Hazard Identification, Risk Assessment and Risk Control (HIRARC) A systematic approach to identifying hazards, assessing the risk associated, and implementing controls to manage those risks (E, 2001).	Comprehensive risk management. Enhances workplace safety. Quantifies risk levels.	Quantification often relies on assumptions. Uncertainty in models.	Jamaluddin et al., 2022	Identified 60 risk matrices in ship recycling yards, categorized as Low, Moderate, High, and Extreme.	Emphasizes the need for advanced protective equipment, better medical facilities, and a safe workplace to enhance workers' livelihoods.	Suitable for industries or sectors where safety is paramount, and there is a need to systematically identify, assess, and control risks to prevent accidents and ensure regulatory compliance.

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
	Structural equation modelling A statistical technique that allows for testing of a conceptual or theoretical model, by examining relationships among observed and latent variables (Kline, 2023)	Allows for testing of theoretical constructs. Can handle complex relationships among variables.	Requires a large sample size. Model misspecification can lead to inaccurate conclusions.	Zhou Q. et al., 2021	Identified factors affecting personal safety during ship recycling, including disposal of hazardous materials, dismantling operation safety, and management.	Highlights the necessity of addressing various factors to enhance personal safety during ship dismantling.	Applicable in research where the aim is to understand the structural relationship between observed and latent variables, especially in social science, psychology, and business research to validate theoretical models.
	Survival Analysis A statistical approach used to predict the time until an event of interest or endpoint (such as death or failure) occurs. (Hosmer et al., 2011)	Handles censored data. Can incorporate various types of explanatory variables.	Requires appropriate data collection and preprocessing. Prone to model assumptions.	Hai et al., 2021 Rahman et al., 2019			Widely used in medical research to predict patient survival time, and in engineering for failure time analysis. Also applicable in customer churn prediction in business analytics.
Resources	**Material Flow Analysis** A systematic assessment of the flows and stocks of materials within a system defined in space and time. (Brunner & Rechberger, 2016)	Provides a systematic overview of material usage. Can identify inefficiencies and waste in a system.	Data-intensive and may require estimations. Limited by the accuracy and availability of data.	Sujauddin M. et al., 2017	Ship-breaking industry significantly contributes to steel production in Bangladesh.	Highlights the pivotal role of the ship-breaking industry in national steel production.	Useful in assessing the flow of materials in various industries and can be applied to waste management, resource efficiency, and environmental impact assessment.
	Numerical Analysis Utilizes algorithms to obtain numerical approximations for problems that might be	Can handle complex mathematical problems and models. Applicable to various scientific and	Accuracy and stability depend on the chosen algorithm and model. May require substantial	Mansour A.E. et al., 2013	Explored the feasibility of using End-of-Life (EoL) ships as energy hubs to extract renewable energy.	Introduces a novel concept of utilizing EoL ships for energy extraction, requiring further exploration and practical trials.	Applicable in various fields like engineering, physics, finance, and any domain requiring solutions to

Theme	Method /description	Strengths	Limitations	Study	Key Findings	Implications	Methodological Applicability
	deterministic or probabilistic. (Quarteroni et al., 2007)	engineering domains.	computational resources for complex problems.				mathematical problems.
	Regression Analysis A statistical method that investigates the relationships between dependent and independent variable. (Douglas C. et al., 2012)	Can predict outcomes. Identifies relationships among variables.	Assumes a linear relationship. Sensitive to outliers. .	Alizadeh A.H. et al., 2016	Identified that scrapping probability is influenced by variables like age, vessel size, earnings, interest rates, and market conditions.	Provides insights into factors influencing ship scrapping decisions.	Applicable in various research fields where the relationship between variables needs to be established and predictions are essential, such as economics, epidemiology, environmental science, and more.
Social	**Critical scenario method** A method that explores different possible and plausible futures through critical engagement with present conditions and potential changes. (Pettigrew, 1992)	Enables exploration of various future possibilities. Encourages critical thinking about current practices.	Can be speculative and not always precisely predictive. May be influenced by present-day biases.	Cairns G., 2014	Identified that workers in the ship-breaking industry in Bangladesh are situated at the "bottom of the pyramid" and their situation is unlikely to change without significant socio-economic and political shifts.	Highlights the need for radical changes in socio-economic and political structures to alter the future of the ship-breaking industry and its workers.	Applicable in various fields where exploring potential futures and developing strategic foresight is crucial, such as policy-making, business strategy, and environmental planning.
	Participatory rural assessment A method that involves the community in the research process, utilizing local knowledge and enabling people to analyze their own conditions (Chambers, 1994).	Facilitates community involvement and empowerment. Utilizes local knowledge and insights.	Can be influenced by community biases. May be time-consuming and resource intensive.	Ahamad A.F. et al., 2021	Workers in ship recycling yards lack basic facilities and are exposed to occupational health hazards due to working in a risky environment. Over 60% reported injuries or physical issues.	Indicates a critical need for improved working conditions, protective equipment, and medical facilities in ship recycling yards.	Applicable in community-based research, development projects, and social work where local insights and collaborative planning are essential.

RQ3: Future Research directions

The extensive review of ship recycling research papers has uncovered a range of areas ripe for future exploration. These areas cover a broad spectrum, from environmental challenges to technical innovations, legal frameworks, economic models, health and safety concerns, resource management, and social factors. This expanded discussion aims to delve into these areas, highlighting their potential to transform ship recycling practices.

Environmental Challenges and Management:

The environmental aspect of ship recycling demands urgent attention, particularly in the continuous monitoring of toxic trace metals and the remediation of sea pollution. Future studies should explore innovative methods for detecting and mitigating the impact of hazardous substances, including chemical weapons and radioactive waste. Research in this area is crucial for the development of more sustainable recycling practices and for minimizing the ecological footprint of the industry.

Technical Optimization and Efficiency:

Technological advancements hold the key to optimizing ship recycling processes. Future research should focus on employing advanced methodologies, such as Discrete Event Simulation, to streamline operations in various recycling zones. Additionally, there is a need to systematically study and evaluate the range of technologies currently used in ship recycling. This includes identifying the most efficient tools and methods for different recycling tasks, ultimately leading to higher productivity and cost-effectiveness.

Legal and Regulatory Frameworks:

The legal dimension of ship recycling is another critical area for future research. This includes investigating the certification processes of recycling facilities and the need for a universal liability regime, especially in light of the European Union's regulatory framework. Research in this area could provide insights into how international standards can be effectively implemented and monitored, ensuring compliance and promoting best practices globally.

Economic Models and Circular Economy:

The economic aspect of ship recycling, particularly in the context of a circular economy, offers vast potential for future research. Studies could explore the application of digital technologies in real-world circular economy case studies, improving supply chain models and infrastructures. Moreover, an in-depth analysis of the global scale implications of the circular economy, connecting continents and industries, could reveal new insights into how circularity can be achieved on a larger scale.

Health & Safety Practices:

In the domain of health and safety, there is an urgent need to improve the safety culture in less committed shipbreaking firms and further investigate the exposure to total dust and chemical agents. Additionally, examining the cost factors affecting human safety during dismantling activities can provide a more comprehensive understanding of the economic impact on safety measures.

Resource Utilization Strategies:

Exploring new concepts in resource utilization, such as using end-of-life vessels (EOLVs) for renewable energy extraction, presents an innovative approach to ship recycling. This line of research could revolutionize the traditional scrapping methods, offering sustainable alternatives that benefit both the environment and the industry.

Social aspect:

The social dimension in ship recycling is an area that requires significant research focus. Future studies should examine the multidimensionality of union participation and its effects in the informal sector.

Understanding the social dynamics is key to improve worker conditions and enhance the overall safety of recycling operations.

Human Factors

The current research landscape shows a notable gap in addressing human factors, especially in accident investigations to enhance safety learning. However, the industry's approach to reporting safety events is inadequately addressing this need. Currently, safety events reporting often hinder rather than help safety learning, primarily due to their lack of depth and detail. This superficial reporting fails to capture the human factors involved, blocking a comprehensive understanding of incidents, and thereby obstructing the development of effective preventative strategies.

Furthermore, integrating Human Factors principles into future research on ship recycling could yield considerable benefits. This includes focusing on human behaviours, system ergonomic design, cognitive workload, human-system interaction, and organisational factors. The creation and implementation of human-centric systems and procedures for cutting-edge sustainable ship recycling operations are imperative. Consequently, there is a pressing need for an increased focus on these aspects by researchers.

5. Conclusion

This systematic literature review and bibliometric analysis has provided a comprehensive exploration of the current state of ship recycling research, as reflected in the Scopus database. Our analysis has identified pivotal contributions from countries such as Turkey, India, Bangladesh, the USA, China, the UK, and Indonesia, highlighting the global scope of ship recycling research. Prominent journals like the Marine Pollution Bulletin and the Journal of Cleaner Production have emerged as key platforms for disseminating findings in this field, underscoring the interdisciplinary nature of the research.

Through our in-depth review, we have distilled the research into primary thematic areas – Environmental, Technical, Health and Safety, Economic, Legal, Resource, and Social Studies. Each theme encapsulates a range of challenges and innovations pertinent to ship recycling, reflecting the complexity and multifaceted nature of the industry. The recent uptick in economic and legal research, particularly post-2016, signals a shift in focus towards more holistic and regulatory aspects of ship recycling.

Our analysis has also uncovered a notable gap in the Human Factors domain within ship recycling research. This absence is significant, considering the integral role of human behaviour, ergonomics, and cognitive aspects in ensuring safety and efficiency in such a labour-intensive industry. Addressing this gap could lead to significant advancements in creating safer, more efficient, and more humane recycling practices.

The identified future research directions, particularly the innovative concept of using end-of-life vessels as renewable energy sources and the need for in-depth social research, open new avenues for transformative studies in this field. These emerging trends hold the potential to redefine ship recycling practices, aligning the more closely with global sustainability and circular economy goals.

For policymakers, this review offers valuable insights into the current research landscape, providing guidance on future investments and policy formulation. For researchers, the identified themes, methodologies, and research gaps present opportunities for targeted, innovative investigations that can further enrich the field.

While this review provides a comprehensive overview of the field, it is not without limitations. The reliance on Scopus as the primary database may have excluded some scholarly contributions. However, the breadth and depth of the analysis conducted here offer a significant understanding of ship recycling research. Future reviews may consider a broader range of sources, including white papers, industry perspectives, and governmental documents, to provide a more holistic view of the industry's challenges and opportunities.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used AI-based tools to Proofread the manuscript and improve its readability. After using these tools, the authors reviewed and edited the content, as needed, and take full responsibility for the content of the publication.

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Appendix-A

Table 4: Basic Information including (Titles, Authors names, year, and themes) of selected Studies.

#	Title	Authors	Year	Theme
1	Capacity retirement in the dry bulk market: A vessel-based logit model	Alizadeh A.H.; Strandenes S.P.; Thanopoulou H.	2016	Economic
2	The market for ship demolition	Buxton I.L.	1991	
3	Econometric analysis of the ship demolition market	Knapp S.; Kumar S.N.; Remijn A.B.	2008	
4	Perspective of Circular Economy in Bangladesh: A Comprehensive Review Towards Ship Demolition Industry	Ahasan S., Zaman F.N., Ahmed T.	2021	
5	Role and potential of the circular economy in managing end-of-life ships in china	Steuer B., Staudner M., Ramusch R.	2021	
6	Circular economy, proximity, and shipbreaking: A material flow and environmental impact analysis	Rahman S.M.M., Kim J.	2020	
7	Ship demolition activity: A monetary flow process approach	Karlis T., Polemis D.	2016	
8	The ship recycling market in Brazil - The Amazon potential	Benjamin C., Figueiredo N.	2020	
9	Comparison of ship dismantling processes in India and the U.S.	Ahluwalia R.S., Sibal P., Govindarajulu S.	2004	
10	Ship deconstruction cost models	Creese R.C., Nandeshwar A., Sibal P., Ahluwalia R., Iskander W.H., Klishis M., McKendall A., Whaley D., Boettner J., Jaramillo J., Martin M., Oganezov K.	2002	
11	Disruption in Circularity? Impact analysis of COVID-19 on ship recycling using Weibull tonnage estimation and scenario analysis method	Rahman S.M.M., Kim J., Laratte B.	2021	
12	Feasibility study on the financial aspect of green ship recycling yard business model	Sunaryo, Hanura A.R., Hussein F.	2020	
13	The dynamics of fleet size and shipping profitability: the role of steel-scrap prices	Andrikopoulos A., Merika A., Merikas A., Tsionas M.	2020	
14	Survival analysis of the world ship demolition market	Yin J., Fan L.	2018	
15	Modelling and forecasting the demolition market in shipping	Kagkarakis N.D., Merikas A.G., Merika A.	2016	
16	Political markets: Recycling, economization and marketization	Gregson N., Watkins H., Calestani M.	2013	
17	Demolishcon - The standard contract for recycling of ships	Strand T.C.	2005	
18	Safe and sound scrapping of 'rusty buckets'? the 2009 Hong Kong ship recycling convention	Matz-Lück N.	2010	Legal
19	Legal regulation of the shipbreaking industry in Bangladesh: The international regulatory framework and domestic implementation challenges	Alam S.; Faruque A.	2014	
20	The “Mirror Flags”: Ship registration in globalised ship breaking industry	Alcaidea J.I.; Piniella F.; Rodríguez-Díaza E.	2016	

#	Title	Authors	Year	Theme
21	Regulating Shipbreaking as a Global Activity: Issues of Fragmentation and Injustice	Hadjiyianni I., Kloni A.	2021	
22	European policies on ship recycling: A stakeholder survey	Ignacio Alcaide J., Rodríguez-Díaz E., Piniella F.	2017	
23	Policy compliance recommendations for international shipbreaking treaties for Bangladesh	Rahman S.M.M., Mayer A.L.	2016	
24	A gap analysis of ship-recycling practices in Indonesia	Sunaryo S., Djatmiko E., Fariya S., Kurt R., Gunbeyaz S.	2021	
25	Ship recycling: An important mile stone for India	Reddy N.G.K.	2014	
26	The public–private governance regime on sustainable ship recycling: An in-depth analysis	Glinski C.	2022	
27	The Recycling of Ships Act 2019: Prospects for a Sustainable Ship Recycling in India	Mathew E.	2022	
28	Determining the effects of implementing IMO's Hong Kong Convention's requirements on the productivity of a ship recycling yard by using discrete event simulation	Fariya S., Gunbeyaz S.A., Kurt R.E., Turan O.	2022	
29	New roles and responsibilities of flag states and port states in the context of the Hong Kong international convention for the safe and environmentally sound recycling of ships, 2009	Durak O.S.	2020	
30	International law on ship recycling and its interface with EU law	Argüello Moncayo G.	2016	
31	A Comparison of Ship-Recycling Legislation Between Chinese Law and the 2009 Hong Kong Convention	Zhao Y., Chang Y.-C.	2014	
32	Liability of shipowners and classification societies for environmental damage and unsafe working conditions at recycling yards	Glinski C.	2022	
33	Economic and environmental perspectives of end-of-life ship management	Choi J.-K., Kelley D., Murphy S., Thangamani D.	2016	Environment and Economic
34	The life cycles' particularities in romanian shipbuilding industry	Nicolae F.M., Popa C., Beizadea H., Nistor F.	2010	
35	Local added value and environmental impacts of ship scrapping in the context of a ship's life cycle	Ko N.; Gantner J.	2016	
36	Unexpected side effects of the EU Ship Recycling Regulation call for global cooperation on greening the shipbreaking industry	Lin L., Feng K., Wan Z., Wang P., Kong X., Zhang N., Hubacek K., Li J.	2022	
37	Aquatic health index of coastal aquaculture activities at south-eastern coast of Bangladesh	Barua P., Rahman S.H.	2021	
38	Applications of life cycle assessment (LCA) in shipping industry	Nicolae F., Popa C., Beizadea H.	2014	Environmental
39	Environmental impacts of ship scrapping in Bangladesh	Amin S.M.N.; Billah M.	2007	
40	Environmental hazards associated with open-beach breaking of end-of-life ships: a review	Barua S.; Rahman I.M.M.; Hossain M.M.; Begum Z.A.; Alam I.; Sawai H.; Maki T.; Hasegawa H.	2018	

#	Title	Authors	Year	Theme
41	The effect of ship scrapping industry and its associated wastes on the biomass production and biodiversity of biota in in situ condition at Alang	Tewari A.; Joshi H.V.; Trivedi R.H.; Sravankumar V.G.; Raghunathan C.; Khambhaty Y.; Kotiwar O.S.; Mandal S.K.	2001	
42	Scrapping probabilities and committed CO2 emissions of the international ship fleet	Held M.; Stolz B.; Hoffmann J.; Georges G.; Bolla M.; Boulouchos K.	2021	
43	Environmental assessment of aromatic hydrocarbons-contaminated sediments of the Mexican Salina Cruz Bay	González-Macías C.; Schifter I.; Lluch-Cota D.B.; Méndez-Rodríguez L.; Hernández-Vázquez S.	2007	
44	Indices for Assessing Potential Environmental Hazard from Future Ship Scrapping Process, Determinable in Ship Design Stage	Liberacki R.	2018	
45	Shipbuilding trends in response to environmental issues	Klein H.J.	2007	
46	Ship Scrapping and the environment—the buck should stop!	Sinha S.	1998	
47	Distribution, enrichment and accumulation of heavy metals in coastal sediments of Alang-Sosiya ship scrapping yard, India	Reddy M.S.; Basha S.; Sravan Kumar V.G.; Joshi H.V.; Ramachandraiah G.	2004	
48	Seasonal distribution and contamination levels of total PHCs, PAHs and heavy metals in coastal waters of the Alang-Sosiya ship scrapping yard, Gulf of Cambay, India	Srinivasa Reddy M.; Basha S.; Joshi H.V.; Ramachandraiah G.	2005	
49	Shipbreaking at Alang-Sosiya (India): An ecological distribution conflict	Demaria F.	2010	
50	Effect of ship scrapping activities on the soil and sea environment in the coastal area of Chittagong, Bangladesh	Islam K.L.; Hossain M.M.	1986	
51	Quantification and classification of ship scraping waste at Alang-Sosiya, India	Srinivasa Reddy M.; Basha S.; Sravan Kumar V.G.; Joshi H.V.; Ghosh P.K.	2003	
52	Spatial distribution and ecological risk assessment of potentially toxic metals in the Sundarbans mangrove soils of Bangladesh	Islam M.M., Akther S.M., Hossain M.F., Parveen Z.	2022	
53	Hazardous waste from the global shipbreaking industry: Historical inventory and future pathways	Lin L., Feng K., Wang P., Wan Z., Kong X., Li J.	2022	
54	Toxic metal pollution and ecological risk assessment in water and sediment at ship breaking sites in the Bay of Bengal Coast, Bangladesh	Ali M.M., Islam M.S., Islam A.R.M.T., Bhuyan M.S., Ahmed A.S.S., Rahman M.Z., Rahman M.M.	2022	
55	Vertical distribution and contamination assessment of heavy metals in sediment cores of ship breaking area of Bangladesh	Hossain M.B., Runu U.H., Sarker M.M., Hossain M.K., Parvin A.	2021	
56	Elevated concentrations of mercury and methylmercury in the Gadani shipbreaking area, Pakistan	Kakar A., Liem-Nguyen V., Mahmood Q., Jonsson S.	2021	
57	Study on status quo of shipbreaking sector and strategies	Shen W., Xing G.	2017	
58	Organic and heavy metal pollution in shipbreaking yards	Yılmaz A., Karacık B., Yakan S.D., Henkelmann B., Schramm K.-W., Okay O.S.	2016	

#	Title	Authors	Year	Theme
59	Heavy metal pollution in sediments and mussels: assessment by using pollution indices and metallothionein levels	Okay O.S., Ozmen M., Güngördü A., Yılmaz A., Yakan S.D., Karacık B., Tutak B., Schramm K.-W.	2016	
60	Taxonomic profiling of bacterial community structure from coastal sediment of Alang-Sosiya shipbreaking yard near Bhavnagar, India	Patel V., Munot H., Shah V., Shouche Y.S., Madamwar D.	2015	
61	Micro-organic pollutants and biological response of mussels in marinas and ship building/breaking yards in Turkey	Okay O.S., Karacik B., Güngördü A., Ozmen M., Yilmaz A., Koyunbaba N.C., Yakan S.D., Korkmaz V., Henkelmann B., Schramm K.-W.	2014	
62	Investigation of elemental and radiological contamination of soils in two shipyards in Chittagong, Bangladesh	Uddin M.S., Barua B.S., Shariff M.A., Hasan M.M., Rashid M.A., Kamal M.	2014	
63	Biodegradation of phenanthrene in bioaugmented microcosm by consortium ASP developed from coastal sediment of Alang-Sosiya ship breaking yard	Patel V., Patel J., Madamwar D.	2013	
64	Polycyclic aromatic and aliphatic hydrocarbons pollution at the coast of Aliaĝa (Turkey) ship recycling zone	Neşer G., Kontas A., Ünsalan D., Altay O., Darilmaz E., Uluturhan E., Küçüksezgin F., Tekoĝul N., Yercan F.	2012	
65	Heavy metals contamination levels at the Coast of Aliaĝa (Turkey) ship recycling zone	Neşer G., Kontas A., Ünsalan D., Uluturhan E., Altay O., Darilmaz E., Küçüksezgin F., Tekoĝul N., Yercan F.	2012	
66	Shipbreaking and e-waste: The international trade in hazardous waste continues	Stairs K.	2004	
67	Pseudomonas aeruginosa Derived Biosurfactant as a Potential Biosensor for Heavy Metal Detection: A Possibility Using Microfluidic Approach	Sharma P., Gautam S., Debnath S., Debnath M.	2022	
68	Assessment of terrestrial radionuclides in the sandy soil from Guliakhali beach area of Chattogram, Bangladesh	Roy D., Siraz M.M.M., Dewan M.J., Pervin S., Rahman A.F.M.M., Khandaker M.U., Yeasmin S.	2022	
69	Assessment of health risks associated with potentially toxic element contamination of soil by end-of-life ship dismantling in Bangladesh	Alam I., Barua S., Ishii K., Mizutani S., Hossain M.M., Rahman I.M.M., Hasegawa H.	2019	
70	Monitoring of metal pollution in waterways across Bangladesh and ecological and public health implications of pollution	Kibria G., Hossain M.M., Mallick D., Lau T.C., Wu R.	2016	
71	Investigation of spatial and historical variations of air pollution around an industrial region using trace and macro elements in tree components	Odabasi M., Tolunay D., Kara M., Ozgunerge Falay E., Tuna G., Altiok H., Dumanoglu Y., Bayram A., Elbir T.	2016	
72	High Concentrations of Organic Contaminants in Air from Ship Breaking Activities in Chittagong, Bangladesh	Nøst T.H., Halse A.K., Randall S., Borgen A.R., Schlabach M., Paul A., Rahman A., Breivik K.	2015	
73	Biomonitoring the spatial and historical variations of persistent organic pollutants (POPs) in an industrial region	Odabasi M., Ozgunerge Falay E., Tuna G., Altiok H., Kara M., Dumanoglu Y., Bayram A., Tolunay D., Elbir T.	2015	
74	Characterization of PM using multiple site data in a heavily industrialized region of turkey	Kara M., Hopke P.K., Dumanoglu Y., Altiok H., Elbir T., Odabasi M., Bayram A.	2015	
75	Spatial distribution and source identification of trace elements in topsoil from heavily industrialized region, Aliaga, Turkey	Kara M., Dumanoğlu Y., Altıok H., Elbir T., Odabası M., Bayram A.	2014	

#	Title	Authors	Year	Theme
76	Monitoring the drastic growth of ship breaking yards in Sitakunda: A threat to the coastal environment of Bangladesh	Abdullah H.M., Mahboob M.G., Banu M.R., Seker D.Z.	2013	
77	Shipping hazardous waste: Implications for economically developing countries	Sonak S., Sonak M., Giriyan A.	2008	
78	Factors influencing green ship recycling: A conceptual framework and modeling	Zhou Q., Du Z., Liu J., Liang J., Jiao Y.	2021	
79	Heavy metal concentrations and its impact on soil microbial and enzyme activities in agricultural lands around ship yards in Chattogram, Bangladesh	Chowdhury N., Rasid MdM.	2021	
80	Physicochemical characterisation of seawater at area of ship dismantling activities	Titah H.S., Pratikno H., Moesriati A.	2019	
81	Simultaneous bioaugmentation and biostimulation to remediate soil contaminated by ship dismantling in Bangkalan District, Indonesia	Nadhirawaty R., Titah H.S.	2019	
82	Removal of Iron using Isolated Bacteria (Vibrio alginolyticus) in seawater at Ship Dismantling Area	Titah H.S., Pratikno H., Moesriati A.	2019	
83	Isolation and screening of resistant bacteria of heavy metal (Fe) at ship dismantling	Titah H.S., Pratikno H. , Moesriati A., Putera R.I., Imron M.F.	2018	
84	Isolation and screening of diesel degrading bacteria from ship dismantling facility at Tanjungjati, Madura, Indonesia	Titah H.S., Pratikno H., Moesriati A., Imron M.F., Putera R.I.	2018	
85	Pollution from EOLV dismantling and the corresponding countermeasures	Zhang H.	2016	
86	Characterization of heavy metal and antibiotic resistant bacteria isolated from aliaga ship dismantling zone, Eastern Aegean Sea, Turkey	Kacar A., Kocyigit A.	2013	
87	Levels and spatial distribution of gaseous polychlorinated biphenyls and polychlorinated naphthalenes in the air over the northern South China Sea	Li Q., Xu Y., Li J., Pan X., Liu X., Zhang G.	2012	
88	Decommissioning of a FSO containing hazardous waste: A successful story	Chaîneau C.-H., Bourguignon J.-C., Goubard G., Bang P., Jean P., Lefebvre B., Blankestijn T.P., Ayuk E.T.	2012	
89	Spatial and temporal variation and air-soil exchange of atmospheric PAHs and PCBs in an industrial region	Kaya E., Dumanoglu Y., Kara M., Altiok H., Bayram A., Elbir T., Odabasi M.	2012	
90	Modelling of environmental impacts of ship dismantling	Carvalho I.S., Antão P., Soares C.G.	2011	
91	Dry deposition and soil-air gas exchange of polychlorinated biphenyls (PCBs) in an industrial area	Bozlaker A., Odabasi M., Muezzinoglu A.	2008	
92	Concentrations of heavy metals in urban soils of Talcahuano (Chile): A preliminary study	Tume P., Bech J., Sepulveda B., Tume L., Bech J.	2008	
93	Bioaccumulation of polychlorinated biphenyls in mullet fish in a former ship dismantling harbour, a contaminated estuary, and nearby coastal fish farms	Fu C.-T., Wu S.-C.	2005	
94	New normal baseline data during nationwide lock down due to Covid 19 pandemic in the world's largest ship recycling yard at Alang, India	Chanchpara A., Sonpal V., Mehta G., Sahoo T.P., Thorat R.B., Ray S., Haldar S.	2021	

#	Title	Authors	Year	Theme
95	A fuzzy best–worst method (BWM) to assess the potential environmental impacts of the process of ship recycling	Soner O., Celik E., Akyuz E.	2022	
96	Marine waste-sources, fate, risks, challenges and research needs	Dabrowska J., Sobota M., Swiader M., Borowski P., Moryl A., Stodolak R., Kucharczak E., Zieba Z., Kazak J.K.	2021	
97	Environmental impacts of steel ship hulls building and recycling by life cycle assessment (LCA)	Önal M., Neşer G., Gürsel K.T.	2021	
98	Shipping and ship recycling related oil pollution detection in çandarlı Bay (Turkey) using satellite monitoring	Eronat A.H., Bengil F., Neşer G.	2019	
99	Does open-beach ship-breaking affect the mineralogical composition of soil more adversely than typical industrial activities?	Rahman I.M.M., Mutsuddi R., Jii N., Barua S., Ahmmad B., Kibria M.G., Hossain M.M., Begum Z.A., Dey B.K., Hasegawa H.	2019	
100	A model for the life cycle analysis of ships: Environmental impact during construction, operation and recycling	Mountaneas A., Georgopoulou C., Dimopoulos G., Kakalis N.M.P.	2015	
101	The shipbreaking industry in Turkey: environmental, safety and health issues	Neşer G., Ünsalan D., Tekoğul N., Stuer-Lauridsen F.	2008	Environment, Health & Safety
102	Ship-owners' stance to environmental and safety conditions in ship recycling. A case study among Norwegian shipping managers	Schøyen H.; Burki U.; Kurian S.	2017	
103	Shipbreaking in the developing world: Problems and prospects	Rousmaniere P.; Raj N.	2007	
104	A novel approach to estimating potential maximum heavy metal exposure to ship recycling yard workers in Alang, India	Deshpande P.C.; Tilwankar A.K.; Asolekar S.R.	2012	
105	A review of ship breaking and rig scrapping in the gulf of Mexico	Kaiser M.J.	2008	
106	Ship Breaking and Recycling Industry of Bangladesh; Issues and Challenges	Rabbi H.R.; Rahman A.	2017	
107	Environmental hazards and health rights of workers in shipbreaking in Bangladesh	Uddin M.K., Nobi M.N., Islam A.N.M.M.	2022	
108	Living with toxic development: Shipbreaking in the industrializing zone of Sitakunda, Bangladesh	Dewan C.	2020	
109	Risk assessment of heavy metals in selected marine fish species of gadani shipbreaking area and Pakistan	Kakar A., Hayat M.T., Abbasi A.M., Pervez A., Mahmood Q., Farooq U., Akbar T.A., Ali S., Rizwan M., El-Serehy H.A., Abdel-Daim M.M.	2020	
110	Assessing energy-based co2 emission and workers' health risks at the shipbreaking industries in bangladesh	Mitra N., Ahmad Shahriar S., Lovely N., Khan S., Rak A.E., Kar S.P., Khaleque A., Mohd Amin M.F., Kayes I., Abdus Salam M.	2020	
111	Spatial distribution, water quality, human health risk assessment, and origin of heavy metals in groundwater and seawater around the ship-breaking area of Bangladesh	Hasan A.B., Reza A.H.M.S., Siddique M.A.B., Akbor M.A., Nahar A., Hasan M., Zaman M.N., Hasan M.I., Moniruzzaman M.	2023	
112	Impact of ship-Breaking activities on the coastal environment of Bangladesh and a management system for its sustainability	Hossain M.S., Fakhruddin A.N.M., Chowdhury M.A.Z., Gan S.H.	2016	

#	Title	Authors	Year	Theme
113	Ship recycling in India- environmental stock taking	Ahmad M.	2022	Environment & Legal
114	Marine Pollution Prevention in Bangladesh: A Way Forward for Implement Comprehensive National Legal Framework	Alam M.W., Xiangmin X.	2019	
115	Life cycle assessment of ships	Shama M.A.	2004	Environment & Technical
116	A sustainable shipbreaking approach for cleaner environment and better wellbeing	Rizvi M.J., Islam M.R., Adekola O., Margaret O.N.	2020	
117	Hazardous materials analysis and disposal procedures during ship recycling	Du Z., Zhang S., Zhou Q., Yuen K.F., Wong Y.D.	2018	
118	Integration of environmental aspects in product development and ship design	Källmar K., Sundqvist T.K., Sundin E.	2013	
119	Safety Analysis and Ship Recycling Yard Evaluation of Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships	Jamaluddin, Zaman M.B., Pitana T., Prastowo H., Priyanta D., Siswantoro N., Hasanuddin, Purnomo A., Sunaryo, Hariyanto S.	2022	Health & Safety
120	Shipbreaking in Bangladesh: Organizational responses, ethics, and varieties of employee safety	Tanha M., Michelson G., Chowdhury M., Castka P.	2022	
121	Cancer attributable to asbestos exposure in shipbreaking workers: A matched-cohort study	Wu W.-T., Lin Y.-J., Li C.-Y., Tsai P.-J., Yang C.-Y., Liou S.-H., Wu T.-N.	2015	
122	Cancer incidence of Taiwanese shipbreaking workers who have been potentially exposed to asbestos	Wu W.-T., Lin Y.-J., Shiue H.-S., Li C.-Y., Tsai P.-J., Yang C.-Y., Liou S.-H., Wu T.-N.	2014	
123	Mortality among shipbreaking workers in Taiwan-A retrospective cohort study from 1985 to 2008	Wu W.-T., Lu Y.-H., Lin Y.-J., Yang Y.-H., Shiue H.-S., Hsu J.-H., Li C.-Y., Yang C.-Y., Liou S.-H., Wu T.-N.	2013	
124	Safety and health in shipbreaking	Bailey P.J.	2005	
125	Mortality among former shipbreaking workers - A 13-year retrospective follow-up study in Taiwan	Liu Y.-K., Yang G.-Y., Wu T.-N., Lin R.S., Sung F.-C.	2003	
126	Metal exposure during ship repair and shipbreaking procedures	Mattorano D., Harney J., Cook C., Roegner K.	2001	
127	Lead toxicity in the shipbreaking industry: The Ontario experience	Nosal R.M., Wilhelm W.J.	1990	
128	Exposure to paint degradation products when welding flame cutting, or straightening painted steel	Engström B., Hnnriks-Enkfirman M.-L., Anas E.	1990	
129	Occupational lead exposure in Finland. V. Shipyards and shipbreaking	Tola S., Karskela V.	1976	
130	Lead over-absorption in a population of oxy-gas burners	Taylor W., Molyneux M.K.B., Blackadder E.S.	1974	
131	Workers of alang-sosiya: A survey of working conditions in a ship-breaking yard, 1983-2013	Sahu G.	2014	
132	Asbestos-related disease in banlgadeshi ship breakers: A pilot study	Courtice M.N., Demers P.A., Takaro T.K., Vedal S., Ahktar Ahmad S.K., Davies H.W., Siddique Z.	2011	
133	Working conditions in ship-breaking: A case of Alang Yard	Misra H.	2007	
134	Study on the health hazards of scrap metal cutters.	Ho S.F., Wong P.H., Kwok S.F.	1989	

#	Title	Authors	Year	Theme
135	Hexavalent chromium exposures and exposure-control technologies in American enterprise: Results of a NIOSH field research study	Blade L.M., Yencken M.S., Wallace M.E., Catalano J.D., Khan A., Topmiller J.L., Shulman S.A., Martinez A., Crouch K.G., Bennett J.S.	2007	
136	Workers' exposure to dust and potentially toxic elements during steel cutting in two ship dismantling cases	Gunbeyaz S.A., Giagloglou E., Kurt R.E., Rogge K.G., Alkaner S., McKenna S.A., Turan O., Lord R.	2023	
137	A study on factors affecting workers' safety during ship recycling	Zhou Q., Liang J., Du Z., Zhu H., Jiao Y.	2021	
138	Mortality among workers exposed to asbestos at the shipyard of Genoa, Italy: A 55 years follow-up	Merlo D.F., Bruzzone M., Bruzzi P., Garrone E., Puntoni R., Maiorana L., Ceppi M.	2018	
139	Investigation of occupational noise exposure in a ship recycling yard	Kurt R.E., McKenna S.A., Gunbeyaz S.A., Turan O.	2017	
140	Assessment of the future mesothelioma disease burden from past exposure to asbestos in ship recycling yards in India	Singh R., Cherrie J.W., Rao B., Asolekar S.R.	2020	
141	A study on evaluating the status of current occupational training in the ship recycling industry in Bangladesh	Gunbeyaz S.A., Kurt R.E., Baumler R.	2019	
142	The European Ship Recycling Regulation and its market implications: Ship-recycling capacity and market potential	Solakivi T., Kiiski T., Kuusinen T., Ojala L.	2021	Legal & Economic
143	Can ship recycling be a sustainable activity practiced in Brazil?	Ocampo E.S., Pereira N.N.	2019	
144	IAMUS AGA 17: The vessel recycling and the ship cemeteries of southeast Asia	Antolín M.N.	2017	
145	The impact of ship scrapping subsidies on fleet renewal decisions in dry bulk shipping	Yang Z.; Jiang Z.; Notteboom T.; Haralambides H.	2019	
146	Herd behavior in the drybulk market: an empirical analysis of the decision to invest in new and retire existing fleet capacity	Papapostolou N.C.; Pouliasis P.K.; Kyriakou I.	2017	
147	Ship breaking industry and its impacts on environment	Akten N.; Koldemir B.; Yaran A.; Irtem S.S.; Elmas G.	2007	
148	Designing an EU Ship Recycling Licence: A Roadmap	Devaux C., Nicolaï J.-P.	2020	
149	Breaking Basel: The elements of the Basel Convention and its application to toxic ships	Moen A.E.	2008	
150	Exporting responsibility - Shipbreaking in South Asia - International trade in hazardous waste	Paul K.	2004	
151	Mapping the supply chain of ship recycling	Hsuan J., Parisi C.	2020	
152	Challenges and solutions for ship recycling in China	Du Z., Zhu H., Zhou Q., Wong Y.D.	2017	
153	Demandeur pays: The EU and funding improvements in South Asian ship recycling practices	Yujuico E.	2014	
154	Challenges and opportunities for the future of recreational boat scrapping: The Spanish case	Martínez-Vázquez R.M.; Milán-García J.; De Pablo Valenciano J.	2022	Overview
155	Technological and economic study of ship recycling in Egypt	Welaya Y.M.A.; Abdel Naby M.M.; Tadros M.Y.	2012	

#	Title	Authors	Year	Theme
156	Characterization of ship breaking industry in Bangladesh	Sujauddin M., Koide R., Komatsu T., Hossain M.M., Tokoro C., Murakami S.	2015	
157	Ship recycling in Pakistan - Environment & economics	Shahid M.	2005	
158	Non-entry into force of the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009: An analysis from the perspective of India, Pakistan and Bangladesh	Mishra S.	2018	
159	Return to Chittagong: ten years since the "postcard"	Cairns G.M.	2017	
160	Postcard from Chittagong: Wish you were here?	Cairns G.	2007	
161	Ship Recycling-The Need of A Life Cycle Approach	Chockalingam G., Sivasami K., Thangalakshmi S.	2022	
162	Sustainability challenges and enablers in resource recovery industries: A systematic review of the ship-recycling studies and future directions	Dey A., Ejohwomu O.A., Chan P.W.	2021	
163	Ship recycling, market imperfections and the relevance of a consortium of ship recycling nations in the Indian subcontinent	Mathew E.	2021	
164	Developing sustainable green ship recycling facilities in indonesia: Investigation of current situation	Fariya S., Gunbeyaz S.A., Kurt R.E., Sunaryo S., Djatmiko E.B.	2020	
165	Toward green and sustaianable ship recycling industry in Indonesia	Sunaryo, Djatmiko E.B., Kurt R.E.	2019	
166	Aspects and impacts of ship recycling in Bangladesh	Rahman S.	2017	
167	Ship recycling and marine pollution	Chang Y.-C., Wang N., Durak O.S.	2010	
168	A statistical overview of ship recycling	Mikelis N.E.	2008	
169	The IMO'S work on ship recycling	Dimakopoulos S.	2005	
170	Recycling of Marine structures and ships in the UK	Stephenson P.M.	2005	
171	An assessment for energy potential of solid waste from ship scraping yard at Alang - Sosiya, India	Reddy M.S., Joshi H.V., Basha S., Kumar V.G.S.	2004	Resources
172	Wave energy extraction using decommissioned ships	Mansour A.E.; Pedersen P.T.; Paik J.K.	2013	
173	Modeling the energy content of combustible ship-scrapping waste at Alang-Sosiya, India, using multiple regression analysis	Reddy M.S.; Basha S.; Joshi H.V.; Kumar V.G.S.; Jha B.; Ghosh P.K.	2005	
174	Ship Breaking and the Steel Industry in Bangladesh: A Material Flow Perspective	Sujauddin M., Koide R., Komatsu T., Hossain M.M., Tokoro C., Murakami S.	2017	
175	Database for dismantling of obsolete vessels	Ahluwalia R.S., Sibal P., Govindarajulu S.	2004	
176	Preliminary concept and feasibility studies on ocean energy device design from used ships	Mukherjee D., Mansour A.E.	2010	
177	Life cycle assessment of steel in the ship recycling industry in Bangladesh	Rahman S.M.M., Handler R.M., Mayer A.L.	2016	Resources & Environmen
178	How social ties influence metal resource flows in the Bangladesh ship recycling industry	Mizanur Rahman S.M., Mayer A.L.	2015	Social

#	Title	Authors	Year	Theme
179	Organising experience of informal sector workers – a road less travelled	Balasubramanian G., Sarkar S.	2020	Social, Health &
180	Uncovering discursive framings of the Bangladesh shipbreaking industry	Rahman S.M.M., Schelly C., Mayer A.L., Norman E.S.	2018	
181	A critical scenario analysis of end-of-life ship disposal the "bottom of the pyramid" as opportunity and graveyard	Cairns G.	2014	
182	Skill and education in income determination: A case study of unorganised workers of alang	Misra H.	2008	
183	Livelihood assessment and occupational health hazard of the ship- breaking industry workers at chattogram, bangladesh	Ahamad A.F., Schneider P., Khanum R., Mozumder M.M.H., Mitu S.J., Shamsuzzaman M.M.	2021	
184	Investigating the prospects of using a plasma gasification plant to improve the offer price of ships recycled on large-sized 'green' yards	Jain K.P., Pruyn J.	2018	Technical & Resource
185	Quantitative assessment of material composition of end-of-life ships using onboard documentation	Jain K.P., Pruyn J.F.J., Hopman J.J.	2016	
186	Hybrid induction-oxygen cutting process for faster, more efficient, and less costly scrapping of off-shore petroleum platforms	Jones J.E., Rhoades V.L., Dydo J.R.	2019	Technical
187	Application of computing technology in ship recycling	Kamath Y.R., Sivaprasad K., Jayaram S.	2019	
188	Improving ship design process to enhance ship recycling	Jain K.P., Pruyn J.F.J., Hopman J.J.	2016	
189	Technical feasibility study of the introduction of ship breaking to a shipyard	Rudevics A., Priednieks V.	2015	
190	A life cycle approach to shipbuilding and ship operation	Tincelin T., Mermier L., Pierson Y., Pelerin E., Jouanne G.	2010	
191	Safe and cost-minimum planning system for disassembling process of ship-hull considering environmental impact	Matsubara M., Koga T., Aoyama K.	2007	
192	Ship breaking or scuttling? A review of environmental, economic and forensic issues for decision support	Devault D.A.; Beilvert B.; Winterton P.	2017	
193	Hybrid induction-plasma cutting a new technology for high speed metal cutting	Jones J.E.; Mann M.D.; Rhoades V.L.; Holverson T.	2014	
194	Holistic ship design optimization	Papanikolaou A.	2010	
195	Development of destruction module design system for a ship breaking planning	Aoyama K.; Xi W.C.; Ishikawa T.; Koga T.	2010	
196	A software tool for disposal of obsolete vessels	Ahluwalia R.S.; Govindarajulu S.	2005	
197	The environmental impact analysis of hazardous materials and the development of green technology in the shipbreaking process	Yan H., Wu L., Yu J.	2018	
198	Development of a logic-based product life-cycle management (LBPLM) system for shipbuilding industry-conceptual development	Sharma R., Kim T.-W.	2010	
199	Development of a logic based Product Lifecycle Management (PLM) system for shipbuilding industry	Sharma R., Kim T.-W.	2009	

#	Title	Authors	Year	Theme
200	Establishment of a knowledge data base to support ship recycling	Karpowicz A., Bruce G., Sinha A.	2005	
201	Safer ship dismantling facilities	Van Wijngaarden A.M.	2005	
202	Strategic guidance based on the concept of cleaner production to improve the ship recycling industry	Jain K.P., Pruyn J., Hopman H.	2018	
203	Sustainable design of ship breaking industry in developing countries	Khan I., Chowdhury H., Alam F., Kumar A.	2012	
204	Design for sustainable ship dismantling based on triple bottom line perspective	Ozturkoglu Y., Kazancoglu Y., Ozkan-Ozen Y.D.	2022	
205	Investigation of different cutting technologies in a ship recycling yard with simulation approach	Gunbeyaz S.A., Kurt R.E., Turan O.	2022	
206	Material flow analysis (MFA) as a tool to improve ship recycling	Jain K.P., Pruyn J.F.J., Hopman J.J.	2017	
207	Development of ship-specific recycling plan to improve health safety and environment in ship recycling yards	Hiremath A.M., Pandey S.K., Asolekar S.R.	2016	
208	Significant steps in ship recycling vis-a-vis wastes generated in a cluster of yards in Alang: A case study	Hiremath A.M., Tilwankar A.K., Asolekar S.R.	2015	
209	A novel approach to estimating resource consumption rates and emission factors for ship recycling yards in Alang, India	Deshpande P.C., Kalbar P.P., Tilwankar A.K., Asolekar S.R.	2013	
210	Design for ship recycling	Sivaprasad K., Nandakumar C.G.	2013	
211	Dismantling of civilian nuclear powered fleet technical support vessels. Engineering solutions	Kulikov K.N., Nizamutdinov R.A., Abramov A.N.	2011	
212	Decommissioning and dismantling solution development for volodarsky civil nuclear fleet support ship	Kulikov K.N., Nizamutdinov R.A., Abramov A.N., Tsubanikov A.I.	2009	
213	Identification of sustainable practices applied to ship recycling	Sant' Ana J.F., da Silva Filho A.B., Pereira N.N.	2023	
214	Development Strategy of Eco Ship Recycling Industrial Park	Sunaryo S., Aidane M.A.	2022	
215	Integrated ship recycling industrial estate design concept for Indonesia	Sunaryo, Tjitrosoemarto B.A.	2022	
216	Safe and Environment-friendly approach to recycling of Tanker ship	Shah Y.C.	2021	
217	Environmentally friendly ship recycling yard design for general cargo ship up to 30.000 DWT and ship-sets: Tug and barge	Sunaryo, Indianto A.F.	2020	
218	New hybrid induction cutting processes for ship salvage and recycling	Jones J.E., Rhoades V.L., Mann M.D., Surufka T.S., Dydo J.R., Holverson T.	2020	
219	A sustainable and preventative risk management model for ship recycling industry	Ozturkoglu Y., Kazancoglu Y., Ozkan-Ozen Y.D.	2019	
220	Estimating the amount of ship recycling activity using remote sensing application	Watagawa M., Shinoda T., Hasegawa K.	2016	
221	Guidance plan for ship recycling based on disassembly concept	Jayaram S., Sivaprasad K., Nandakumar C.G.	2015	
222	Influence of ship design on ship recycling	Jain K.P., Pruyn J.F.J., Hopman J.J.	2015	

#	Title	Authors	Year	Theme
223	Development and validation of three-step risk assessment method for ship recycling sector	Garmer K., Sjöström H., Hiremath A.M., Tilwankar A.K., Kinigalakis G., Asolekar S.R.	2015	
224	A methodology for a 'design for ship recycling'	McKenna S.A., Kurt R.E., Turan O.	2012	
225	Environmental friendly recycling of FRP-sandwich ship hulls	Hedlund-Åström A., Luttropp C., Reinholdsson P.	2005	
226	Recycling of ships made of glass reinforced polyester	Jastrzębska M., Rutkowska M., Jurczak W.	2005	
227	Green passport - Putting procedures into practice	Andersen A.B., Sverud T.	2005	
228	Closed supply network modelling for end-of-life ship remanufacturing	Chhetri P., Nikkhah M.J., Soleimani H., Shahparvari S., Shamlou A.	2022	

Table 5: Top Cited studies related to ship recycling.

ID	Name of paper	Authors, year	Source	Publisher	Citations	Theme	Aim of Study	Methodology	Category Quartile	Impact Factor
1	Distribution, enrichment and accumulation of heavy metals in coastal sediments of Alang-Sosiya ship scrapping yard, India	Reddy M.S. et al. (2004)	Marine Pollution Bulletin	Elsevier	140	Environment	The degree of heavy metal contamination has been studied in sediments from the intertidal zone of this ship scrapping yard	Total digestion technique is used to analyze samples	Q1	7.001
2	Holistic ship design optimization	Papanikolaou A. (2010)	Computer Aided Design	Elsevier	119	Technical	Provides a brief introduction to the holistic approach to ship design optimization by defining generic ship design optimization problems and demonstrates its solutions.	Advanced optimization techniques for the computer-aided generation	Q1	3.652
3	Seasonal distribution and contamination levels of total PHCs, PAHs and heavy metals in coastal waters of the Alang-Sosiya ship scrapping yard, Gulf of Cambay, India	Srinivasa Reddy M. et al. (2005)	Chemosphere	Elsevier	97	Environment	Investigate seasonal distribution and contamination levels of dissolved and/or dispersed total petroleum hydrocarbons (PHCs), total polycyclic aromatic hydrocarbons (PAHs) and heavy metals in seawater during high tide	Quantitative analysis of the possible relationships among 13 variables	Q1	8.943
4	Shipbreaking at Alang-Sosiya (India): An ecological distribution conflict	Demaria F. (2010)	Ecological Economics	Elsevier	94	Environment	The Alang-Sosiya yard (India) is studied with particular attention to toxic waste management	Data from interviews, official documents, direct and participant observation have been combined using the case study research methodology (Yin, 2003)	Q1	6.536
5	Heavy metals contamination levels at the Coast of Aliağa (Turkey) ship recycling zone	Neşer G. et al. (2012)	Marine Pollution Bulletin	Elsevier	77	Environment	Concentrations of heavy metals and organic carbon in sediment of the Aliağa Bay were investigated to evaluate an environmental risk assessment from metals contamination in 2009-2010	Total digestion technique and atomic absorption spectrophotometer	Q1	7.001

ID	Name of paper	Authors, year	Source	Publisher	Citations	Theme	Aim of Study	Methodology	Category Quartile	Impact Factor
6	Spatial and temporal variation and air-soil exchange of atmospheric PAHs and PCBs in an industrial region	Kaya E. et al. (2012)	Atmospheric Pollution Research	TUNCAP	74	Environment	Investigate air and soil samples in Aliaga industrial region in Izmir during different seasons in 2009 and 2010 to determine the spatial and seasonal variations of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs).	Ambient air samples were collected by passive sampling during four seasons in 2009 and 2010 at forty different sites in Aliaga Soil samples were also collected at the air sampling sites during the summer period	Q1	4.831
7	The effect of ship scrapping industry and its associated wastes on the biomass production and biodiversity of biota in in situ condition at Alang	Tewari A. et al. (2001)	Marine Pollution Bulletin	Elsevier	59	Environment	This research study the concentrations of heavy metals, petroleum hydrocarbons, and bacterial contamination in Alang industrial zone	Sampling using van veen graps, Total digestion technique is used to analyze samples	Q1	7.001
8	Ship recycling and marine pollution	Chang Y.-C. et al. (2010)	Marine Pollution Bulletin	Elsevier	56	Overview	This paper discusses the historical background, structure and enforcement of the '2009 Hong Kong International Convention on the Safe and Environmentally Sound Recycling of Ships.'	Review available information regarding Hong Kong International convention	Q1	7.001
9	The shipbreaking industry in Turkey: environmental, safety and health issues	Neşer G. et al. (2008)	Journal of Cleaner Production	Elsevier	53	Environment, Health & Safety	This study addresses the challenges that face Aliağa shipbreaking yards to claim green recycling capacity	Case study	Q1	11.072
10	Polycyclic aromatic and aliphatic hydrocarbons pollution at the coast of Aliaĝa (Turkey) ship recycling zone	Neşer G. et al. (2012)	Marine Pollution Bulletin	Elsevier	49	Environment	Polycyclic aromatic hydrocarbons (PAHs) and aliphatic hydrocarbons in sediment of the Aliaĝa Bay were investigated to evaluate an environmental risk assessment from PAHs contamination in 2009-2010	Threshold Effect Level (TEL) and Probable Effect Level (PEL) weight of evidence approach was used as sediment quality guideline	Q1	7.001
11	Quantification and classification of ship	Srinivasa Reddy M. (2003)	Marine Pollution Bulletin	Elsevier	46	Environment	Addressing different types of solid wastes generated from ship scrapping processes at Alang sosiya	The quantity and composition of these solid wastes were collected for a	Q1	7.001

ID	Name of paper	Authors, year	Source	Publisher	Citations	Theme	Aim of Study	Methodology	Category Quartile	Impact Factor
	scraping waste at Alang-Sosiya, India						shipbreaking yards, their composition and quantity.	period of three months and the average values are presented in this work.		
12	Monitoring the drastic growth of ship breaking yards in Sitakunda: A threat to the coastal environment of Bangladesh	Abdullah H.M. et al. (2013)	Environmental Monitoring and Assessment	Springer	45	Environment	Investigate the extent of ship breaking activities in Bangladesh along the Sitakunda coast and its effect on environment	various spatial and non-spatial data were obtained, including remote sensing imagery, statistical records and published reports.	Q2	3.307