Ship Recycling in Indonesia: Analysis of Compliance with National Regulations and International Standards

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This study employs a mixed-method approach, combining bibliometric mapping of sixty-two selected publications with a systematic qualitative analysis of twelve primary studies to analyse the implementation of ship recycling in Indonesia. It identifies critical gaps between national regulations and international standards, specifically the Hong Kong Convention (HKC). The findings reveal a fragmented regulatory landscape across environmental, maritime, and industrial sectors, resulting in a low average maturity level of 2.1 out of 4.0 among existing yards. The research highlights that only 16% of yards maintain adequate occupational health and safety (OHS) conditions, with hazardous practices, such as beaching and improper management of toxic metals (Pb, Hg, Cd), posing significant risks. With 20% of Indonesia's 37,722-vessel fleet, now exceeding thirty years of age, the study projects an urgent demand for managing two million tons of LDT scrap. The results emphasise that the primary barrier is not the absence of law but weak enforcement and infrastructure deficiencies. The paper proposes a transition towards centralised Ship Recycling Facility (SRF) hubs in strategic zones like Bojonegara and Kamal and the adoption of a service-provider business model to enhance sustainability and ensure full alignment with global HKC standards.

KEY WORDS
~ Ship recycling
~ Environmental impact
~ National regulations
~ International standards
~ Sustainable practices

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1. INTRODUCTION

Indonesia, as the world's largest archipelago, depends heavily on its vast maritime fleet, which includes over 25,000 registered ships (Buchary *et al.*, 2006; Supriyanto, 2015; Pulungan, 2024; Sari *et al.*, 2024,2025). A significant portion of these vessels are now over twenty-five years old and approaching the end of their service life (Fariya *et al.*, 2020). As these aging ships are phased out, responsible disposal through ship recycling becomes essential to mitigate environmental damage and recover valuable materials (Mannan *et al.*, 2024). When conducted under proper standards, ship recycling improves safety conditions for workers and allows for the recovery of materials like steel and aluminium (Mannan *et al.*, 2023). However, based on the (Akriananta and Suastika, 2017), it may be stated that the reality in Indonesia is that much of the activity remains informal and poorly regulated, particularly in areas like Cilincing and Madura, which lack basic safety procedures.

Although Indonesia has established several legal and institutional frameworks, primarily under the authority of the Ministry of Transportation, these regulations often fall short in their comprehensive implementation. More critically, they are not yet fully aligned with international agreements, such as the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (HKC) (Oktaviany, 2019; Prabowo, 2019). This misalignment leaves a wide regulatory gap that compromises both environmental standards and worker safety (Fariya *et al.*, 2020). The dominant method of ship recycling in Indonesia remains "beaching," a practice notorious for hazards such as exposure to toxic materials and unpredictable sea conditions (Fariya *et al.*, 2016; Mannan *et al.*, 2024). To address these issues, experts have pushed for "green" ship recycling yards equipped with modern technology, such as dry ice blasting and oxy-acetylene cutting (Sornn-Friese *et al.*, 2021; ElMenshawy *et al.*, 2024).

This effort ties in closely with broader environmental goals in the region, specifically the Association of Southeast Asian Nations (ASEAN) transition toward a circular economy. Ship recycling plays a key role in this transformation by reducing material waste and supporting economic resilience (Ramli and Michelle, 2023). Despite this potential, progress in Indonesia is limited by bureaucratic fragmentation and a lack of coordination. While countries like Bangladesh and India (Abdullah *et al.*, 2023; Günes *et al.*, 2024), are already investing in upgraded infrastructure, Indonesia is still positioned at a critical crossroads (Mannan *et al.*, 2024). This paper aims to bridge the existing knowledge gap by critically analysing Indonesia's current regulatory framework and its specific misalignments with the HKC. By evaluating the discrepancy between statutory requirements and on-ground practices, this research proposes actionable recommendations to align national maritime policies with global sustainability expectations.

While previous studies have touched upon the environmental impacts of shipbreaking, a significant knowledge gap exists regarding the quantitative maturity of Indonesian yards and the specific thematic alignment of national regulations with the Hong Kong Convention (HKC). Most existing literature focuses on technical modernisation without addressing the fragmented nature of the legal framework, comprising environmental, shipping, and industrial laws, that creates a "legal grey area" for operational compliance. Furthermore, there is a lack of synthesis regarding the projected scrap demand from Indonesia's rapidly aging fleet of 37,722 vessels against current facility capacities (Elizabeth *et al.*, 2024). To bridge these gaps, this research aims to map the scholarly landscape of ship recycling in Indonesia to identify dominant research themes and collaborative networks, while evaluating the discrepancy between the formal national regulatory framework and on-ground operational realities using empirical maturity indices. Consequently, the study proposes actionable strategic directions, such as centralised Ship Recycling Facility (SRF) hubs and integrated hazardous waste (B3) protocols, to align the domestic industry with international sustainability benchmarks. To achieve these objectives, the study utilises a three-stage analytical approach, beginning with a descriptive and bibliometric mapping analysis conducted in publications indexed in global databases extracted from Scopus, using VOSviewer to visualise keyword co-occurrences and subject area distributions. This is followed by a systematic qualitative review applied to twelve primary studies, specifically focused on Indonesian shipyards, extracting empirical data on maturity levels, OHS compliance percentages, and fleet age statistics in order to provide a robust evidentiary basis for the proposed policy reforms.

2. LITERATURE REVIEW

2.1. Ship Recycling

Ship recycling is the process of recycling end-of-life vessels to recover materials such as steel and non-ferrous metals for reuse. While this industry supports environmental sustainability through material recovery, it also poses significant risks to worker safety and environmental health, particularly in developing nations. Currently, recycling activities are concentrated in South Asia, specifically India, Bangladesh, and Pakistan, where standards for safety and environmental protection often remain insufficient. To mitigate these issues, the European Union (EU) has implemented the Ship Recycling

Regulation (SRR), ensuring that EU-flagged vessels are processed only in certified facilities (Solakivi et al., 2021; Hadjiyianni and Pouikli, 2024b).

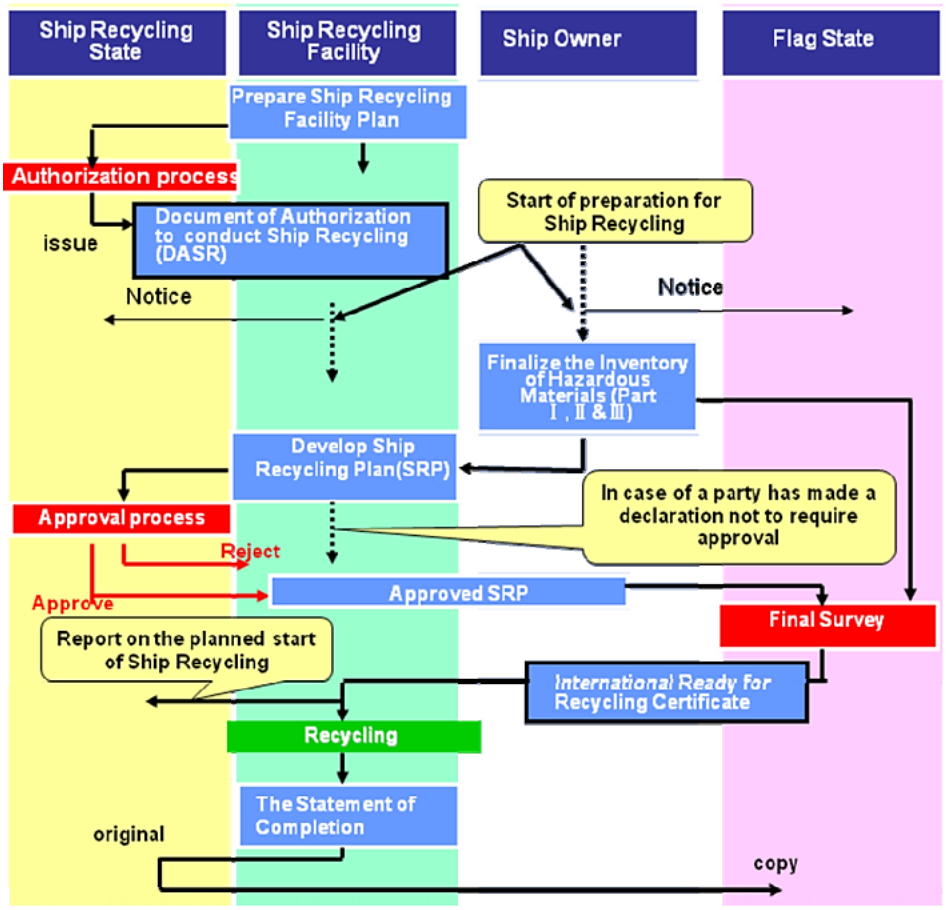

Figure 1. Ship Recycling Workflow (IMO, 2012a)

The standard workflow of ship recycling in Figure 1 involves the sale of vessels, transport to recycling yards, and the removal of hazardous materials like asbestos and oils. International efforts to standardise these practices have led to the International Maritime Organisation (IMO) guidelines and the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (HKC). Despite these frameworks, high implementation costs remain a barrier for major recycling nations. To improve the industry, international agreements like the Hong Kong Convention (HKC) and the EU's Ship Recycling Regulation (SRR) have established legal obligations focusing on safety and hazardous waste management (IMO, 2012a). However, global implementation faces significant hurdles; major recycling nations like Bangladesh and India often struggle to meet these requirements due to high operational costs (Chang *et al.*, 2010). For further regulatory alignment, the European Union has adopted regulations that require recycling yards to meet specific environmental and safety standards. While these regulations promote stricter measures, such as impermeable flooring and advanced waste systems, ongoing oversight remains essential to balance economic benefits with worker safety and environmental protection (Mikelis, 2008, 2019). Ultimately, the industry continues to face compliance challenges, particularly in developing countries where the majority of recycling activities occur.

2.2. Regulatory Frameworks for Ship Recycling

The regulatory frameworks governing ship recycling provide critical guidelines for ensuring safe and environmentally sound practices. The International Maritime Organisation (IMO) and other global bodies have established stringent rules to manage hazardous materials and protect worker health (Celik *et al.*, 2024). A cornerstone of these regulations is the Inventory of Hazardous Materials (IHM), which tracks substances like asbestos and heavy metals throughout a ship's life (Hiremath *et al.*, 2016) Under IMO regulations, shipowners must develop a Ship Recycling Plan (SRP), outlining safe recycling sequences (Turk Loydu, 2014). Furthermore, facilities must be authorised by competent authorities to handle toxic waste, and vessels must undergo surveys to verify compliance before recycling begins (Jain *et al.*, 2014). These protocols, supported by the HKC, ensure that ships are inspected and certified for responsible recycling (Hadjiyianni and Pouikli, 2024a). Table 1 below summarises some of the essential IMO regulations based on previous research by Sari and Darojat (2025).

IMO Rule	Summary of Requirements
Development of the Inventory of Hazardous Materials (IMO, 2023)	Vessels are required to compile and maintain a documented record of all dangerous substances on board (such as lead or asbestos), which must undergo periodic verification.
Development of the Ship Recycling Plan (IMO, 2011)	A dedicated strategy must be formulated for each vessel, detailing the chronological recycling steps and protocols for handling toxic waste.
Safe and Environmentally Sound Ship Recycling (IMO, 2012a)	Recycling yards are mandated to implement an operational roadmap designed to safeguard personnel, protect the ecosystem, and regulate hazardous substances.
Survey and Certification of Ships under the Hong Kong Convention (IMO, 2012c)	Before decommissioning, ships must be formally inspected to secure an International Certificate regarding their Inventory of Hazardous Materials.
Authorisation of Ship Recycling Facilities (IMO, 2012b)	Facilities are required to obtain official permits from governing bodies, proving their adherence to safety, ecological, and toxic material management criteria.
Inspection of Ships under the Hong Kong Convention (IMO, 2012d)	Authorities must conduct vessel examinations to confirm that all mandatory documentation is present and that hazardous materials are managed according to international law.

Table 1. Summary of International Maritime Organisation (IMO) Framework and Requirements for Ship Recycling

With proper regulations in place, this framework supports the development of a more sustainable and safe ship recycling industry. As noted in study by Alcaide *et al.* (2017), it highlights how the EU Ship Recycling Regulation has influenced the global industry by advocating for stricter safety and environmental standards.

3. METHODS

This research adopts a comprehensive three-stage methodology that can be seen in Figure 2, to analyse the study and implementation of ship recycling in Indonesia in accordance with national regulations and international standards. The first stage involves a descriptive analysis, where a preliminary search has been conducted across maritime databases, resulting in 62 sorted articles that provide a broad overview of Indonesia's maritime fleet and existing recycling landscape. The second stage focuses on a bibliometric analysis using VOSviewer software to evaluate research trends, influential authors, and international collaborations from 31 sorted articles. The third stage utilises a systematic analysis framework adapted from Sari et al. (2026), originally based on the PRISMA methodology by Page *et al.* (2020, 2021). This stage involves a deep qualitative evaluation of 12 primary articles to identify specific gaps between regulatory frameworks and actual shipyard practices in Indonesia.

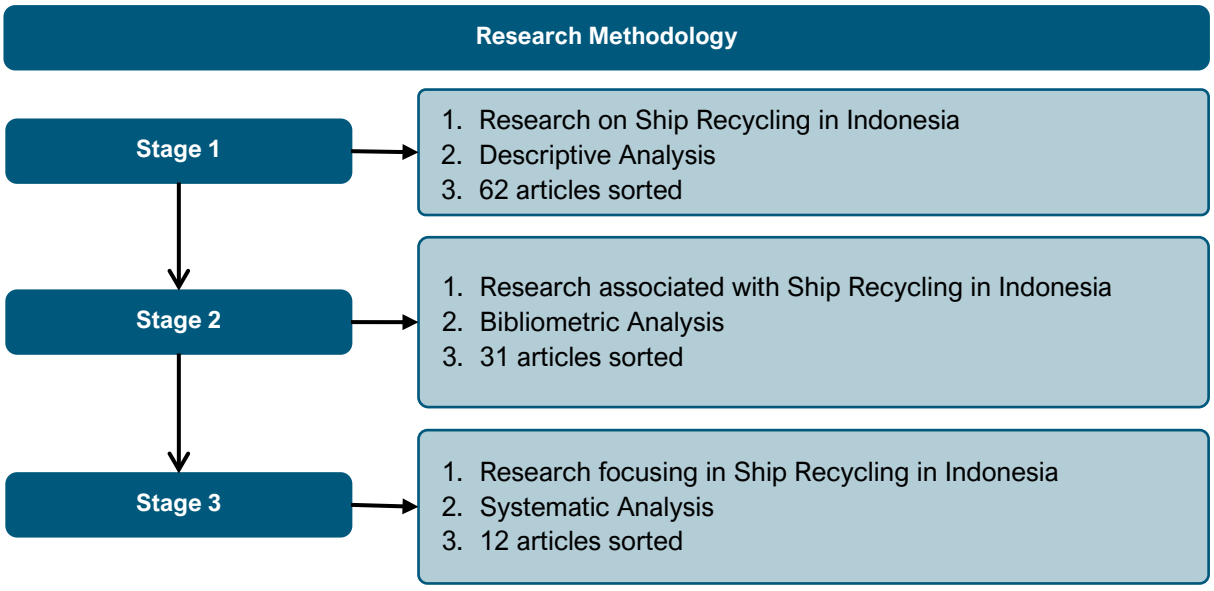

Figure 2. Three-Stage Research Methodology Framework

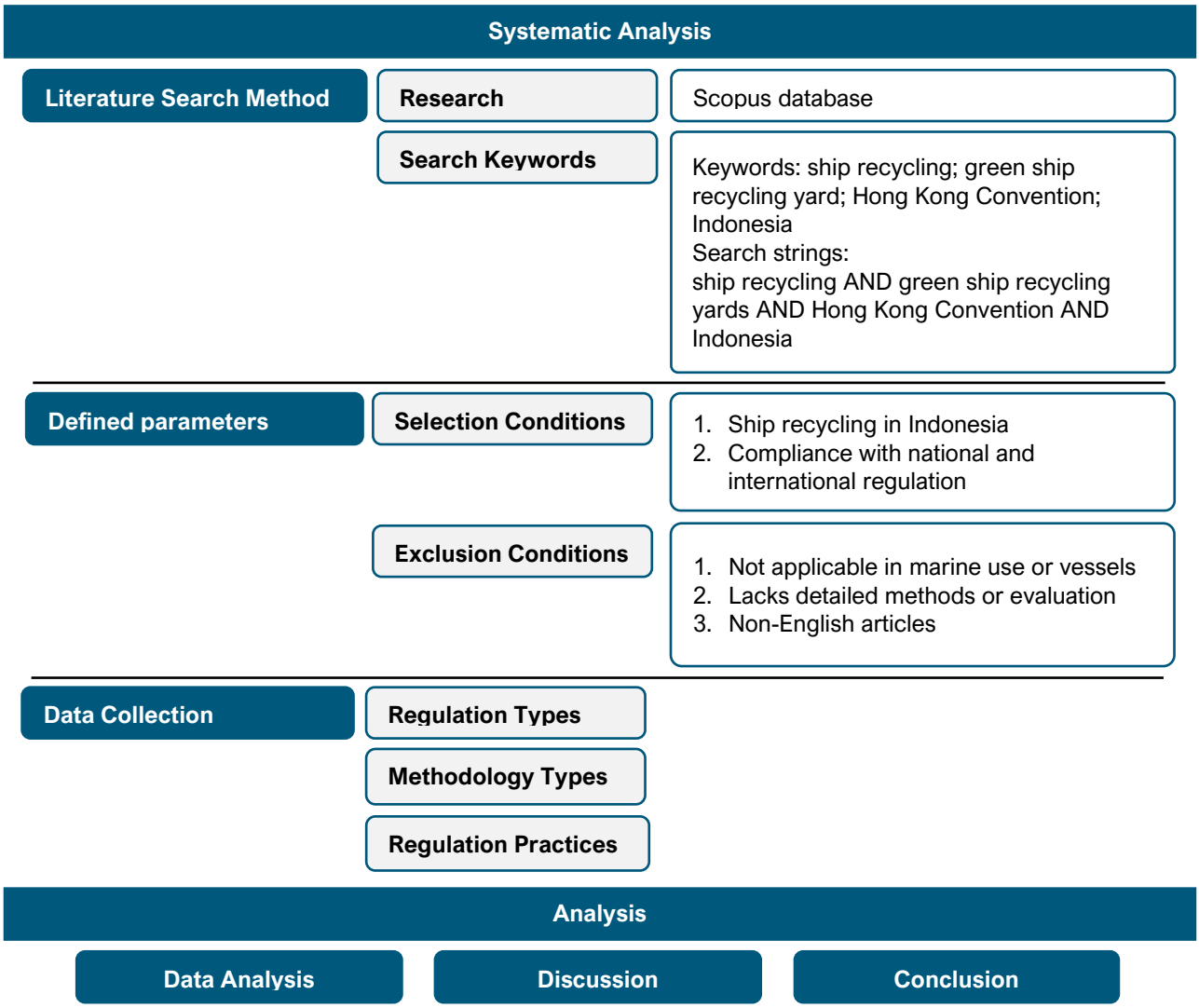

Figure 3. PRISMA Workflow

The systematic analysis stage specifically utilises the Scopus database as the primary data source. The literature search method employs a specific search string: “TITLE-ABS-KEY (ship recycling AND green ship recycling yards AND Hong Kong Convention AND Indonesia)" as illustrated in Figure 3. The search was limited to documents published between 2005 and 2025 to capture the evolution of the industry since Presidential Instruction No. 5/2005. The methodology defines parameters for selection by focusing on ship recycling within the Indonesian context and applies exclusion conditions for studies not applicable to marine vessels or those lacking detailed technical evaluation. Data collection is then categorised based on regulation types, methodology types, and recorded regulation practices to facilitate a rigorous analysis of the current industry status.

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Bibliometric and Literature Mapping Results

The descriptive analysis of 62 selected publications indicates that ship recycling research related to Indonesia is primarily concentrated within specific academic disciplines, providing a purely descriptive mapping of the current literature landscape. As illustrated in Figure 4, Environmental Science represents the largest subject area with 14 publications, followed closely by Engineering with 13 publications. This distribution reflects a dominant scholarly focus on environmental impacts, pollution control, and the technical modernisation of ship recycling facilities, rather than regulatory or policy-oriented analysis at this stage. Figure 4 shows the distribution of research across disciplines. The concentration on Environmental Science and Engineering highlights the technical nature of existing studies, which often prioritise pollution mitigation over legal framework analysis.

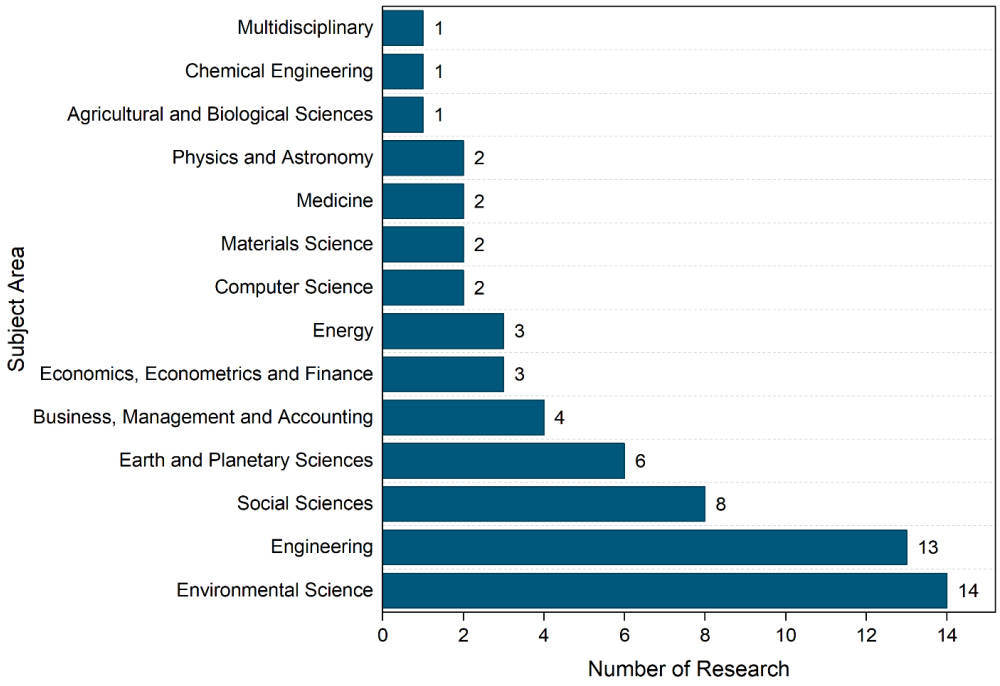

Figure 4. Distribution of Ship Recycling Research by Subject Area

The co-authorship analysis, conducted for authors with a minimum of three publications and five citations, shows Indonesia occupying a central position in the global research network. Figure 5 highlights authors such as Kurt, Rafet Emek (6 publications, 34 citations) and Gunbeyaz, Sefer Anil (5 publications, 33 citations), who demonstrate strong collaborative link strengths. Within the Indonesian research context, Sunaryo emerges as a key contributor with 4 publications and 45 citations, indicating a substantial impact on national-level ship recycling studies and policy-related discussions.

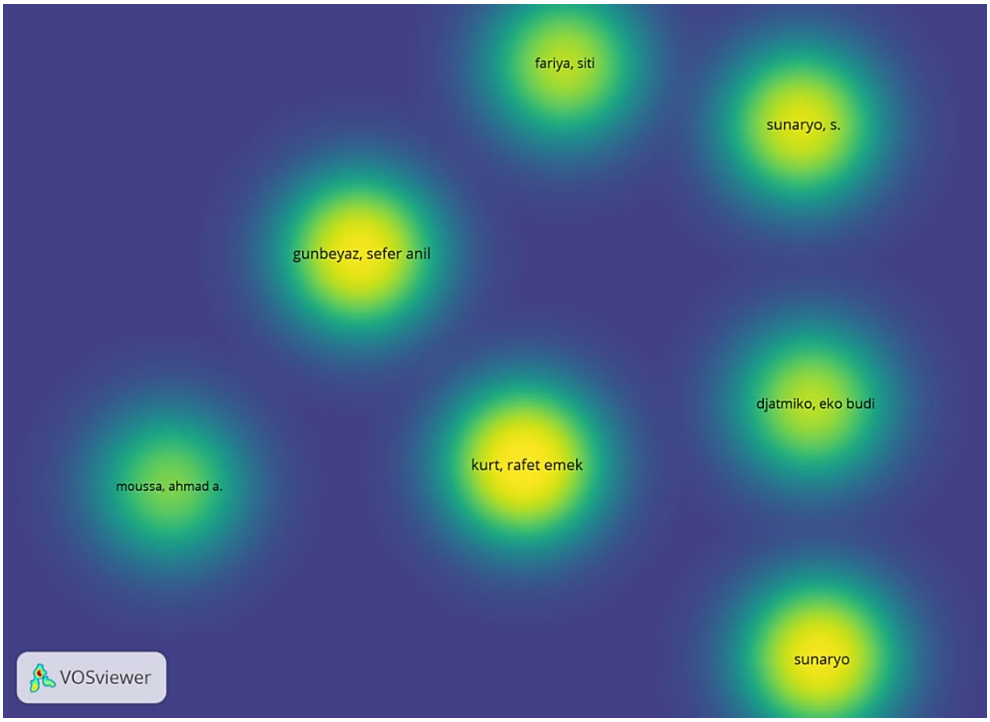

Figure 5. Co-authorship Network Density Map of Prominent Authors

An analysis of international research collaboration further reveals the global dimension of ship recycling studies related to Indonesia. As shown in Figure 6, Indonesia accounts for the highest number of publications (13 documents), while the United Kingdom exhibits the highest citation impact, with 89 citations derived from ten publications. This pattern suggests

that international collaboration plays a significant role in advancing analytical frameworks, particularly in relation to regulatory alignment and technological standards.

The conceptual structure of ship recycling research, as presented in Figure 7, identifies "ship recycling" as the central node. It is strongly linked with thematic clusters, such as “sustainable development,” “occupational health and safety,” and “gap analysis”. These clusters highlight a research trajectory moving towards environmental sustainability and the identification of operational mismatches. These thematic clusters form the analytical basis for examining regulatory alignment and implementation gaps in Indonesia.

Figure 6. Co-authorship Countries Network

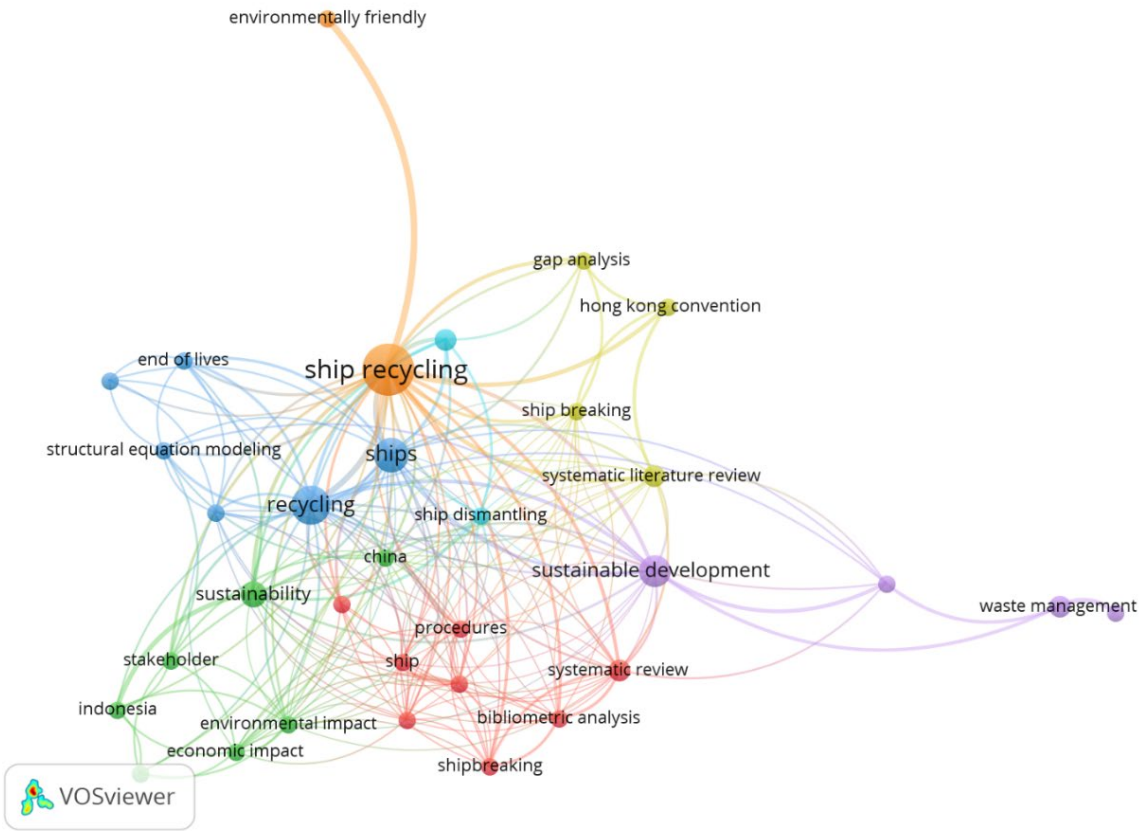

Figure 7. Mapping of Keywords Co-occurrence in Ship Recycling Research

4.1.2. National Regulatory Framework for Ship Recycling in Indonesia

Before identifying gaps, it is essential to establish the existing legal foundation. The systematic review identifies a broad, yet fragmented regulatory framework governing ship recycling activities in Indonesia. These regulations provide a fragmented but formal legal basis for ship recycling activities in Indonesia. As summarised in Table 2, the applicable national regulations are categorised into three primary groups:

a. Environmental Protection: Primarily governed by Law No. 32/2009 on Environmental Protection and Management and Government Regulation No. 101/2014 regarding the management of hazardous and toxic (B3) waste.
b. Shipping and Maritime Safety: Rooted in Law No. 17/2008 on Shipping and Government Regulation No. 21/2010 on Maritime Environmental Protection.
c. Industrial and Operational Regulations: Including Minister of Transportation Regulation No. PM 29/2014 (updated to PM 24/2022) and Government Regulation No. 31/2021 on the Implementation of the Shipping Sector.

Regulation	Regulatory Details and Scope
Minister of Transportation Regulation No. PM 29/2014, amended by No. PM 24/2022, on Maritime Environmental Pollution Prevention (Menteri Perhubungan RI, 2022)	Governs the administrative procedures, mandatory certifications, and oversight for recycling both Indonesian-flagged vessels and foreign ships within national territory.
Government Regulation No. 31/2021 on Implementation of the Shipping Sector (Republik Indonesia, 2021a)	Promotes the establishment of ship recycling facilities, while mandating adherence to international safety and ecological standards within the maritime sector.
Government Regulation No. 31/2021 on Risk-Based Business Licensing (Republik Indonesia, 2021b)	A risk-based licensing framework that governs business activities across multiple sectors, including maritime and industrial operations, by mandating specific environmental standards, safety certifications, and hazardous waste (B3) management protocols essential for the legal and sustainable operation of ship recycling facilities.
Government Regulation No. 31/2020 on the Addition of State Capital Participation of the Republic of Indonesia into the Share Capital of the Limited Liability Company (Persero) PT Permodalan Nasional Madani (Republik Indonesia, 2020)	Supports the expansion of maritime-related industries by providing capital to PT Permodalan Nasional Madani to stimulate investment in sustainable recycling technologies.
Circular Letter No. 19/PK/DK/2019 (Menteri Perhubungan RI, 2019)	Outlines specific operational guidelines to ensure that ship decommissioning processes align with environmental protection and safety benchmarks.
Minister of Industry Regulation No. 40/2016 on Industrial Estate Guidance (Republik Indonesia, 2016)	Contains provisions regarding industrial security and maritime operations essential for safe vessel decommissioning and shipyard activities.
Government Regulation No. 142/2015 on Industrial Estates (Republik Indonesia, 2015)	Directs the supervision of industrial estates for ship recycling, including operational protocols and certification requirements for decommissioning.
Ministry of Transportation Regulation No. 29/2014 on Prevention of Maritime Environmental Pollution (Menteri Perhubungan RI, 2014)	Mandates strict pollution prevention standards that must be implemented by all vessels undergoing the recycling process.
Government Regulation No. 101/2014 on the Management of Hazardous and Toxic Waste (Republik Indonesia, 2014)	Defines the legal framework for the handling and disposal of hazardous and toxic (B3) waste generated during maritime and recycling operations.
Government Regulation No. 21/2010 on Maritime Environmental Protection (Republik Indonesia, 2010)	Focuses on the protection of the marine environment through the mitigation and management of pollution from ship and port-related activities.
National Law No. 32/2009 on Environmental Protection and Management (Republik Indonesia, 2009)	Provides a broad statutory basis for environmental management, specifically addressing pollution risks associated with industrial ship recycling.
National Law No. 17/2008 on Shipping (Republik Indonesia, 2008)	Regulates general shipping activities, including safety protocols and maritime pollution controls applicable to the shipbreaking industry.
Presidential Instruction No. 5/2005 on Cabotage Principle (Republik Indonesia, 2005)	Affirms Indonesia's commitment to implementing international maritime standards, including those relevant to the national shipbreaking sector.

Table 2. National Regulations for Ship Recycling in Indonesia

Collectively, these regulations establish a formal legal basis for ship recycling operations; however, they were not designed as an integrated framework specifically aligned with international standards. While laws like Law No. 17/2008 and Law No. 32/2009 provide general obligations, critical elements required under the Hong Kong Convention (HKC), such as a mandatory Inventory of Hazardous Materials (IHM), a specific certification system for recycling facilities, and explicit prohibitions against harmful practices like beaching remain absent or insufficiently detailed within the current national framework.

4.1.3. Regulation–Practice Gaps Identified in Existing Studies

Based on a qualitative analysis of 12 primary studies, significant discrepancies exist between Indonesia's regulatory framework and actual shipyard practices. These gaps are not merely a result of missing laws but are driven by three primary factors: (1) systematic non-compliance despite existing regulations, (2) partial regulatory coverage, and (3) implementation barriers such as high costs and infrastructure deficiencies. It is important to note that not all identified gaps stem from the absence of regulations; many arise from weak enforcement and limited compliance at the yard level. These regulation–practice gaps, summarised in Table 3, reveal that non-compliance is widespread, even where regulatory instruments formally exist.

Ref. No	Author	Regulations Referenced	Regulation–Practice Gap
1	Sunaryo *et al.* (2020)	a. Presidential Instruction No. 5/2005 b. Ministry of Transportation Regulation No. 29/2014 c. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Ship recycling activities in Indonesia often neglect environmental and safety regulations. b. Many shipyards are not in compliance with the Hong Kong Convention. c. Hazardous waste (such as asbestos and PCBs) is frequently mismanaged.
2	Sunaryo and Indianto (2024)	a. Government Regulation No. 101/2014 b. Ministry of Transportation Regulation No. 29/2014 c. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Ship recycling often does not meet safety and environmental standards. b. Existing practices fail to meet safety and environmental standards; current yard layouts do not support the containment of toxic residues.
3	Sunaryo et al. (2021)	a. National Law No. 17/2008 b. Government Regulation No. 21/2010 c. Ministry of Transport Regulation No. PM 29/2014 d. Ministry of Transportation Regulation No. 29/2014 e. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Conventional yards do not follow regulations. b. Even modern yards do fully not comply, particularly regarding waste handling and IHM (Inventory of Hazardous Materials). c. Regulatory compliance is seen as costly and complicated.
4	Fariya *et al.* (2021)	a. IMO 2011 Development of the Ship Recycling Plan b. IMO 2012 Safe and Environmentally Sound Recycling of Ships c. IMO 2012 Inspection of Ships under the Hong Kong Convention	a. Indonesian yards often lack planning and awareness, leading to unsafe practices. b. Structured risk assessment tools, like the one proposed, aim to bridge this gap.
5	Agung and Afriansyah (2021)	a. National Law No. 17/2008 b. Government Regulation No. 31/2021 c. Ministry of Transportation Regulation No. 29/2014 d. Circular Letter No. 19/PK/DK/2019	a. Regulations only partially cover ship types (mainly ≥100 GT, but not clearly ≥500 GT). b. No enforcement clarity. c. Absence of prohibitions on harmful methods like beaching. d. Lack of compliance frameworks, leading to environmental risks and legal vulnerabilities.
6	Sunaryo and Tjitrosoemarto (2022)	a. Government Regulation No. 142/2015 b. Minister of Industry Regulation No. 40/2016 c. Ministry of Transportation Regulation No. 29/2014 d. Government Regulation No. 101/2014 e. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. No yard meets the complete national or international standards. b. The methods used are unsafe and harmful to the environment.
7	Sunaryo and Aidane (2022)	a. National Law No. 17/2008 b. Government Regulation No. 21/2010 c. Ministry of Transportation Regulation No. 29/2014 d. Government Regulation No. 101/2014 e. Government Regulation No. 142/2015 f. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. No facility meets both national and international standards. b. A major disconnect between regulation contents and on-ground practice.

8	Jamaluddin *et al.* (2022)	a. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Many yards do not meet basic safety and environmental standards. b. The average compliance (maturity) level is 2.1 out of 4. c. 55% of assessed items fall into the category of "non-existent or untreated."
9	Hariyanto *et al.* (2023)	a. National Law No. 17/2008 b. Government Regulation No. 31/2020 and No. 31/2021 c. Government Regulation No. 21/2010 d. Ministry of Transportation Regulation No. 29/2014 e. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Shipbreaking facilities are traditional, under-regulated, and use basic technology. b. Lack of compliance with environmental safety and occupational standards. c. There is a mismatch between IMO's Hong Kong Convention principles and actual field practices.
10	Mutmainnah *et al.* (2024a)	a. National Law No. 32/2009 b. Government Regulation No. 101/2014 c. IMO 2012 Safe and Environmentally Sound Recycling of Ships	a. Many shipbreaking yards operate with insufficient oversight, lack of B3 (hazardous waste) handling procedures, and non-compliance with safety standards.
11	Elizabeth *et al.* (2024)	a. National Law No. 17/2008 b. Presidential Instruction No. 5/2005 c. Minister of Transportation Regulation No. PM 29/2014, amended by No. PM 24/2022	a. Infrastructure gap exist, while the fleet grew from 6,041 ships in 2005 to 37,722 in 2022, yards lack the technical training and capacity to meet international standards.
12	Azhar *et al.* (2024)	a. Government Regulation No. 5/2021 b. National Law No. 32/2009	a. The low priority given to environmental criteria compared to economic factors. b. The practice in Indonesian shipyards often ignores waste management and energy efficiency standards set by the government.

Table 3. Study of Ship Recycling Practices and Identified Regulation–Practice Gaps in Indonesia

Thematic clusters identified in the literature further clarify the nature of these gaps. A primary concern lies in the systematic non-compliance regarding the handling of B3 waste and OHS, which is clearly reflected in the low maturity levels (2.1/4.0) found in field assessments. This issue is exacerbated by limitations in regulatory coverage; for instance, Law 17/2008 and PM 29/2014 do not yet explicitly mandate an Inventory of Hazardous Materials (IHM) for all domestic vessels. Compounding these challenges are significant implementation barriers, specifically the high cost of compliance and the persistent lack of specialised infrastructure, such as on-land recycling facilities that could replace the hazardous beaching method. Consequently, many yards continue to operate in a "legal grey area", where formal regulations exist but have little impact on daily operations.

4.1.4. Environmental and Occupational Safety Issues Identified

In addition to regulatory gaps, the reviewed studies document a range of environmental and occupational safety issues associated with ship recycling practices in Indonesia. Table 4 synthesises these findings, clarifying that the identified problems and strategic recommendations are derived from existing literature rather than the authors' independent proposals. Key issues identified include hazardous waste (B3) mismanagement, marine pollution from heavy metals, and significant OHS risks stemming from infrastructure deficiencies.

Ref. No	Environmental Issues	Recommendations
1	a. Contamination caused by toxic substances such as asbestos and PCBs. b. Insufficient infrastructure for secure waste containment and pollution mitigation.	a. Utilise a service provider business model to improve economic sustainability. b. Coordinate regulatory efforts between the Ministries of Industry, Transportation, and Environment. c. Develop ship recycling yards in strategic zones like Bojonegara, Banten, near major ports and steel mills. d. Form alliances with specialised hazardous waste processing plants.
2	High probability of toxic waste leakage and general marine pollution.	a. Establish specialised on-land ship recycling facilities. b. Enforce rigorous compliance with the Hong Kong Convention. c. Incorporate hazardous waste management systems directly into yard architecture. d. Partner with professional waste disposal organisations. e. Provision yards with advanced mechanical equipment and safety mechanisms.

3	Accumulation of poisonous waste in shorelines and heavy metal deposits (e.g., Pb, Hg, Cd) in seafloor sediments.	a. Ensure extensive distribution of regulations to all industry participants. b. Provide state-sponsored financial incentives. c. Streamline administrative registration workflows. d. Advocate for environmental management and OHS training. e. Harmonise and align all overlapping current regulations.
4	Ecological threats, including harmful emissions, fuel residues, and acoustic pollution.	a. Expand the use of the Three Step Online Tool for risk management. b. Foster deeper collaboration between interdisciplinary specialists. c. Launch more comprehensive education and awareness initiatives. d. Ensure state policies are synchronised with international risk standards.
5	Degradation of the marine environment and the potential for cross-border pollution.	a. Formally ratify the HKC and update domestic legislation accordingly. b. Create inclusive regulations that specifically cover vessels of 500 GT and above. c. Prohibit destructive practices such as beaching. d. Formulate technical manuals and rigorous inspection frameworks. e. Improve cooperation and legal enforcement between different agencies.
6	Broad environmental degradation and ineffective toxic (B3) waste handling.	a. Conceptualise and construct centralised ship recycling industrial zones. b. Integrate all necessary supporting industries within these zones. c. Ensure industrial zone layouts meet all legal mandates. d. Apply Block Plan strategies to maximise spatial efficiency.
7	a. Pollution profiles comparable to heavy manufacturing, involving hazardous chemicals and toxic metals. b. Poorly governed and inadequate waste processing systems.	a. Construct eco-friendly industrial parks based on global benchmarks. b. Deploy management models involving both public and private sectors. c. Focus on developing core infrastructure and ensuring legal adherence. d. Strengthen safety facilities and personnel training.
8	Worker contact with dangerous materials and absence of structured waste disposal.	a. Modernise existing facilities to meet Hong Kong Convention requirements. b. Deploy formal OHS management frameworks. c. Boost the quality of training and the use of protective gear (PPE). d. Strengthen government oversight and monitoring activities. e. Create Standard Operating Procedures for high-danger operations.
9	Inadequate management of hazardous (B3) materials.	a. Create ship recycling facility (SRF) hubs in Kamal and Bojonegara. b. Refine domestic laws to mirror the Hong Kong Convention. c. Attract capital investment through government-led incentives. d. Improve synergy between ship recycling, steel production, and waste management sectors.
10	a. Deterioration of soil and water quality due to paint, oil, and asbestos. b. Unsafe handling of toxic (B3) materials.	a. Realign domestic laws with the Hong Kong Convention. b. Fund infrastructure projects and technical training. c. Strengthen the coordination between various government bodies. d. Establish a unified national database for ship recycling analytics. e. Encourage public-private collaboration to modernise yards.
11	General water and soil contamination, air toxins from incinerating waste, and threats to worker health.	a. Set up rigorous and inclusive protocols for handling waste. b. Focus on legal reinforcement and stricter policing of rules. c. Prioritise skill development and capacity building. d. Invest in the technological advancement of recycling facilities.

Table 4. Environmental Issues and Recommended Strategic Actions for the Indonesian Ship Recycling Industry

Thematic synthesis of these findings highlights a critical need for structural reform within the Indonesian ship recycling sector. Central to the environmental challenge is the accumulation of heavy metals and toxic chemicals, such as Lead (Pb), Mercury (Hg), and Cadmium (Cd), which pose long-term risks to marine ecosystems and coastal soil quality, as documented by Sunaryo *et al.* (2021b). This ecological threat is exacerbated by the prevalence of traditional recycling methods that lack secure containment for hazardous materials like asbestos and polychlorinated biphenyls (PCBs), a concern emphasised by Mutmainnah *et al.* (2024b).

Furthermore, the safety of the workforce remains a primary concern; empirical evaluations by Jamaluddin et al. (2022) reveal that current facilities often operate with maturity levels as low as 2.1 out of 4.0, with only 16% of assessed yards maintaining adequate OHS conditions. The urgency of addressing these deficiencies is underscored by the scale of upcoming decommissioning needs; Elizabeth *et al.* (2024) point out that 20% of the national fleet is now over thirty years old, creating a projected two million tons of Light Displacement Tonnage (LDT) scrap that requires immediate management protocols. Addressing these systemic issues requires a transition toward eco-friendly industrial parks and centralised recycling hubs, such as the strategic zones proposed for Bojonegara and Kamal, which aim to integrate specialised B3 waste processing and modern infrastructure directly into the facility architecture to replace destructive beaching practices.

4.2. Discussion

4.2.1. National Regulations versus International Standards

A direct comparison between national laws and the Hong Kong Convention (HKC) reveals critical misalignments in procedural and technical requirements. While Indonesia has established a formal legal basis through Law No. 17/2008 and PM 24/2022, the current framework remains fragmented and lacks the integrated rigor mandated by international standards. Specifically, national regulations do not yet explicitly mandate an Inventory of Hazardous Materials (IHM) or a comprehensive certification system for yards equivalent to the HKC's Authorisation of Ship Recycling Facilities. Furthermore, the absence of an explicit prohibition on "beaching" allows this environmentally hazardous method to persist, despite its high potential for soil and marine contamination. These regulatory gaps signify that, while national laws provide general environmental protection, they do not fully incorporate the operational standards necessary for "green" ship recycling.

4.2.2. Compliance Issues in Existing Ship Recycling Practices

The primary challenge in Indonesia lies not only in regulatory alignment but in the persistent non-compliance observed at the yard level. Traditional yards, such as those in Madura and Cilincing, operate with a low maturity level (averaging 2.1 out of 4.0), where safety protocols and personal protective equipment (PPE) are often neglected. This low compliance results in severe environmental degradation; inadequate handling of toxic substances like asbestos, PCBs, and heavy metals (Pb, Hg, Cd) leads to significant contamination of coastal soil and marine ecosystems. These issues are exacerbated by a lack of specialised infrastructure for waste containment, leading to toxic fumes and oil residues leaking into surrounding waters. Empirical studies highlight that this degradation is particularly acute in yards utilising the beaching technique, where the lack of secure secondary containment facilitates the spread of hazardous materials into seafloor sediments.

4.2.3. Policy Implications and Study Limitations

The findings suggest that harmonising national regulations with the HKC is a necessary step but remains insufficient without robust enforcement and institutional coordination between the Ministries of Transportation, Industry, and Environment. A more coordinated approach is required to create a unified certification and monitoring process. However, this study acknowledges certain limitations: it is a review-based analysis derived from twelve primary academic sources and lacks direct field audits. While these sources provide a consistent consensus on the state of the industry, the lack of primary field data may limit the granularity of findings regarding real-time compliance improvements in specific modernising shipyards. Additionally, with 20% of Indonesia's fleet, which grew to 37,722 ships by 2022, being over thirty years old, the pressure on enforcement mechanisms will likely intensify as the demand for recycling services increases.

4.2.4. Strategic Directions for Sustainable Ship Recycling

To advance towards sustainability, Indonesia must adopt a multi-faceted strategy that moves beyond descriptive regulation towards structural reform. Establishing centralised Ship Recycling Facility (SRF) hubs in strategic locations such as Bojonegara or Kamal, which are located near major steel mills and ports, is critical for reducing the industry's environmental footprint. These hubs should integrate hazardous waste management systems directly into their architecture to ensure secure containment. Furthermore, adopting a "service provider" business model could enhance the financial viability of green facilities, providing the necessary capital for technological modernisation and HKC compliance. Ultimately, a phased ratification of the Hong Kong Convention is recommended to provide a clear roadmap for facility modernisation, ensuring that the projected two million tons of scrap steel generated from old vessels can be processed in a safe and environmentally sound manner.

5. CONCLUSION

The findings indicate that ship recycling practices in Indonesia face systemic challenges driven by a significant disconnect between a formal, albeit fragmented, regulatory framework and actual shipyard operations. The thematic mapping reveals that, while Environmental Science dominates the research landscape, regulatory implementation remains the primary barrier. Indonesia has established laws spanning environmental protection (Law 32/2009), shipping safety (Law 17/2008), and industrial licensing (PP 31/2021). However, weak enforcement has resulted in a low industry maturity level of 2.1 out of 4.0. Empirical evidence shows that only 16% of assessed facilities meet international OHS standards, leading to persistent reliance on hazardous "beaching" methods and the mismanagement of toxic substances like asbestos, PCBs, and heavy metals (Pb, Hg, Cd).

The urgency for reform is underscored by the fact that 20% of the national fleet is currently over thirty years old, necessitating the capacity to process approximately two million tons of LDT scrap steel. To address these issues, this research concludes that Indonesia must shift from fragmented oversight towards integrated management within centralised Ship Recycling Facility (SRF) hubs, specifically in strategic zones like Bojonegara and Kamal. Strengthening OHS enforcement through mandatory IHM (Inventory of Hazardous Materials) and adopting a "service provider" business model are essential steps to ensure financial viability. Ultimately, the phased ratification of the Hong Kong Convention (HKC) is not merely a legal requirement but a strategic necessity to transform Indonesia's ship recycling industry into a sustainable contributor to the global circular economy.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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