



## Integrating Green Ship Recycling into Indonesia's Circular Economy Roadmap: A Geoda-Based Spatial Analysis

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### Abstract

Indonesia holds a strategic opportunity to develop Green Ship Recycling (GSR) as part of its transition toward a circular economy, particularly with the obligation to ratify the Hong Kong International Convention (HKC) 2009 by June 2025. However, GSR has not been fully integrated into the Circular Economy Roadmap 2025–2045, despite pressing issues of hazardous waste, material efficiency, and sustainable resource management. This study aims to demonstrate the crucial role of GSR in Indonesia's circular economy and provide evidence-based policy recommendations for building a national GSR ecosystem. Data from 38 provinces were analyzed using GeoDa through multiple regression and spatial autocorrelation. The regression model shows a strong fit ( $R^2 = 0.829$ ; Adjusted  $R^2 = 0.803$ ;  $p < 0.001$ ), with metal recyclers ( $\beta = 1.166$ ), non-metal recyclers ( $\beta = 0.564$ ), and hazardous waste facilities ( $\beta = 0.141$ ) significantly supporting shipyard growth, while steel plants negatively affect development ( $\beta = -0.309$ ). Spatial autocorrelation and LISA cluster analysis identified Riau Islands, East Java, Jakarta, and West Java as strategic hubs for GSR cluster development. The findings highlight those shipyards, recyclers, waste handlers, and steel manufacturers tend to cluster spatially, reinforcing the feasibility of establishing integrated GSR ecosystems in Indonesia. Such clustering could reduce dependence on volatile raw material imports by strengthening domestic recycled steel supply chains. Overall, this study provides empirical support for integrating GSR into Indonesia's circular economy roadmap by enhancing cross-ministerial coordination, prioritizing cluster-based development, and ensuring alignment with HKC to promote sustainable and green ship recycling.

**Keywords:** Circular Economy, Geoda, Green Ship Recycling, Hong Kong Convention, Spatial Analysis

### 1. Introduction

The circular economy is an economic model designed to maximize the value of products, materials, and resources for as long as possible, thereby reducing waste generation (Perivier et al., 2022). This model contributes to reduced waste production and resource costs, thereby reducing risks in the supply chain, pollution, and climate change, and can provide added value to the ecosystem (Tola et al., 2023a). The "6R" approach—recovery, redesign, and remanufacture, while reduce, reuse, and recycle are fundamental principles, maximize resource efficiency and minimize environmental impacts such as CO<sub>2</sub> emissions (Okumus et al., 2023).

Indonesia, as a maritime country, has a large shipping industry, including the ship recycling sector (Surjadi, 2023). In the context of a circular economy, Green Ship Recycling (GSR) aims to recycle ships in an environmentally friendly and sustainable manner (Fariya, 2018). The International Maritime Organization (IMO) (Maritime Organization, 1978) has created the IMO Guidelines on Ship Recycling, issued in 2009 through the Hong Kong International Convention, to ensure that ships being recycled after reaching the end of their operational life do not pose unwanted risks to human safety and health or the environment (Otsubo,

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2014). Meanwhile, on June 26, 2025, Indonesia, as a member of the International Maritime Organization (IMO), must have ratified the Hong Kong International Convention (2009) for the Safe and Environmentally Sound Recycling of Ships.

GSR presents considerable circular economic opportunities. It can absorb thousands of workers in coastal shipyards. (Sunaryo & Mutmainnah, 2025) and meet the growing demand for recycled steel in construction, automotive, and shipbuilding (Hariyanto et al., 2023) with nearly 14,000 vessels registered by BKI in 2023, about 40% of which are reaching end-of-life. This is particularly relevant for the Indonesian Iron and Steel Industry Association (IISIA), as Indonesia has imported an average of 1.64 million tons of steel annually over the past decade, a figure expected to rise. Using EoL ships can therefore reduce import dependency while strengthening domestic supply chains (Okumus et al., 2024).

The importance of this study is heightened by Indonesia's current development trajectory. Rapid resource-based industrial expansion, especially in coastal and port areas, is increasing pressure on environmental quality, waste governance, and industrial sustainability. At the same time, environmental governance challenges remain persistent, including uneven hazardous waste handling capacity, fragmented institutional coordination, and disparities in industrial readiness across provinces. In this context, the absence of GSR from Indonesia's strategic circular economy agenda represents not only a policy gap but also a missed opportunity to align maritime industrial development with resource efficiency and low-carbon transition goals.

This issue is particularly timely because Indonesia's Low Carbon Development Indonesia (LCDI) agenda and Circular Economy Roadmap 2025–2045 currently prioritize sectors such as food, plastics, electronics, construction, and textiles (Bappenas, 2024). while transportation manufacturing, including ship recycling, remains largely overlooked. For instance, ship recycling can avoid substantial environmental impacts relative to primary steel production, which remains highly carbon intensive (Rahman & Kim, 2020). As steelmaking contributes around one-quarter of global industrial CO<sub>2</sub> emissions, ship-derived scrap steel offers an important decarbonization opportunity. This omission is significant because evidence from other regions shows that circular practices in dismantling and recycling industries can generate major environmental and economic gains. Countries like China have demonstrated that policy-driven green recycling (Steuer et al., 2021) can enhance competitiveness, while developing nations gain socioeconomic benefits through scrap recovery, job creation, and industrial growth (Mannan et al., 2024).

Globally, the ship recycling industry is dominated by Bangladesh, India, and Pakistan, which together account for more than 80% of scrapping volumes (UNCTAD, 2022). At the same time, volatility in global steel prices highlights the vulnerability of industries that depend on primary raw materials (Trading Economics, 2025). Recycled steel already accounts for about 30% of production (Jain & Pruyn, 2020), and demand is projected to grow as industries pursue emission reduction targets. Expanding GSR in Indonesia could therefore strengthen industrial resilience, improve raw material self-sufficiency, and support national decarbonization efforts. However, policy support remains limited, and spatial evidence on the distribution of supporting actors is still lacking.

Accordingly, this paper examines the strategic role of green ship recycling in Indonesia's circular economy transition and addresses the current policy gap through a GeoDa-based spatial analysis. By identifying potential GSR clusters and regional disparities in ecosystem readiness, this study provides evidence-based insights to support the integration of green ship recycling into Indonesia's Circular Economy Roadmap 2025–2045.

## **2. Methods**

This study adopts a quantitative spatial approach using GeoDa to examine the integration of green ship recycling into Indonesia's circular economy roadmap. The analysis focuses on the spatial linkages between ship recycling yards and supporting actors, including port authorities, scrap recyclers, waste handling facilities, and steel manufacturers. Spatial analytical tools, including multiple linear regression, Moran's I, and LISA, are applied to assess spatial relationships and identify clustering patterns or potential hotspots. The results are then visualized through thematic maps and interpreted to highlight key opportunities, regional disparities, and policy directions for integrating GSR into the national circular economy agenda.

### **2.1 Data Collection**

The GSR ecosystem can be analyzed to determine whether the areas are interconnected between ship recycling yard and scrap dealer companies, waste handling facilities, port authorities, and other stakeholders (Sornn-Friese et al., 2021). In this study, data on these variables were compiled at the provincial level to capture the distribution and relative concentration of facilities that constitute the GSR ecosystem in Indonesia (Table 1). This provincial mapping is important because the viability of green ship recycling depends not only on the existence of individual actors, but also on their territorial co-location and functional proximity within a regional value chain. Several interdependent actors play critical roles in this ecosystem.

- 1) Port Authority (KSOP I–IV): Operating under PM No. 36 of 2012, the Harbormaster and Port Authority Offices are responsible for the regulation, control, and supervision of commercial port activities. Their oversight ensures that ship dismantling and recycling activities remain compliant with maritime safety and environmental protection standards.
- 2) Ship Recycling Yards (KBLI 33151): dismantle end-of-life vessels through sorting, shredding, and hazardous waste segregation. Registered under the Ministry of Industry of the Republic of Indonesia through the SIIINas (National Industrial Information System), these yards often rely on

- subcontractors such as metal scrap recyclers, dealers, and waste management firms. Sustainable spatial planning and integrated coastal management are therefore critical to support environmentally friendly ship recycling (Jambak et al., 2025).
- 3) Waste Management Companies: Essential for handling hazardous materials (waste), such as oils, chemicals, asbestos, and heavy metals generated during ship dismantling. Permits are issued by the Ministry of Environment and Forestry (KLHK), ensuring that hazardous waste is managed safely in accordance with environmental regulations PP No. 101 of 2014. Effective circular economy planning requires spatially informed location choices to ensure sustainable waste management (Parwoto et al., 2025).
  - 4) Metal and Non-Metal Recyclers: KBLI 38301 covers the recycling of ferrous and non-ferrous metal scrap into secondary materials, directly contributing to steel production. KBLI 38302 focuses on recycling non-metallic materials into industrial supply chains. Not only contributes to a circular economy but also minimizes the environmental impacts associated with landfill operations (Widyarsana et al., 2025).
  - 5) Scrap Dealers: Function as intermediaries and link shipbreaking operations with connecting upstream dismantling operations with downstream steelmaking processes (steel manufacture), such as basic iron (KBLI 24101) and steel milling (KBLI 24102).

Table 1: Number of Actors in the Green Ship Recycling (GSR) Ecosystem by Province

Province	Ship Recycling Yard	Port Authority	Metal Recyclers	Non-Metal Recyclers	Waste Handling	Steel Manufacture
Aceh	0	5	0	0	2	0
Bali	0	3	0	1	0	1
Banten	5	1	5	25	16	70
Bengkulu	1	1	0	0	0	0
DI Yogyakarta	0	0	0	0	0	0
DKI Jakarta	9	5	2	4	46	18
Gorontalo	0	2	0	0	0	0
Jambi	1	3	0	2	2	0
West Java	2	2	2	21	40	50
Central Java	9	3	1	12	8	11
East Java	12	7	12	25	20	56
West Kalimantan	5	3	0	0	3	2
South Kalimantan	7	3	0	1	0	2
Central Kalimantan	0	6	0	0	0	0
East Kalimantan	8	4	0	0	4	1
North Kalimantan	1	1	0	0	0	1
Bangka Belitung Islands	1	3	0	1	0	0
Riau Islands	28	3	12	21	5	4
Lampung	0	2	0	0	3	1
Maluku	0	2	0	0	0	0
North Maluku	0	1	0	0	0	1
West Nusa Tenggara	2	3	0	0	1	0
East Nusa Tenggara	0	5	0	0	0	0
Papua	0	3	0	0	0	0
West Papua Barat	0	2	0	0	0	0
Southwest Papua	0	0	0	0	0	0
Highland Papua	0	0	0	0	0	0
South Papua	0	0	0	0	0	0
Central Papua	0	0	0	0	0	0
Riau	1	9	0	2	7	1
West Sulawesi	0	0	0	0	0	1
South Sulawesi	2	2	0	1	1	5
Central Sulawesi	0	2	1	0	0	8
Southeast Sulawesi	3	2	0	0	0	0
North Sulawesi	1	2	0	0	0	1
West Sumatera	0	1	0	1	0	2
South Sumatera	1	2	0	0	2	1
North Sumatera	0	6	1	0	4	12

As shown in Table 1, the distribution of GSR actors is highly uneven across provinces. A small number of provinces, such as Riau Islands, East Java, DKI Jakarta, Banten, and West Java, exhibit a relatively more complete ecosystem structure, indicating stronger readiness for GSR development. By contrast, many other provinces still show limited actor presence, suggesting fragmented value-chain support and weaker institutional or industrial capacity. Thus, the key message of the table is that GSR readiness in Indonesia is spatially differentiated rather than nationally uniform. This descriptive evidence supports the overall objective of the study by providing the empirical basis for the subsequent GeoDa-based spatial analysis, which examines whether these actors are spatially concentrated, clustered, or dispersed across Indonesia and identifies where major ecosystem gaps remain.

## 2.2 Data Processing using GeoDa

Regression analysis is an analysis that can be used to measure the influence of an independent variable on a dependent variable. The multiple regression method uses equations to calculate data (Wuryandari et al., 2014). Inferential analysis illustrates the influence of one dependent variable (Y) on five independent variables (X). The research used GeoDA data processing software. Multiple Linear Regression:

$$Y = \beta_0 + \beta_1.X_1 + \beta_2.X_2 + \beta_3.X_3 + \beta_4.X_4 + \beta_5.X_5 + e \quad (1)$$

Y: Ship Recycling Yard

$\beta_0$ : Constant

$\beta_1$ - $\beta_5$ : Variable Regression Coefficient

e: Error/Remainder

X: Independent variables

X<sub>1</sub>: Port Authority (KSOP)

X<sub>2</sub>: Metal Recyclers

X<sub>3</sub>: Non-Metal Recyclers

X<sub>4</sub>: Waste Handling

X<sub>5</sub>: Steel Manufacture

Spatial autocorrelation measurements for spatial data can be calculated using the Moran's Index method. In this study, the analysis method is limited to the Moran's Index method. The Moran's Index (Moran's I) is the most widely used method for calculating global spatial (Gede et al., 2018). This method can indicate clustered patterns or trends in space. For this case, n = 38 provinces and p = 5 variables, each variable is standardized as follows:

$$z_{ik} = \frac{(x_{ik} - \bar{x}_k)}{s_k} \quad (2)$$

The standardized feature vector for province *i* is:

$$z_i = [z_{i1}, z_{i2}, \dots, z_{i5}]^T \quad (3)$$

The spatial lag vector is computed as:

$$(WZ)_i = \sum_{j=1}^n w_{ij}z_j \quad (4)$$

Then the Multivariate Local Moran's I for province is:

$$I_i^{MV} = z_i^T (WZ)_i = \sum_{k=1}^5 z_{ik} \left( \sum_{j=1}^{38} w_{ij}z_j \right) \quad (5)$$

Where:

*n* = number of analysis units (in this case, 38 provinces).

*i* = province

*j* = neighboring province

*k* = variable (e.g., there are 5 variables: KSOP port, metal recycling, non-metal recycling, waste handling, and steel manufacture).

*x<sub>i</sub>* = variable value in province *i*.

$\bar{x}$  = average across all provinces.

*s* or *s<sub>k</sub>* = standard deviation for the variable (univariate or k-th).

*w<sub>ij</sub>* = element of the spatial weight matrix *W*

The range of Moran's Index values in the case of a standardized spatial weighting matrix is  $-1 \leq I \leq 1$ . A value of  $-1 \leq I < 0$  indicates negative spatial autocorrelation, whereas a value of  $0 < I \leq 1$  indicates positive spatial autocorrelation (Aditya Putri, 2023). A Moran's Index value of zero indicates no clustering. The Moran's Index value does not guarantee measurement accuracy if the weighting matrix used is an unstandardized weighting matrix. To identify the presence of spatial autocorrelation, a Moran's Index significance test is performed. In GeoDa, both univariate and multivariate Local Moran's I can be computed directly. Moran Scatterplot can be used to identify spatial balance or influence, LISA (Local Indicators of Spatial Association). According to Zhukov (2010), the quadrants in the Moran Scatterplot are as follows:

- 1) High-High (HH): High values surrounded by high values are potential industrial clusters.
- 2) Low-Low (LL): Low values surrounded by low values are underdeveloped areas.
- 3) High-Low (HL): High values surrounded by low values are positive outliers.
- 4) Low-High (LH): Low values surrounded by high values are negative outliers.

LISA results indicate local spatial association (HH, LL) and outliers (HL, LH) and should not be interpreted as causality. The identified clusters are sensitive to the spatial weight matrix (*W*) specification and row-standardization, and LISA also involves multiple local significance tests, so cluster maps should be treated as indicative hotspots for planning follow-up rather than definitive evidence. Since the analysis is at the provincial level, results may be affected by scale/boundary effects (MAUP).

### 3. Result and Discussion

Indonesia has a strategic location, and several shipyards have begun implementing environmentally friendly practices, although they are still in their preliminary stages (Sulistyoningrum, 2023). The requirements for the effective entry into force of the Hong Kong International Convention (HKC) 2009 were fulfilled on June 26, 2023, namely, a minimum of 15 countries ratifying, covering 40% of the world's merchant ships' GT, and 3% of ship recycling volume (Hariyanto et al., 2024). With 22 countries as of June 2023, HKC officially came into effect in June 2025 for all IMO members, including Indonesia.

Through the Regulation of the Minister of Transportation of the Republic of Indonesia Number 24 of 2022, especially Articles 51–55 supporting the implementation of the Hong Kong Convention (HKC). Starting from the need for an inspection before issuing a certificate of readiness for disposal, the inspection includes a list of hazardous material inventories, disposal plans, and authorization requirements for the implementation of disposal facilities (Hariyanto et al., 2024).

The development of Green Ship Recycling in coastal areas of Indonesia must consider several strategic spatial factors. Proximity to international shipping lanes is a major aspect because it determines the ease of access to used ships to be recycled. In addition, the availability of 99 existing shipyards or ship recycling facilities (Figure 1) is the initial capital for conversion to a more environmentally friendly system. The map displays the geographical distribution of ship recycling and repair companies classified under KBLI 33151 across Indonesia. The spatial pattern shows clusters of companies concentrated in Java, Sumatra, and Kalimantan, with additional facilities spread across Sulawesi, Maluku, Papua, and other coastal regions. This distribution highlights the strategic positioning of green ship recycling industries near major maritime routes and port cities.



Figure 1. Displays a list of Shipyards using Google Earth based on KBLI code 33151 and regional.

#### 3.1 Interpretation of Multiple Linier Regression

The regression analysis shows a Multiple R value of 0.91 (Table 2), which indicates a strong positive correlation between the dependent variable and the set of independent variables. The R-Square (0.829) suggests that approximately 82.9% of the variation in the dependent variable can be explained by the independent variables included in the model. This indicates an elevated level of explanatory power. The adjusted R Square (0.803), which accounts for the number of predictors and sample size (38 observations), confirms the robustness of the model, showing that over 80% of the variability is still explained even after adjustment.

Table 2. Result Regression Classic

Multiple R	R Square	Adjusted Square	R	Standard Error	Observations	Significance F
0.91037471	0.828782113	0.802840008		2.311379895	38	9.74855E-12

The standard error of 2.31 reflects the average distance that the observed values fall from the regression line. Given the scale of the dependent variable, this error level appears low, supporting the accuracy of predictions. Finally, the significance F value ( $9.75 \times 10^{-12}$ ), confirming that the predictors jointly contribute to explaining ship recycling yard distribution.

Table 3. Result Regression Statistics

Variable	Coefficients	Standard Error	t-Statistic	Probability
Intercept	1.037859272	0.603823632	1.718811946	0.095018023
Port Authority	0.044016521	0.195359548	0.225310312	0.82312738

Variable	Coefficients	Standard Error	t-Statistic	Probability
Metal Recyclers	1.166100325	0.289799165	4.02382224	0.00031444
Non-Metal Recyclers	0.563793174	0.17278001	3.263069454	0.002566361
Waste Handling	0.140649044	0.053376392	2.635042179	0.012714861
Steel Manufacture	-0.30861046	0.055575893	-5.55295537	3.60525E-06

Metal recyclers show the strongest positive association with ship recycling yard development ( $\beta = 1.166$ ,  $p < 0.001$ ), followed by non-metal recyclers ( $\beta = 0.564$ ,  $p = 0.003$ ). Hazardous waste handling capacity also contributes positively ( $\beta = 0.141$ ,  $p = 0.013$ ), highlighting the role of environmental infrastructure in supporting GSR operations. In contrast, port authority presence is not a significant predictor ( $\beta = 0.044$ ,  $p = 0.823$ ), suggesting that administrative oversight alone does not translate into yard development. Steel manufacture is negatively associated with ship recycling yards ( $\beta = -0.309$ ,  $p < 0.001$ ), indicating that provinces with stronger steel production may rely more on existing industrial pathways or compete for inputs, reducing the development of dedicated ship recycling yards.

### 3.2 Integration Spatial Analysis using LISA (Local Indicators of Spatial Association) and Moran Scatterplot

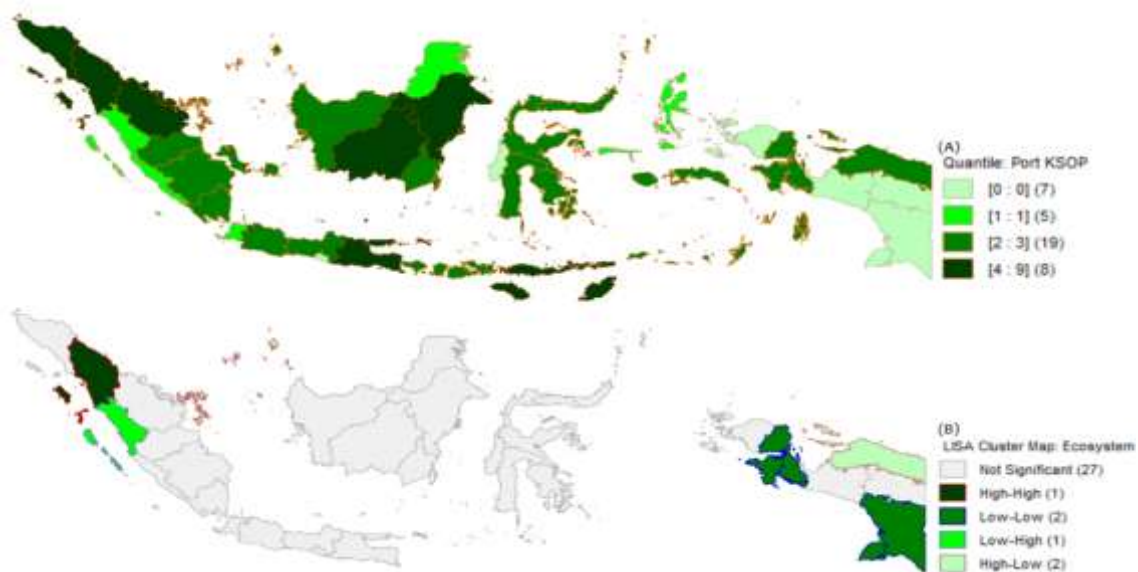


Figure 2 Spatial Distribution of KSOP Port Authorities and Ecosystem Clusters in Indonesia.  
Source: Data analysis of 99 port authority KSOP I-IV in PM No. 36 of 2012.

Map (A) shows the distribution of KSOP (Port Authority Offices) across Indonesian provinces using quantile classification (Figure 2). Darker colors indicate provinces with a higher number of KSOP offices, reflecting stronger institutional presence in port governance and highlighting the uneven distribution of port administrative infrastructure across Indonesia. Map (B) presents the LISA (Local Indicators of Spatial Association) cluster map, which identifies spatial clustering patterns of the maritime ecosystem related to ship recycling development. High-High and High-Low cluster (e.g., Northern Sumatra & Riau Islands) can be prioritized as a core ecosystem hub for national GSR development. Low-Low (e.g., parts of Papua) are underdeveloped areas and Low-High areas (West Sumatra) where ecosystem infrastructure is lacking, and targeted investment or coordination is needed. The comparison of the two maps indicates that the presence of KSOP offices does not necessarily correspond with spatial clusters of ship recycling ecosystem development, suggesting that port governance institutions alone are not a statistically significant factor in the establishment of ship recycling yards.



Figure 3 Spatial Distribution of Metal Recyclers and Ecosystem Clusters in Indonesia.  
 Source: Data analysis of 36 metal recyclers from KBLI 38301 through SIINas in July 2025.

Map (A) shows an uneven spatial distribution of metal recycling infrastructure, with activities concentrated in several regions while many provinces have limited or no facilities (Figure 3). Map (B) presents the LISA cluster map, which identifies spatial relationships within the metal recycling ecosystem. High–Low clusters (e.g., the Riau Islands) indicate areas with relatively strong local recycling activity surrounded by weaker neighboring regions, suggesting potential strategic hubs for expanding the national metal recycling ecosystem. Low–High clusters (e.g., Central Java) represent areas with limited local recycling infrastructure despite stronger surrounding regions, indicating the need for targeted investment and infrastructure development. These findings suggest that metal recyclers play a significant role in supporting ship recycling development, as provinces with more metal recycling facilities show a higher likelihood of establishing ship recycling yards.



Figure 4 Spatial Distribution of Non-Metal Recyclers and Ecosystem Clusters in Indonesia.  
 Source: Data analysis of 117 non-metal recyclers from KBLI 38302 through SIINas in July 2025.

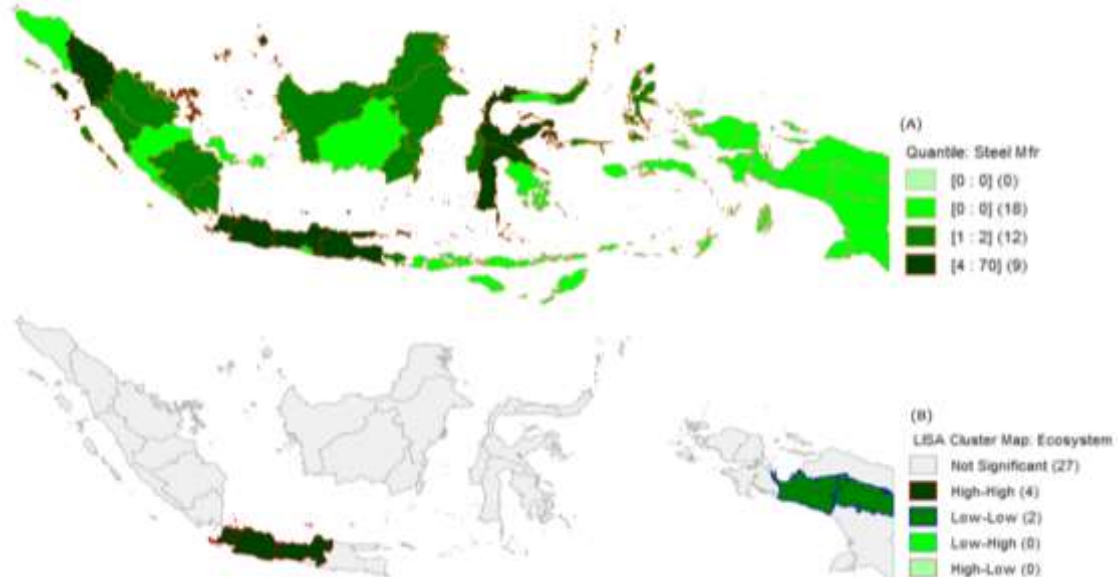
Map (A) shows an uneven spatial distribution of non-metal recycling infrastructure across Indonesia, with activities concentrated in only a limited number of provinces while many others have very few or no facilities at all (Figure 4). Map (B) presents the LISA cluster map, which identifies spatial relationships within the non-metal recycling ecosystem. High–High clusters, such as West Java, DKI Jakarta, and Central Java, indicate provinces with strong local non-metal recycling activity that are also surrounded by areas with relatively supportive ecosystem performance, suggesting core regions for strengthening circular economy integration. High–Low clusters, such as the Riau Islands, represent provinces with relatively strong local recycling activity but weaker surrounding areas, indicating their potential role as strategic hubs for wider ecosystem expansion. These findings suggest that non-metal recyclers also have an important supporting

role in ship recycling development, particularly in provinces where stronger recycling ecosystems may enhance the potential for integrated and sustainable green ship recycling practices.



*Figure 5 Spatial Distribution of Waste Handling and Ecosystem Clusters in Indonesia.*  
 Source: Data analysis of 164 hazardous waste facilities permitted by KLHK, access in July 2025.

Map (A) shows an uneven spatial distribution of hazardous waste handling facilities across Indonesia, with activity concentrated in a limited number of provinces while many others have relatively low or no facility presence (Figure 5). Map (B) presents the LISA cluster map. High–High clusters, such as West Java and parts of East Java, indicate provinces with strong local concentrations of hazardous waste management facilities that are also surrounded by areas with similarly strong ecosystem performance, suggesting major hubs for integrated waste handling and circular economy support. High–Low clusters, such as the Riau Islands, represent provinces with relatively strong local waste handling activity but weaker surrounding regions, indicating spatial isolation despite local capacity. These findings suggest that hazardous waste facilities are an essential supporting component for green ship recycling development, since provinces with stronger waste handling ecosystems are more likely to provide the environmental infrastructure required for safe and sustainable ship recycling operations.



*Figure 6 Spatial distribution of Steel manufacture and Ecosystem Cluster in Indonesia.*  
 Source: Data analysis of 249 steel plants from KBLI 24101 and 24102 trough SIINas in July 2025.

Map (A) shows an uneven spatial distribution of steel manufacturing facilities across Indonesia, with strong concentrations in major industrial provinces such as Banten, East Java, and West Java, while many other provinces have only limited activity (Figure 6). Map (B) presents the LISA cluster map, High–High clusters, such as Banten, East Java, and South Sulawesi, indicate provinces with strong local steel manufacturing activity that are also surrounded by areas with similarly high ecosystem performance, marking

them as important regional industrial hubs. Low–Low clusters, such as Papua and West Papua, represent provinces with low local activity and similarly weak surrounding regions, reflecting structural limitations in industrial capacity and connectivity. These findings suggest that steel manufacturing is a key downstream component in supporting green ship recycling development, because provinces with stronger steel production ecosystems are better positioned to absorb recycled materials and strengthen circular economy linkages.

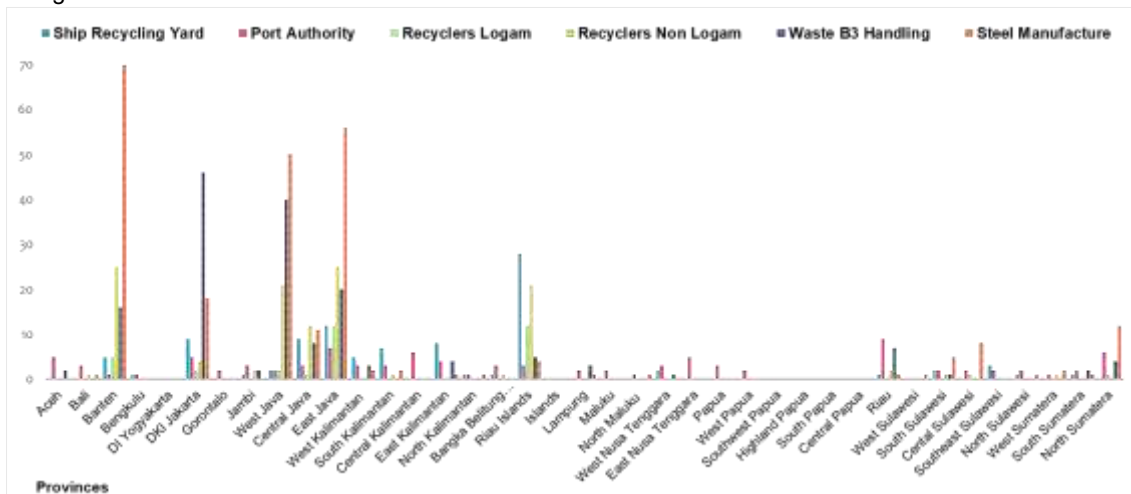


Figure 7 Distribution of ship recycling ecosystem components across Indonesian provinces. Source: Processed from provincial-level data (2025).

Strategic hubs to develop a national Green Ship Recycling ecosystem (Figure 7) include the Riau Islands (28 shipyards, 12 metal recyclers), East Java (12 shipyards, 12 metal recyclers), Jakarta (9 shipyards, 46 waste facilities), and West Java (2 shipyards, 40 waste facilities, 50 steel companies).

In GeoDa, local significance for LISA is commonly reported at  $p < 0.05$  (default) and  $p < 0.01$  (more stringent). Significance symbols: \* =  $p < 0.05$ ; \*\* =  $p < 0.01$ . The scatterplot matrix (Figure 8) displays the correlation between X key variables in Indonesia’s green ship recycling ecosystem as Shipyards (Y): Port KSOP, Metal Recyclers (Recycle M), Non-Metal Recyclers (Recycle NM), Waste Handling Companies, and Steel Manufacturers (Steel Mfr):

1. Metal Recycle – Shipyards: Strong and significant positive correlation (1.529\*\*)
2. Non-Metal Recycle– Shipyards: Strong significant positive correlation (0.469\*\*)
3. Waste Handling – Shipyards: Significant positive correlation (0.173\*)
4. Metal Recycle Steel – Manufacturer: Strong and significant positive correlation (3.464\*\*)
5. Steel Manufacturer – Recycle Non-Metal: Strong and significant positive correlation (0.388\*\*)
6. The relationship between the industrial variables (Recycle, Waste, Steel) is mutually reinforcing, which is logical in the context of production and waste management.
7. Port KSOP – All variables: Weak and non-significant correlations

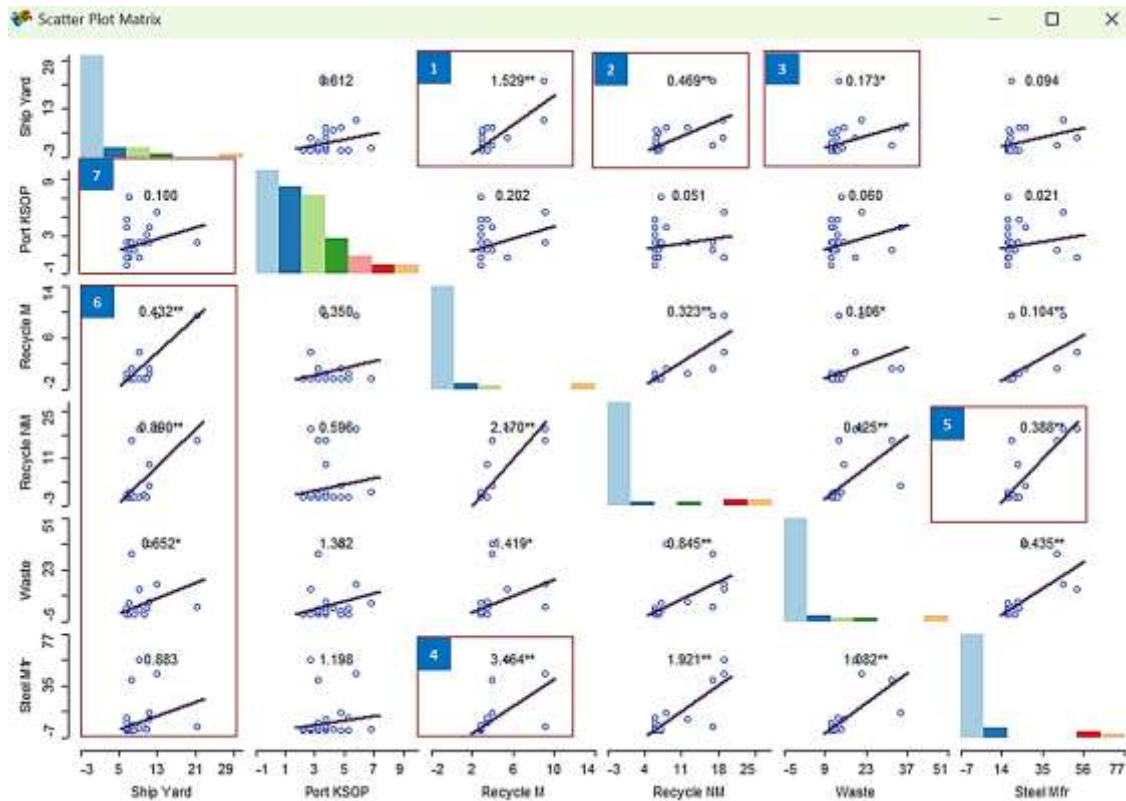


Figure 8 Scatterplot matrix 5 variable for the significance map and cluster map

The scatterplot matrix demonstrates that shipyards, recyclers, waste handlers, and steel manufacturers tend to cluster spatially, reinforcing the feasibility of creating Green Ship Recycling Clusters in Indonesia. This clustering not only supports efficient resource circulation but also reduces dependency on volatile raw material imports by strengthening domestic recycled steel supply chains.

The spatial clustering patterns revealed by LISA and the Moran scatterplot translate into actionable coastal and regional planning priorities. Provinces repeatedly identified as strategic hubs (e.g., Riau Islands, East Java, Jakarta, and West Java) can be designated as priority industrial zones for GSR, where land-use allocation, port–industry interfaces, and environmental safeguards (buffers and hazardous-waste siting) are planned in an integrated manner. These hubs also provide a strong basis for eco-industrial cluster development, enabling shared infrastructure for waste handling, materials recovery, logistics, and skills development to strengthen circular supply chains and reduce fragmentation among actors. Meanwhile, low–low patterns indicate regions where enabling infrastructure remains limited, informing regional development strategies that emphasize staged investment, inter-provincial collaboration, and connectivity to support future GSR ecosystem expansion.

### 3.3 Evidence-Based Policy: Green Ship Recycling (GSR) in Indonesia

This section presents a synthesis of the analytical evidence obtained through GeoDa-based spatial and regression analyses and translates it into actionable policy recommendations. This study aims to bridge empirical findings with regulatory and industrial strategies that can accelerate the integration of Green Ship Recycling (GSR) into Indonesia's Circular Economy Roadmap 2025–2045. Policy implications from these findings are multifaceted, the following table summarizes the key analytical findings alongside the proposed policy measures and identifies the relevant stakeholders responsible for implementation.

Table 4 Evidence-Based Policy Green Ship Recycling (GSR) in Indonesia

Spatial Analytical Evidence (GeoDa)	Policy Recommendation	Justification
Metal recyclers ( $\beta = 1.166, p < 0.001$ ) have the strongest positive effect on shipyard growth.	Prioritize investment & incentives for metal recycling industries in coastal clusters.	Strongest driver of GSR ecosystem expansion. Stakeholders: Ministry of Industry (Kemenperin), Ministry of Investment/BKPM, private scrap industry associations.
Non-metal recyclers ( $\beta = 0.564, p = 0.003$ ) also support shipyard development.	Promote integration of non-metal recyclers (ship's furniture, machinery, navigation, etc.) into GSR clusters.	Diversifies resource circulation, reduces waste leakage. Stakeholders: Kemenperin, KLHK, local governments, non-metal recycling SMEs.

Spatial Analytical Evidence (GeoDa)	Policy Recommendation	Justification
Hazardous waste facilities ( $\beta = 0.141$ , $p = 0.013$ ) significantly boost shipyard capacity.	Build/upgrade hazardous waste management hubs in strategic provinces.	Compliance with HKC; critical for safe dismantling & worker protection. Stakeholders: KLHK (main regulator), Bappenas (planning), Provincial governments, certified Hazard operators.
Steel plants ( $\beta = -0.309$ , $p < 0.001$ ) negatively correlate with shipyard growth.	Regulate scrap allocation & create contracts to balance supply between shipyards & steel industry.	Prevents competition that weakens shipyard viability. Stakeholders: Ministry of Trade, Ministry of Industry, steel industry associations, shipyard operators.
Port Authorities (KSOP) not significant in regression.	Reorient KSOP role toward coordination & one-stop services, not as sole determinant of GSR growth.	Presence of KSOP alone does not ensure shipyard development. Stakeholders: Ministry of Transportation (Kemenhub), Harbormaster Offices (KSOP I–IV).
Spatial LISA results: High-High clusters = Kep. Riau, East Java; Low-Low = Papua & West Papua; High-Low = Kep. Riau; Low-High = Central Java.	Develop eco-industrial GSR clusters in Kep. Riau, East Java, Jakarta, and West Java; monitor & uplift Low-Low areas.	Empirical hotspots with dense actor networks should be prioritized. Stakeholders: Bappenas, Kemenperin, provincial governments, local universities for spatial monitoring.
Clustering of shipyards, recyclers, waste handlers, steel manufacturers shown in scatterplot matrix ( $R^2 = 0.829$ ).	Form integrated Green Ship Recycling Clusters with shared infrastructure, training centers, and financing schemes.	Spatial synergy reduces dependency on raw imports and increases circular efficiency. Stakeholders: Bappenas, BKI Ship Classification, Ministry of Manpower, BRIN (research & training). Integrate economic feasibility and cross-sectoral policy frameworks to ensure long-term sustainability (Shabrina et al., 2025).

#### 4. Conclusion

This study shows that the integration of Green Ship Recycling (GSR) into Indonesia's Circular Economy Roadmap 2025–2045 should be understood as the development of an interconnected ecosystem rather than a stand-alone dismantling activity. The findings indicate that metal recyclers, non-metal recyclers, hazardous waste facilities, and steel manufacturers play important roles in shaping the readiness of ship recycling development, although their spatial contributions vary across provinces. The spatial analysis identifies the Riau Islands, East Java, DKI Jakarta, West Java, and Banten as the most promising areas for integrated GSR development due to their stronger ecosystem support and clustering patterns. Overall, the study confirms that integrating GSR into the circular economy agenda requires not only strategic locations, but also stronger industrial linkages, waste management capacity, and cross-sectoral policy coordination to support a more sustainable and resource-efficient ship recycling system.

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