Exploring the Drivers and Barriers for Circular Economy Implementation in the Mining Industry: An ISM Approach

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Abstract: Mining is an important sector in the development of Indonesian and world civilization. With the largest-ever record of waste volumes and the potential for significant environmental impact, the industry is under constant pressure to maintain and improve environmental performance while remaining economically profitable. This can be achieved by implementing a circular economy. The circular economy is still in its infancy in this sector, and the driving forces and barriers for its implementation are unknown. This study aims to identify the key drivers and barriers and to understand the interactions between factors by using the interpretive structural modeling (ISM) method. This research identified 20 drivers, with the key being the existence of a clear national action plan and technical regulations, and 17 barriers, with the key barrier being the difficulty of incorporating the circular economy as the company's core business. These key factors will assist practitioners and decision-makers in understanding, overcoming, and utilizing them to implement a circular economy in their companies.

Keywords: barriers; circular economy; drivers; Interpretive Structural Modeling; ISM; mining industry

1. Introduction

Metal supplies are the backbone of global civilization[1)]. Forecasters project that demand will rise significantly, rising from 9.49 billion tons in 2020 to 19.52 billion tons by 2060[2)]. In Indonesia, the mining industry accounted for an average of 77% of the export volume between 2013 and 2020, ranking among the top 5 sectors in terms of contribution to the national gross domestic product (GDP)[3,4)]. In the future, mining operations in Indonesia are also anticipated to gain more significance in tandem with the government's downstream mining initiative[5,6)].

Mining in Indonesia is defined as part or all of the stages of activity in the context of the research, management, and exploitation of minerals or coal, which include general investigation, exploration, feasibility studies, construction, mining, processing and refining, transportation and sales, as well as post-mining activities[7)]. There are three primary mineral commodities: metals, non-metals, and rocks[8)]. This research focuses on metals. Mining activities, which are currently based on a linear economic model, have resulted in significant environmental impacts[9)]. The production of primary materials has impacts ranging from 1.3 to 20 times higher than those of secondary materials[2)]. Only about 13% of hazardous and toxic waste (B3) hasbeen utilized, despite its utilization potential reaching 81%[10–12)], especially in wastewater, rock waste, slag, and leached ore [9,13)]

These environmental impacts necessitate that the mining industry implement a circular economy[14)]. The circular economy is an economic system that changes the concept of 'end-of-life to reduce, reuse, recycle, and recover materials in the process of production, distribution, and consumption; operates at micro, meso, and macro levels; and aims to achieve sustainable development[15)]. A circular economy in the mining industry has the potential to reduce environmental pollution[13)], minimize waste[16)], and reduce greenhouse gas emissions[17)] while increasing metal production and generating profits[18)]. Opportunities to recover technically and economically feasible mining materials will also be lost if the mining sector does not adopt this concept[9)].

The 4R framework (reduce, reuse, recycle, and recover) has been applied in various mining locations[13,19)].

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Reduction is the application of production technologies that minimize waste, such as dry processing technology[20]. Reuse is carried out by reusing raw materials for various mining purposes, such as water and chemicals[21,22]. Recycling is the utilization of waste as construction raw materials[23]. Recovery is re-mining the primary metal and other metals from tailings waste[24]. Although widely practiced outside Indonesia, these practices are still minimally implemented in the country, considering that the circular economy in this industry is still in its early stages of development[24,25].

The application, which is still in its early stages, needs to facilitate development in this industry by understanding the driving and barrier factors for implementing a circular economy[14,26] and overcoming the challenges associated with its implementation[27]. The purpose of the research is to be achieved by the following research questions:

1) What are the driving factors that can implement a circular economy?
2) What are the key barriers to implementing a circular economy?

Although prior studies have examined the drivers and barriers of circular economy adoption in the mining industry, most have relied on content analysis of corporate initiatives or on review-based and conceptual approaches[28]. Such approaches identify relevant factors but rarely model the structural interrelationships among them or establish which factors are most influential in driving the transition. Moreover, decision-support frameworks that prioritize enablers and barriers for the mining sector in emerging and developing economies remain limited, and evidence is concentrated in a few national contexts. In Indonesia, where mining is central to the economy, yet the circular economy is still at an early stage, no study has structured and prioritized these factors for the sector's specific regulatory and industrial conditions. This study addresses that gap by identifying, structuring, and prioritizing the key drivers and barriers of circular economy implementation in the Indonesian mining industry using the Interpretive Structural Modeling (ISM) method and MICMAC analysis.

Therefore, research is needed to identify and describe relationships and to determine the key barriers and drivers for implementing a circular economy in the Indonesian mining industry. The structure of this research article is as follows. Section 1 "Introduction"; Section 2 "Literature Review"; Section 3 "Materials and Methods"; Section 4 "Results"; Section 5 "Discussion"; and the last Section 6 "Conclusion".

2. Literature Review

a) Mining Industry Development in Indonesia

Indonesia's mining industry has been active since 1789, with the first official record dating back to that year. The industry's development was slow until the 1960s when the government introduced the Contract of Work (KK) scheme, facilitating cooperation between domestic and foreign companies. The scheme led to rapid growth in permits and was eventually replaced by Mining Business Permits (IUP) in 2009[29]. The industry continues to be optimized to maximize Indonesia's mining wealth for the people's prosperity[30]

b) Circular economy applications in the mining industry

The hierarchical circular economy practice framework suggests that resource preservation and reintegration of products or byproducts are not limited to recycling[15]. Strategies for implementing a circular economy in the mining industry include reducing waste, reusing input materials, processing mining waste into construction materials, and recovering metal minerals from tailings[19].

c) Multi-Criteria Decision Making (MCDM)

Decision-makers face complex problems that require multidisciplinary knowledge, including technical, economic, environmental, social, political, and regulatory expertise[31]. MCDM is a practical and powerful tool for conducting scientific qualitative and quantitative analysis, helping decision-makers solve problems with conflicting criteria[31,32]. To address four types of issues: selection, sorting, ranking, and description[32].

d) Interpretive Structural Modeling (ISM)

Warfield introduced the Integrative Self-Interaction Matrix (ISM) to help develop a hierarchical system structure[33,34]. ISM is used in this research for five reasons:

1) to consider the interrelationships of driving and barrier factors for circular economy implementation[35,36];
2) to understand the key factors that influence other factors[14,36];
3) to accommodate the many stakeholders involved in the transition to a circular economy[37,38];
4) to be small, requiring significant research contributions[39]; and
5) for its simplicity and computational time efficiency compared to other Multi-Current Decision Making (MCDM) methods[34].

e) Drivers and Barriers of Circular Economy in the Mining Industry

Research on the circular economy in mining has increasingly focused on identifying the factors that enable or hinder its adoption[28] reviewed circular economy initiatives across three large mining companies and, through content analysis, evaluated the barriers, drivers, and triggers of the transition, arguing that the industry can accelerate progress by learning from other sectors. In emerging and developing economies, decision-support studies have applied structured prioritization methods and found organizational factors to be among the most critical enablers. At the same time, environmental and regulatory

conditions were the most pressing barriers to address. Similarly, more comprehensive analyses of resource recovery in developing nations conclude that laws, policies, market conditions, and technological competence all work together to determine adoption. They also advocate for systems-thinking techniques that explicitly link the various aspects.

Taken together, these studies establish that an interdependent set of regulatory, organizational, technological, and economic factors governs circular economy adoption in mining. They also share two limitations. First, factors are frequently identified in isolation, without modeling how they influence one another or which are structurally most influential. Second, evidence is concentrated in a limited number of contexts, and prioritization frameworks tailored to the regulatory and industrial conditions of specific developing countries, such as Indonesia, remain scarce. These gaps motivate the structural, interrelationship-based approach adopted in the present study.

3. Materials and Methods

a) Materials

The list of driving and barrier factors from various research articles may not be valid and applicable in Indonesia. Other experts may not necessarily agree on the factors proposed by one expert. Therefore, the driving and inhibiting factors were validated. Validation was performed by evaluating each factor using the modified kappa statistic. Validation was conducted through expert questionnaires. Based on previous research, the expert criteria were deemed appropriate in this study. The five experts assessed the validity of 33 driving factors and 32 inhibiting factors by completing the provided questionnaires.

In this study, a panel of five experts was engaged, a size grounded in the principle of expert-judgment calibration. Calibration refers to the degree to which the assessed probability of an event (p%) corresponds to its actual frequency of occurrence[40] demonstrates relative to a single expert, a panel of three to five experts produces a substantial and statistically significant improvement in calibration, whereas expanding the panel beyond approximately ten experts yields little additional benefit. A panel of five, therefore, balances the quality of judgment against diminishing returns. Table 1 shows the experts participating in the study.

Based on the validation results, 20 driving factors and 17 barrier factors met the validity requirements and were declared valid. All initial driving factors are validated, as shown in Table 2. All initial barrier factors validated are shown in Table 3. These valid factors were then assessed for their interrelationships using the ISM method.

b) Methods

The research comprises 6 stages, as shown in the methodology flowchart in Figure 1. Data collection was conducted through the expert questionnaire. After the Expert completed the questionnaire, the indicators were validated using the CVI and modified kappa methods. The results from expert validation, 20 driven factors, and 19 barrier factors meet the validity requirement and are declared valid. The valid factors will then be assessed for their interrelationships using the ISM method.

The research employs the ISM method, which consists of six steps. The six steps are as follows[34]:

1) Structural self-interaction matrix (SSIM): This matrix describes the relationships among variables using the verb "cause"[41]. There are four possible relationships among the factors (V, A, X, or O)[46].
2) Reachability matrix: The VAXO in the SSIM is translated into a 1 or 0 value in the reachability matrix[47]. The transitivity rules are checked after decoding the VAXO[34,42,43].

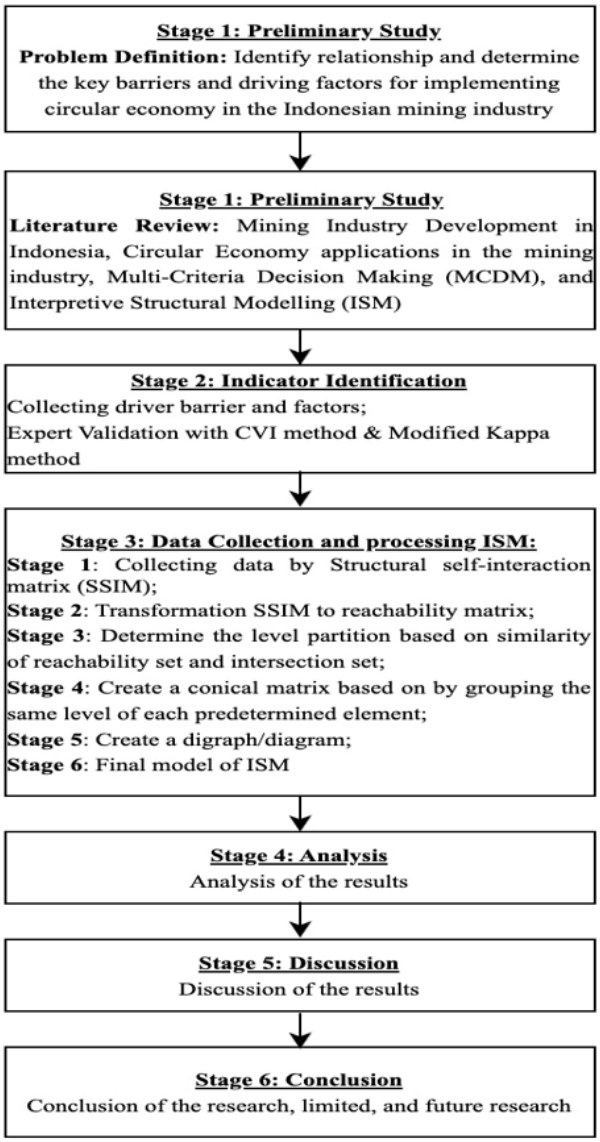


Fig. 1: Flowchart of methodology

3) Level partition: The reachability set consists of horizontal elements (i) and antecedent sets (j)[43], with the intersection set determined by looking at the similarity between the two sets[47].
4) Matrix conical: The conical matrix is developed by grouping the same level of each predetermined element by placing them close together[42]. The total driving power is determined from the sum of horizontal elements (i), and the dependence power is obtained from the sum of vertical elements (j)[42].
5) Digraph arrangement: The conical matrix is used to construct relationship digraphs or diagrams between elements. If element (1) is related to element (2), a 1-way arrow is formed, and if the relationship is the other way around, an arrow is formed in two directions[34]
6) ISM final model: The diagram nodes are replaced with the initial sentences or statements they represent[36].

Table 1: Background of the Expert

No Expert	Role/Position	Sector & Region	Experience years	Stages
E1	Environmental Manager & Acting Head of Mine Engineering	Gold Mining, Kalimantan	>20 years	Validation & ISM
E2	Environmental & Permitting Consultant	Mining Industry (cross–company)	>10 years	Validation & ISM
E3	Environmental Manager	Gold Mining, Sulawesi	>20 years	Validation & ISM
E4	Researcher	Solid & hazardous (B3) waste management	>10 years	Validation & ISM
E5	Environmental Manager	Gold-Silver mining, Sumatra	>20 years	Validation & ISM

Table 2: List of Driving Factors

DA	Dimensions	Factor	Description	Source
1	Financial	Increased mining prices	High metal prices can justify the utilization of tailings for metal recovery	24)
2		Waste area costs	Waste storage/disposal costs can be reduced through waste utilization, resulting in less final waste.	24,44)
3		Reduced production costs	The costs of extracting production resources (energy, raw materials, water, etc.) are lower.	45)
4		New sales potential	By selling byproducts/waste from production processes, companies can create new revenue streams.	45)
5	Market	Decreased metal ore quality	The reduction in ore quality means that tailings can be considered as a new metal source.	24)
6		Initial dominance of certain industries	Inevitable industry dominance can provide sufficient byproduct/waste streams that can be utilized	27)
7		Company Branding	The application of the circular economy gives a positive image for the company	Suggested by experts
8		Buyer/Client Trust	The application of a circular economy increases the trust of clients/partners in producers	Suggested by experts
9	Policy and Regulatory	Supportive tax regulations	Taxes will encourage industry players to implement circular economy behavior, and increase government budgets to promote the implementation of related practices	46)
10		Clear technical regulations	The existence of technical regulations to detail more general rules, such as incentive mechanisms	25,45)
11		The existence of a national action plan	Preparation of a national action plan that contains programs and work plans to support the implementation of a circular economy	25,45)
12	Organizational	Planning that considers waste utilization	Tailings dam design that considers the usefulness of future utilization will facilitate circular economy practices	24)
13		Existence of inter-company facilitators	The existence of facilitators, such as associations that support the circular economy implementation	27)
14		Environmental award	Giving awards so that they become a motivation for circular economy actors	Suggested by experts
15		SDGs and ESG	Support and implementation of SDGs and ESG programs by companies can encourage circular economy practices	Suggested by experts

DA	Dimensions	Factor	Description	Source
16		Environmental Management System	Compliance with the ISO 140001 environmental management system standard	Suggested by experts
17		Community development programs	Circular economy practices have the potential to be integrated into the implementation of corporate CSR programs	Suggested by experts
18	Operational	Good connecting infrastructure	The existence of infrastructure such as toll roads, trains, ports, or airports near industries/industrial areas	27)
19		Reduction of hazardous waste for environmental safety	Industrial players can reduce the risk of environmental impacts by utilizing tailings	24)
20		Tailings utilization technology	The existence of pyrometallurgical, hydrometallurgical, or biotechnology technologies for the remaining tailings	19,,24)

Table 3: List of Barrier Factors

BA	Dimensions	Factor	Description	Source
1	Financial	Lack of economic analysis methods	Companies/organizations do not yet have an economic calculation method for investment and circular-economy operations.	14)
2		Low price of virgin materials	The low price of virgin materials makes industry players pay less attention to resource efficiency and the potential for waste utilization	14,46,47)
3		Lack of capital from financial institutions	Investment is needed for the transition to a circular economy. However, debtors such as banks are still unable to channel many investments	14,47)
4	Market	Lack of market availability	Market demand for circular economy products in mining is still low	14)
5		Lack of the role of SMEs	There are no MSMEs that focus on the utilization of mining waste.	14,24)
6		Lack of marketing activities	Lack of corporate marketing activities related to the circular economy	47)
7	Policy and Regulatory	Weak enforcement of regulations related to environmental pollution	The implementation and transparency of enforcing rules against environmental polluters have not gone well	Suggested by experts
8		Lack of integration of environmental monitoring between the central and local governments	A planned monitoring schedule within 1 year is required, involving all stakeholders from the regional-central; the results of environmental monitoring/inspection progress need to be monitored	Suggested by experts
9		Too many hazardous waste classifications	Too many classifications make it difficult for third-party companies to manage B3 waste.	Suggested by experts
10	Organizational	Lack of knowledge regarding the potential of the circular economy	Understanding regarding the content, amount, and potential benefits of tailings/waste utilization is lacking	14)
11		Lack of top management support	There is no understanding or support/will from top management	14,47)
12		Low company initiative	The rate of company initiatives to implement the circular economy remains low.	14)
13		The company's core business	Circular economy activities are outside the company's core business	24)
14		Training cost allocation	Lack of training to understand circular economy concepts	47)
15		Lack of coordination between organizational functions	Strong integration of company functions facilitates the implementation of green innovation.	47)
16	Operational	Lack of addressing social issues	Mining operations can trigger social issues and conflicts, exacerbated by poor management by the government and companies,	14)
17		Environmental risk uncertainty	Old mines and waste storage facilities pose an environmental risk if they are to be reopened for utilization	14,24)

4. Results

The ISM method yields the final diagram, as shown in Figure 2 and Figure 3. In addition to the final ISM diagram, a MICMAC (cross-impact matrix multiplication applied to classification) diagram is also produced, which is used to classify factors based on driving power and dependence power[43]. The MICMAC diagram is shown in Figure 4 and Figure 5.

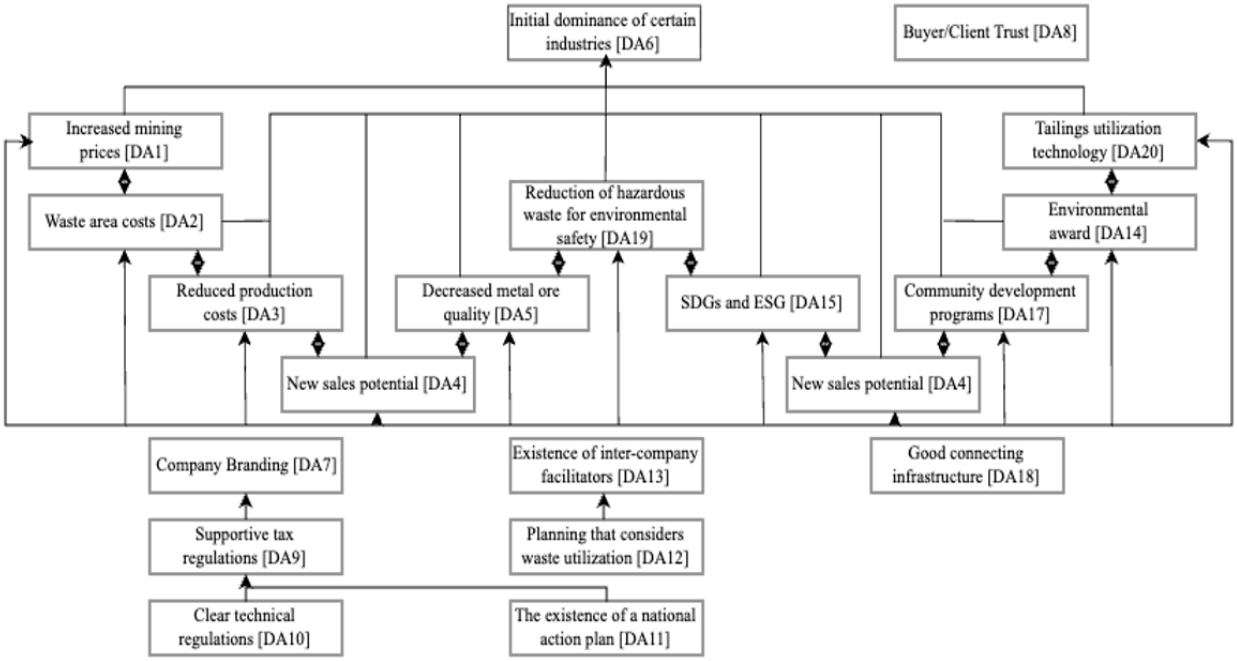


Fig. 2: Driver Model Diagram

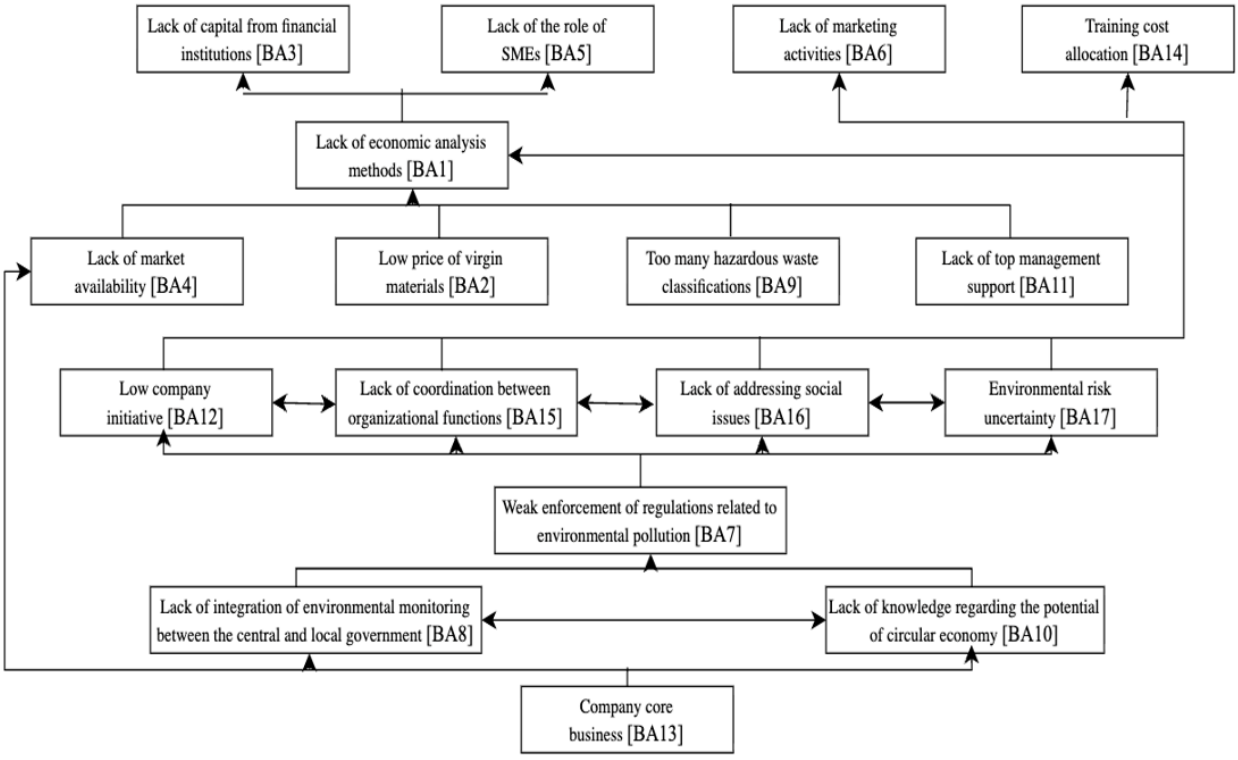


Fig. 3: Barriers Model Diagram

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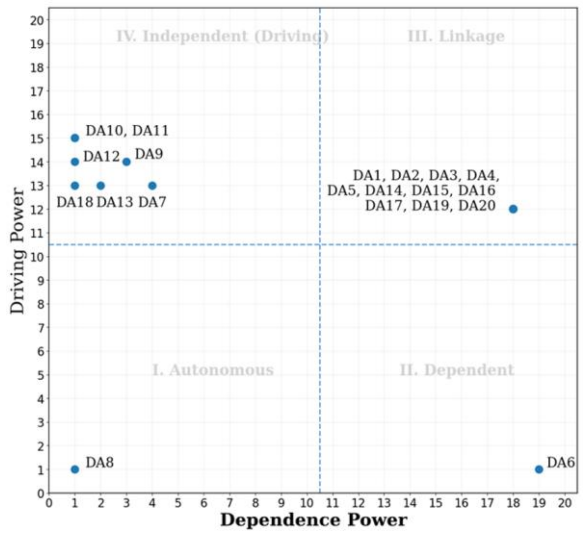


Fig. 4: Drivers MICMAC Diagram

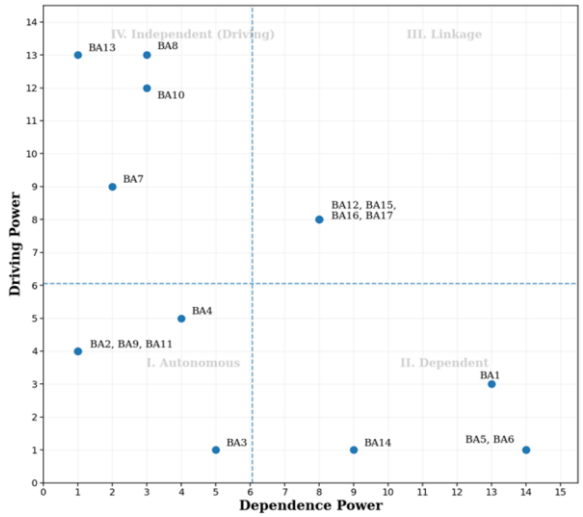


Fig. 5: Barriers MICMAC Diagram

5. Discussion

a) MICMAC Analysis

The MICMAC diagram is a tool used to analyze the influence of various factors on a system. It uses two axes: dependence power and driving power. Dependence power indicates the influence of other factors on a given factor, while driving power shows how a high value of a factor affects other factors. The diagram is divided into four quadrants: quadrant 1 (autonomous), quadrant 2 (dependent), quadrant 3 (relatedness), and quadrant 4 (driving). Autonomous clusters have weak influence; dependent clusters have weak influence but are heavily influenced; and driving clusters have decisive influence. Addressing these factors will affect other clusters, making it easier to address them[14]. Accordingly, the factors located in the driving cluster were prioritized in this study as the most strategic levels for circular economy implementation in the mining industry.

The Buyer/client trust factor (DA8) is in quadrant 1, or the autonomous cluster. This means that DA8 is poorly connected to other factors, either through causal or correlational relationships. Therefore, efforts to address this factor will have little impact on other factors, making it unsuitable for priority. DA8 is completely isolated, with no relationship to any other factor.

Initial dominance of certain industries (DA6) is in quadrant 2, or the dependent cluster. This means that DA6 tends to have little influence on other factors, but is heavily influenced by them, making it unsuitable for priority. While increased client trust can encourage companies to adopt a circular economy, it is driven by many other factors.

Increasing mining material prices (DA1), waste area costs (DA2), reduced production costs (DA3), new sales potential (DA4), decreased metal ore quality (DA5), environmental award (DA14), SDGs and ESG (DA15), environmental management system (DA16), community development programs (DA17), reduction of hazardous waste for environmental safety (DA19), and tailings utilization technology (DA20) are factors found in quadrant 3, or the linkage cluster. This means that factors in this quadrant significantly influence and are influenced by other factors. Factors addressed in this cluster will easily influence other factors.

Factors such as company branding (DA7), supportive tax regulations (DA9), clear technical regulations (DA10), the existence of a national action plan (DA11), planning that considers waste utilization (DA12), the existence of inter-company facilitators (DA13), and good connecting infrastructure (DA18) are factors found in quadrant 4, or the drivers cluster. Factors in this quadrant can drive other factors because they have high driving power so that they can be prioritized for action.

b) Analysis of Key Drivers

The key driving factor for implementing a circular economy in the mining industry is the existence of a national action plan (DA11), a presidential regulation that outlines sustainability reports[48], which require companies to adapt and modify their decisions, processes, strategies, and activities. These programs and activities are set out in a 5-year work plan, supporting the achievement of a circular economy in line with national goals[49]. In Indonesia context, presidential regulations rank fourth in the regulatory hierarchy, making them the highest form of regulation to encourage the transition[50]; as a foundational driver, they set the strategic direction on which subordinate factors depend.

Clear technical regulations (DA10) are ministerial regulations that provide detailed guidance on implementing circular economy activities in the mining industry[51]. These regulations can impact the adoption of tailings utilization technology (DA20) and the reduction of hazardous waste for environmental safety (DA19); this cascading influence explains their location in the

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driving cluster. The prominence of regulation is consistent with the fact that mining is subject to some of the most stringent and detailed regulatory requirements among industrial sectors, so regulatory clarity is a precondition for embedding circularity.

The centrality of the regulatory dimension echoes prior studies, although its role differs by context[47] found that government policies and regulations constituted the most important factors to circular economy adoption, and a study of the Chilean copper–mining sector similarly attributed slow uptake to an inadequate regulatory framework and weak compliance mechanism[52]. In those settings, the regulatory framework was weak or absent, thereby acting as a barrier. In contrast, in the Indonesian context, the presence of an explicit national plan and detailed technical regulations transforms the same dimension into the leading driver. This contrast indicates that regulation is consistently the most influential factor in mining circularity, and that it acts as either a driver or a barrier, depending on whether an enabling regulatory framework is in place. Therefore, the key drivers for implementing circular economy practices (recycling and recovery) in Indonesia's mining industry are the existence of a national action plan (DA11) and clear technical regulations (DA10).

c) Analysis of Key Barriers

The key barrier to incorporating the circular economy is the company's core business (BA13), which is the primary reason for its existence[53]. In Indonesia, metal mineral mining companies focus on producing metal minerals[54], excluding activities that do not create or contribute to their production[55]. Companies can overcome this by incorporating non-financial reporting for the public, such as sustainability reports[48], which requires companies to adapt and modify their decisions, processes, strategies, and activities. Circular economy activities can be reported through three approaches: integrating reporting, reporting as a subsection of the annual report, and a stand-alone report. Integrating reporting is the most effective approach for embedding the circular economy into a company's core business, as it is more comprehensive and exerts a greater influence on core operations[48]. At present, however, the current approach is limited to fulfilling obligations and ignoring the completeness of environmental activities carried out.

The prominence of organizational, business–oriented barriers are consistent with prior research in the mining sector[47] reported that organizational barriers carried among the highest intensity in Indian mining, and[56] identified organizational–alongside technological and regulatory ones – as central to circular economy adoption in the African mining context. The recurrence of organizational and business-oriented barriers across emerging economies supports the validity of our findings. It suggests that embedding the circular economy into corporate strategy, rather than treating it as a peripheral compliance activity, is a shared challenge for the mining industry.

d) Maximizing the influence of driving and barrier factors

National action plans and technical regulations[57] must adhere to prevailing social norms[58], particularly those related to the core business activities of mining companies in Indonesia. The core business of these companies involves the production and processing of minerals, from ore extraction to the refining of target metal[54,59]. However, recycling and recovery processes[15,60] do not align well with this core business and are therefore difficult to apply in the Indonesian mining industry[24]. Therefore, the government should focus on implementing reduction and reuse[19], which aim to avoid waste generation and minimize resource consumption at the source and are more consistent with companies' mineral-production focus. Accordingly, the government should also develop national action plans and technical regulations to regulate these two types of circular economy, ensuring they align with the company's focus and core business. This alignment directly addresses the key barriers (BA13) by embedding circularity within, rather than alongside, the companies' primary value-creating activity.

e) Theoretical and Practical Implications

Theoretically, this study expands the drivers-barriers literature in mining by extending beyond factor identification to a structured, hierarchical model of how factors influence one another. The ISM and MICMAC approach shows that regulatory variables, more specifically, a national action plan and explicit technical regulations, occupy the driving cluster and hence impact the behavior of dependent factors. In contrast, earlier studies highlighted facilitators and barriers[28]. This clarifies the widely held belief that regulation is important by noting that it serves as the main driver rather than a barrier in an enabling regulatory environment.

Practically, the results show that policy efforts are most successful when they focus on the motivating factors and integrate circularity into businesses' primary mineral-production operations rather than in addition to them. For regulators, this means prioritizing reduction- and reuse-oriented tools that align with Indonesian companies' focus on mineral output. The driver–barrier structure and the ISM and MICMAC procedure are transferable, and the general approach can be applied to other resource-intensive industries to prioritize circular economy interventions, provided the factor set is respecified to their conditions, even though the model is based on the Indonesian mining context.

f) Limitation and Future Research

This study's limitations also point to areas that need

further investigation. An expert panel first identified the factor set and its relationships. Expert-based evaluations are intrinsically subjective and might be strengthened by more thorough surveys; however, the panel represented a diverse range of jobs and geographic regions. Second, the results may not immediately apply to coal or non-metallic minerals because the analysis concentrates on the metal-mineral sector of Indonesian mining. Third, future research could combine ISM-MICMAC with quantitative methods like structural equation modeling or DEMATEL-based ANP to determine the structure and relative influence of elements but not the size of their effects. Lastly, it would be possible to determine how context-specific or generalizable the observed driver-barrier structure is by conducting comparative studies across nations or mineral commodities.

6. Conclusion

This study identifies the key enabling and barrier factors that must be addressed to implement a circular economy in the Indonesian mining sector. The most pressing enabling factors include clear technical regulations and a national action plan. The most critical obstacle is the company's fundamental commercial operations. To expedite the shift to a circular economy within the mining sector, stakeholders must focus on key elements. The key factors can be addressed by implementing an integrated environmental report as part of the company's core business. Stakeholders should prioritize addressing this factor and maximize its influence relative to other factors to minimize obstacles and difficulties in implementing a circular economy.

The key driving and barrier factors in this context suggest that regulators need to develop national action plans, and that technical guidelines should be drafted with a focus on the core activities of mining companies, specifically the production of metal minerals. Driving factors must be adaptable to practices that enable companies to either increase yields or minimize production costs, thereby simplifying their implementation. Stakeholders must address factors influencing the adoption of a circular economy to enable successful implementation in the Indonesian mining sector.

Addressing key factors will facilitate the easier resolution of other factors. Further study can examine the underlying causes and obstacles in more detail, ultimately leading to a more inclusive list of influences[1)]. The scope of the metal mineral mining industry can be broadened to include all relevant minerals or narrowed to specific companies, revealing potential disparities in the factors influencing them. The mining industry enables stakeholders to tailor their strategies in response to factors within their area of focus.

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Nomenclature

Symbol	Description
ESG	Environmental, Social, & Governance
GDP	Gross Domestic Product
ISM	Interpretive Structural Modeling
IUP	Mining Business Permits
KK	Contract of Work
MCDM	Multi-Criteria Decision Making
MICMAC	Cross-impact matrix multiplication applied to classification
SDGs	Sustainable Development Goals
SSIM	Structural self-interaction matrix

References

1) S.K. Haldar, “Mineral Economics,” in: Mineral Exploration, Elsevier, 2013: pp. 251–266. doi:10.1016/b978-0-12-416005-7.00013-1
2) OECD, “Global Material Resources Outlook to 2060,” OECD Publishing, Paris, 2019. doi:10.1787/9789264307452-en.
3) Statistics Indonesia (BPS), “Export volume by main country of destination (net weight: thousand tons), 2000–2021,” (2022). https://www.bps.go.id/statictable/2014/09/08/1009/volume-ekspor-menurut-negara-tujuan-utama-berat-bersih-ribu-ton-2000-2021.html (accessed October 13, 2022).
4) Statistics Indonesia (BPS), “[2010 series] Distribution of quarterly GDP at current prices, 2010 series (percent), 2022,” (2022). https://www.bps.go.id/indicator/11/106/1/-seri-2010-distribusi-pdb-triwulanan-seri-2010-atas-dasar-harga-berlaku.html (accessed October 13, 2022).
5) R. Pahlevi, “Two more added, a total of 21 smelters in Indonesia as of 2021,” (2022). https://databoks.katadata.co.id/datapublish/2022/01/24/bertambah-2-total-ada-21-smelter-di-indonesia-hingga-2021 (accessed December 18, 2022).
6) A. Wahab, “What is wrong with the Indonesian mining industry? A brief review from a macroeconomic perspective,” *Jurnal Ekonomi Trend*, **9** (2) 57–67 (2021). doi:10.31970/trend.v9i2.218.
7) Government of the Republic of Indonesia, “Law of the Republic of Indonesia No. 4 of 2009 on Mineral and Coal Mining,” Jakarta, (2009)
8) Ministry of Energy and Mineral Resources of the Republic of Indonesia, “Regulation of the Minister of

Energy and Mineral Resources No. 5 of 2017 on Increasing the Added Value of Minerals through Domestic Mineral Processing and Refining Activities," Jakarta, (2017).
9) É. Lèbre, G. Corder, and A. Golev, "The role of the mining industry in a circular economy: a framework for resource management at the mine site level," J. Ind. Ecol., 21 (3) 662–672 (2017). doi:10.1111/jiec.12596.
10) Statistics Indonesia (BPS), "Environment Statistics of Indonesia 2021: Energy and Environment," (2021).
11) Ministry of Environment and Forestry of the Republic of Indonesia, "Statistics of the Ministry of Environment and Forestry 2019," Center for Data and Information, Ministry of Environment and Forestry, Jakarta, (2020). https://statistik.menlhk.go.id/sisklhkX/assets/publikasi/file/1.pdf (accessed November 16, 2022).
12) V.A. Dihni, "Indonesia generated 60 million tons of hazardous and toxic (B3) waste in 2021," (2022). https://databoks.katadata.co.id/datapublish/2022/02/09/indonesia-hasilkan-60-juta-ton-limbah-b3-pada-2021 (accessed September 14, 2022).
13) B.G. Lottermoser, "Recycling, reuse and rehabilitation of mine wastes," Elements, 7 (6) 405–410 (2011). doi:10.2113/gselements.7.6.405.
14) V. V. Gedam, R.D. Raut, A.B. Lopes de Sousa Jabbour, and N. Agrawal, "Moving the circular economy forward in the mining industry: challenges to closed-loop in an emerging economy," Resources Policy, 74 102279 (2021). doi:10.1016/j.resourpol.2021.102279.
15) J. Kirchherr, D. Reike, and M. Hekkert, "Conceptualizing the circular economy: an analysis of 114 definitions," Resour. Conserv. Recycl., 127 221–232 (2017). doi:10.1016/j.resconrec.2017.09.005.
16) R. Balanay, and A. Halog, "Charting policy directions for mining's sustainability with circular economy," Recycling, 1 (2) 219–231 (2016). doi:10.3390/recycling1020219.
17) E. van der Voet, L. van Oers, M. Verboon, and K. Kuipers, "Environmental implications of future demand scenarios for metals: methodology and application to the case of seven major metals," J. Ind. Ecol., 23 (1) 141–155 (2019). doi:10.1111/jiec.12722.
18) A. Young, M.L. Barreto, and K. Chovan, "Towards a circular economy approach to mining operations: key concepts, drivers and opportunities," Report prepared for Natural Resources Canada, Materials Efficiency Research Group and Enviro Integration Strategies, Canada, (2021).
19) L.A. Cisternas, J.I. Ordóñez, R.I. Jeldres, and R. Serna-Guerrero, "Toward the implementation of circular economy strategies: an overview of the current situation in mineral processing," Mineral Processing and Extractive Metallurgy Review, 43 (6) 775–797 (2022). doi:10.1080/08827508.2021.1946690.
20) S.C. Chelgani, and A.A. Neisiani, "Dry Mineral Processing," Springer International Publishing, Cham, 2022. doi:10.1007/978-3-030-93750-8.
21) K.D. Miller, M.J. Bentley, J.N. Ryan, K.G. Linden, C. Larison, B.A. Kienzle, L.E. Katz, A.M. Wilson, J.T. Cox, P. Kurup, K.M. van Allsburg, J. McCall, J.E. Macknick, M.S. Talmadge, A. Miara, K.A. Sitterley, A. Evans, K. Thirumaran, M. Malhotra, S.G. Gonzalez, J.R. Stokes-Draut, and S. Chellam, "Mine water use, treatment, and reuse in the United States: a look at current industry practices and select case studies," ACS ES&T Engineering, 2 (3) 391–408 (2022). doi:10.1021/acsestengg.1c00244.
22) G.M. Mudd, "Sustainability reporting and water resources: a preliminary assessment of embodied water and sustainable mining," Mine Water Environ., 27 (3) 136 (2008). doi:10.1007/s10230-008-0037-5.
23) P. Kinnunen, M. Karhu, E. Yli-Rantala, P. Kivikytö-Reponen, and J. Mäkinen, "A review of circular economy strategies for mine tailings," Clean. Eng. Technol., 8 100499 (2022). doi:10.1016/j.clet.2022.100499.
24) P. Kinnunen, and A.H. Kaksonen, "Towards circular economy in mining: opportunities and bottlenecks for tailings valorization," J. Clean. Prod., 228 153–160 (2019). doi:10.1016/j.jclepro.2019.04.171.
25) A.W.H. Fasa, "Legal aspects and Indonesian government policies on the circular economy to achieve the sustainable development goals," *Jurnal RechtsVinding*, **10** (3) 339–357 (2021).
26) A. de Jesus, and S. Mendonça, "Lost in transition? drivers and barriers in the eco-innovation road to the circular economy," Ecological Economics, 145 75–89 (2018). doi:10.1016/j.ecolecon.2017.08.001.
27) A. Neves, R. Godina, S. G. Azevedo, C. Pimentel, and J. C.O. Matias, "The potential of industrial symbiosis: case analysis and main drivers and barriers to its implementation," Sustainability, 11 (24) 7095 (2019). doi:10.3390/su11247095.
28) A. Upadhyay, T. Laing, V. Kumar, and M. Dora, "Exploring barriers and drivers to the implementation of circular economy practices in the mining industry," Resources Policy, 72 (2021). doi:10.1016/j.resourpol.2021.102037.
29) P. van der Eng, "Mining and Indonesia's economy: institutions and value adding, 1870–2010," CEI Working Paper Series No. 2014-5, Center for Economic Institutions, Institute of Economic Research, Hitotsubashi University, Tokyo, (2014). https://cei.ier.hit-u.ac.jp/English/pdf/wp2014-5.pdf

30) B. Devi, and D. Prayogo, "Mining and development in Indonesia: an overview of the regulatory framework and policies," Action Research Report, International Mining for Development Centre (IM4DC), Perth, Australia, (2013).
31) A. Kumar, B. Sah, A.R. Singh, Y. Deng, X. He, P. Kumar, and R.C. Bansal, "A review of multi criteria decision making (MCDM) towards sustainable renewable energy development," Renewable and Sustainable Energy Reviews, 69 596–609 (2017). doi:10.1016/j.rser.2016.11.191.
32) F. Sitorus, J.J. Cilliers, and P.R. Brito-Parada, "Multi-criteria decision making for the choice problem in mining and mineral processing: applications and trends," Expert Syst. Appl., 121 393–417 (2019). doi:10.1016/j.eswa.2018.12.001.
33) P. Jia, A. Diabat, and K. Mathiyazhagan, "Analyzing the sscm practices in the mining and mineral industry by ISM approach," Resources Policy, 46 76–85 (2015). doi:10.1016/j.resourpol.2014.04.004.
34) R. Attri, N. Dev, and V. Sharma, "Interpretive structural modelling (ISM) approach: an overview," *Research Journal of Management Sciences*, **2** (2) 3–8 (2013). ISSN: 2319-1171.
35) I.H. v. Gue, M.A.B. Promentilla, R.R. Tan, and A.T. Ubando, "Sector perception of circular economy driver interrelationships," J. Clean. Prod., 276 123204 (2020). doi:10.1016/j.jclepro.2020.123204.
36) K. Mandic, V. Bobar, and B. Delibašić, "Modeling Interactions Among Criteria in MCDM Methods: A Review," in: Decision Support Systems V – Big Data Analytics for Decision Making, 1st ed., Springer Cham, 2015: pp. 98–109. doi:10.1007/978-3-319-18533-0_9.
37) T. Ekvall, M. Hirschnitz-Garbers, F. Eboli, and A. Śniegocki, "A systemic and systematic approach to the development of a policy mix for material resource efficiency," Sustainability, 8 (4) 373 (2016). doi:10.3390/su8040373.
38) L. Milios, "Towards a circular economy taxation framework: expectations and challenges of implementation," Circular Economy and Sustainability, 1 (2) 477–498 (2021). doi:10.1007/s43615-020-00002-z.
39) R. Kumar, and P. Goel, "Exploring the domain of interpretive structural modelling (ISM) for sustainable future panorama: a bibliometric and content analysis," Archives of Computational Methods in Engineering, 29 (5) 2781–2810 (2022). doi:10.1007/s11831-021-09675-7.
40) S.C. Hora, "Probability judgments for continuous quantities: linear combinations and calibration," *Management Science*, **50** (5) 597–604 (2004). doi:10.1287/mnsc.1040.0205.
41) Sushil, "Interpreting the interpretive structural model," Global Journal of Flexible Systems Management, 13 (2) 87–106 (2012). doi:10.1007/s40171-012-0008-3.
42) N. Ahmad, and A. Qahmash, "SmartISM: implementation and assessment of interpretive structural modeling," Sustainability, 13 (16) 8801 (2021). doi:10.3390/su13168801.
43) C. Mi, Y. Chen, C.-S. Cheng, J.L. Uwanyirigira, and C.-T. Lin, "Exploring the determinants of hot spring tourism customer satisfaction: causal relationships analysis using ISM," Sustainability, 11 (9) 2613 (2019). doi:10.3390/su11092613.
44) T.D. Yıldız, "Waste management costs (wmc) of mining companies in turkey: can waste recovery help meeting these costs?," Resources Policy, 68 101706 (2020). doi:10.1016/j.resourpol.2020.101706.
45) T. Domenech, R. Bleischwitz, A. Doranova, D. Panayotopoulos, and L. Roman, "Mapping industrial symbiosis development in Europe_typologies of networks, characteristics, performance and contribution to the circular economy," Resour. Conserv. Recycl., 141 76–98 (2019). doi:10.1016/j.resconrec.2018.09.016.
46) X. Song, Y. Geng, H. Dong, and W. Chen, "Social network analysis on industrial symbiosis: a case of gujiao eco-industrial park," J. Clean. Prod., 193 414–423 (2018). doi:10.1016/j.jclepro.2018.05.058.
47) R.K. Singh, A. Kumar, J.A. Garza-Reyes, and M.M. de Sá, "Managing operations for circular economy in the mining sector: an analysis of barriers intensity," Resources Policy, 69 101752 (2020). doi:10.1016/j.resourpol.2020.101752.
48) J. Maniora, "Is integrated reporting really the superior mechanism for the integration of ethics into the core business model? an empirical analysis," Journal of Business Ethics, 140 (4) 755–786 (2017). doi:10.1007/s10551-015-2874-z.
49) Government of the Republic of Indonesia, "Presidential Regulation No. 59 of 2017 on the Implementation of the Achievement of Sustainable Development Goals," Jakarta, (2017).
50) N. Ishak, "Legal politics of regulating amendments to the 1945 Constitution of the Unitary State of the Republic of Indonesia," *Jurnal Supremasi Hukum*, **5** (2) (2016). doi:10.14421/sh.v5i2.2011.
51) Ministry of Energy and Mineral Resources of the Republic of Indonesia, "Regulation of the Minister of Energy and Mineral Resources No. 26 of 2018 on the Implementation of Good Mining Practices and Supervision of Mineral and Coal Mining," Jakarta, (2018).
52) A.P. Muñoz-Lagos, L. Seguí-Amórtegui, and J.P. Vargas-Norambuena, "Circular economy for strategic management in the copper mining industry," Sustainability (Switzerland), 17 (14) (2025).

doi:10.3390/su17146364.

53) J. Broady-Preston, and W. Swain, “What business are we in? value added services, core business and national library performance,” Performance Measurement and Metrics, 13 (2) 107–120 (2012). doi:10.1108/14678041211241323.
54) Sujoko, and J.H. Tjakraatmadja, “System dynamic models as a basis strategy development of tin ore production optimization case study: Indonesia tin mining company,” *Jurnal Aplikasi Manajemen*, **11** (4) 559–566 (2013).
55) D. Gošnik, “Core business process management and company performance,” Management, 14 (1) 59–86 (2019). doi:10.26493/1854-4231.14.59-86.
56) V. Osei, C. Bai, D. Asante-Darko, and M. Quayson, “Evaluating the barriers and drivers of adopting circular economy for improving sustainability in the mining industry,” Resources Policy, 86 (2023). doi:10.1016/j.resourpol.2023.104168.
57) N. Huda, “The position of regional regulations in the hierarchy of laws and regulations,” *Jurnal Hukum IUS QUIA IUSTUM*, **13** (1) 27–37 (2006).
58) M.A. Eisenberg, “Corporate law and social norms,” Columbia Law Rev., 99 (5) 1253-1292 (1999). doi:10.2307/1123456.
59) T. Baatartogtokh, “State of outsourcing in the mining industry: an overview,” Master’s Thesis, The University of British Columbia, Vancouver, (2016). doi:10.14288/1.0340026
60) A.J. Whitworth, E. Forbes, I. Verster, V. Jokovic, B. Awatey, and A. Parbhakar-Fox, “Review on advances in mineral processing technologies suitable for critical metal recovery from mining and processing wastes,” Clean. Eng. Technol., 7 100451 (2022). doi:10.1016/j.clet.2022.100451.