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# SUSTAINABILITY ASSESSMENT OF POST-MINING LAND USING MULTIDIMENSIONAL SCALING: INSIGHTS FROM THE INDONESIAN COAL MINING SECTOR

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**ABSTRACT**

This study aims to evaluate the sustainability of post-mining land at PT Insani Baraperkasa (PT. IBP) using the Multidimensional Scaling (MDS) method to offer recommendations for land management that incorporates technical and quantitative approaches aligned with sustainable development principles and environmental protection in mining areas. The study examines five (5) main dimensions (environmental, social, economic, technical, and institutional), using a combination of data collection methods such as surveys, environmental impact assessments, and social dialogues with local communities. The MDS method provided a quantitative analysis of sustainability across these dimensions, offering a comprehensive evaluation of post-mining sustainability. Results indicated that PT. IBP overall sustainability index is moderately sustainable, with an average score of 61%. The dimensions of economics and technical aspects scored relatively higher, indicating positive progress. However, the social dimension, particularly Community Anxiety (S4) and High Conflict (S2), showed significant room for improvement. Quantitative recommendations to address High Conflict (S2) include adjustments in blasting schedules, improvement of community infrastructure, and regular stakeholder consultations. Environmental management strategies, such as rehabilitating the Riparian Ecosystem (S3) and promoting Biodiversity (S2) conservation, were also emphasized to enhance environmental sustainability. In conclusion, this research highlights the necessity of integrating technical methods and multi-dimensional management strategies spanning environmental, social, economic, technical, and institutional factors to achieve long-term sustainability in post-mining areas.

***Key-words:*** *Post-mining; Coal mining; Blasting; Multidimensional scaling; Sustainable development.*

## 1. INTRODUCTION

Human activities in the industrial sector, especially extractive industries such as mining, have had significant impacts on the environment. Mining is considered one of the sectors with the largest contribution to global ecological damage, especially due to the increasing scale and intensity of natural resource exploitation in many developing countries (Mudd, 2007). The growing scale, scope, and severity of environmental impacts due to mining activities have become a major concern for governments, researchers, and communities. This activity not only changes the work site's physical environment, but its effects often extend to areas outside the mining area, causing serious ecosystem degradation (Badakhshan et al., 2023). Mining systematically causes habitat fragmentation, biodiversity loss, and land degradation that may take decades to recover (Gholami et al., 2024).

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The environment, as a fundamental aspect of human life, is composed of physical (abiotic), biological (biotic), and social components. Studies indicate that mining operations can interfere with the intricate relationships between these elements, leading to significant alterations in local ecosystem functions (Hamdani et al., 2024; Pantelic et al., 2023). Specifically, mining activities result in considerable shifts in soil, water, and air quality, all of which are essential for sustaining biotic life (Efendi et al., 2021). For instance, water contamination from mining runoff frequently leads to the deterioration of water supplies relied upon by both humans and wildlife living near mining areas (Hermon et al., 2023). Recent advancements in field-based measurement techniques, including soil erosion quantification, water quality testing, and air pollutant monitoring, have provided more precise insights into the extent of environmental changes induced by mining operations. These methodologies enable a clearer understanding of the impacts on sustainability, informing better mitigation strategies. Additionally, the social dimension, including local traditions, ethics, and cultural practices, is often affected by mining activities, which create land-use disputes and lead to changes that conflict with community values and beliefs (Malyukova et al., 2023).

In Indonesia, the Production Operation Mining Business License, or IUP-OP, governs the entire process of mining activities, from exploration to post-mining, as outlined in Government Regulation No. 3/2020. This regulation mandates adherence to operational standards to balance resource extraction and environmental protection. However, in developing countries, where ecological oversight is often weak, enforcing these standards is challenging (Nzereogu et al., 2024; Maliganya et al., 2023). Effective enforcement is essential to prevent irreversible environmental harm and to promote sustainable development. Mining operations typically use two (2) main methods (open-pit and underground mining). Research by Efendi et al. (2024) highlights the distinct environmental impacts of these methods. Open-pit mining, for instance, causes extensive surface-level ecological damage, leading to significant land-use changes and the loss of crucial habitats. To better quantify such impacts, advancements in environmental measurement techniques, such as high-resolution topographic surveys, sediment load analysis, and ground vibration monitoring, have been instrumental. These tools enable precise assessments of land degradation, erosion rates, and community-level disruptions, providing actionable data for mitigation strategies.

Ministerial Decree No. 1827 K/30/MEM/2018 highlights the critical need for comprehensive monitoring of the environmental impacts associated with various mining methods, particularly in the management of water resources and hazardous waste. Open-pit mining, in particular, poses significant environmental challenges, especially due to damage caused by blasting. Research by Martínez et al. (2021) indicates that vibrations resulting from blasting can lead to structural damage in nearby buildings and disrupt local communities. These vibrations also adversely affect residents' quality of life, causing considerable discomfort for those living near mining sites. To address these issues, mining companies are required to comply with national standards such as the Indonesian National Standard (SNI) 7571:2010, which provides specific guidelines for managing the impacts of blasting. Advancements in seismological tools have further enhanced the precision of monitoring blast impacts, enabling better adherence to both national and international standards.

In addition to addressing blast-related concerns, the effective handling of waste and the implementation of land reclamation measures are critical to reducing the environmental harm caused by mining. Proper waste management and reclamation efforts can prevent further pollution of air, soil, and water (Jiang et al., 2023). Research conducted by Gusman et al. (2021); Damseth et al. (2024) on post-mining land emphasizes that effective reclamation not only restores ecological functionality but also creates economic opportunities, such as transforming land for agricultural or forestry purposes. Techniques like soil quality assessments have proven instrumental in evaluating reclamation outcomes, ensuring that rehabilitated lands align with sustainability objectives. A thorough assessment of post-mining land sustainability can be achieved using the Multidimensional Scaling (MDS) method. This approach has been demonstrated to effectively identify critical factors influencing environmental sustainability (Nazki et al., 2024; Wagianto et al., 2024).

For instance, a case study at PT. Ansaf Inti Resources (PT. ANSAF), a subcontractor for PT Insani Baraperkasa (PT. IBP), employed MDS analysis to evaluate the sustainability of post-mining land in the Separi Block. This study provided significant insights into best practices for environmentally responsible land management (Liu et al., 2019). The application of MDS allows researchers and policymakers to simultaneously evaluate multiple environmental variables, offering a multidimensional perspective on sustainability. This analysis has proven especially useful in identifying key factors such as soil fertility, vegetation regrowth, and water quality that determine the success of land reclamation initiatives. By pinpointing these factors, MDS supports evidence-based policymaking, guiding both the government and mining companies toward the sustainable use of post-mining land. While mining contributes significantly to economic growth, it also brings substantial environmental challenges that require responsible mitigation strategies. Effective efforts, including waste management, advanced land reclamation techniques, and regular environmental monitoring, are essential to minimize these adverse effects. Emerging tools like MDS play a vital role in achieving these goals by ensuring that post-mining land is rehabilitated to support sustainable ecosystems.

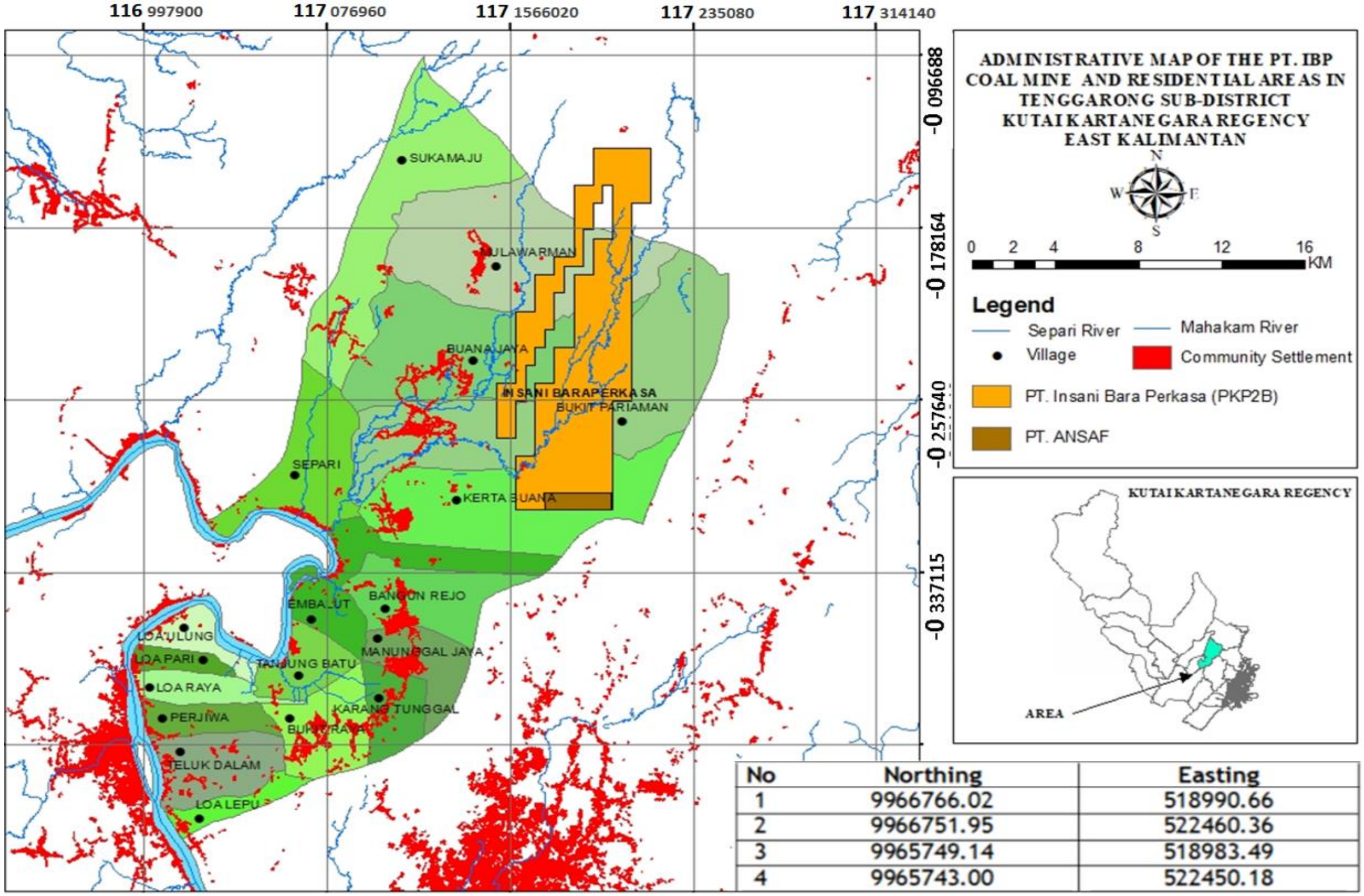
This study aims to evaluate the sustainability of post-mining land at PT. IBP by utilizing the MDS method. This multi-dimensional approach provides a robust analytical framework for addressing complex geographical challenges. By integrating multiple dimensions including ecological, social, economic, technical, and institutional factors this study proposes land management strategies that support sustainable development and prioritize environmental protection in mining regions through precise and systematic evaluations.

## 2. METHODS

The study location was selected because mining activities in this area have been ongoing for an extended period, and the land reclamation process has already commenced. This situation provides an opportunity for a more accurate assessment of post-mining land sustainability. The concept of sustainable development emphasizes meeting present needs without compromising the ability of future generations to meet theirs (Azizah et al., 2023). According to Aryantie et al. (2023), this concept arose as a response to unsustainable economic growth, which often leads to environmental degradation, social inequality, and long-term economic losses. This study was conducted at PT. ANSAF, a subcontractor of the Separi Block of PT. IBP, located at the Berambai site, covers an area of approximately 182 hectares. Administratively, the study site is situated within Kertabuana Village, Buana Jaya Village, and Mulawarman Village in the Tenggarong Seberang Sub-district, Kutai Kartanegara Regency, East Kalimantan Province, as shown in **Figure 1** below.

This method seeks to assess and analyze the sustainability of post-mining land by examining it through multiple dimensions, including environmental, social, economic, technical, and institutional factors. The comprehensive application of the MDS method allows for detailed measurement and analysis of sustainability, providing a holistic understanding of the post-mining land's current condition and the main areas requiring improvement for long-term sustainable development (Soubbotina, 2004; Anas et al., 2013). The main dimensions and indicators of post-mining land sustainability in the context of sustainable development are outlined in **Table 1** below.

The study approach begins with compiling relevant dimensions, such as environmental, economic, social, technical, and institutional, related to the impacts of blasting vibration in coal mining. Main indicators for each dimension are selected to be measured quantitatively (Ansahar et al., 2022). After that, vibration impact data are collected for each dimension, and geostatistical methods are used to model the spatial distribution of the impacts. MDS analysis is applied to reduce the data and visualize the relationship between locations based on the impacts of various dimensions. The results of this analysis help evaluate how similar or different the impacts are at each location and are used to assess the sustainability of the impacts. Continuous monitoring is carried out to ensure that the strategies implemented are effective in reducing vibration impacts and maintaining sustainability at each location. More detailed sustainability categories based on index values resulting from MDS analysis can be seen in **Table 2** below.




| No | Northing | Easting |
|---|---|---|
| 1 | 9966766.02 | 518990.66 |
| 2 | 9966751.95 | 522460.36 |
| 3 | 9965749.14 | 518983.49 |
| 4 | 9965743.00 | 522450.18 |

**Fig. 1.** Map of study location.

**Table 1.**
**Main dimensions and indicators of post-mining land sustainability.**

| Pillars | Descriptions | Indicators |
|---|---|---|
| Environmental | Development should consider its impact on the natural environment, including wise use of natural resources, biodiversity preservation, efficient waste management, and protection of vulnerable ecosystems. | S1: Ecosystem<br>S2: Biodiversity<br>S3: Riparian Ecosystem<br>S4: Social Conflict<br>S5: Resource Provision<br>S6: Air Management<br>S7: Community Nutrition<br>S8: Erosion Prevention |
| Social | Sustainable development must promote social inclusion, justice, and well-being for all layers of community. This includes poverty alleviation, access to quality education and healthcare, gender equality, and human rights protection. | S1: Education and Research<br>S2: High Conflict<br>S3: Health Insurance<br>S4: Community Anxiety<br>S5: Community Life<br>S6: Tradition and Culture<br>S7: Resources<br>S8: Recreation |
| Economic | Sustainable development requires inclusive and environmentally-friendly Economic growth. It focuses on developing sustainable Economic sectors, creating decent jobs, reducing Economic inequality, and utilizing resources efficiently. | S1: Income<br>S2: Well-being<br>S3: Pollution<br>S4: Tourism<br>S5: Agriculture<br>S6: Trade<br>S7: Transportation<br>S8: Industry |
| Technical | The technical aspect involves the use of technology and innovation in mining operations, which impacts working conditions and operational efficiency. | S1: Occupational Health and Safety<br>S2: Mining Safety Management System (SMKP)<br>S3: Ground Vibration<br>S4: Environmental Impact<br>S5: Road Vibration<br>S6: Building Vibration<br>S7: Human Vibration<br>S8: Equipment Vibration |
| Institutional | The institutional aspect encompasses regulations that protect workers' rights, ensure a safe working environment, provide social protection, and regulate overall mining operations. | S1: Licensing<br>S2: Environmental Regulations<br>S3: Labor Laws<br>S4: Occupational Health and Safety<br>S5: Corporate Social Responsibility (CSR)<br>S6: Mining Regulations<br>S7: Labor Rights<br>S8: CSR/RIPPM |

**Table 2.**
**Sustainability categories based on index values resulting from MDS analysis.**

| Index values | Categories |
|---|---|
| 0.00 - 24.99 | Not Sustainable |
| 25.00 - 49.99 | Less Sustainable |
| 50.00 - 74.99 | Moderately Sustainable |
| 75.00 - 100.00 | Sustainable |

## 3. RESULTS

### 3.1. Dimensions of sustainability index

*3.1.1. Environmenalt dimension*

The MDS analysis results for the environmental dimension reveal that several main attributes significantly impact environmental sustainability. The leverage graph indicates that Social Conflict (S4) has the most substantial effect on changes in ordination, with a leverage value of 6.88, highlighting its critical role in influencing environmental sustainability. This analysis emphasizes the necessity of considering a range of social, ecological, and resource management factors to enhance environmental sustainability. For additional details, please see **Figure 2** below:


**Fig. 2.** 1) Sustainability index result for environmental dimension and 2) Leverage analysis result.

The MDS analysis results for the sustainability of post-mining land at PT. IBP highlights significant variations in environmental sustainability across different areas. The ordination graph shows that some areas score relatively high on the post-mining sustainability scale, with values of 69.92 and 60.07, indicating moderate sustainability levels. However, other areas demonstrate lower sustainability, with scores ranging from 51.07 to 54.09, reflecting variability in performance. Social Conflict (S4) is identified as a major factor influencing post-mining land sustainability, as evidenced by a root mean square change of 6.88 when this factor is excluded. This implies that addressing social conflicts could substantially enhance overall sustainability. Furthermore, the Riparian Ecosystem (S3) and Resource Provision (S5) also play main roles, with root mean square changes of 5.43 and 4.67, respectively, emphasizing the importance of effective ecosystem and resource management in post-mining areas. These findings align with Ai et al. (2020), who stress the importance of social factors, such as conflict resolution, in achieving long-term sustainability for post-mining land. Similarly, Gastauer et al. (2018) highlight the critical role of rehabilitating riparian ecosystems and ensuring efficient resource management for sustainability. While strategies such as Erosion Prevention (S8) and improving Community Nutrition (S7) contribute to sustainability, their impact is less pronounced compared to social and ecosystem factors. Biodiversity Conservation (S2), with a root mean square change of 3.03, also reinforces the ecological foundation necessary for sustainability. In conclusion, the findings confirm that a holistic approach involving social and ecological collaboration among government, companies, and communities is crucial to ensuring the long-term sustainability of post-mining land at PT. IBP.

*3.1.2. Social dimension*

The MDS analysis results for the social dimension highlight several attributes that significantly impact sustainability. Among these, the Community Anxiety (S4) attribute has the highest influence on coordination changes, with a leverage value of 6.62, indicating its crucial role in shaping social sustainability. This analysis underscores the importance of addressing social concerns such as Community Anxiety (S4), High Conflict (S2), and Health Insurance (S3) to enhance social sustainability. Strategies aimed at reducing High Conflict (S2) and Community Anxiety (S4), along with improving access to health services and enhancing Community Life (S5), are essential for promoting optimal social sustainability. For further details, refer to **Figure 3** below:

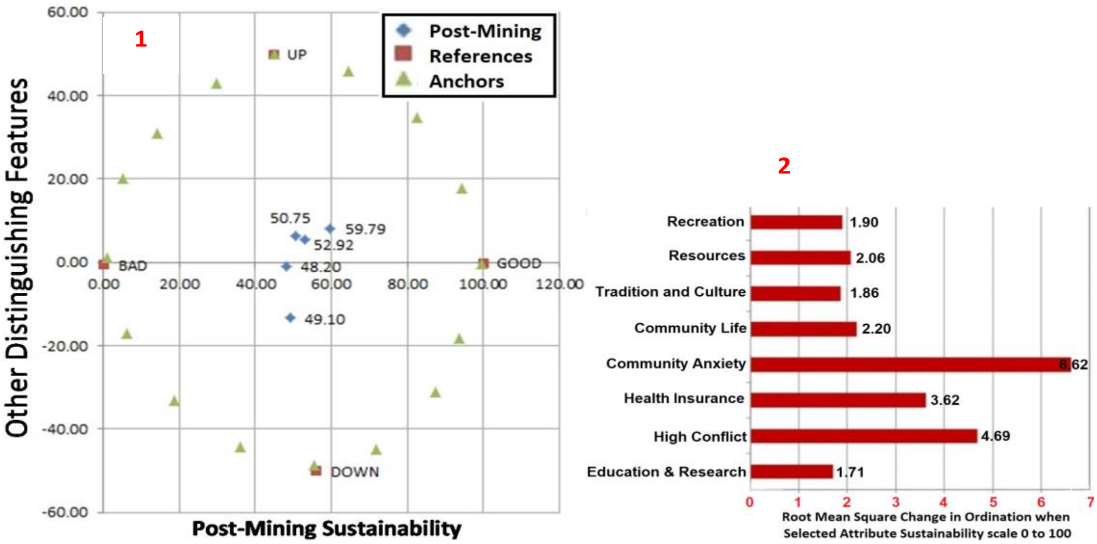



**Fig. 3.** 1) Sustainability index result for social dimension and 2) Leverage analysis result.

The MDS analysis results regarding the social dimensions of post-mining land sustainability at PT. IBP identified several critical social factors that significantly affect sustainability. One of the most prominent factors is Community Anxiety (S4), which has a root mean square change value of 6.42. This underscores that Community Anxiety (S4) related to the impacts of post-mining activities is a pressing issue that warrants serious consideration. Such anxiety may arise from uncertainties concerning the economic, health, and environmental prospects following mining operations. Another important factor is High Conflict (S2), with a value of 4.59. Elevated levels of conflict signify tensions within communities over post-mining land management, often due to unequal resource distribution or company policies. Additionally, Health Insurance (S3), which has a value of 3.62, plays a role in influencing social sustainability, emphasizing the necessity of access to health coverage for communities surrounding post-mining sites. A deficiency in health protection can exacerbate Community Anxiety (S4) and intensify the social burden. Conversely, the factors of Tradition and Culture (S6) and Community Life (S5) exhibit lower influences, with values of 1.86 and 2.20, respectively. This suggests that while aspects of Tradition and Culture (S6) and Community Life (S5) remain relatively stable, they still require attention to prevent potential deterioration due to post-mining activities. Research by García-Sánchez et al. (2021) indicates that social sustainability in post-mining areas heavily depends on how mining companies address the anxiety and uncertainties faced by local communities. Furthermore, Botezan et al. (2020) emphasize the significance of providing adequate social security, including Health Insurance (S3), alongside access to Education and Research (S1), to help alleviate Community Anxiety (S4) and establish a solid foundation for long-term social sustainability. In conclusion, to enhance social sustainability on post-mining land at PT. IBP, initiatives should concentrate on reducing Community Anxiety (S4), effectively managing High Conflict (S2), and improving access to Health Insurance (S3). These measures will contribute to social stability and ensure ongoing sustainability in the area.

### 3.1.3. Economic dimension

The MDS analysis results for the economic dimension highlight several attributes that significantly impact sustainability. Among these, the Trade (S6) attribute exhibits the highest leverage value of 12.24, indicating that trade is the most influential economic factor affecting overall economic sustainability. This finding implies that changes or instability in the Trade (S6) sector can have a considerable impact on economic sustainability as a whole. Additionally, the analysis indicates that economic sustainability is notably influenced by Trade (S6), Tourism (S4), and Well-being (S2). To enhance long-term economic sustainability, it is essential to implement strategies that strengthen these sectors while addressing the adverse effects of Pollution (S3). For further details, please see **Figure 4** below:

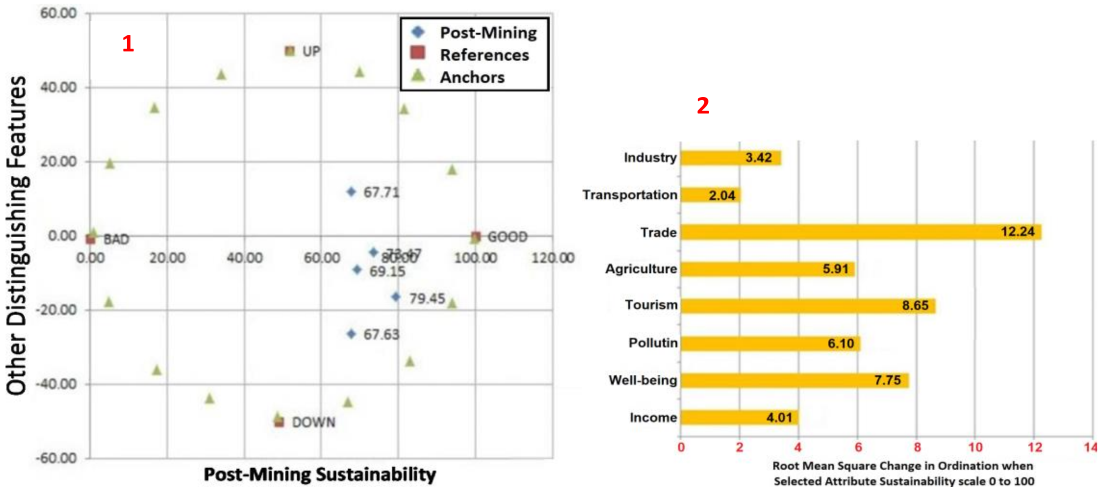



**Fig. 4.** 1) Sustainability index result for economic dimension and 2) Leverage analysis result.

The MDS analysis results regarding the economic dimension of post-mining land sustainability at PT. IBP reveal several main economic factors influencing sustainability. The most significant of these is Trade (S6), which has a root mean square change value of 12.24. This indicates that effective management of Trade (S6) is a critical driver of economic sustainability in post-mining areas. Ensuring stability in the trade sector is essential for the economic viability of these areas. In addition to Trade (S6), the Tourism sector (S4) plays a substantial role in promoting economic sustainability, with a root mean square change value of 8.65. Tourism can provide an important alternative source of income for communities in post-mining areas, particularly through the sustainable use of restored natural resources. By developing tourism in these areas, local communities can diversify their economic opportunities significantly. Pollution (S3) also stands out as a vital factor within the economic framework, with a value of 6.10. This highlights the importance of effective environmental management and pollution reduction in enhancing economic sustainability, as maintaining environmental quality can attract other economic activities, such as Agriculture (S5) and Tourism (S4). Furthermore, Well-being (S2) and Income (S1) also significantly impact sustainability, with values of 7.75 and 4.01, respectively. Well-being is essential for ensuring socio-economic stability in post-mining communities; when well-being is secured, the likelihood of conflicts and social issues that could negatively affect the local economy is diminished. Research by Everingham et al. (2022) suggests that economic sustainability in post-mining areas heavily relies on economic diversification and reducing dependence on the mining industry. Strategies that promote the growth of the Trade (S6) and Tourism (S4) sectors are commonly adopted to enhance overall economic stability in these contexts. Kretschmann (2020) also noted that mitigating the effects of Pollution (S3) is crucial not only for environmental health but also for fostering economic conditions that support Well-being (S2) and attract investment. In conclusion, achieving improved economic sustainability for post-mining land at PT. IBP necessitates a focus on diversifying the economy, particularly in the Trade (S6), Tourism (S4), and Agriculture (S5) sectors, along with implementing effective Pollution (S3) management strategies. Enhancing the Well-being (S2) and Income (S1) of local communities will provide a strong foundation for sustained economic growth in the area.

### *3.1.4. Technical dimension*

The MDS analysis results for the technical dimension highlight several main attributes that significantly impact sustainability from a technical perspective. Ground Vibration (S3) emerges as the most influential factor, with a leverage value of 14.15, indicating its substantial effect on the ordination and its role as a primary driver of technical sustainability. Similarly, Building Vibration (S6) also plays a critical role, with a leverage value of 14.06, underscoring the importance of managing vibrations on building structures to ensure technical sustainability. Overall, the findings suggest that technical sustainability in mining operations is heavily dependent on the effective management of Ground Vibration (S3), Road Vibration (S5), Building Vibration (S6), and Environmental Impact (S4). To achieve comprehensive technical sustainability, it is crucial to optimize occupational safety and health standards and implement effective risk management practices. For further details, see **Figure 5** below:

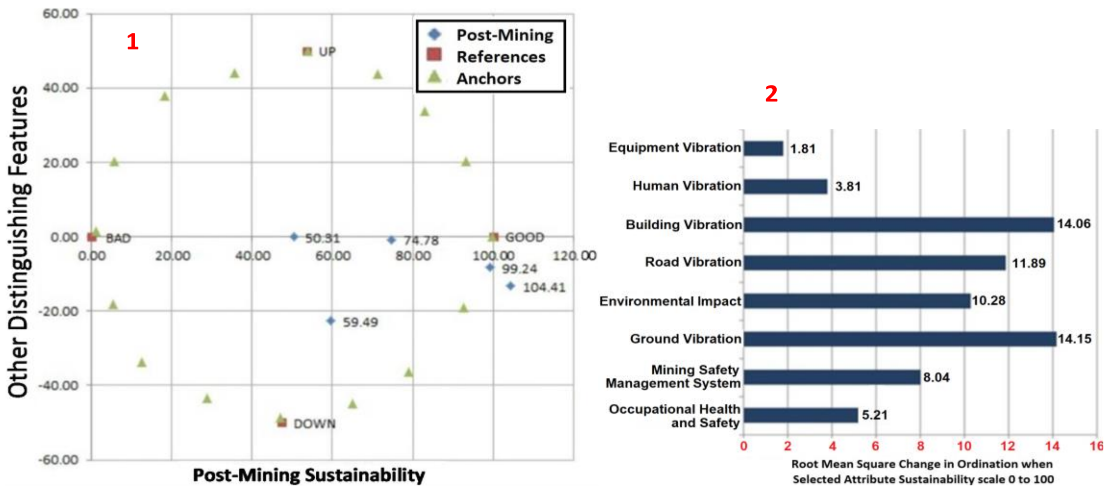



**Fig. 5.** 1) Sustainability index result for technical dimension and 2) Leverage analysis result.

The MDS analysis for the technical dimension of post-mining land sustainability at PT. IBP identifies several main factors that significantly influence sustainability. The most prominent factor is Ground Vibration (S3), with a root mean square change value of 14.15. This indicates that managing Ground Vibration (S3), resulting from mining activities is crucial for the technical sustainability of post-mining areas. Proper control of Ground Vibration (S3) is essential for preserving both environmental stability and infrastructure in the area. Building Vibration (S6) and Road Vibration (S5) also play important roles, with root mean square change values of 14.06 and 11.89, respectively. These values highlight the importance of maintaining infrastructure that is impacted by mining operations, such as roads and buildings. Without effective management, excessive vibrations from mining activities and traffic could damage infrastructure and negatively affect the quality of life for nearby communities. Additionally, Environmental Impact (S4) with a value of 10.28 underscores the significance of mitigating pollution and land degradation to enhance long-term sustainability in post-mining areas. Other factors, such as SMKP (S2) and Occupational Health and Safety (S1), with values of 8.04 and 5.21 respectively, also contribute to sustainability.

Implementing effective SMKP systems and health and safety protocols can further strengthen technical sustainability. Research by Lee & Lim (2020) highlights that mitigating Environmental Impact (S4) in mining areas can reduce the risk of larger environmental issues, supporting overall sustainability. In conclusion, achieving better technical sustainability in the post-mining land of PT. IBP requires focused efforts on managing Ground Vibration (S3), Building Vibration (S6), Road Vibration (S5), Environmental Impact (S4), and ensuring effective SMKP implementation (S2). Addressing these technical factors will help secure long-term sustainability for both the environment and local communities.

### *3.1.5. Institutional dimension*

The MDS analysis for the institutional dimension highlights several attributes that significantly influence sustainability. Among these, Labor Laws (S3) stand out with the highest leverage value of 9.14, indicating that labor regulations play a main role in shaping institutional sustainability. This finding suggests that enhancing legal protections for workers has a considerable impact on overall sustainability. Additionally, the analysis shows that institutional sustainability is heavily affected by Labor Laws (S3), Mining Regulations (S6), and Occupational Health and Safety (S4). Strengthening regulatory frameworks, boosting Corporate Social Responsibility (CSR) initiatives (S5), and ensuring robust worker protections are essential for fostering long-term institutional sustainability. For further details, refer to **Figure 6** below:

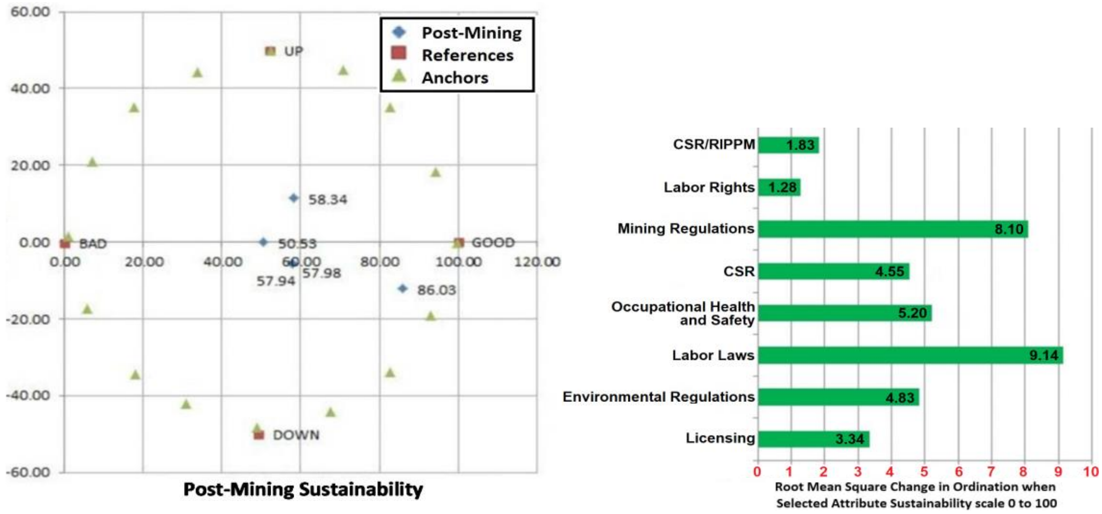



**Fig. 6.** 1) Sustainability index result for institutional dimension and 2) Leverage analysis result.

The MDS analysis of the institutional dimension in post-mining land sustainability at PT. IBP identifies several main institutional attributes that influence sustainability. Labor Laws (S3) emerged as the most influential factor, with a root mean square change value of 9.14, highlighting that robust and equitable labor regulations play a crucial role in fostering institutional sustainability. Adherence to these laws ensures the welfare and stability of workers in post-mining areas, ultimately enhancing public trust in mining companies and institutions. Mining Regulations (S6) also have a significant impact, with a value of 8.10, indicating that strict enforcement and compliance with mining laws are essential for creating a stable institutional framework that supports sustainability. Similarly, Occupational Health and Safety (S4) management, with a value of 5.20, is vital for maintaining a safe working environment and ensuring long-term sustainability. Additionally, Corporate Social Responsibility (CSR) initiatives (S5) play an important role, as evidenced by a root mean square change value of 4.55. Active engagement in CSR activities strengthens the relationship between mining companies and local communities, contributing to both social and economic sustainability in post-mining areas. According to Jenkins & Yakovleva (2006), strong regulatory frameworks are fundamental to sustaining institutional stability in mining areas, covering essential aspects such as Occupational Health and Safety (S4) and Labor Rights (S7). Similarly, Djumarno et al. (2024) underscore the critical role CSR (S5) plays in building positive corporate-community relations, which is main to maintaining social stability and institutional sustainability. In conclusion, the findings suggest that enhancing institutional sustainability at PT. IBP requires a focus on enforcing Labor Laws (S3) and Mining Regulations (S6), as well as expanding CSR efforts (S5). A comprehensive approach to regulation and social responsibility will help create a safe, stable environment that supports long-term sustainability in post-mining areas.

### 3.2. Sustainability index values

In multi-dimensional terms, the current sustainability index value of PT. IBP (existing condition) is an average of 61% which is included in the fairly sustainable category. This means that when viewed from the strength sustainability side, it can be said that PT. IBP is included in the moderately sustainable category for sustainable development because on average the sustainability dimensions are found to be in the fairly sustainable category (Environment: 54.09%, Social: 50.75%, Economic: 69.15%, Technical: 74.78%, Institutional: 57.98%). More clearly, the sustainability index value for the environmental, social, economic, technical, and institutional dimensions can be seen in the chat radar in **Figure 7** below:

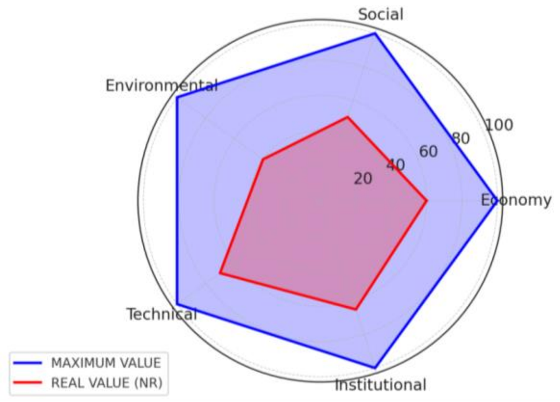



**Fig. 7.** Multi-dimensional sustainability of PT. IBP.

The results of the MDS analysis on the coal mine sustainability index show that although there are some minor errors in the attribute scoring procedure, most of the differences in scores come from differences of opinion among the experts involved. The stability level of the MDS analysis remains high, with negligible data errors and minimal data loss. In addition, the S-stress value obtained is quite high, indicating good accuracy of the modeling results. **Table 3** below presents the results of the Monte Carlo analysis which confirms the value of the multidimensional sustainability index with a high level of confidence.

**Table 3.**

**Results of Monte Carlo analysis for the MDS index with a 95% confidence level.**

| No | Sustainability dimensions | MDS Results (%) | Monte Carlo Results (%) | Differences (%) |
|---|---|---|---|---|
| 1 | Environment | 54.09 | 53.68 | 0.41 |
| 2 | Social | 50.75 | 49.03 | 1.72 |
| 3 | Economic | 69.15 | 59.04 | 10.11 |
| 4 | Technical | 74.78 | 56.39 | 18.39 |
| 5 | Institutional | 57.98 | 52.73 | 5.25 |

The relatively high coefficient of determination ($R^2$) ranging from 0.8834 to 0.9389 indicates that the attributes in this analysis represent 92-95% of the sample variability, thus illustrating strong model accuracy. In addition, the low S-stress values (0.1402-0.1669) indicates a very good level of configuration accuracy for each dimension, as described in **Table 4** below:

**Table 4.**

**Results of S-stress values and Determination Coefficient ($R^2$).**

| No | Sustainability dimensions | S-Stress Values | $R^2$ Values |
|---|---|---|---|
| 1 | Environment | 0.1443 | 0.9375 |
| 2 | Social | 0.1477 | 0.9389 |
| 3 | Economic | 0.1402 | 0.9266 |
| 4 | Technical | 0.1669 | 0.8834 |
| 5 | Institutional | 0.1661 | 0.9260 |

To address social conflicts caused by blasting vibrations in the PT. IBP mining area, the proposed solution includes several important stages. These stages are designed to reduce the negative impacts of vibrations on the community and the environment, as well as strengthen the relationship between the mine and the local community. The recommended stages can be seen in **Table 5** below.

**Table 5.**

**Strategy to mitigate social conflict due to blasting vibrations.**

| Main Stages | Sub-Stages | Descriptions |
|---|---|---|
| Impact identification and assessment | Social survey | Conduct surveys to understand social impacts and community complaints |
| | Environmental impact assessment | Evaluate vibration impacts on infrastructure and public health |
| Consultation and communication | Community dialog | Hold meetings with the community to explain the impacts and mitigation |
| | Information sharing | Provide clear information about blasting schedules and vibration intensity |
| Mitigation plan development | Blasting schedule adjustment | Adjust blasting schedules to avoid disrupting community activities |
| | Vibration intensity reduction | Implement controlled and eco-friendly blasting techniques |
| | Infrastructure repair | Routine inspections and repairs to affected infrastructure |
| Implementation of preventive measures | Monitoring and supervision | Install sensors to monitor vibrations in real-time |
| | Training and awareness | Provide training to workers and the community on vibration mitigation |
| Evaluation and adjustment | Effectiveness evaluation | Regularly review and evaluate the effectiveness of mitigation measures |
| | Mitigation plan adjustment | Adjust the mitigation plan based on evaluation results |
| Community relations building | Community development program | Implement community assistance programs and invest in local infrastructure |
| | Feedback and adaptation | Receive community feedback and make adjustments as needed |
| Reporting and transparency | Regular reporting | Produce regular reports on vibration impacts and mitigation actions |
| | Transparency | Ensure full information disclosure to the community and stakeholders |

## 4. CONCLUSIONS

The conclusion of this study shows that post-mining land at PT. IBP falls into the fairly sustainable category, with an average sustainability index of 61%, encompassing five (5) main dimensions: environmental, social, economic, technical, and institutional. In the environmental dimension, social conflict (S4) is identified as the most influential factor, highlighting the importance of conflict management and ecosystem rehabilitation in maintaining environmental sustainability. In the social dimension, community anxiety (S4) and high conflict (S2) are the primary factors impacting social sustainability, underscoring the need for conflict management strategies and improved access to health services to mitigate the negative effects of mining activities on the community. In the economic dimension, trade (S6) emerges as a crucial factor for ensuring economic sustainability, further supported by the growth of the tourism sector and effective pollution control. For the technical aspect, managing ground vibration (S3) and safeguarding infrastructure, including buildings and roads, are essential to maintaining technical stability. In the institutional realm, labor regulations (S3) and the implementation of CSR initiatives play pivotal roles in upholding institutional sustainability. The novelty of this study lies in its comprehensive approach to evaluating post-mining land sustainability by integrating multidimensional analysis across ecological, social, economic, technical, and institutional factors. It also provides fresh insights into the long-term effects of mining, particularly in managing social conflict and fostering post-mining economic growth. Moreover, the use of the MDS method in the context of coal mining in Indonesia presents a novel approach, offering a new perspective on assessing mining sustainability in the country. Overall, this study highlights the significance of a multidimensional strategy that involves collaboration among the government, companies, and local communities to ensure the long-term sustainability of post-mining land at PT. IBP. A holistic and sustainable management plan is necessary to ensure that post-mining land contributes to sustainable development, protects the environment, and improves the welfare of nearby communities.

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