Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 22, No 3, 2025, 837-851
Article available at [homepage presipitasi]

Regional Case Study

Integrating Mining Management Strategy with Mining Area Sustainability Index

Riza Nur Fajrin Majid[1]*, Khursatul Munibah[2], Dyah Tjahyandari Suryaningtyas[2], Nisa Latifa[3]

[1] Regional Planning Science Study Program, Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Jalan Raya Bogor Darmaga, Bogor, 16680, Indonesia
[2] Division of Regional Development Planning, Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University, Jalan Raya Bogor Darmaga, Bogor, 16680, Indonesia
[3] Laboratory of Regional Planning, Graduate School of Global Environmental Studies, Kyoto University, Japan 606-8501
* Corresponding Author, email: rizanurfajrinmajid@apps.ipb.ac.id

Abstract

Mining in Central Bangka Regency has continued to grow since the era of regional autonomy, with the dominance of alluvial tin mining which has a major impact on the environment. The rise of unconventional mining has exacerbated land degradation, increased the area of critical environments, and reduced the quality of ecosystems. This study aims to assess the value of sustainability based on the Mining Area Sustainability Index as a basis for formulating development policies. The results show that mining activities cause a reduction in forest cover and an increase in the level of environmental criticality, especially due to unconventional mining which is difficult to control. The community has a positive perception of mining activities. The results showed a sustainability score in the less sustainable category (42.55), with the environmental aspect as the lowest aspect. To improve the sustainability score, a moderate policy scenario was chosen as the best strategy, focusing on managing environmental impacts, utilizing ex-mining land, and improving community health and safety. With the right policy approach and synergy between stakeholders, the sustainability of the mining sector in Central Bangka Regency can be achieved.

Keywords: Central Bangka; mining activities; mining management strategy; sustainability index

1. Introduction

The mining sector is an important pillar of national development. Mineral resource exploitation has become a strategic instrument in increasing state and local revenues (Ericsson & Löf, 2019). However, mining-based development often focuses on only one dimension, namely economic growth (Mancini & Sala, 2018). The development paradigm that judges success only by the achievement of economic growth as an indicator of successful development at the national and regional levels is a major challenge in creating a balance between economic progress and development sustainability. The positive contribution of the mining sector to economic growth is not directly proportional to social and environmental impacts. In fact, the mining sector has not made a significant contribution to improving the welfare of the community, including local residents around the mine (Yu et al., 2024).

Bangka Belitung Islands Province is one of the largest tin producers in Indonesia, so tin mining, environmental damage and community welfare continue to be hot topics among the people of Bangka Belitung. Central Bangka Regency is one of the regencies in Bangka Belitung, relying on the mining sector as the main support of the economy, with a contribution of 19% to GRDP and driving economic growth of 5.16% in 2023 (BPS, 2024). However, the social and environmental impacts of mining activities are not proportional to its economic contribution. Per capita income in the region is 11% lower than the provincial average and school dropout rates are increasing as children prefer to work as miners (Ahmad et al., 2022). In terms of the environment, land degradation (Sukarman et al., 2020), decreased soil quality (Wulandari et al., 2022), and changes in coastal ecosystems are getting worse due to the rampant unconventional mining (Kurniawan & Mustikasari, 2019). The Land Quality Index of Central Bangka Regency in 2023 was 39.26% (poor category), which shows the significant impact of land conversion and resource exploitation without sustainability principles (DLH, 2024).

Geologically, Bangka Island has tin reserves scattered in alluvial deposits, making the extraction process easier and at the same time increasing the risk of re-exploitation on reclaimed land. (Suryaningtyas et al., 2019). Meanwhile, rampant unlicensed mining remains a serious challenge despite the government's establishment of a Mining Business License (Olvera & Lizuka, 2023). Unlicensed mining activities have a wide impact on the environment and hinder sustainable development, so a measure of development success that can be applied at the national and local levels is needed (Shi et al., 2019).

The mining sector is the dominant sector in Central Bangka Regency, which has a strategic role in supporting the sustainable development planning process (Bappeda, 2021). Sustainable development demands social, economic and environmental balance measured through relevant indicators to support appropriate decision-making (Hák et al., 2016). However, the measurement of mining sector-based development is still mostly done on a global and national scale, while mining-producing regions have not yet become the main focus of regional development policies. Each mining region has different social, economic and environmental characteristics. The mismatch of sustainability indicators can hamper the planning and policy-making process at the local level. Therefore, an evaluative approach is needed that is able to integrate the three dimensions of sustainability in a contextual manner and can be operationalized in mining area management practices.

This research assesses the sustainability of the mining sector in Central Bangka Regency through the Mining Area Sustainable Index (MASI) approach to measure economic, social and environmental dimensions. The novelty of this research lies in the application of the MASI approach in a local context, which has not been widely used as a basis for formulating development policies in mining-producing areas. This research not only measures the level of sustainability with a multi-aspect approach, but also integrates the results into spatial planning and development policy scenarios based on priority areas. Thus, this research contributes to filling the methodological and practical gap in sustainable mining management at the subnational level, especially in areas with high pressure due to mining activities such as Central Bangka Regency. The results of this research can provide an overview of mining sustainability and formulate data-based sustainable mining activity management strategies to support sustainable development planning that is in line with the local context.

2. Methods

2.1 Study Area

This research was conducted in Central Bangka Regency, Bangka Belitung Islands Province, Indonesia, which consists of six sub-districts and 56 villages bordered by Pangkalpinang City in the north, Karimun Strait in the east, and Bangka Strait in the west and South Bangka Regency in the south, as shown in Figure 1. The total area of Central Bangka Regency is approximately 226,903 ha or 13.81% of the Bangka Belitung Islands Province (BPS, 2024). It is surrounded by 12 small islands with a coastline length of ± 195 km. The natural conditions of Central Bangka Regency are mostly lowlands, valleys and a small part is hilly. The soil in Central Bangka Regency has an average pH (degree of acidity) below five and contains tin ore and other minerals such as quartz sand, kaolin and mountain stone (BPS, 2022). Central Bangka Regency has two main morphologies: low alluvial plains (0-30 m above sea level) with alluvium deposits, utilized for agriculture, mining, and settlements, and plains to small hills (0-190 m above sea level) with metamorphic, igneous, and sedimentary rocks, functioning for plantations, agriculture, mining, and groundwater recharge (Bappeda, 2021). The research was conducted in Central Bangka because Central Bangka Regency is known as a tin-producing region in Indonesia, especially in the Bangka Belitung Islands Province. Almost 30% of the area is tin mining land, both managed by large companies and smallholder mining businesses (Rusfina & Hermawan, 2019).

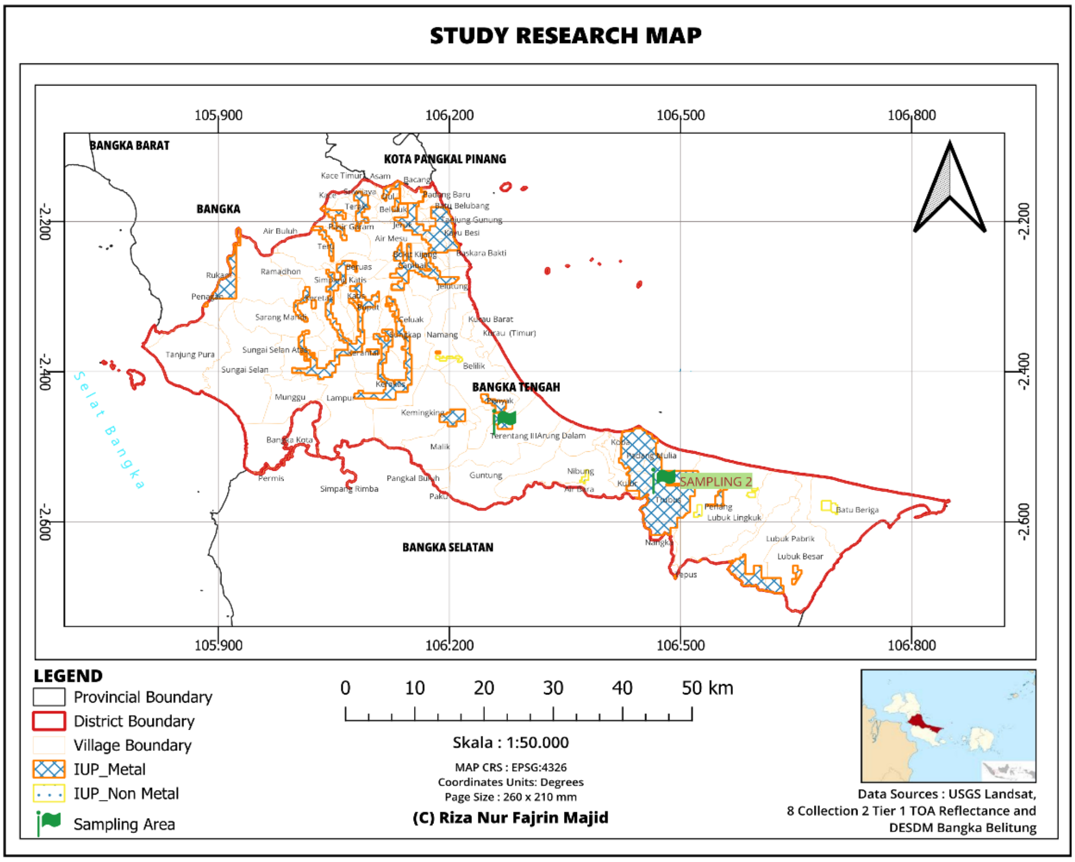

Figure 1. Study area

2.2 Data Collection

In this research we used primary data and secondary data. Primary data was obtained from groundchecks, questionnaire surveys and in-depth interviews. Field checks were conducted to ensure the accuracy of the data and to adjust it to the factual conditions at the research location. In-depth interviews were conducted with expert respondents (researchers, local government, industry professionals and community representatives) to obtain more detailed information. Secondary data consists of remote sensing data, namely Landsat-8 images, Sentinel 2A images and supporting data collected from various agencies in accordance with the substance to be studied. The tools used are a set of computers equipped with QGIS 3.36.2, Google Collaboratory, Google Earth Engine, MSA Exsimpro, and Microsoft Office and Global Positioning System (GPS). Data collection was conducted from October 2024 to February 2025, during which we consulted with 8 experts from various fields related to mining management including academics, NGOs, miners, policy makers and communities.

2.3 Data Analysis

The Mining Area Sustainability Index (MASI) is a multidimensional concept used to comprehensively assess the sustainability of mining areas. MASI considers not only economic outcomes, but also local community welfare and environmental preservation (Yu et al., 2024). MASI assessment is based on three main aspects: economic, social and environmental. Factor analysis is an important first step in analyzing sustainability (Fauzi, 2019). The identification of characterizing indicators (Table 1) is based on several important indicators used for sustainability assessment in mining areas (Yu et al., 2024). The assessment criteria in defining the MASI framework indicators are based on an exploratory approach sourced from the perspectives of academics, policy makers, business people and community organizations on issues in the management of mining activities. We used in-depth interviews, scenario planning and in-person expert polls, which were reinforced by various literature studies supporting this research. Semi-structureinterviews and literature review to analyze facd interviews featured direct questions while scenario planning integrated insights from the expert tors for determining sustainability status scores.

Table 1. Assessment criteria for mining area sustainability index

Aspects	Indicator Symbol	Sustainability Indicators	Assessment Indicator
Economic	C1	Enterprise	Effect of mining on community income and local businesses
	C2	Innovation	Resource utilization in the creation of new business opportunities
	C3	Recycle	Sustainability of ex-mining land utilization
Social	C4	Community	Community perception of the existence of mining
	C5	Society	Impact on residents' safety and health
	C6	Heritage	Impact of mining on socio-cultural values and local tourism
Environment	C7	Land	Conditions of land degradation and biodiversity disturbance
	C8	Pollution	Environmental pollution due to mining activities
	C9	Technology	Percentage of vegetation cover

Source: Yu et al. (2024)

Sustainable development can be achieved if the three pillars of economy, social and environment are considered in a balanced and integrated manner. Each pillar has an important role and supports each other to ensure human well-being and the preservation of the earth in the future. Each aspect has indicators that play an important role in sustainable development (Purvis et al., 2018). Sustainability analysis will be conducted for the economic, social and environmental dimensions using the Multiaspect Sustainability Analysis (MSA) method (Figure 2). MSA is a powerful rapid calculation method for assessing sustainability performance across activities, institutions and companies. This rapid assessment approach uses existing databases compiled by experts or respondents who meet the criteria, allowing for rapid evaluation without re-analysis or model development.

This measurement method integrates data from literature studies and expert research using a structured questionnaire model with several answer options on a Likert scale. The selected factors must be ranked easily, objectively, and on a scale of "bad" to "good" (Pitcher and Preikshot 2001; Firmansyah 2022). Forum Group Discussion (FGD) were conducted to improve the results of the analysis, as shown in Figure 3. The FGD integrated professional perspectives on the variables to be considered while the desk study offered scientifically based factors and indicators from academic sources. Through in-depth interviews and FGD sourced from several expert respondents. The assessment technique involves selecting indicators based on actual conditions or expert judgment. In addition to evaluating current conditions, it may also assess future scenarios ((Firmansyah, n.d.)). This helps identify necessary strategies to maintain the sustainability of an organization's status.The output results of the MSA method, such as uncertainty errors, leverage factors and status indices, help policymakers create scenarios and sustainability plans to develop a sustainable forest (Naegler et al., 2021).

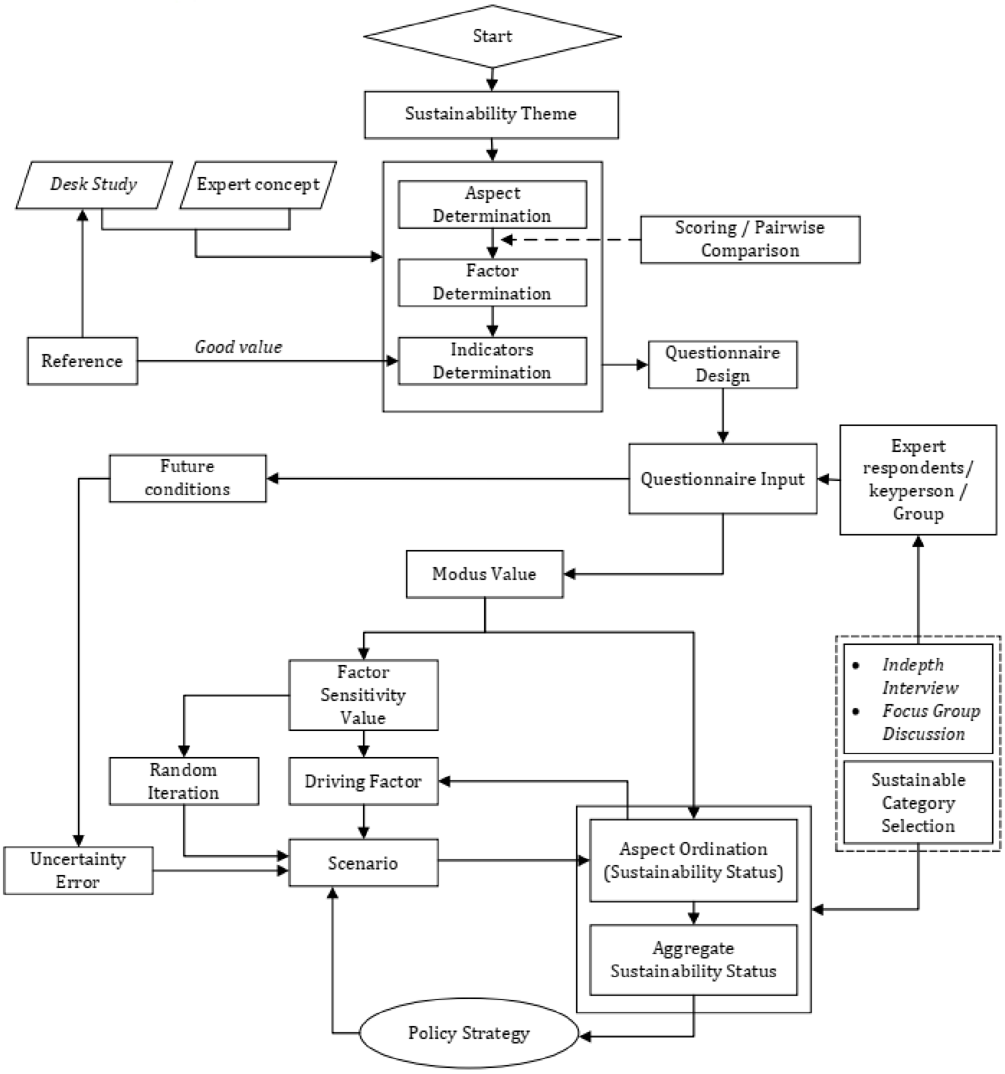

Figure 2. Conceptual MSA Approach (modified from Firmansyah (2022))

Determination of indicators is adjusted to each aspect. The assessment of indicators in each aspect is carried out with the agreement of expert respondents. The number of experts is adequate and has high precision is 3 to 7 expert respondents (Hora, 2014). The aspect assessment was carried out by 7 expert respondents. The results of the assessment scale from respondents are in the form of a score table and leverage factors from each aspect. The aggregate status value is the average status value in each aspect. each aspect. The aggregate status value is the average status value in each aspect. The sustainability score has the following equation (1):

$$Y = \frac{y1+y2+y3+\cdots+yn}{n} = \frac{\sum yn}{n} \quad (1)$$

Where:
y is the index value or value (sustainability/performance)
Y is the aspect status value and n is the number of aspects.

Table 2. Index categories and sustainability status

Index Value (%)	Sustainable Status
0 – 25	Unsustainable
> 25 – 50	Low Sustainable
> 50 – 75	Sustainable
> 75 – 100	Very Sustainable

Source: Firmansyah (2022)

In this study, the index ranges from 0% - 100%. The value of the range, the closer to 100% means that the value has a better status, while the value closer to 0% means that it has a worse value. This study uses 4 categories of index and sustainability status as shown in Table 2 below. Policy recommendations consider the results of the MSA assessment which consists of 5 components, namely aggregate and aspect status values, future conditions, leverage factor analysis, factor validation and sustainability status. Leverage factor analysis is principally to detect dominant factors in aspects (Firmanysah, 2022). The results of the MSA analysis show that MASI is between 0% and 100%. To achieve sustainability status, the MASI value must at least exceed 50%.

After obtaining the sustainability index value, mapping conditions based on the status of the ordination results is needed to strengthen the analysis of actual conditions and support the selection of appropriate policy scenarios. The ordination results produce a classification of status into several categories, namely: good, priority, important, urgent, poor, and illogical. Each category reflects the level of urgency of handling and the policy direction that needs to be taken (Firmansyah, 2022). The order of importance of each status is presented in Figure 3 as a basis for determining the priority scale of sustainable development policy interventions in mining areas.

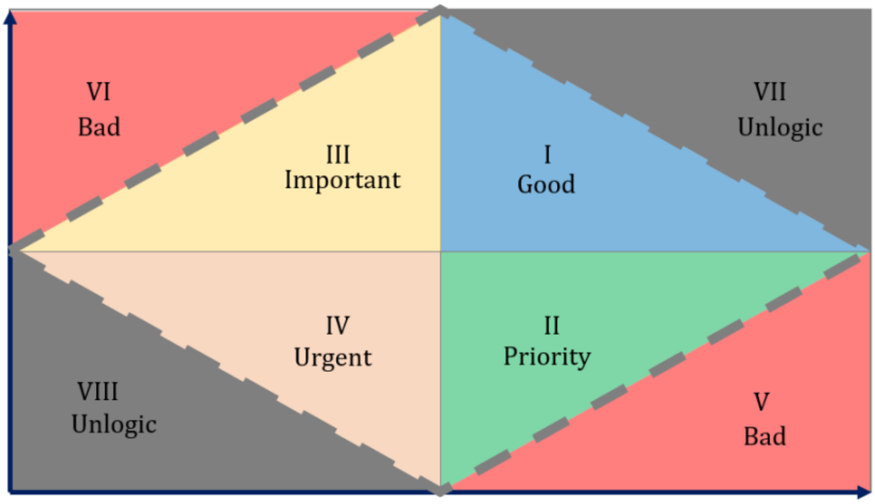

Figure 3. Determination of conditions based on ordination

The determination of condition status based on the results of future ordination is grouped into eight categories that represent the level of policy urgency. Groups I-IV reflect rational conditions with consecutive priority levels from urgent to good, based on a combination of x (current conditions) and y (future projections) values. Meanwhile, groups V-VIII indicate conditions with high uncertainty and assessment bias, so they are considered not worthy of being used as a basis for policy making without further clarification from experts. Therefore, policy formulation is recommended to focus first on groups IV (urgent) to I (good), in order to address critical conditions in a tiered and effective manner.

3. Result and Discussion

3.1. Environment Aspect

The sustainability index analysis of mining areas in Central Bangka shows that the ecological aspect has a sustainability value of 33%, which means that the current condition is less sustainable (Figure 4). Based on the results of the sustainability projection in this aspect, it shows a value of 38%, meaning that this condition is likely to continue to worsen in the future if appropriate policy efforts are not made. Compared to the aggregate mining sustainability index value of 42.55%, the ecological aspect is still below average. This result shows that the level of sustainability of ecological aspects is in an urgent condition, so that comprehensive improvement efforts are needed through appropriate policies and better environmental management to improve current conditions that are still less sustainable.

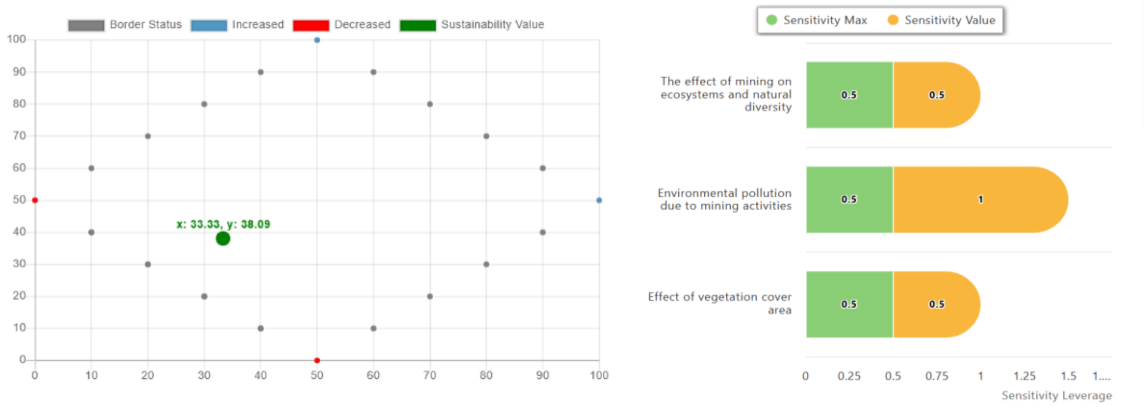

Figure 4. Sustainability index and sensitivity of environment leverage factors

Leverage factor analysis shows three main factors that strongly influence ecological sustainability in tin mining activities, namely environmental pollution, land degradation and decreased vegetation cover. First, environmental pollution mainly comes from liquid and solid waste from mining activities. Liquid waste, such as puddles of excavated water and residual lubricants from heavy equipment, has the potential to pollute groundwater and surrounding waters, degrade water quality and disturb aquatic biota (Prasodjo et al., 2015). Meanwhile, solid waste such as stripped soil has the potential to cause river erosion and sedimentation (Ashraf & Jamwal, 2022), and exacerbate post-mining land degradation (Vaverková et al., 2019). Second, land degradation and biodiversity disruption are significant impacts of top soil stripping and tailings disposal activities. These processes damage soil structure, topography and the balance of local ecosystems, including hydrological systems and flora and fauna habitats. Removal of vegetation for land clearing exacerbates erosion and affects soil quality (Ahirwal & Pandey, 2022), while changes in soil physical and chemical properties inhibit natural revegetation (Uzarowicz et al., 2020). Third, the extent of vegetation cover has decreased dramatically due to surface mining. Most of the mining area was previously secondary forest, which has now turned into scrub or unproductive land. This condition indicates ecological degradation that requires attention in land rehabilitation efforts and restoration of vegetation cover as part of a post-mining environmental sustainability strategy.Of these three factors, environmental pollution due to mining activities is the most influential factor on ecological sustainability.

Environmental pollution due to mining activities in Central Bangka Regency is caused by mining systems that do not apply the principles of Good Mining Practice. Tin extraction activities produce a very large amount of waste. The total waste material (tailings) produced can vary between 10-99.99% of the total mined material (Asmarhansyah et al., 2017). The rise of unlicensed small-scale mining or unconventional mining has an impact on ecosystem damage due to mud from the TI site which is discharged into the river flow so that it pollutes river water (Rusfina & Hermawan, 2019). River water around the mining area becomes cloudy as a result of being used to wash tin beans from mining. Not only that, mining activities also cause the watershed to become shallow, because the remaining mud from the excavation is dumped by miners into the surrounding rivers (Muslih et al., 2014). The flow of river water that empties into the sea carries mud sediments into the sea disturbing the balance of the ecosystem in the sea and destroying the beauty of the beach which was originally white sand turning into gray-black and dirty (Ibrahim, 2015).

3.2. Economic Aspect

The sustainability index analysis of mining areas in Central Bangka shows that the economic aspect has a sustainability value of 50, which means that the current condition is sustainable (Figure 5). Based on the results of the sustainability projection in this aspect, it shows a value of 53.57, meaning that there is potential for improvement in the future, although it is still within the limits that need attention. This value shows that although the economic aspect is classified as sustainable, its position is still at the lower threshold of the category. Compared to the aggregate value of the mining sustainability index, the economic aspect is slightly above average, but still requires policy strengthening to ensure economic sustainability in the long term.

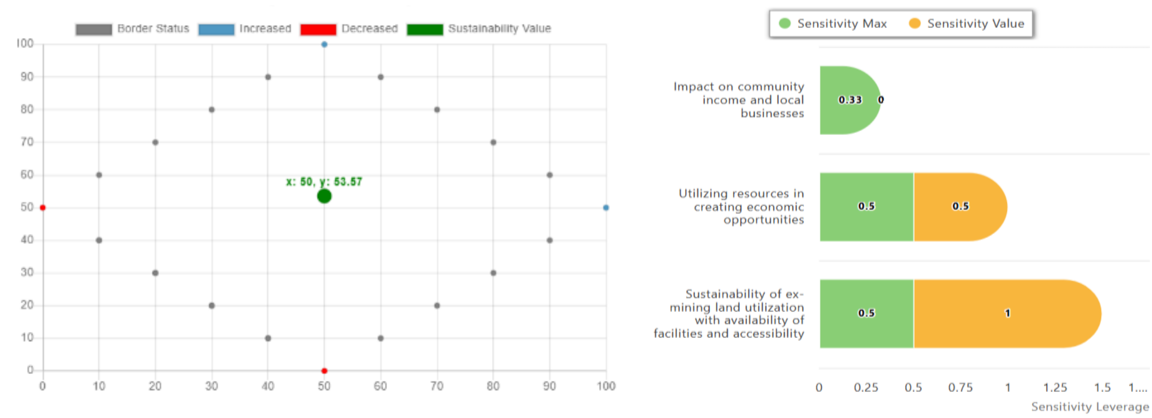

Figure 5. Sustainability index and sensitivity of economic leverage factors

The main leverage factors in the sustainability of the economic aspects of mining areas consist of three dominant attributes. First, the sustainability of post-mining land use is strongly influenced by the availability of basic infrastructure and regional accessibility (Beretić & Plaisant, 2019). Utilization of post-mining land for productive sectors such as agriculture, tourism, or small and medium industries requires the support of transportation facilities, utility networks, and basic social facilities. Successful post-mining land utilization depends on basic infrastructure, such as road access, electricity and public facilities (Kivinen, 2017), which support the development of agriculture, tourism, fisheries and small and medium industries (Servou et al, 2023) Second, resource utilization in creating new business opportunities shows that mining activities have the potential to catalyze local economic growth (Dikgwatlhe & Mulenga, 2023). On the income side, mining improves community welfare through job creation (Narrei & Pour, 2019) and increased purchasing power (Ahadis etl., 2020), which in turn boosts the growth of small and medium enterprises (Tazhibekova et al., 2024). With the right empowerment strategy, this sector can encourage the emergence of supporting businesses and increase the economic capacity of communities around the mine. Third, the effect of mining on community incomes and local businesses confirms that the mining industry contributes directly and indirectly to income generation and small business growth. However, high dependence on the sector risks creating economic inequality and vulnerability to fluctuations in mining production. Economic dependence on the mining sector risks income instability when mining activity declines, and has the potential to trigger local inflation due to uneven increases in purchasing power (Ranosz, 2014).

Of the three factors, the sustainability of ex-mining land use is the most influential. This suggests that if the planning process for mining activities in post-mining land recovery is not optimized, the long-term economic potential may be hindered. Sustainable post-mining land use requires careful evaluation of potentials and limitations, and a focus on the future post-mining landscape to avoid degraded and underutilized areas (Kivinen, 2017). Therefore, careful planning is required in the provision of infrastructure and accessibility so that post-mining land can be optimally utilized. Synergies between the government, mining companies, and local communities must be strengthened to ensure that post-mining lands not only recover ecologically, but also provide sustainable economic and social benefits for local communities (Sulaiman et al., 2025). In addition, the development of products and innovations that are created are able to drive the local economy through various trainings including entrepreneurial provision and motivation as well as including fostered partners (local small and medium industry players) in various local product exhibitions on a local, national and international scale.

3.3. Social Aspect

The sustainability index analysis of mining areas in Central Bangka Regency shows that the social aspect has a sustainability value of 44.33%, which means that the current condition is less sustainable (Figure 6). Based on the results of the sustainability projection on the aspect shows a value of 48.81%, meaning that this condition is likely to continue to worsen in the future if the right policy is not carried out, to ensure social sustainability in the long term.

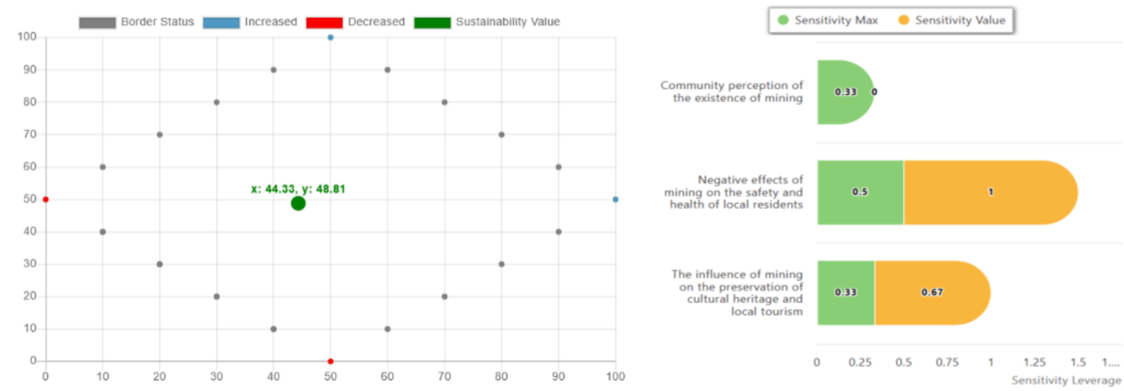

Figure 6. Sustainability index and sensitivity of social leverage factors

Of the three factors, the negative impact of mining on the safety and health of local residents is the most significant. The results of research by Sánchez et al. (2019) showed that innovation and technology play a crucial role in improving the sustainability of mining activities, especially in the environmental aspect which dominates the impact of innovation by 60.9%. This finding confirms the importance of comprehensive mitigation efforts through the use of science and technology to realize safe, environmentally friendly and sustainable mining practices. The application of low-emission technologies and increased resource efficiency throughout the mining life cycle are key in facing the challenges of resource exploitation in the modern era.Therefore, comprehensive mitigation efforts are needed through the use of science and technology to realize safe, environmentally friendly and sustainable mining management. In addition, the impact on socio-cultural values and tourism also needs to be considered, considering that tourism has the potential to become an alternative economic sector for the community. Mining activities in Central Bangka Regency have a significant impact on social aspects, especially in terms of safety, health, socio-cultural values, and community perceptions. The ecological impact of tin mining activities on Bangka Island is heavy metal contamination that accumulates in the environment. One of the heavy metals found in the post tin mining area is lead (Pb). Mycoremediation is one method that can be used to reduce lead pollution in post tin mining areas (Darlingga et al., 2022). In addition, mining changes the social structure and cultural values of local communities from being dependent on agriculture and fisheries to being more dependent on the mining sector. The influx of migrant workers as a result of rational choices in migration triggers the dynamics of cultural acculturation that has the potential to cause social conflict (Aswani & Shivashankar, 2022). although some post-mining land such as Lake Pading has been successfully converted into a tourist area that provides economic and ecological benefits. In terms of perceptions, 46.2% of communities view the mine as having a negative impact, while 50.75% view it positively, reflecting an imbalance in perceived benefits and impacts. Although companies have contributed through taxes, royalties and community development programs, many residents perceive that business interests take precedence over social and environmental welfare.

3.4. Sustainability Value and Management Scenarios of MASI-based Mining Activities

Sustainability analysis using the Mining Area Sustainability Index approach on environmental, economic, and social aspects shows that all three aspects are in the poor or less sustainable category (Table 3). The sustainability index value of the Central Bangka Regency mining area, 42.55 (Figure 6), shows that the results are less sustainable, meaning that the management of mining activities in Central Bangka Regency must be improved to become more sustainable. The aspect that has the highest sustainability value is the economic aspect of 50, followed by the social aspect of 44.33 and the lowest is the ecological aspect of 33.33. The sustainability index value has been factor validated, with the aim of testing the error and diversity of factor scores or attributes assessed by experts. Table 3 shows that the validation status value of each aspect and the total average value is no more than 5%. These validation scores indicate that errors in scoring each attribute or factor are relatively small, variations in scoring due to differences in opinion are relatively small in data entry errors, procedural errors that can reduce missing data are also relatively small.

Table 3. Sustainability index value and validation status

Aspects	Sustainability Index	Validation	Conditions	Sustainability Status
Economic	50	4	Good	Sustainable
Social	44,33	4,67	Important	Low Sustainable
Environment	33,33	3,33	Urgent	Low Sustainable
Aggregates	42,55	4,00	Improvements	Low Sustainable

Based on the results of the sustainability analysis of the three aspects (environment, economic and social) there are 3 sensitive attributes. Of the nine attributes measured, there are three main attributes that act as leverage factors in improving the sustainability of the region. These attributes are leverage factors in determining and influencing the sustainability index value of the mining area, including: (1) Environmental pollution due to mining activities, (2) Sustainability of ex-mining land utilization and (3) Negative effects of mining on the safety and health of residents.

The less sustainable conditions shown by the sustainability analysis with the MASI approach reflect weaknesses in the implementation of mining policies (Akhmaddhian et al., 2023). The possibility of changing conditions for each key factor in the management of mining activities in the future has different variations, depending on the level of influence and uncertainty it has. The selection of scenarios is based on the results of prospective analysis of sustainability status values, where leverage factors are used to identify strategic variables that have a significant influence on the direction of change (Firmansyah, 2022). Through discussions with stakeholders, scenario weighting and prioritization scores were obtained, reflecting collective agreement in determining policy direction. The moderate scenario was chosen because it offers a realistic approach with a focus on improving the most sensitive factors in each dimension of sustainability, so it is expected to have a measurable impact and can be implemented in the medium term.

The results of implementing the moderate policy scenario show a significant improvement in the sustainability of the mining area in Central Bangka Regency (Figure 7), with the aggregate sustainability index value increasing to 59.22, which falls into the sustainable category. The operationalization of this scenario was formulated by involving all relevant stakeholders through FGDs and in-depth interviews with discussions on factors that must be considered, challenges and opportunities, as well as implementation strategies for successful efforts to manage mining activities. This increase occurred due to intervention in one of the most sensitive leverage factors in each aspect, namely environmental pollution due to mining activities in the environmental aspect (Chien et al., 2021), sustainable utilization of ex-mining land in the economic aspect (Hamdani et al., 2021), and the negative influence of mining on the safety and health of residents in the social aspect (Haryadi et al., 2022). After policy implementation, the sustainability value of the environmental aspect increased to 50, the economic aspect reached 66.77, and the social aspect rose to 61, all of which experienced a significant increase compared to the existing conditions. With this realistic approach, the moderate scenario is proven to be able to improve the balance between mining activities and environmental, social and economic sustainability, so it is a strategic step that can be applied in efforts to improve mining management in the region.

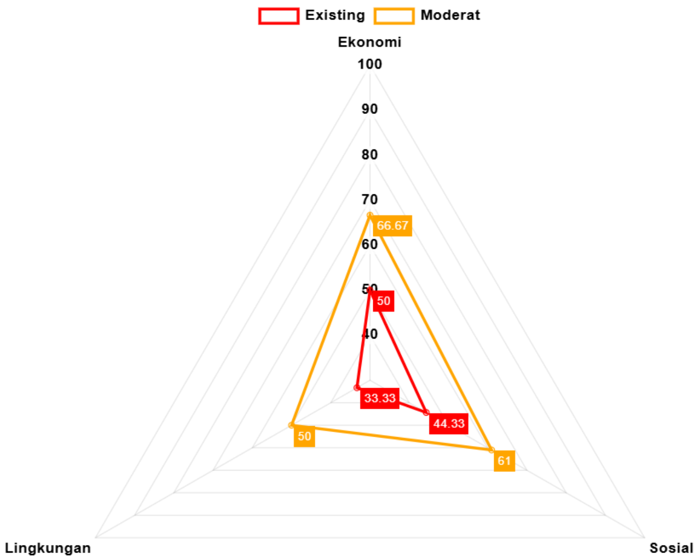

Figure 7. MASI value flyer diagram with moderate policy scenario

Sustainable mining management strategies in Central Bangka Regency cover ecological, economic and social aspects with an integrated approach. From the ecological aspect, the policy focuses on preventing and controlling pollution through land restoration by utilizing local resources (Erfandi, 2017), monitoring the management of mining activities in a strict and integrated manner to minimize ecosystem degradation (Prasodjo et al., 2015). From an economic aspect, the government encourages post-mining business diversification (Fernández-Vázquez, 2022) through investment incentives, development of productive sectors such as agroforestry (Suryaningtyas et al., 2019) and ecotourism (Wildan & Sukardi, 2020) and strengthening regulations related to reclamation funding to ensure community economic sustainability (Listiyani et al., 2023). Meanwhile, from the social aspect, strategies are directed at improving health services (Smith et al., 2016), risk mitigation education (Taupan et al., 2024) and community participation in environmental monitoring (Shandro et al., 2011) to reduce health impacts due to mining activities. The implementation of this policy requires synergy between the government, mining companies and communities to create a balance between environmental sustainability, economic growth and social welfare.

4. Future Prospect and Challenges

The results of this study provide a significant practical contribution to the formulation of sustainability-based mining management strategies, especially in areas with similar characteristics to Central Bangka Regency. The Mining Area Sustainability Index (MASI) approach allows local governments, mining industry players and other stakeholders to identify priority aspects that need to be improved, especially in the environmental and social dimensions. The findings of this research can be implemented in the formulation of adaptive land reclamation policies, post-mining economic diversification programs, and strengthening community health services affected by mining activities.

The strategies formulated in the moderate scenario have greater potential when integrated with a spatial dynamic systems approach. Spatial dynamical systems can integrate scenario planning with spatial simulation to predict policy impacts (Cai et al., 2020). The application of this method enables the development of a comprehensive grand design to support local government efforts in realizing sustainable development programs, especially in the mining sector. Through the simulation of long-term scenarios, system dynamics can identify linkages between strategic variables, such as governance dynamics, demographic pressures, climate change, and energy transition. This approach also provides a strong analytical framework in formulating adaptive and responsive policies to local and global dynamics. Thus, the integration of dynamical systems in mining sustainability planning can increase the effectiveness of policy interventions and strengthen the social-ecological resilience of affected areas.

5. Conclusions

This study shows that the level of sustainability of the mining sector in Central Bangka Regency is still relatively unsustainable, mainly due to the non-optimal application of good and proper mining principles. Through the Mining Area Sustainability Index (MASI) approach, a moderate scenario is identified as the most realistic strategy to encourage sustainability improvements through pollution control and environmental reclamation, post-mining economic diversification, and improved community health and safety. A negative correlation was also found between the economic sustainability index and the socio-environmental sustainability index, indicating that mining-based economic growth still has a negative impact on social and ecological aspects. These findings emphasize the importance of sustainability-based economic transformation and synergy between the government, industry players and communities in achieving balanced development. To strengthen the results, future studies are recommended to integrate spatial-temporal data through remote sensing technology, apply participatory approaches, and utilize system dynamics methods to design sustainable development grand designs that are adaptive to climate change, demographic dynamics, governance, and energy transition.

Acknowledgement

The authors would like to thank IPB University for supporting research in the Regional Planning Science Postgraduate Study Program and would like to thank Pusbindiklatren Bappenas for sponsoring this research.

References

Ahadis, H, Zakaria, W, Banuwa, I, and Lindrianasari, L. 2020. Mining regulation and its impact on public welfare. International Journal of Geomate 19(72), pp. 225–230.

Ahirwal, J, and Pandey, V. 2020. Restoration of mine degraded land for sustainable environmental development. Restoration Ecology 29.

Ahmad, R, Syafira, A, Y, Sholichah, A, F, Alvionita, L, and Kodir, A. 2022. Derita di balik tambang: Contestation of political economy interests in tin mining in Bangka Belitung. SOCIOGLOBAL: Journal of Sociological Thought and Research 6(2), pp. 114–132.

Akhmaddhian, S, Budiman, H, Bhandari, R, and Najicha, F. 2023. The strengthening government policies on mineral and coal mining to achieve environmental sustainability in Indonesia, Africa and Germany. BESTUUR.

Asmarhansyah, and Hasan, R. 2017. Reklamasi lahan bekas tambang timah sebagai lahan pertanian di Kepulauan Bangka Belitung. In: Prosiding seminar nasional agroinovasi spesifik lokasi untuk ketahanan pangan pada era masyarakat ekonomi ASEAN. Lampung: Balai Besar Pengkajian dan Pengembangan Teknologi Pertanian.

Ashraf, S, and Jamwal, R. 2022. Conservation plan for Tawi River, India, using geoinformatics techniques. Arabian Journal of Geosciences 15, pp. 1–18.

Aswani, D, and Shivashankar, B. 2022. Review of literature related to labour migration: Types, causes, and impacts. International Journal of Management, Technology, and Social Sciences 191, 224.

BAPPEDA (Badan Perencanaan Pembangunan Daerah Kabupaten Bangka Tengah). 2021. Regional medium-term development plan of Central Bangka Regency 2021 - 2026. Koba: Bappeda.

Beretić, N, and Plaisant, A. 2019. Setting the methodological framework for accessibility in geo-mining heritage settings—An ongoing study of Iglesiente Area (Sardinia, Italy). Sustainability.

BPS (Badan Pusat Statistik Kabupaten Bangka Tengah). 2022. Central Bangka Regency in figures 2021. Koba, Indonesia: BPS.

BPS (Badan Pusat Statistik Kabupaten Bangka Tengah). 2024. Central Bangka Regency in figures 2023. Koba, Indonesia: BPS.

BPS (Badan Pusat Statistik Provinsi Kepulauan Bangka Belitung). 2024. Bangka Belitung Province in figures 2023. Pangkalpinang, Indonesia: BPS.

Cai, Z, Wang, B, Cong, C, and Cvetkovic, V. 2020. Spatial dynamic modelling for urban scenario planning: A case study of Nanjing, China. Environment and Planning B: Urban Analytics and City Science 47, pp. 1380 - 1396.

Darlingga, M, Lingga, R, and Kurniawan, A. 2022. Isolation, identification, and metal resistance testing of soil fungi (Rhizosphere) from Bangka tin post-mining. Biolink (Journal of Health Industry Environmental Biology).

Dikgwatlhe, P, and Mulenga, F. 2023. Perceptions of local communities regarding the impacts of mining on employment and economic activities in South Africa. Resources Policy.

DLH (Dinas Lingkungan Hidup Kabupaten Bangka Tengah). 2024. Environmental quality index report 2023. Koba, Indonesia: DLH.

Dorian, J, and Humphreys, H. 1994. Economic impacts of mining. Natural Resources Forum 18, pp. 17-29.

Erfandi, D. 2017. Landscape management of ex-mine land: Land restoration by utilizing local resources (In-Situ). Journal of Land Resource 11(2), pp. 55-66.

Ericsson, M, and Löf, O. 2019. Mining's contribution to national economies between 1996 and 2016. Mineral Economic 32, 223-250.

Fauzi, A. 2019. Sustainability analysis techniques. Jakarta, Indonesia: PT Gramedia.

Fernández-Vázquez, E. 2022. Mine closures and local diversification: Job diversity for coal-mining areas in a post-coal economy. The Extractive Industries and Society 12, 10108.

Firmansyah, I. 2022. Multiaspect sustainability analysis. Expert Simul Progr Artic 1(1), pp. 1-14.

Hák, T, Janoušková, S, and Moldan, B. 2016. Sustainable development goals: A need for relevant indicators. Ecological Indicators 60, 565-573.

Hamdani, A, H, Hutabarat, J, and Muhamadsyah, F. 2021. The sustainable management of post-mining landuse: An AHP aaproach a case study: Ex-sand mining in Indramayu Regency. Journal of Geological Sciences and Applied Geology 4(3), pp. 1-5.

Haryadi, D, Ibrahim, I, and Darwance, D. 2022. Environmental law awareness as social capital strategic in unconventional tin mining activities in the Bangka Belitung Islands. Society.

Hora, S, C. 2014. Probability judgments for continuous quantities: Linear combinations and calibration. Management Science 50(5), pp.597-604.

Ibrahim, I. 2015. The impact of unconventional tin mining that damages the ecosystem in Bangka Belitung. Selisik: Journal of Law and Business 1(1), pp.77-90.

Kivinen, S. 2017. Sustainable post-mining land use: Are closed metal mines abandoned or re-used space?. Sustainability 9, 1705.

Kurniawan, A, and Mustikasari, D. 2019. Review: Mekanisme akumulasi logam berat di ekosistem pascatambang timah. Jurnal Ilmu Lingkungan 17, pp. 408-415.

Lee, C, Wang, C, Thinh, B, Purnama, M, and Sharma, S. 2024. Corporate leverage and leverage speed of adjustment: Does environmental policy stringency matter? Pacific-Basin Finance Journal 85, 102344.

Listiyani, N, Said, M, and Khalid, A. 2023. Strengthening reclamation obligation through mining law reform: Indonesian experience. Resources 12(5), 56.

Mancini, L, and Sala. 2018. Social impact assessment in the mining sector: Review and comparison of indicators frameworks. Resources Policy 57, pp. 98-111.

Muslih, K, Adiwilaga, E, M, and Adiwibowo, S. 2014. Pengaruh penambangan timah terhadap keanekaragaman ikan sungai dan kearifan lokal masyarakat di Kabupaten Bangka. Limnotek: Perairan Darat Tropis di Indonesia 21(1): pp. 52–63.

Naegler, L, Becker, J, Buchgeister, W, Hauser, H, Hottenroth, T, Junne, U, Lehr, O, Scheel, R, SchmideScheele, S, Simon, C, Sutardhio, I, Tietze, P, Ulrich, F, indéterminée, T, Viere, A, and Weidlich. 2021. Integrated multidimensional sustainability assessment of energy system transformation pathways Sustainability 13(9), 5217.

Narrei, S, and Ataee-Pour, M. 2019. Assessment of personal preferences concerning the social impacts of mining with choice experiment method. Mineral Economics 34, 39-49.

Olvera, B, and Iizuka, M. 2023. The mining sector: Profit-seeking strategies, innovation patterns, and commodity prices. Industrial and Corporate Change 33(4), pp. 986-1010.

Prasodjo, E, Sitorus, S, R, P, Pertiwi, S, and Putri, E, I, K. 2015. Sustainable coal mining environmental management policy model (case study of coal mining around Samarinda City, East Kalimantan). Journal of Coal Technology and Minerals 11(1), pp. 49-60.

Purvis, B, Mao, Y, and Robinson, D. 2018. Three pillars of sustainability: In search of conceptual origins. Sustainability Science 14, 681-695.

Ranosz, R. 2014. Mining and its role in the global economy. Gospodarka Surowcami Mineralnymi-mineral Resources Management 30, pp. 5-20.

Rusfiana, Y, and Hermawan, D. 2019. Potensi bencana alam pasca penambangan timah inkonvensional di Kabupaten Bangka Tengah Provinsi Kepulauan Bangka Belitung: Perspektif ketahanan wilayah. Jurnal Konstituen 1(1), pp. 59-76.

Sánchez, A, J, Velasco-Muñoz, J, Belmonte-Ureña, L, and Manzano-Agugliaro, F. 2019. Innovation and technology for sustainable mining activity: A worldwide research assessment. Journal of Cleaner Production.

Servou, A, Paraskevis, N, Roumpos, C, and Pavloudakis, F. 2023. A geospatial analysis model for the selection of post-mining land uses in surface lignite mines: Application in the Ptolemais Mines, Greece. Sustainability 15(19).

Shandro, J, Veiga, M, Shoveller, J, Scoble, M, and Koehoorn, M. 2011. Perspectives on community health issues and the mining boom-bust cycle. Resources Policy 36, pp.178-186.

Shi, Y, Ge, X, Yuan, X, Wang, Q, Kellett, J, Li, F, and Ba, K. 2019. An integrated indicator system and evaluation model for regional sustainable development. Sustainability 11(7) 2183.

Smith, N, Ali, S, Bofinger, C, and Collins, N. 2016. Human health and safety in artisanal and small-scale mining: An integrated approach to risk mitigation. Journal of Cleaner Production 129, pp. 43-52.

Sulaiman, Hatta, M, and J. 2025. Sustainable recovery strategies for ecosystem restoration and conservation post-ASGM. EcoVision: Journal of Environmental Solutions.

Sukarman, S, Gani, R, and Asmarhansyah, A. 2020. Tin mining process and its effects on soils in Bangka Belitung Islands Province, Indonesia. SAINS TANAH - Journal of Soil Science and Agroclimatology 17(2), 180-189.

Suryaningtyas, D, T, Sulistijo, B, Iskandar, Sudadi, U, Kusumo, A, D, and Srihartati, Y. 2019. Handbook for available best practices in reclamation of alluvial tin landmines in Indonesia. Bogor, Indonesia: Schutte P, Moller A. Hannover.

Taupan, M, Abbas, B, and Supriaddin, N. 2024. The influence of miners' knowledge and behavior on environmental management at PT. Daka Group. Journal of Business Management and Economic Development 2(03), pp. 1068–1077.

Tazhibekova, K, Kocherbaeva, A, and Suleimenova, M. 2024. Study of business development priorities in the mining industry. Trudy Universiteta.

Uzarowicz, Ł, Wolińska, A, Błońska, E, Szafranek-Nakonieczna, A, Kuźniar, A, Słodczyk, Z, and Kwasowski, W. 2020. Technogenic soils (Technosols) developed from mine spoils containing Fe sulphides: Microbiological activity as an indicator of soil development following land reclamation. Applied Soil Ecology 156, 103699.

Vaverková, M, Maxianová, A, Winkler, J, Adamcová, D, and Podlasek, A. 2019. Environmental consequences and the role of illegal waste dumps and their impact on land degradation. Land Use Policy 89, 104234.

Wildan, W, and Sukardi, S. 2020. Effectiveness of ecotourism sector-based economic strengthening models for local community entrepreneurial competencies. Journal of Environmental Management and Tourism 11, 314-321.

Wulandari, D, Agus, C, Rosita, R, Mansur, I, and Maulana, A. 2022. Impact of tin mining on soil physio-chemical properties in Bangka, Indonesia. Jurnal Sains &Teknologi Lingkungan 14(2), pp. 114-121.

Yu, H, Zahidi, I, Fai, C, Liang, D, and Madsen, D. 2024. Elevating community well-being in mining areas: The proposal of the mining area sustainability index (MASI). Environmental Sciences Europe 36, 71.