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Evaluation of the Conformity of the Sustainable Remediation Concept to the Success of Revegetation (Case Study: PT Arutmin Indonesia Tambang Satui)

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KEYWORDS
revegetation, land remediation, sustainable remediation.

ABSTRACT
Indonesia is one of the largest coal producers in the world, but its mining activities have negative impacts on the environment, such as land degradation with low fertility, high acidity, and heavy metal content. Land remediation using the revegetation method is one of the main solutions to mitigate these impacts. Revegetation aims to restore the ecological function of the land by planting vegetation that is adaptive to degraded soil conditions. This study aims to evaluate the success of remediation of ex-coal mining land at PT Arutmin Indonesia Tambang Satui through revegetation. The evaluation was carried out based on the guidelines of the KLHK Circular Letter Number SE./MENLHK/SETJEN/KUM.1/1/2024, and considering its suitability with the concept of sustainable remediation which includes environmental, social, and economic aspects. The methods used are quantitative descriptive and survey, with data collection through field observation, analysis, and literature studies. The results of the study showed a revegetation success value of 87, which is categorized as "good" and acceptable according to the KLHK guidelines. However, these guidelines only cover environmental aspects, without integrating social and economic aspects, which are important components in sustainable remediation. This study recommends the integration of social and economic dimensions into the assessment of revegetation success to support a more comprehensive sustainable remediation approach.

1. INTRODUCTION

Coal is one of the main mineral export commodities for Indonesia, contributing significantly to the country's economy (Agus et al., 2014). However, coal mining activities are not free from serious negative impacts on the ecosystem and environment. The mining process often produces waste containing elements such as iron (Fe) and manganese (Mn) in high concentrations, and causes the soil pH to become acidic (Prayogo and Ihsan, 2018). This condition can cause various environmental problems, such as soil degradation, water pollution, and decreased biodiversity. Former coal mining areas often have soil with low fertility, high acidity levels, and heavy metal content that is detrimental if not managed properly (Dowarah et al., 2009; Widyati, 2009; Prayogo and Ihsan, 2018).

To overcome these environmental impacts, remediation is one of the methods used to restore the condition of ex-mining land to make it more fertile and suitable for reuse. Remediation is the process of cleaning or removing pollutants from soil, water, and other environments to restore natural conditions to a healthier and safer state (Barrera, et al., 2023). There are various types of remediation methods that can be applied to ex-mining land, including phytoremediation, bioremediation, and chemical remediation. Phytoremediation uses plants to stabilize or remove contaminants from the soil, while bioremediation involves microorganisms to degrade pollutants, and chemical remediation uses certain chemicals to neutralize or bind pollutants in the soil (Das et al., 2023; Wang et al., 2022).

Revegetation is one of the remediation methods often used in ex-coal mining areas, where certain types of plants that are adaptive to degraded soil conditions are planted to restore ecological functions and restore soil fertility (Tripathi et al., 2016; Ghose, 2004; Sheoran et al., 2010; Mukhopadhyay et al., 2014). This process involves planting trees or other vegetation that can survive in harsh environmental conditions, and have the ability to improve soil structure and increase organic matter content (Martínez-Moreno et al., 2022; Pambudi et al., 2023). Revegetation not only helps reduce erosion and soil pollution, but also plays a role in increasing biodiversity and improving local microclimate (Tripathi et al., 2016; Ghose, 2004; Sheoran et al., 2010; Mukhopadhyay et al., 2014).

One of the important stages in implementing remediation is evaluation to assess the effectiveness and success of remediation implementation at a location (Pandit et al., 2020). The Indonesian government, through the Ministry of Environment and Forestry (KLHK), has set a reference for revegetation assessment in Circular Letter Number: SE./MENLHK/SETJEN/KUM.1/1/2024 concerning Guidelines for Forest Reclamation Due to Use of Forest Areas which must be used as a guideline by the coal mining industry in carrying out revegetation success assessments. This guideline includes various parameters that must be met to ensure that ex-mining land has undergone significant improvements and can be returned to more productive uses.

The success of a revegetation program is not only marked by the growth of vegetation, but also by the health and fertility of the plants planted. Healthy and fertile growth of revegetation plants indicates that the remediation process carried out has been successful, because the soil that was initially degraded and polluted has returned to having conditions that support plant growth. Research by Martínez-Moreno et al. (2022) shows that the growth of fertile revegetation plants in former coal mining land is an indicator that the soil has improved, especially in terms of increasing organic matter content and decreasing heavy metal concentrations. This is in line with research by Pambudi et al. (2023), which found that improving soil quality, such as a more neutral pH and decreasing toxic metal content, is positively correlated with the success of vegetation growth in former mining land. Research by Beslemes et al. (2023) also supports this view, stating that optimal plant growth in remediated land indicates that the phytoremediation process is successful in stabilizing and restoring soil ecosystem functions.

However, in practice, the assessment of revegetation success often only focuses on the technical environmental aspects, while the economic and social aspects which are also important parts of the concept of sustainable remediation are often neglected (Pambudi et al., 2023; Heriyanto et al., 2023; Hou et al., 2020). Sustainable remediation not only requires physical environmental restoration, but also considers the social and economic impacts of remediation activities. This approach emphasizes the importance of combining technical, social, and economic aspects in a holistic unit, so that the remediation program not only contributes to ecological restoration, but also supports the welfare of the surrounding community and the sustainability of the local economy.

The former mining land of PT Arutmin Indonesia, especially the Satui Mine, is one example of a case where revegetation has been implemented as the main remediation method. However, the success of this remediation implementation needs to be evaluated comprehensively, not only from a technical perspective but also in terms of its compliance with the principles of sustainable remediation. This evaluation is important to ensure that the revegetation process carried out not only meets the environmental standards set by the Ministry of Environment and Forestry, but also supports the social and economic sustainability of the surrounding community.

This study aims to assess the success of remediation carried out using the revegetation method at the Satui Mine based on the references set out in the Circular Letter of the Ministry of Environment and Forestry Number: SE./MENLHK/SETJEN/KUM.1/1/2024. Furthermore, this study will evaluate the suitability of the results of the success assessment with the concept of sustainable remediation.

2. METHOD

Location determination

This study uses a quantitative descriptive approach and survey (Sugiyono, 2018). The quantitative descriptive method is used to describe the condition of variables through data such as photos, interviews, observations, and documentation (Bungin, 2015). The survey method focuses on collecting field data.

Location and Time of Research

The research was conducted from August to December 2024 in the revegetation area of the 2018 planting year, Pit Gatotkaca, PT Arutmin Indonesia Tambang Satui, Satui District, Tanah Bumbu Regency, South Kalimantan, with an area of 4.88 ha. This location is 1.94 km from Bukit Baru Village as the nearest residential area.

Initial Data Collection

A preliminary study was conducted to understand the general condition of the site using literature, maps, and historical data. The research location was digitized using ArcMap 10.8 software.

Area Measurement

Area data was obtained using a GPS device and processed in ArcMap 10.8 to produce a map in shapefile format.

Determining Sampling Points

Sampling intensity is determined based on SE./MENLHK/SETJEN/KUM.1/1/2024 with a coverage of 10% of the total area. Sampling points are created using the measure grid menu in ArcMap 10.8.

Vegetation Data Collection

Data on the number and types of plants were collected using a 40 m x 25 m plot at the sampling point. Plants with a height of >50 cm were counted and recorded according to the technical design of the reclamation.

Plant Health Assessment

Plant health is assessed using a scoring method in accordance with P. 60/Menhut-II/2009 and SE./MENLHK/SETJEN/KUM.1/1/2024.

Data analysis

The growth percentage is calculated using the formula:

$$Presentase\ Tumbuh = \frac{Realisasi\ Jumlah\ Tanaman\ Sehat}{Rencana\ Jumlah\ Tanaman} \times 100\%$$

The data obtained from the measurement results in the field are calculated using the formula using the help of Microsoft Excel Office 365 software.

Success Value

Referring to the circular letter SE./MENLHK/SETJEN/KUM.1/1/2024, the calculation of the total success value is carried out using the following formula;

$$TN = \sum_{i=1}^{n} [\frac{TSi}{SMi} x\ Bi]$$

Information:

TN	: Total Value
TSi	: Total Score of Criteria Assessment i
SMi	: Maximum Value of Criteria
n	: Number of Criteria
Bi	: Weight For Criteria
i	: Total Maximum Value

The total value obtained will produce the following conclusions:

a. Total value >80 (more than eighty), good category, meaning the results of the reclamation implementation are acceptable.

b. Total value of 60-80 (sixty to eighty), moderate category, meaning that the results of the reclamation implementation are accepted with the note that improvements need to be made until a value of >80 (more than eighty) is achieved.

c. Total value <60 (less than sixty), poor category, meaning the reclamation results are unacceptable and intensive maintenance is required.

3. RESULT AND DISCUSSION

Revegetation Land Conditions

The dominant vegetation found is Sengon Laut for fast-growing plants and Mango for insert plants/fruits. In addition, there are also cover crops dominated by the Calopogonium mucunoides species. The revegetation stage on ex-mining land begins with rearranging the embankment. Land arrangement involves rearranging the topography of the mining area, such as reducing slope gradients, filling mine holes, and forming terraces. The purpose of this stage is to reduce the risk of soil erosion, landslides, and waterlogging in areas with extreme topography. Steep slopes have the potential to cause soil loss due to erosion. By arranging the land to be more stable, the revegetation process can be carried out properly because the plants have a supporting medium (Rahmawati et al., 2022).

After the reorganization, the land will be added with topsoil. Topsoil is the topmost layer of soil that is rich in organic matter and essential microorganisms with the aim of increasing soil fertility and providing a good growing medium for plants. This stage is important because mining soil is usually poor in nutrients and has an acidic pH. The addition of topsoil creates a supportive environment for plant roots to grow, accelerating the revegetation process (Santoso et al., 2022). Research by Smith et al (2019) shows that the addition of topsoil can increase planting success by up to 75%, with faster plant growth in the first year compared to areas without topsoil. After the topsoil is spread, covercrop planting will be carried out. Covercrop functions to protect the soil from erosion, add nitrogen to the soil, and provide a supportive microenvironment for the main plants. In addition, covercrop also helps maintain soil stability while increasing soil fertility through nitrogen fixation. This plant also accelerates the decomposition process of organic matter (Widjaja et al., 2022). Research by Li et al in 2018 showed that the use of cover crops increased soil nitrogen content by up to 20% in the first two years of coal mine reclamation.

Sengon laut (*Paraserianthes falcataria*) is a pioneer and fast-growing plant species that is very suitable for revegetation of ex-mining land, including coal mines. The success of sengon laut on marginal land such as ex-mining is due to several of its superior characteristics. Sengon laut can grow in soil with low fertility levels, including nutrient-poor soils such as mine tailings. Sengon laut roots have nodules that are able to form a symbiosis with Rhizobium bacteria for nitrogen fixation, thereby helping to increase the nitrogen content in the soil. This allows it to grow in disturbed and less fertile soils (Dahliana et al., 2024; Orwa et al., 2009). Sengon laut is also one of the fastest growing trees in the world. This plant can reach a height of up to 7 meters in one year under ideal conditions. This makes it a plant of choice for revegetation because it can immediately provide ground cover and reduce erosion (Orwa et al., 2009; Lightwood, 2024). Sengon laut's extensive roots help improve soil aeration and drainage. In addition, the fallen leaves and twigs enrich the soil with organic matter, helping to gradually improve soil structure and fertility (Orwa et al., 2009; Lightwood, 2024).

Mango was chosen in the revegetation program because of its adaptability to marginal soil conditions. Its strong and branched root system is not only effective in holding the soil on slopes but also helps in groundwater retention. Planting mango provides additional benefits in the form of fruit yields that can be utilized by the local community, which strengthens the economic and social dimensions of the revegetation project. Mango can survive in soils with low pH (around 5.5) and produces productive fruit after the third year of planting on reclaimed land (Bhattacharya et al., 2020). Research by Widyaningsih et al. (2021) in a mining area in Kalimantan showed that the combination of sengon laut and productive plants such as mango significantly increased soil organic matter content by up to 45% within five years. In addition, planting local and productive tree species has been successful in creating a stable ecosystem in mining areas, with an increase in insect and bird populations, which contribute to the regeneration of natural ecosystems (Smith et al., 2019).

Revegetation Success Rate

The success value based on SE./MENLHK/SETJEN/KUM.1/1/2024 is obtained from several assessment parameters such as the realization of the revegetation area against the plan, number of plants, percentage of plant growth, plant conditions, and the percentage comparison of the number of pioneer plants and MPTS. After that, the value weighting is carried out which then produces a reclamation success value with the following explanation:

a. Total value >80 (more than eighty), good category, meaning the results of the reclamation implementation are acceptable.

b. Total value of 60-80 (sixty to eighty), moderate category, meaning that the results of the reclamation implementation are accepted with the note that improvements need to be made until a value of >80 (more than eighty) is achieved.

c. Total value <60 (less than sixty), poor category, meaning the reclamation results are unacceptable and intensive maintenance is required.

The assessment summary table and scoring results can be seen in tables 1 and 2.

Each PU has different plant conditions as shown in table 1. The assessment begins by creating a quadrant of measurement plots measuring 40m x 25m. Determination of measurement plots with these dimensions is in accordance with the Regulation of the Minister of Forestry of the Republic of Indonesia Number: P.60 / Menhut-II / 2009 concerning Guidelines for Assessing the Success of Forest Reclamation. In addition, a study conducted by Napitupulu et al in 2020 also used a 40m x 25m measurement plot to assess the survival rate in a forest rehabilitation area. Furthermore, the number of Sengon Laut trees and mango trees is recorded in the measurement plot. Each tree whose number is recorded must be checked for tree health conditions consisting of 3 categories, namely healthy, unhealthy and dying in accordance with SE. / MENLHK / SETJEN / KUM.1 / 1/2024 and P.60 / Menhut-II / 2009. Based on P.60/Menhut-II/2009, the 3 categories of plant health are explained as follows:

1. Healthy plants have a fresh appearance, straight stems, and dense crowns. This condition is generally achieved through routine maintenance, such as weeding, tilling, fertilizing, and controlling pests and diseases.
2. Unhealthy plants show abnormal growth, often characterized by yellow or abnormally colored leaves and bent stems.
3. Dying plants have very poor growth, usually caused by pest or disease attacks, so there is little chance of recovery even if treated.

After the data is collected, data processing is carried out to obtain a recapitulation of values as shown in table 1.

The first measurement plot has a total number of plants of 111 trees with a growth percentage of 87.39%. Pioneer plants in plot 1 have a healthy condition percentage of 96.30% (52 healthy plants) and for local plants have a healthy condition percentage of 78.96% (45 healthy plants). The percentage of healthy local plants in this plot is the smallest compared to other plots. In plot 2, the growth percentage obtained is 93.41%. This value is the largest value with all pioneer plants included in the 100% healthy category. Meanwhile, local plants in plot 2 have a healthy percentage of 85% (34 healthy plants, 3 less healthy plants, and 3 dying plants). Furthermore, in plot 3, the growth percentage obtained is 91.95% with the number of healthy pioneer plants as many as 55 trees (out of 59 trees) and healthy local plants as many as 25 trees (out of 28 trees). The next plot is plot 4. The results obtained are the percentage of growth in plot 4 of 88.42%. The condition of healthy pioneer plants is 97.56% (40 healthy plants 1 less healthy) and the condition of healthy local plants is 81.48%. Finally, in plot 5, the results of the percentage of growth were 84.13% with the percentage of healthy conditions of each pioneer and local plant being 78.13% and 90.32%. The percentage of healthy local plant conditions in plot 5 is the largest compared to the other plots. These diverse conditions can be caused by many factors such as soil physical conditions, soil organic content, heavy metal contamination, local climate conditions, and the presence of soil microorganisms (Basu et al., 2022; Chen et al., 2023; Jiskani et al., 2023; Kumar et al., 2020; Mishra et al., 2020; Singh et al., 2011).

The leaves of sengon laut (*Paraserianthes falcataria*) in reclamation areas can turn yellow, fall off, or curl due to various environmental factors, soil conditions, and pest or disease attacks. Yellowing leaves are often associated with deficiencies of nitrogen (N), phosphorus (P), or potassium (K). Soil in ex-mining areas tends to be poor in nutrients due to the loss of nutrient-rich topsoil layers (Sitorus et al., 2022).

Table 1. Plant Assessment Summary Table

No	Measurement Plot (PU)	%	Pioneer					Local					%	%
		Grow	Pioneer Plants	Plant Conditions			%	Local Plants	Plant Conditions			%	Pioneer	Local
				Healthy	Unwell	Miserable	Healthy		Healthy	Unwell	Miserable	Healthy		
1.	1	87.39	54	52	2	-	96.30	57	45	8	4	78.95	53.61	46.39
2.	2	93.41	51	51	-	-	100.00	40	34	3	3	85.00	60.00	40.00
3.	3	91.95	59	55	4	-	93.22	28	25	-	3	89.29	68.75	31.25
4.	4	88.42	41	40	1	-	97.56	54	44	8	2	81.48	47.62	52.38
5.	5	84.13	32	25	5	-	78.13	31	28	2	-	90.32	47.17	52.83
Sum/Average		89.06	237	223	12	0	93.04	210	176	21	12	85.01	55.43	44.57

Table 2. Success Value Scoring Table

No.	**Block/Plot**	**Location**	**Revegetation**															**TOTAL VALUE**	
			Planting						**Local Plants**								Total Weight		
			Area		Percentage growth	Number of plants	Mark		Plant species composition			Plant health		Mark					
			%	Mark	Mark	Mark	Amount	Weight	Pioneer (%)	Local (%)	Mark	%	Mark	Amount	Weight				
1	Gatotkaca	New Hill Village	100.00	5	5	5	15	5	55.43	44.57	4	85.01	2	6	4		9	87	Good

Nitrogen deficiency can inhibit chlorophyll synthesis, causing chlorosis in leaves. Ex-mining soil often has a pH that is not suitable for plant growth (too acidic or alkaline) and contains heavy metals such as Fe, or Mn which can be toxic. This can damage the root system and inhibit nutrient absorption (Rahmawati et al., 2021). In addition, several studies in reclamation areas also show that extreme environmental conditions often occur, such as drought or high temperatures, which cause abiotic stress in plants. This stress triggers plant protection mechanisms, such as leaf rolling to reduce water loss through transpiration (Haryono & Santoso, 2020). Attacks by diseases such as leaf rust (*Phakopsora pachyrhizi*) or pests such as leaf caterpillars can also cause physical and physiological damage to sengon laut leaves. Reclamation areas often lack biodiversity that can suppress pest populations naturally (Utami et al., 2023).

The extreme conditions mentioned can also cause plant death if they persist. After the recapitulation of the value is known, it is continued with the scoring stage of the revegetation success value. This value is obtained from the average of each parameter in the value recapitulation table, so that the value can be weighted. It is known in table 2 that the revegetation success value obtained is 87. Based on SE./MENLHK/SETJEN/KUM.1/1/2024, if the total value is >80 (more than eighty) then it is included in the good category and it can be concluded that the results of the reclamation implementation are acceptable. "Good" plant health conditions indicate the potential for ecological sustainability, but regular monitoring is still needed to ensure that plants not only grow but also develop optimally (Guo et al., 2021).

The success of revegetation of ex-mining land is a key indicator in ensuring the achievement of sustainable remediation goals. This is measured not only from a technical aspect, but also through its contribution to improving environmental quality, increasing biodiversity, and reducing negative impacts due to mining activities.

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The success of revegetation of ex-mining land is a key indicator in ensuring the achievement of sustainable remediation goals. This is measured not only from a technical aspect, but also through its contribution to improving environmental quality, increasing biodiversity, and reducing negative impacts due to mining activities.

The technical success of revegetation is seen from the high percentage of plant growth, which reflects initial success through the selection of adaptive plant species, good planting techniques, and appropriate land management. Pioneer plants, such as Acacia or Leucaena, play an important role in improving soil structure and increasing organic matter. Research by Guo et al. (2021) shows that pioneer plants can increase soil microbial activity, reduce erosion, and stabilize soil moisture. In addition, the use of local plants and fruit plants supports native fauna to return to their habitat, improves nutrient cycling, and maintains ecosystem identity. Research by Aznar-Sánchez et al. (2022) revealed that local plants increase ecosystem resilience to environmental change while reducing the risk of invasion by alien species. Biodiversity increases with increasing vegetation, supporting local fauna that play a role in ecosystem processes, such as pollination and natural pest control.Wi

Although environmental aspects receive primary attention, the assessment of revegetation success contained in SE./MENLHK/SETJEN/KUM.1/1/2024 does not fully cover the social dimension. In fact, the success of revegetation in the concept of sustainable remediation must also consider its impact on the surrounding community (Hou & Al-Tabbaa, 2014). Economic aspects are also not included in the guidelines for assessing the success of revegetation. In fact, successful revegetation can provide significant economic value, such as:

a. Sustainable Production: Local plants and fruits can provide products in the form of fruit, wood, or medicinal materials, which have economic value for the community.
b. Ecotourism: Successful reclaimed land can be developed into nature-based tourism attractions, as was done in the mine reclamation project in Australia (Cao et al., 2021).
c. Employment: Revegetation projects create jobs in rural areas.
d. Community Empowerment: Involving local communities in revegetation projects improves their economic well-being through skills training and access to natural resources (González et al., 2020).

To achieve sustainability, evaluation of revegetation success must integrate social and economic dimensions into the assessment framework. This includes:

1. Assessment of community perceptions of the benefits of revegetation.
2. Monitoring of public health impacts related to air quality and the environment.
3. Analysis of the economic potential of revegetation land for local communities.

With this approach, revegetation is not only a technical solution to environmental damage but also provides significant social and economic benefits, supporting sustainability in post-mining areas.

CONCLUSION

The results of the study showed a revegetation success score of 87, which is categorized as "good" and acceptable according to the KLHK guidelines. However, these guidelines only cover environmental aspects, without integrating social and economic aspects, which are important components in sustainable remediation. This study recommends the integration of social and economic dimensions into the assessment of revegetation success to support a more comprehensive sustainable remediation approach.

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