Organic material selection for soil amendment on mine reclamation with analytic hierarchy process

by Bambang Joko Priatmadi

Received: 18 May 2021 | Revised: 6 August 2021 | Accepted: 29 August 2021

DOI: 10.1002/tqem.21807

RESEARCH ARTICLE

WILEY

Organic material selection for soil amendment on mine reclamation with analytic hierarchy process

Efendi Eko Mulyono[1] | Muhammad Ruslan[2] | Bambang Joko Priatmadi[3] | Fadly H. Yusran[3]

[1] Postgraduate Program, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia

[2] Faculty of Forestry, Department of Forestry, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia

[3] Faculty of Agriculture, Department of Soil Science, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia

Correspondence
Efendi Eko Mulyono, Postgraduate Program, Lambung Mangkurat University, Jalan A. Yani KM 36 Banjarbaru, South Kalimantan 70714, Indonesia.
Email: 1740511310005@mhs.ulm.ac.id

Abstract

Soil quality is a frequent problem hindering mine reclamation success. Much research conducted on this problem proposed the application of organic material for soil amendment. However, most of the soil amendment research only focused on the usability of organic material, such as providing nutrients, improving soil properties, and adsorbing hazardous elements. Considering that reclamation is a complex activity, we propose a comprehensive assessment of both technical and managerial aspects on the selection of organic material due to the distinctive properties of each organic material. This study aimed to assess the criteria that influence the organic material selection and determine the most suitable alternative of organic material in mine reclamation. The assessment was Analytic Hierarchy Process (AHP) with the expert choice concept. The criteria used in this study were availability, cost, usability, ease of application, and side effects. Oil palm empty fruit bunch (EFB) compost, rice husk charcoal, cattle manure, and guano were selected. This study showed that availability was the principal factor, followed by usability, cost, ease of application, and side effects. The analysis also showed that the most suitable organic material was oil palm EFB compost with a global priority of 0.363, followed by rice husk charcoal (0.244), cattle manure (0.218), and guano (0.175).

KEYWORDS
Analytic Hierarchy Process, organic material, reclamation, soil amendment

1 | INTRODUCTION

Coal is a primary natural resource that generates electricity in the world. It also plays a vital role as an energy source in several industries such as steel smelting, aluminum, and cement. In addition, coal mining has become the primary source of income for several countries to support development and improve people's welfare. However, coal mining activities applying open-pit methods negatively impact the environment, such as flora and fauna damage, decreased soil fertility, and water and air pollution (Mansur, 2012). To reduce these impacts, a reclamation following the principles of good mining practices is the best way. Reclamation aims to organize, restore, and improve the quality of the environment and ecosystem to restore its purposive function.

Several indicators of reclamation success are the existence of soil and water conservation and the availability of fertile soil as a medium for plant growth (Iskandar et al., 2012). Soil has a significant function in plant productivity, maintains environmental quality, and improves plants' and animals' health (Bünemann et al., 2018). Soil fertility is the most frequent problem found in mine reclamation. Reclamation requires fertile soil to supply adequate and balanced nutrients for plant growth. Soil fertility also emphasizes the absence of toxic elements that inhibit plant growth. Soil fertility needs special attention because it is the most crucial factor determining plant growth (Tanaka et al., 2013).

Soil fertility can be increased by improving nutrient content using organic material as a substitute for NPK, the chemical fertilizer broadly used in mine reclamation (Iskandar et al., 2012). Apart from being a nutrients provider, organic materials also have advantages in improving soil properties and adsorb hazardous elements. Application of soil amendments in mine reclamation depends on organic matter efficiency and the release of sufficient nutrients for plants (Zornoza et al., 2016). Implementing proper techniques and technology of environmental management is expected to reduce the negative impact of mining activities. Currently, several mines have implemented organic amendments in post mine soils because they are cheaper and widely available (Rubén Forján et al., 2017). Implemented organic materials are mulch, compost, animal manure, ash, and biochar.

Many studies investigated the efficacy of organic material to increase fertility and remediate ex-mine soil

Many studies investigated the efficacy of organic material to increase fertility and remediate ex-mine soil (Anawar et al., 2015; Jones et al., 2016; R Forján et al., 2014; Rubén Forján et al., 2017). They help practitioners assess organic material according to its usability. However, material selection considering solely one criterion will not be entirely satisfactory (Zeleny, 2011); there will be a worry on other criteria influence. Unfortunately, discussion on organic material selection for soil amendment based on multi-criteria assessment is limited. A multi-criteria assessment can help practitioners select the most suitable material, as generally done in many manufacturing industries (Emovon & Oghenenyerovwho, 2020).

Mine reclamation carried out on a wide area and in a long-term period requires many organic materials. Every organic material has distinctive characteristics affecting its effectiveness in soil quality improvement, cost, supply easiness, application difficulties, and side effects. Each of these criteria affects the success of soil amendment implementation. Therefore, both technical and managerial considerations are important in an organic material selection strategy (Wicke et al., 2015).

The criteria used in decision-making often have different units, quality characteristics, and relative weight (Erdogan et al., 2017). This decision-making process is likely to be quite difficult and requires a lot of time (Petruni et al., 2019). Therefore, decision-makers must have sufficient knowledge and experience in several scientific fields to assess comprehensively.

Decision-making involving many criteria and the possibility of contradicting each other could be done using the Multi Criteria Decision Making (MCDM) method. The most often MCDM method used in material selection is Analytic Hierarchy Process (AHP), developed by Thomas Lorie Saaty. AHP helps researchers to analyze data, both quantitative and qualitative easily. Calculating consistency ratio (CR) from pairwise comparisons can help minimize the inconsistency level of decision-makers (Emovon & Oghenenyerovwho, 2020). The most critical step in AHP is the selection of criteria (Petruni et al., 2019) because predetermined criteria significantly affect the result of the decision. Refers to the issue, this study's primary goal is to determine the most suitable alternative of organic material for soil amendment in mine reclamation using the AHP method. This study also conducts a detailed assessment for criteria that influences the selection.

2 | MATERIALS AND METHOD

2.1 | Study area

This study was conducted at Arutmin Indonesia, one of the leading Indonesian coal producers in South Kalimantan Province. Arutmin Indonesia's operation is spread across three regencies, Tanah Laut, Tanah Bumbu, and Kotabaru, with a 150 km long distance. It is divided into five mine sites operation, Asamasam mine, Kintap mine, Satui mine, Batulicin mine, and Senakin mine. In 2019, the total of mine reclamation achievement was 8341 ha. This result was not a final realization as the activity will continue until the mine closure stage in 2030.

The study area is in a tropical climate with two seasons, the rainy and the dry season. This region has an air humidity level of 86%–93%, with a maximum humidity of 98% in July and August. This area is classified in the type A climate category, which refers to the climate classification developed by Schmidt and Ferguson. In terms of regional geology, this area belongs to Tanjung, Berai, and Warukin Formation, which formed during Eocene, Oligocene, and Miocene Epoch. Physiography of this area is a sedimentary plain with undulating to a wave with a slope of 0%–25%. The soil type of this region is dominated by Hapludults and Paleudults, which is part of the Ultisols. Based on the physical and chemical properties analysis, the soil has low fertility status. The research location map is shown in **Exhibit** 1.

Apart from having large coal resources, South Kalimantan is also known for its agricultural resources, oil palm plantations, and animal husbandry. It has enormous potential as an organic materials provider. In 2018, oil palm plantations in South Kalimantan reached 425,000 ha with a production of 1.11 million tons. Rice production in South Kalimantan is 1.33 million tons, while livestock such as cows, buffaloes, goats, and sheep was 274.130 (Central Bureau of Statistic of South Kalimantan, 2020). Agricultural areas as sources of organic material spread throughout the province, as described in Exhibit 1 (Peta Rupa Bumi Indonesia, 2021). Furthermore, the existence of Meratus mountain karst clusters comes up with potential guano resources. Guano excavation has been carried out in several places, although in small quantities.

Several common conditions can be considered to say that this assessment is applicable to other coal companies in Indonesia. Arutmin conducted reclamation with the revegetation method by planting fast-growing with local species enrichment; this is the standard reclamation method in Indonesia (BPDASHL Barito, 2017). Arutmin also faces high acidity and low soil-fertility challenges, as found in other coal mining companies (Iskandar et al., 2012). Finally, sources of organic material are spread throughout Indonesia, especially in Sumatra and Kalimantan, the primary coal producers in Indonesia.

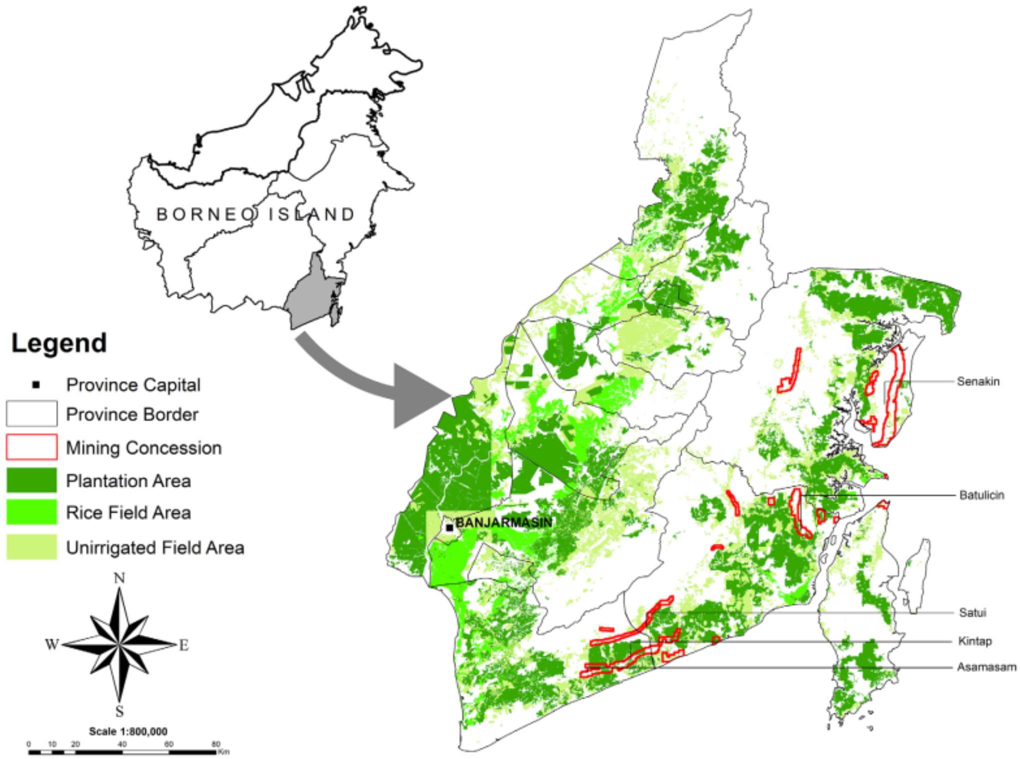

EXHIBIT 1 Research location [Color figure can be viewed at wileyonlinelibrary.com]

2.2 | Decision-making with the AHP method

The AHP is an MCDM method in which the decision-making model refers to expert judgment. Expert judgment is subjective, but the AHP structure can minimize biased decisions (Petruni et al., 2019). In extreme cases, AHP can even be applied with only one respondent (Doloi, 2008). The principles of AHP are systematic, logical, and do not require special knowledge in the field of decision making (Tavares et al., 2008). However, this assessment tries to present qualified experts to get logical and rational judgments.

In this study, seven reclamation experts were taken from across Arutmin's sites operation to capture the specific operating condition of the mine site. The criteria for selected experts were employees with a minimum 8 years of work experience in reclamation, a relevant educational background, and a working function at the supervisory or managerial level. This assessment also carried a site manager responsible for all site operations, including administration, finance, and supply chain. **Exhibit 2** is expert's profiles description involved in the research.

Furthermore, decision-making using the AHP method is carried out by steps (Saaty, 2008) as follows:

1. Defining the problem and goal.
2. Developing a hierarchy of decision-making consisting of goals, criteria, and alternatives.
3. Assessing criteria and alternatives by pairwise comparison.
4. Determining global priority based on criteria weights and local priority to the alternative.

Considering that this study is a part of soil amendment research, the AHP method helps to select the most suitable organic material. AHP method was chosen in this study due to its advantages in describing complex problems into a more structured one (Ramamurthy et al., 2020). Based on literature review, field observations, and expert's proposal, five and 11 sub-criteria were determined to select organic material as described in **Exhibit 3**. Selected organic material alternatives are oil palm empty fruit bunch (EFB) compost (A1), rice husk charcoal (RHC) (A2), cattle manure (A3), and guano (A4). The hierarchical arrangement of AHP components in this study is presented in **Exhibit 4**.

Next, experts gave their opinion by answering a questionnaire form. The questionnaire consists of several pairwise comparisons arranged based on Saaty's scale, as shown in **Exhibit 5**. Experts filled out the online questionnaire through the Google Forms application, making the filling process more practical and well documented. Furthermore, the preference value given by the expert is filled in the pairwise comparison matrix between criteria. This research was supported by Expert Choice 11th Edition as an analysis tool software to make data easy to process. Expert Choice processes the pairwise comparison matrix between main criteria to produce the weight of the main

EXHIBIT 2 Expert profiles

Expert	Role	Educational background	Working experiences (year)
A	Manager	Bachelor of Forestry	24
B	Manager	Bachelor of Agricultural	21
C	Superintendent	Bachelor of Mining Engineering Magister of Environmental Science	16
D	Superintendent	Bachelor of Agricultural	15
E	Superintendent	Bachelor of Environmental Engineering Magister of Environmental Engineering	11
F	Supervisor	Bachelor of Agricultural Magister of Environmental Science	10
G	Supervisor	Bachelor of Landscape Architecture	9

EXHIBIT 3 Criteria and sub-criteria of organic material selection

Criteria	Sub-criteria
Availability	Material abundance
	Material source distance
Cost	Procurement cost
	Operational cost
Usability	Nutrient provider
	Changes in soil properties
	Hazardous elements absorption
Ease of application	Time efficiency
	Equipment efficiency
Side effect	Animal disruption
	Pathogen organism

criteria. The weight of sub-criteria is produced by pairwise comparison matrix between sub-criteria.

Experts assessed the preference between criteria and selection between alternatives for each criterion based on their knowledge and experience. Local priority was processed by Expert Choice in the same way when processing criterion and sub-criteria weights. Expert Choice also calculates CR during the process of weight and local priority calculation. The maximum value of CR required in the AHP is 10%. Finally, the most suitable organic material was selected from the highest global priority determined from adding aggregation of criteria and sub-criteria weight and local priority of alternatives. Global priority is formulated as Equation (1) (Ishizaka & Labib, 2009):

$$p_i = \sum_j w_j . l_{ij} \quad (1)$$

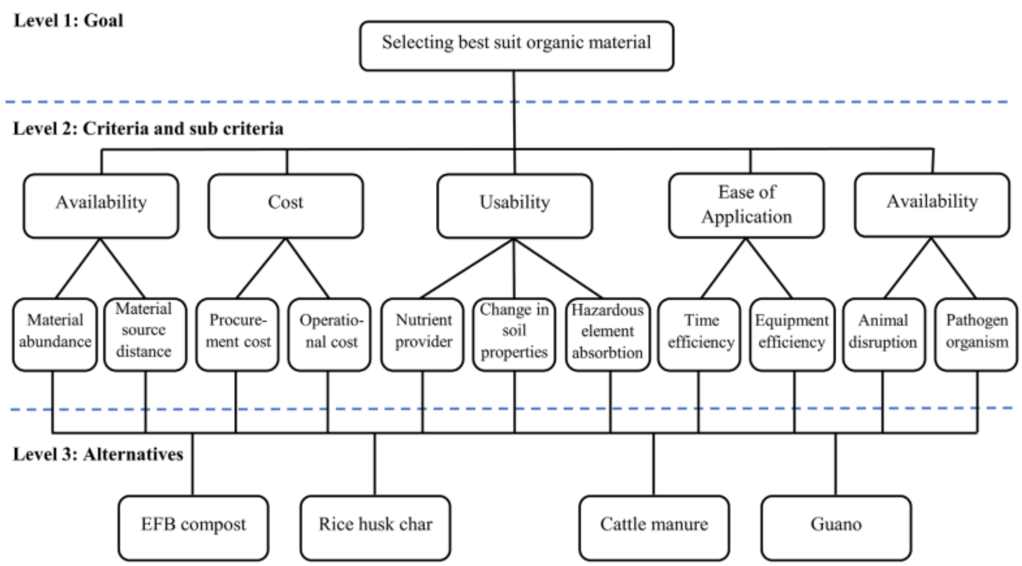

EXHIBIT 4 The hierarchical arrangement of AHP components [Color figure can be viewed at wileyonlinelibrary.com]

EXHIBIT 5 Saaty's scale on the pairwise comparison questionnaire

Degree of importance	Explanation
1	Both factors have the same importance.
3	One factor is slightly more important than the other.
5	One factor is essential or more important than any other factor.
7	One factor is clearly more important than any other.
9	One absolute factor is more important than any other factor.
2, 4, 6, 8	Intermediate value.

where p_i: global priority of alternative i w_j: weight of criterion j l_{ij}: local priority.

Additionally, we can define idealized priorities by dividing each global priority of the alternatives with the highest global priority (Saaty, 2008). It reflects the relative suitability level of other alternatives to the chosen one.

3 | RESULTS AND DISCUSSION

3.1 | Calculation of criteria weight based on AHP

Expert Choice calculated the weight of criteria and sub-criteria with respect to the goal. The weight of the main criteria and sub-criteria on this research can be seen in **Exhibit** 6. Based on the Expert Choice calculation, the CR with respect to goal was 1.4%, and the highest CR with respect to criteria was 2%, so we can say that the determined weight is proper. The weight presented in this research was a combined weight calculated from all experts' combination ratings.

Regarding the weighing score in **Exhibit** 7, we determine material availability as the highest consideration in organic material selection. This result is similar to the research conducted by (Wicke et al., 2015), which emphasized availability as one of the primary considerations in organic material residue for biobased economy usage. Arutmin's reclamation was conducted over a large area and a long-term period of up to 2030. Therefore, a massive supply of organic materials is required to support soil amendment.

Organic materials are known to have a lower nutrient content than chemical fertilizers. Consequently, the organic material amendment can only be continually applied if available in a sufficient quantity. Herein lies the challenge because finding organic materials to meet the availability of materials is quite tricky (Iskandar et al., 2012). Material abundance significantly affects supply certainty and will indicate environmental sustainability (Erdoğan et al., 2021). Material source distance is correlated with travel time, affecting supply continuity (Concu, 2007). However, the material abundance sub-criterion is more critical than material source distance concerning availability. The stagnancy supply risk due to material source distance is easier to manage by increasing the transportation equipment.

The second rank of weight for the criteria was usability. Usability had a slightly lower score than availability. Organic materials usage in reclamation is essential refers to its ability in soil remediation. The soil of ex-mine land has poor quality and is often contaminated with hazardous elements. Hence soil fertility is the most often problem in the reclamation (Iskandar et al., 2012), good soil quality is a high consideration. Organic materials are reliable in improving soil quality. Organic material amendment consists of three remediation processes, improving the soil's physical structure, increasing supply of organic material and soil nutrients, and reducing potentially hazardous elements (Santos et al., 2016; Schulz et al., 2013).

EXHIBIT 6 Global priority determination

		Alternatives			
Criteria	Sub-criteria	A1	A2	A3	A4
Availability	Material abundance	0.108	0.052	0.034	0.018
	Material source distance	0.047	0.017	0.018	0.009
Cost	Procurement cost	0.052	0.025	0.017	0.011
	Operational cost	0.032	0.031	0.032	0.031
Usability	Nutrient provider	0.041	0.022	0.043	0.059
	Changes in soil properties	0.029	0.014	0.011	0.001
	Hazardous elements absorption	0.008	0.012	0.004	0.004
Ease of application	Time efficiency	0.014	0.020	0.027	0.018
	Equipment efficiency	0.010	0.018	0.017	0.013
Side effect	Animal disruption	0.013	0.020	0.009	0.009
	Pathogen organism	0.009	0.013	0.005	0.005
Global priority		0.363	0.244	0.218	0.175

A1 = oil palm empty fruit bunch compost, A2 = rice husk charcoal, A3 = cattle manure, A4 = guano.

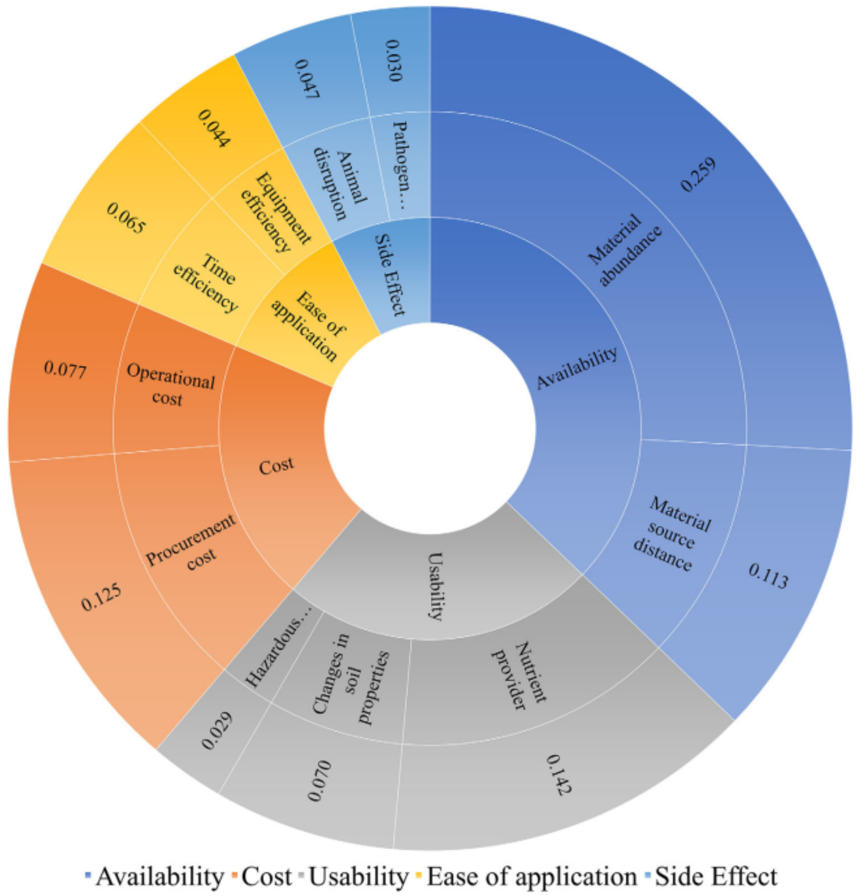

EXHIBIT 7 Weight of criteria and sub-criteria with respect to goal [Color figure can be viewed at wileyonlinelibrary.com]

Nutrient content becomes the most important sub-criteria regarding usability due to its role in supporting plant growth. Essential nutrients must be available in adequate and balanced quantities to support plant growth (Tanaka et al., 2013). The next consideration is the usability related to improving soil properties. Soil amendment using organic material becomes the primary key to improving soil upper layer quality (Iskandar et al., 2012). Horodecki and Jagodzi (2017) reported that increasing soil properties can increase the ability of the soil to absorb nutrients, balance the proportion of water and air in the soil, and support plant root growth. Good aeration in the soil will encourage biochemical. Good aeration will help the decomposition process of organic material into CO_2 and H_2O (Mohamed & Paleologos, 2018).

The third rank of weight in organic material selection was cost, as shown in Exhibit 7. It is the criterion most often used in material selection. It was used by 35 papers from 55 published papers during 1994–2019. It is a crucial factor in selecting organic material as the production principle aims to produce a product at minimum cost while maximizing performance (Emovon & Oghenenyerovwho, 2020). However, the cost is not taken as the highest consideration due to reclamation cost-benefit analysis. Organic material cost is only a part of the maintenance cost in mine reclamation that consists of 13.4% of the total cost (Cahyana et al., 2020). Furthermore, applying organic material will reduce the chemical fertilizer required by plants (Siedt et al., 2021). Cost in this research was consisting of procurement and operational costs.

Mine reclamation applies organic materials in large mass and volume, therefore, the ease of application needs consideration. Organic material is used at the beginning of planting and during plant maintenance. The amendment technique can be done by direct mixing, stirring in a planting pot, or sowing in the planting circle (Mulyono & Haris, 2017). This process requires some working time and supporting equipment. We determine ease of application criteria which consist of time efficiency and equipment efficiency to be the fourth rank.

The criteria for side effects consisting of the potential disturbance by wild animals and the presence of pathogenic organisms in organic material were appointed as the last rank. These criteria directly affect the implementation of soil amendment activity. In contrast, this study classifies environmental effects such as odor, greenhouse gases, and water pollution as indirect impacts for soil amendment to achieve reclamation success. This study ignores the environmental impact from

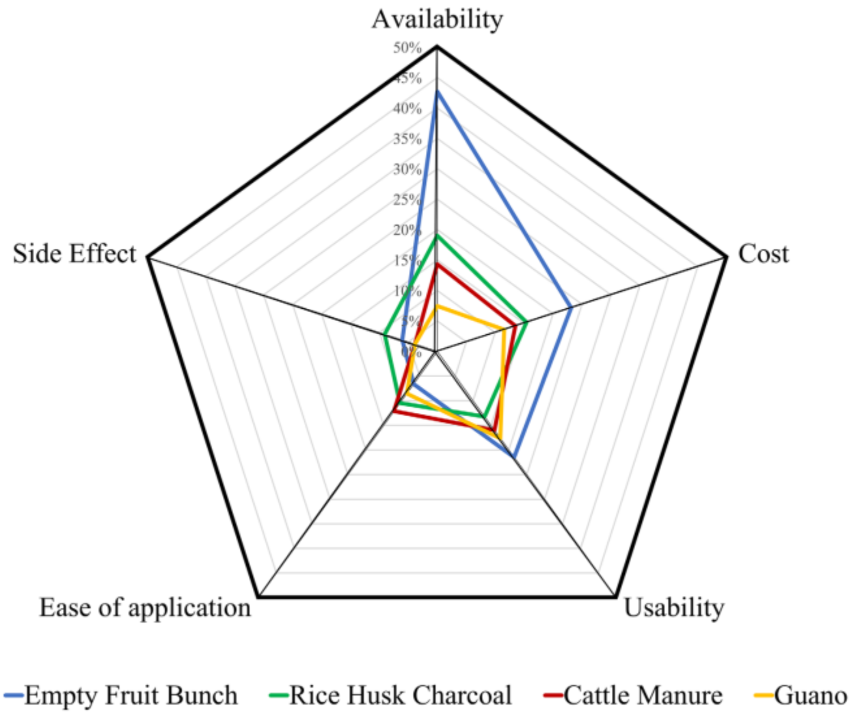

EXHIBIT 8 Relative suitability level of organic material [Color figure can be viewed at wileyonlinelibrary.com]

the selection criteria, so that the study focuses on discussing the criteria that have direct effects.

Some research revealed that some organic material for soil amendment is associated with the pathogenic organism effect. However, the economic justification of soil amendment is not solely based on unpredictable disease suppression but also considers other beneficial effects such as plant nutrient supply (Noble, 2011). Considering that mine reclamation is carried out within a limited access area and far from community settlements, the occurrence of wild animals disturbing the pile of organic material is a tolerable risk. The risk of exposure to pathogenic organisms from reclaimed areas to humans is low because the reclamations area has a long distance from the community.

3.2 | Determination of selected organic material

Expert Choice 11th Edition calculated a pairwise comparison matrix of alternatives to obtain the local priority of organic material for each criterion. It also calculated the local priority CR, and the results showed a maximum value of 2%. The synthesis between criteria weight, subcriteria weight, and local priority of alternative to determine global priority, which refers to Equation 1, is shown in Exhibit 6. This calculation applies distributive mode because the alternatives option is an open system, and one alternative tends to depend on another (Ishizaka & Labib, 2009).

The organic amendment will have different effects on different soil sites (Siedt et al., 2021). This global priority reflects the suitability level of the organic material. Refers to Exhibit 6, EFB compost was the most suitable choice for soil amendment of mine reclamation site. The second priority was RHC, followed by cattle manure and guano. When EFB compost was said to be fully suitable for mine reclamation, there was a relative suitability level of RHC at 67.3%, cattle manure at 60.1%, and guano at 48.2%. This value is determined by dividing the global priority of each alternative by the global priority of EFB. When relative suitability describes in multi-criteria spider chart, it will explain the correlation and leverage of the criteria as shown in **Exhibit** 8.

3.2.1 | EFB compost

EFB compost becomes the main priority to be chosen as a soil amendment on mine reclamation. Sensitivity analysis of Expert Choice showed that availability and cost have a robust effect on the choice of EFB compost. Refers to Exhibit 6, the best suit material due to availability and cost is EFB compost, followed by RHC, cattle manure, and guano. EFB can fulfill the need for organic material in sufficient and sustainable quantities. Oil palm plantations spread across these three regencies (Tanah Laut, Tanah Bumbu, and Kotabaru) can produce 981,000 ton per year of fresh fruit bunch (FFB) (Central Bureau of Statistic of South Kalimantan, 2020). As palm oil processing factories can produce EFB from FFB processing as much as 22%, according to research (Harsono et al., 2013), EFB waste production was 206,000 ton per year. Palm oil processing plants are distributed around the mine location so that the hauling distance is short. In addition, road access to the palm oil processing plant is hardened and coated with asphalt so that it is easy to reach by transport equipment.

The second reason EFB compost became the highest priority is the low procurement cost for EFB compost. Refers to the law of the market, the price of goods depends on supply and demand. Usually, EFB is used as a substitute fertilizer in palm plantations; other applications are limited and small. The low demand for EFB while the large production of waste makes its availability is abundant. EFB application is still limited to the estate near the palm oil mill as a convenient and cheap-disposal method (Bakar et al., 2011). The application of EFB as a substitute fertilizer in palm plantations gave benefited a $3.3 per ton (Anyaoha et al., 2018). Some palm processing plants have not commercialized their EFB waste. They only charge for activity costs to load onto the trucks so that the procurement costs are more influenced by transportation costs from processing plants to reclamation areas. It is similar to research done by Bakar et al. (2011) which emphasizes the transportation cost of EFB is a significant cost factor in palm plantation (Harsono et al., 2013).

The ability to improve soil properties is the third reason for choosing EFB compost. Refers to Exhibit 6, the local priority score of EFB is 0.29, two-fold compared to RHC or three-fold compared to cattle manure and guano. Compost can lower the pH of alkaline soils and increase the pH of acidic soils. Compost has a buffering effect at neutral pH, as stated (Spargo & Doley, 2016); therefore, compost can withstand changes in soil acidity. EFB to palm plants has increased soil pH, aggregate stability, and soil moisture and reduced soil bulk density. EFB also promotes soil detritivore mites abundance, soil fauna feeding activity, and soil microbial activity (Tao et al., 2018). Jones et al. (2016) said that soil amendment with compost could reduce the ion exchange capacity of some trace elements such as Cu, Pb, and Zn. This ability is a result of Cation Exchange Capacity (CEC) increase, as well as an increase in pH and organic matter content. Compost can also increase the electric conductivity because of watering and decomposition of organic matter, which dissolves salts in the soil (R Forján et al., 2014).

Despite the advantages mentioned above, EFB compost has weaknesses regarding ease of application due to the dosage size, which requires large mass and volume. This issue causes the implementation of EFB compost to take longer and supports more equipment. Application of EFB compost needs additional operational costs and may require advanced technology for higher efficiency and quality (Anyaoha et al., 2018). EFB is known to have nutrients content such as 2% K, 0.54% N, 0.19% Mg, and 0.16% P (Harsono et al., 2013); this amount is smaller than the nutrient content of cattle manure and guano. However, the slowly released nutrient content mechanism allows compost to maintain beneficial situations over long periods compared to cattle manure and guano (Siedt et al., 2021). Therefore, EFB compost is known to improve soil properties better rather than provide nutrients.

3.2.2 | Rice husk charcoal

Rice husk charcoal was the second priority in the selection of organic matter. The first reason for this decision was influenced by the ability of rice husk charcoal to absorb hazardous elements and pollutants. Rice husk charcoal has free covalent C bonds (Harsono et al., 2013) so that its pores open and increase its absorption capacity of other substances. Rice husk charcoal will cause multiple reactions, including absorption–desorption, precipitation–dilution, basic acids, and redox reactions following the statement (Anawar et al., 2015) regarding the properties of biochar. RHC improves soil properties by increasing microbial activity, retaining moisture, and holding N during composting. The RHC will increase C-organic in soil because its C-aromatic structure is more resistant to decomposition.

Next, RHC application will not cause side effects in soil amendment. The ability of RHC to absorb hazardous elements directly also plays a role in reducing the side effects of organic material as carriers for pathogenic organisms. Since it does not undergo a decay process (Nurhidayati & Mariati, 2014), RHC will not be targeted by disturber animals such as rats and wild boar. Compared to the advantages above, RHC has the lowest nutrient content compared to another alternative of organic material (Anyaoha et al., 2018; Nurhidayati & Mariati, 2014; Suwarno & Idris, 2007).

3.2.3 | Cattle manure and guano

Cattle manure was determined as the third priority of organic material in reclamation activities. It has a low to average score in its local priority. Cattle manure is easy to apply; hence it has advantages in time efficiency and supports equipment efficiency. It was easy to use by spreading it around the plants or mixing it in the planting medium. It also has higher nutrients, primarily N and P elements, compared to EFB compost and RHC (Anyaoha et al., 2018; Nurhidayati & Mariati, 2014; Suwarno & Idris, 2007). However, cattle manure had weakness in availability criteria, procurement cost, and negative impact of pathogen organism. Some research showed if *Phytium* species, *Rizhoctania solani*, and *Verticillium dahlia* were found from cattle manure compost (Noble, 2011). Cattle manure had a high price and limited availability because it had been widely used, and the competition to get this material was also quite tight.

Guano was assigned as the last priority as an organic material for soil amendment. It has the lowest score in every local priority except nutrient content. However, it has the highest nutrient content compared to other alternatives. It contains large amounts of N and P. Base on its chemical composition and climatic destruction level; guano is divided into nitrogenous guano and phosphatic guano. Nitrogenous guano or fresh guano has 7%–17% N, 8%–15% P_2O_5, and 40%–60% organic matter, while phosphatic guano has 0.2%–2% N, 10%–30% P_2O_5, and organic matter 5%–15%. These nutrient contents are much higher than cattle manure, with N content of 1.23%–2.77% and P_2O_5 of 0.55%–1.89% (Suwarno & Idris, 2007). The limited exploitation of guano is the reason for the high market price (Schnug et al., 2018). Guano resources are limited, so their availability cannot be expected for long-term supply. There is also a threat in the implementation of guano, the presence of pathogenic organisms. The pathogenic microbe contained in guano is *Histoplasma capsulatum* causing histoplasmosis in humans (Ferreira, 2019).

3.3 | Potential of the material combination

As each organic material has unique advantages and drawbacks, a potential strategy is to combine their benefit and minimize the downsides. Since EFB compost has substantial benefits in criteria of availability, cost, and sub-criteria of soil properties, it needs to combine with other materials with significant benefits in the other criteria. Huang et al. (2016) reported the problem of a single application of compost to remediate the contaminated soil. Some research showed the combination of organic materials such as compost and biochar could enhance its effect (Jones et al., 2016; Rubén Forján et al., 2017; Theeba et al., 2012). Refers to the score of local priority and global priority, it seems that RHC is the best alternative to combine with EFB compost. However, combining EFB compost and RCH does not significantly improve the nutrient content, so combining EFB compost with another material needs to be considered.

4 | CONCLUSION

The AHP method helped decision-makers in the selection of the most suitable organic material for mine reclamation. The selection of organic material was based on assessments of the criteria and alternatives. Availability and usability were the most important criteria in organic material selection with weight scores of 0.372 and 0.241, followed by cost and ease of application with 0.202 and 0.109. Side effect had the lowest weight score of 0.077 because of its low impact on the environment and community.

EFB compost was the most suitable organic material for soil amendment in Arutmin Indonesia's mine reclamation site. It had an advantage in availability, ability to improve soil properties, and low cost. The second priority was rice husk charcoal because of its advantages in absorbing hazardous elements and minimal side effects. Cattle manure had been selected as the third priority with the benefits in time efficiency and equipment support efficiency. Guano was the last priority because it low weight score in every local priority except nutrient content. Rice husk charcoal, cattle manure, and guano had a compatibility level between 48% and 67% compared to EFB compost. Further research is needed to examine the combined use of EFB compost and other organic material to optimize their advantages in soil amendment.

ACKNOWLEDGMENT

The authors gratefully acknowledged PT Arutmin Indonesia for the data and support information on this research.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Efendi Eko Mulyono https://orcid.org/0000-0002-4373-2493

REFERENCES

Anawar, H. M., Akter, F., Solaiman, Z. M., & Strezov, V. (2015). Biochar: An emerging panacea for remediation of soil contaminants from mining, industry and sewage wastes. *Pedosphere*, *25*(5), 654–665. https://doi.org/10.1016/S1002-0160(15)30046-1

Anyaoha, K. E., Sakrabani, R., Patchigolla, K., & Mouazen, A. M. (2018). Critical evaluation of oil palm fresh fruit bunch solid wastes as soil amendments: Prospects and challenges. *Resources, Conservation and Recycling*, *136*, 399–409. https://doi.org/10.1016/j.resconrec.2018.04.022

Bakar, R. A., Darus, S. Z., Kulaseharan, S., & Jamaluddin, N. (2011). Effects of ten years application of empty fruit bunches in an oil palm plantation on soil chemical properties. *Nutrient Cycling in Agroecosystems*, *89*(3). 341–349. https://doi.org/10.1007/s10705-010-9398-9

BPDASHL Barito. (2017). Laporan hasil penilaian keberhasilan reklamasi hutan dalam rangka pengurangan PNBP pada areal IPPKH PT Arutmin Indonesia Tambang Batulicin.

Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., & Brussaard, L. (2018). Soil quality – A critical review. *Soil Biology and Biochemistry*, *120*, 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030

Cahyana, R. T., Triantoro, A., & Riswan, R. (2020). Perhitungan rencana biaya reklamasi terhadap lahan bekas penambangan batubara di PT XYZ, Site Kintap, Kabupaten Tanah Laut, Kalimantan Selatan. *Jurnal Himasapta*, *5*(3), 97. https://doi.org/10.20527/jhs.v5i3.2900

Central Bureau of Statistic of South Kalimantan. (2020). *Output tabel dinamis BPS 2018*. https://kalsel.bps.go.id/subject/10/pertambangan

Concu, G. B. (2007). Investigating distance effects on environmental values: A choice modelling approach. *Australian Journal of Agricultural and Resource Economics*, *51*(2), 175–194. https://doi.org/10.1111/j.1467-8489.2007.00381.x

Doloi, H. (2008). Application of AHP in improving construction productivity from a management perspective. *Construction Management and Economics*, *26*(8). https://doi.org/10.1080/01446190802244789

Emovon, I., & Oghenenyerovwho, O. S. (2020). Application of MCDM method in material selection for optimal design: A review. *Results in Materials*, *7*, 100115. https://doi.org/10.1016/j.rinma.2020.100115

Erdogan, S. A., Šaparauskas, J., & Turskis, Z. (2017). Decision making in construction management: AHP and Expert Choice approach. *Procedia Engineering*, *172*, 270–276. https://doi.org/10.1016/j.proeng.2017.02.111

Erdoğan, S., Çakar, N. D., Ulucak, R., Danish, & Kassouri, Y. (2021). The role of natural resources abundance and dependence in achieving environmental sustainability: Evidence from resource-based economies. *Sustainable Development*, *29*(1), 143–154. https://doi.org/10.1002/sd.2137

Ferreira, R. L. (2019). Guano communities. In S. Ikeda, & A. Shapiro (Eds.), *Encyclopedia of Caves* (pp. 474–484). Elsevier. https://doi.org/10.1016/b978-0-12-814124-3.00057-1

Forján, R., Asensio, V., & Covelo, E. F. (2014). Effect of amendments made of waste materials in the physical and chemical recovery of mine soil. *Journal of Geochemical Exploration*, *147*, 91–97. https://doi.org/10.1016/j.gexplo.2014.10.004

Forján, R., Rodríguez-Vila, A., Cerqueira, B., & Covelo, E. F. (2017). Comparison of the effects of compost versus compost and biochar on the recovery of a mine soil by improving the nutrient content. *Journal of Geochemical Exploration*, *183*, 46–57. https://doi.org/10.1016/j.gexplo.2017.09.013

Harsono, S. S., Grundman, P., Lau, L. H., Hansen, A., Salleh, M. A. M., Meyer-Aurich, A., Idris, A., & Ghazi, T. I. M. (2013). Energy balances, greenhouse gas emissions and economics of biochar production from palm oil empty fruit bunches. *Resources, Conservation and Recycling*, *77*, 108–115. https://doi.org/10.1016/j.resconrec.2013.04.005

Horodecki, P., & Jagodziński, A. M. (2017). Tree species effects on litter decomposition in pure stands on afforested post-mining sites. *Forest and Ecology Management*, *406*, 1–11. https://doi.org/10.1016/j.foreco.2017.09.059

Huang, M., Zhu, Y., Li, Z., Huang, B., Luo, N., Liu, C., & Zeng, G. (2016). Compost as a soil amendment to remediate heavy metal-contaminated agricultural soil: Mechanisms, efficacy, problems, and strategies. *Water, Air, and Soil Pollution*, *227*(10), 359. https://doi.org/10.1007/s11270-016-3068-8

Ishizaka, A., & Labib, A. (2009). Analytic hierarchy process and expert choice: Benefits and limitations. *OR Insight*, *22*(4), 201–220. https://doi.org/10.1057/ori.2009.10

Iskandar, Suwardi & Suryaningtyas, D. T. (2012). Reklamasi lahan bekas tambang: Beberapa permasalahan terkait sifat-sifat tanah dan solusinya. Teknologi Pemupukan dan Pemulihan Lahan Terdegradasi, 29–36.

Jones, S., Bardos, R. P., Kidd, P. S., Mench, M., de Leij, F., Hutchings, T., Cundy, A., Joyce, C., Soja, G., Friesl-Hanl, W., Herzig, R., & Menger, P. (2016). Biochar and compost amendments enhance copper immobilisation and support plant growth in contaminated soils. *Journal of Environmental Management*, *30*, 1–12. https://doi.org/10.1016/j.jenvman.2016.01.024

Mansur, I. (2012). Integrating biodiversity conservation and agricultural production in mine reclamation for sustainable development. *Journal of Developments in Sustainable Agriculture*, *7*(1), 97–102. https://doi.org/10.11178/jdsa.7.97

Mohamed, A.-M. O., & Paleologos, E. K. (2018). The soil system. In J. Pierce, & K. McComb (Eds.), *Fundamentals of Geoenvironmental Engineering* (pp. 89–127). Elsevier. https://doi.org/10.1016/B978-0-12-804830-6.00004-1

Mulyono, E. E. & Haris, M. (2017). Aplikasi metode potting pada kegiatan reklamasi PT Arutmin Indonesia Tambang Batulicin. *Temu Profesi Tahunan Perhapi XXVI*, 362–371.

Noble, R. (2011). Risks and benefits of soil amendment with composts in relation to plant pathogens. *Australasian Plant Pathology*, *40*(2), 157–167. https://doi.org/10.1007/s13313-010-0025-7

Nurhidayati, N., & Mariati, M. (2014). Utilization of maize cob biochar and rice husk charcoal as soil amendments for improving acid soil fertility and productivity. *Journal of Degraded and Mining Lands Management*, *2*(1), 223–230. https://doi.org/10.15243/jdmlm.2014.021.223

Peta Rupa Bumi Indonesia. (2021). https://tanahair.indonesia.go.id/portal-web

Petruni, A., Giagloglou, E., Douglas, E., Geng, J., Leva, M. C., & Demichela, M. (2019). Applying Analytic Hierarchy Process (AHP) to choose a human factors technique: Choosing the suitable Human Reliability Analysis technique for the automotive industry. *Safety Science*, *119*, 229–239. https://doi.org/10.1016/j.ssci.2017.05.007

Ramamurthy, V., Reddy, G. P. O., & Kumar, N. (2020). Assessment of land suitability for maize (Zea mays L) in semi-arid ecosystem of southern India using integrated AHP and GIS approach. *Computers and Electronics in Agriculture*, *179*, 105806. https://doi.org/10.1016/j.compag.2020.105806

Saaty, T. L. (2008). Decision making with the Analytic Hierarchy Process. *International Journal of Service Science*, *1*(1), 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Santos, E. S., Arán, D., Abreu, M. M., & de Varennes, A. (2016). Engineered soils using amendments for in situ rehabilitation of mine lands. In M. N. V. Prasad, P. J. de C. Favas, & S. K. Maiti (Eds.), *Bio-Geotechnologies for mine site rehabilitation* (pp. 131–146). Elsevier Inc. https://doi.org/10.1016/B978-0-12-812986-9.00008-7

Schnug, E., Jacobs, F., & Stöven, K. (2018). Guano: The white gold of the seabirds. In H. Mikkola (Ed.), *Seabirds* (pp. 79–100). InTech. https://doi.org/10.5772/intechopen.79501

Schulz, H., Dunst, G., & Glaser, B. (2013). Positive effects of composted biochar on plant growth and soil fertility. *Agronomy for Sustainable Development*, *33*(4), 817–827. https://doi.org/10.1007/s13593-013-0150-0

Siedt, M., Schäffer, A., Smith, K. E. C., Nabel, M., Roß-Nickoll, M., & van Dongen, J. T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment* (Vol., *751*). 141607. https://doi.org/10.1016/j.scitotenv.2020.141607

Spargo, A., & Doley, D. (2016). Selective coal mine overburden treatment with topsoil and compost to optimise pasture or native vegetation establishment. *Journal of Environmental Management*, *182*, 342–350. https://doi.org/10.1016/j.jenvman.2016.07.095

Suwarno, & Idris, K. (2007). Potential and possibility of direct use of guano as fertilizer in Indonesia. *Jurnal Tanah Dan Lingkungan*, *9*(1), 37–43. https://doi.org/10.29244/jitl.9.1.37-43

Tanaka, H., Katsuta, A., Toyota, K., & Sawada, K. (2013). Soil fertility and soil microorganisms. In Atsushi Chitose (Ed.), *Research Approaches to Sustainable Biomass Systems* (pp. 107–142). Elsevier. https://doi.org/10.1016/B978-0-12-404609-2.00005-2

Tao, H. H., Snaddon, J. L., Slade, E. M., Henneron, L., Caliman, J. P., & Willis, K. J. (2018). Application of oil palm empty fruit bunch effects on soil biota and functions: A case study in Sumatra, Indonesia. *Agriculture, Ecosystems and Environment*, *256*, 105–113. https://doi.org/10.1016/j.agee.2017.12.012

Tavares, R. M., Tavares, J. M. L., & Parry-Jones, S. L. (2008). The use of a mathematical multicriteria decision-making model for selecting the fire origin room. *Building and Environment*, *43*(12), 2090–2100. https://doi.org/10.1016/j.buildenv.2007.12.010

Theeba, M., Bachmann, R. T., Illani, Z. I., Zulkefli, M., Husni, M. H. A., & Samsuri, A. W. (2012). Characterization of local mill rice husk charcoal and its effect on compost properties. *Malaysian Journal of Soil Science*, *16*(1), 89–102.

Wicke, B., van der Hilst, F., Daioglou, V., Banse, M., Beringer, T., Gerssen-Gondelach, S., Heijnen, S., Karssenberg, D., Laborde, D., Lippe, M., van Meijl, H., Nassar, A., Powell, J., Prins, A. G., Rose, S. N. K., Smeets, E. M. W., Stehfest, E., Tyner, W. E., Verstegen, J. A., … Faaji, A. P. C. (2015). Model collaboration for the improved assessment of biomass supply, demand, and impacts. *GCB Bioenergy*, *7*(3), 422–437. https://doi.org/10.1111/gcbb.12176

Zeleny, M. (2011). Multiple Criteria Decision Making (MCDM): From paradigm lost to paradigm regained? *Journal of Multi-Criteria Decision Analysis*, *18*(1–2), 77–89. https://doi.org/10.1002/mcda.473

Zornoza, R., Acosta, J. A., Faz, A., & Bååth, E. (2016). Microbial growth and community structure in acid mine soils after addition of different amendments for soil reclamation. *Geoderma*, *272*, 64–72. https://doi.org/10.1016/j.geoderma.2016.03.007

How to cite this article: Mulyono, E. E., Ruslan, M., Priatmadi, B. J., & Yusran, F. H. (2022). Organic material selection for soil amendment on mine reclamation with analytic hierarchy process. *Environ Qual Manage*, *31*(4), 225–234. https://doi.org/10.1002/tqem.21807

Organic material selection for soil amendment on mine reclamation with analytic hierarchy process

ORIGINALITY REPORT

10%	7%	7%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

#	Source	%
1	9pdf.net Internet Source	1%
2	scholarsbank.uoregon.edu Internet Source	1%
3	1library.net Internet Source	1%
4	Praveenkumar Sappidi, Brooks D. Rabideau, C. Heath Turner. "Molecular simulation of the separation of toluene and p-xylene with the thermally-robust ionic liquid triphenyl-p-phenyl sulfonyl phenyl phosphonium", Chemical Engineering Science, 2020 Publication	<1%
5	Beatriz A. Belmonte, Michael Francis D. Benjamin, Raymond R. Tan. "Optimization-based decision support methodology for the synthesis of negative-emissions biochar systems", Sustainable Production and Consumption, 2019 Publication	<1%

6	coek.info Internet Source	<1%
7	www.pjoes.com Internet Source	<1%
8	Ikuobase. Emovon, Okpako Stephen Oghenenyerovwho. "Application of MCDM method in material selection for optimal design: A review", Results in Materials, 2020 Publication	<1%
9	F Razie, A R Saidy, N Aidawati. "The exploration and utilization of functional microorganisms isolated from the tropical peatlands", IOP Conference Series: Earth and Environmental Science, 2019 Publication	<1%
10	download.mckinseyquarterly.com Internet Source	<1%
11	Submitted to Institute of Graduate Studies, UiTM Student Paper	<1%
12	Submitted to Northcentral Student Paper	<1%
13	Moyra Smith. "Environment as provider", Elsevier BV, 2020 Publication	<1%

14	"Resources Use Efficiency in Agriculture", Springer Science and Business Media LLC, 2020 Publication	<1 %
15	Abdul Kodir, Djoko M. Hartono, Herman Haeruman, Irdika Mansur. "Integrated post mining landscape for sustainable land use: A case study in South Sumatera, Indonesia", Sustainable Environment Research, 2017 Publication	<1 %
16	www.hindawi.com Internet Source	<1 %
17	Anwar, Z., M. Irshad, I. Fareed, and A. Saleem. "Characterization and Recycling of Organic Waste after Co-Composting - A Review", Journal of Agricultural Science, 2015. Publication	<1 %
18	faculty.rwu.edu Internet Source	<1 %
19	"Handbook of Assisted and Amendment: Enhanced Sustainable Remediation Technology", Wiley, 2021 Publication	<1 %
20	Hsiao-Hang Tao, Jake L. Snaddon, Eleanor M. Slade, Ludovic Henneron, Jean-Pierre Caliman, Katherine J. Willis. "Application of oil palm empty fruit bunch effects on soil biota and	<1 %

functions: A case study in Sumatra, Indonesia", Agriculture, Ecosystems & Environment, 2018
Publication

21	Mehr Ahmed Mujtaba Munir, Guijian Liu, Balal Yousaf, Md Manik Mian et al. "Contrasting effects of biochar and hydrothermally treated coal gangue on leachability, bioavailability, speciation and accumulation of heavy metals by rapeseed in copper mine tailings", Ecotoxicology and Environmental Safety, 2020 Publication	<1%
22	Mei Huang, Yi Zhu, Zhongwu Li, Bin Huang, Ninglin Luo, Chun Liu, Guangming Zeng. "Compost as a Soil Amendment to Remediate Heavy Metal-Contaminated Agricultural Soil: Mechanisms, Efficacy, Problems, and Strategies", Water, Air, & Soil Pollution, 2016 Publication	<1%
23	doi.nrct.go.th Internet Source	<1%
24	link.springer.com Internet Source	<1%
25	Justin G. Lees, Munawwar Abdulla, Mallory E. Barkl‐Luke, Lital Livni et al. "Effect of exercise on neuromuscular toxicity in oxaliplatin‐treated mice", Muscle & Nerve, 2021	<1%

Publication

26	journals.ekb.eg Internet Source	<1 %
27	"Soil Health", Springer Science and Business Media LLC, 2020 Publication	<1 %
28	Abolfath Moradi, Christopher Teh Boon Sung, Goh Kah Joo, Ahmad Husni Mohd Hanif, Che Fauziah Ishak. "Evaluation of Four Soil Conservation Practices in a Non-Terraced Oil Palm Plantation", Agronomy Journal, 2012 Publication	<1 %
29	B. Swaraj Kumar, James Varghese, Josephkutty Jacob. "Optimal thermochemical material selection for a hybrid thermal energy storage system for low temperature applications using multi criteria optimization technique", Materials Science for Energy Technologies, 2022 Publication	<1 %
30	Dipita Ghosh, Subodh Kumar Maiti. "Biochar ‐ assisted eco ‐ restoration of coal mine degraded land to meet United Nation Sustainable Development Goals", Land Degradation & Development, 2021 Publication	<1 %
31	www.intechopen.com Internet Source	<1 %

32	"International Handbook of Universities 2019", Springer Science and Business Media LLC, 2019 Publication	<1 %
33	Ana P. Pinto, Amarílis de Varennes, José E.F. Castanheiro, Avelino M.A. Balsinhas. "Fly Ash and Lime-Stabilized Biosolid Mixtures in Mine Spoil Reclamation", Elsevier BV, 2018 Publication	<1 %
34	dergipark.org.tr Internet Source	<1 %
35	psasir.upm.edu.my Internet Source	<1 %
36	t-stor.teagasc.ie Internet Source	<1 %
37	www.investigo.biblioteca.uvigo.es Internet Source	<1 %
38	www.mdpi.com Internet Source	<1 %
39	Ebrahim Aghazadeh, Hasan Yildirim. "Assessment the effective parameters influencing the sustainable materials selection in construction projects from the perspective of different stakeholders", Materials Today: Proceedings, 2021 Publication	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		