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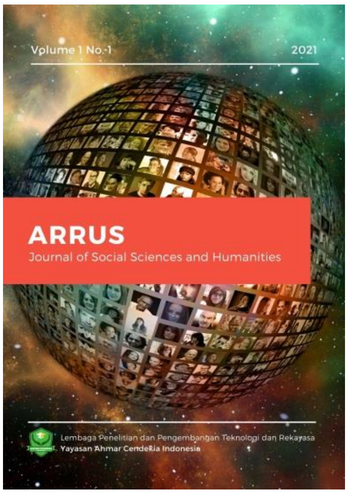

RESEARCH ARTICLE

# Analysis on Environmental ad Economic Benefit Of Activities in Coal Mined Area: A Case Study of Tanjung Enim Mining Site, South Sumatera

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**Abstract:** Tanjung Enim Mining Site, the third oldest coal mining site in Indonesia, has conducted several reclamation activities. However, the leading way to manage the barren areas for both the environmental and economic perspectives is undefined. This research aims to determine the best reclamation activity in the mined-area by having environment and economic comparison through Life Cycle Assessment and cost-benefit analysis. The data is collected through company and government documents, also mining employee's interviews. The assessed scenarios include revegetation; agriculture (oil-palm plantation), and solar panel field. Based on this study, it results in agriculture (oil-palm plantation) as the most feasible and suitable option to be performed in the coal-mined area for both environment and economic aspects though the revegetation gives the modest environment.

**Keywords**: life cycle assessment, post-mining activities, reclamation, cost-and-benefit analysis

## 1. Introduction

Coal mining activities always leave ex-excavated holes or voids, which become barren areas (Nasir et al., 2023; Vo et al., 2022; Yang et al., 2021). It occurs because the coal mining project clears the expected coal mining area from any vegetation on its surface at the beginning of the operation (Ivanova et al., 2022; Kamenopoulos et al., 2021; Liu et al., 2023; Xiao et al., 2021). After the coal exploration, the mined land was just abandoned; backfilled, or not backfilled; replanted, or as it is. Backfilling process refers to dumping overburden and topsoil into a basin of the mined area, then contouring the mined surface area with the assistance of heavy machinery (Daryanto et al., 2018; Hendryx et al., 2020; Shi et al., 2020; Xiao et al., 2021). Because of the acidic mined soil characteristic, the mined land is hardly restored to its original state. Several options to revive the post-mining area are available to be conducted to reduce environmental burdens. Aside from this, the operators look for certain reclamation alternatives that draw some advantages in economic ways. Moreover, aspirations from local communities living around the mined area are also taken into account in assigning reclamation options. Divergent post-mining activities are allowed to be developed in mined areas, such as wildlife habitats, open spaces, agriculture, or residential and commercial based on Good Mining Rules and Supervision of Mineral and Coal Mining that is released by the Ministry of Energy and Mineral Resources of the Republic of Indonesia. However, the leading way to manage the post-mining area according to both the environmental and economic perspectives have not been clearly stated. The rise questions include: What is the most prominent process in each scenario that contribute the highest environmental damage? How much of an environmental burden loss do the existing reclamation processes and other possibilities for reclamation have? How significant is the economic advantage of the current reclamation options and alternative reclamation options? What is the most effective way to manage the land after mining that satisfies both environmental and economic requirements? The answer to these questions can be derived by comparing environmental impacts and financial gains among the reclamation methods and pot-mining activities to decide the most effective reclamation methods from both standpoints.

The objective of this study is to compare the environmental impacts and economic benefits of certain reclamation options in order to determine the effective options for handling the mined area according to the environmental and economic perspectives. LCA is one of the environmental analysis tools that offer the potential for providing such criteria and measures needed for comparing the environmental merits of alternatives (Gunamantha et al., 2012). In this case, the Life Cycle Assessment (LCA) is performed to result in particular impacts as a parameter for environmental damage related to human health, ecosystem biodiversity, and resource scarcity. Cost-benefit analysis, or CBA, is the process of comparing the projected or estimated costs and benefits (or opportunities) associated with a project decision to determine whether it makes sense from a business perspective (Stobierski, 2019). Certain indicators are decided to execute the analysis, including return on investment (ROI), net present value (NPV), benefit-cost ratio (BCR), payback period, and internal rate of return (IRR).

The case of the Tanjung Enim Mining Site in Muara Enim Regency of South Sumatra Province is chosen to be studied because of its heterogeneous preferences in managing coal-mined areas. The system boundary of the life cycle of the studied case begins when the area has been explored, or when the backfilling process is going to be initiated; and ends when the area has been utilized according to designated post-mining activities. Distinct reclamation actions have been conducted in its three operated pits from five mining pits in total, then those are determined as assessed scenarios in this study. The revegetation process and oil palm plantation development, as agriculture options, have been conducted in different mined pits. Aside from this, another mined pit is being planned to be developed as a solar panel field.

At present, the regency complies with Indonesia's government, to be specific with the Regulation of the Ministry of Energy and Mineral Resources Number 26 of 2018 which regulates principles and requirements for conducting reclamation in mining areas. The post-mining activities in mined locations should be performed by considering two aspects, which are minimizing adverse environmental effects of surface mining and returning mined lands to beneficial end-use. This research is expected to provide insight into environmentally suitable options for making the decision in establishing the option of post-mining activities by considering the feasibility of the reclamation action. The finding of this research can be used to formulate specific plans or strategies to reduce the environmental burdens of the post-mining area and also gain the benefit from the selected reclamation options, particularly in an economic way.

## 2. Literature Review

According to the Ministry of Energy and Mineral Resources Regulation Number 26 of 2018 concerning Implementation of Good Mining Rules and Supervision of Mineral and Coal Mining, reclamation is defined as an activity that is carried out comprehensively during the mining business stages to regulate, restore, and improve the quality of the environment and ecosystem so that it can function properly again according to its allotment. Using a variety of techniques, surface mining's detrimental environmental consequences are diminished and mined sites are restored to productive use. End uses can include open spaces, habitats for wildlife, agriculture, or the development of homes and businesses. Reclamation techniques include those that stabilize slopes, stop erosion and sedimentation, and avoid or minimize impacts on wildlife habitats. So, mine reclamation might be defined as the act of restoring mined land to its natural or economically viable state.

Mining reclamation must be done by the mining industry. This regulation is described in Government Regulation Number 78 of 2010 regarding Reclamation and Post-mining. The reclamation must proceed while abiding by specific criteria, including the management of the mining environment, the preservation of minerals and coal, and workplace health and safety. Prior to beginning the mining activity, mining companies should present the reclamation plan for the mined area. In the event that this reclamation plan is broken, the mining business license can be revoked. Therefore, in accordance with the Regulation of Ministry Energy and Mineral Resources of the Republic of Indonesia Number 18 of 2008 concerning Reclamation and Mining Termination, mining companies are required to submit an annual report on the implementation of reclamation activities to the minister, governor, or regent/mayor in accordance with their respective authorities.

The mined land can be rehabilitated for a number of purposes, including agriculture, the construction of solar panel fields, and re-vegetation. Revegetation, also known as replanting, is a process used to repair and restore damaged vegetation on land that has previously been used as a forest area, according to Regulation of Forestry Ministry of Republic Indonesia Number P.4 of 2011 about Forest Reclamation Guidance. Field preparation, nursery and/or seed acquisition, planting, and plant upkeep are all steps in the process of revegetation (BNI, 2021; Report, 2021). One alternative to mining is agriculture, particularly for plant types like oil palm and rubber trees. Because of their ability to withstand acidic soil, these plants were chosen. According to Directorate of Agriculture India (2007), oil palm trees can thrive in soil with a pH range of 4 to 6. Besides, based on the experience of the West Ombilin post-mining area in South Sumatera, the mined land could be transformed into a solar panel farm. According to, solar power facilities need between 1.5 and 2.3 hectares (ha) of land per MWp (USAID, 2010).

## 3. Research Method and Materials

### *3.1. Life Cycle Assessment*

The phase classification of the LCA study follows ISO 14040 Environmental management. Life cycle assessment. Principles and framework, which comprises four phases. The first phase is defining the goal and scope of the assessment. The second phase is compiling the life cycle inventory. These phases follow by the third phase, which is conducting a life cycle impact assessment. Lastly, the final phase of this assessment is interpreting the result. The LCA was performed to gain a comparative assessment of the environment of each scenario on reclamation and post-mining activities.

In the goal and scope definition phase, it is defined that the study proposes to compare three scenarios of reclamation and post-mining activities in coal-mined areas in the Tanjung Enim Mining Site. To perform the comparison, a fixed point, which is called a functional unit, is compulsory to be defined as a reference for the assessment. The functional unit has been established as a 1-month of backfilling process or 43 hectares of backfilled area. The number of the backfilled area is determined by considering the coal production of Tanjung Enim Mining Site in April 2019 as 1,500,000 CCM. Core data of each process in each scenario is compiled as foreground data, while detail data is considered as background data. The existing and planned reclamation options are assigned as follows:

Scenario 1: revegetation. The mined land is cultivated with eucalyptus trees.
Scenario 2: agriculture, particularly oil-palm plantation. The scenario involves the harvesting of fresh fruit bunches.
Scenario 3: solar panel field. Operation of the solar power plant is included.

All scenarios involve backfilling process and land preparation steps. The inputs, outputs, and processes of each scenario are defined through the material flow analysis and are depicted in the figure 1, 2, & 3.

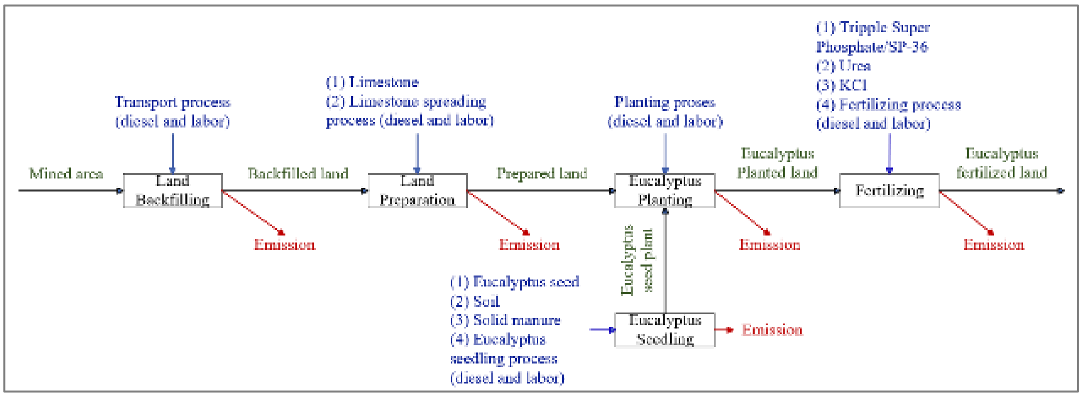

**Figure 1.** The material and process flow of the revegetation scenario (eucalyptus cultivation)
Source: Author Analysis, 2022

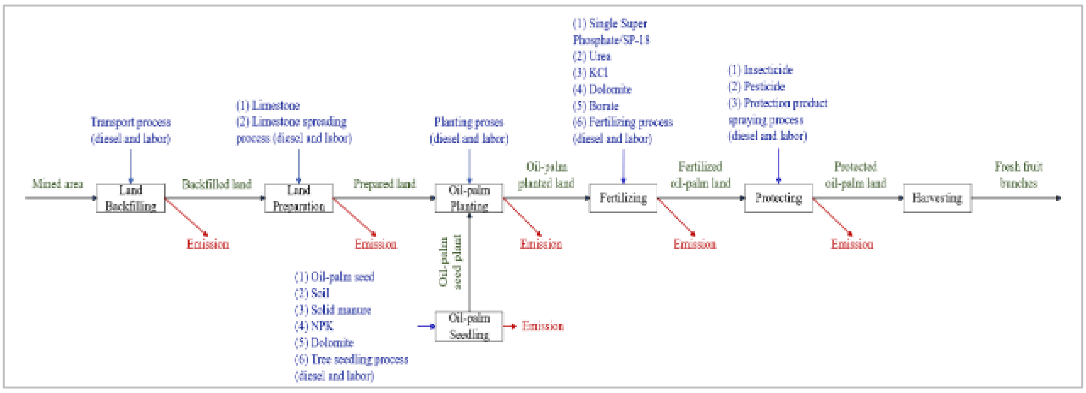

**Figure 1.** The material and process flow of agriculture scenario (oil-palm plantation)
Source: Author Analysis, 2022

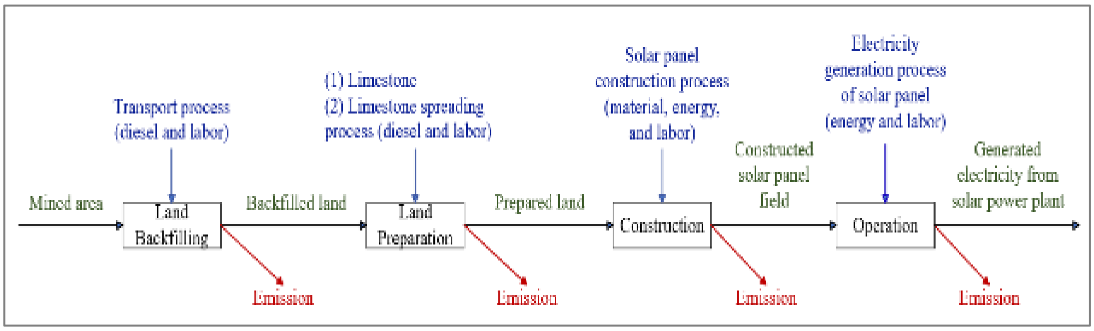

**Figure 2.** The material and process flow of solar panel field
Source: Author Analysis, 2022

The assessed emission burdens comprise three environmental damages: damage related to human health; damage related to ecosystem or biodiversity; and damage related to resource scarcity. The damage related to human health consists of 8 impacts, which involve global warming, stratospheric ozone depletion, ionizing radiation, ozone formation, fine particulate matter formation, human carcinogenic toxicity, human non-carcinogenic toxicity, and water consumption. Aside from this, the damage related to the ecosystem covers 12 parameters from global warming for both terrestrial and freshwater ecosystems, ozone formation of terrestrial ecosystems, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, land use, to water consumption for both terrestrial and aquatic ecosystems. Mineral and fossil resource scarcities are the only 2 impacts that are included in damage related to the resources.

From the defined goal and scope, various kinds of data are compiled in the life cycle inventory of all scenarios. Since some data are not ready-to-use data for designated LCA software, several calculations needed to be conducted, including overburden and required fuel calculation. Most of the data from the backfilling process are gained from the mining site of the study area. The backfilled overburden and required fuel are calculated to determine the transport process in tkm (ton kilometer) units and the number of fuels in liter units. The overburden is analyzed by multiplying the overburden in bcm or bank cubic meter and its density. The coal production, stripping ratio, shrinkage factor, and swell factor are considered in calculating the overburden in bcm. The table 1 indicates the coal and overburden's characteristic for determining number of materials that involve in land backfilling process.

**Table 1**. Characteristic of coal and overburden in Tanjung Enim Mining Site

| Characteristic | Coal | Overburden |
|---|---|---|
| Density in ton/m$^3$ | 1.3 | 2.1 |
| Stripping ratio | 1 | 4.3 |
| Swell factor | - | 1.2 |
| Shrinkage factor | - | 0.9 |

Source: PT. Bukit Asam, Tbk, 2019

The backfilling and land preparation process are conducted in all assessed scenarios. The backfilling process consists primarily of hauling overburden from the front mining operation to the disposal area using diesel-powered haul trucks. It takes 14 heavy equipment, including 3 loader vehicles and 11 haulers to shift the overburden from the mining area to the designated disposal location, which is about 2.4 kilometers in distance. The whole backfilling process consumes nearly 3.5 million liters of diesel fuel in creating 43 ha of backfilled area. This process is represented as an input material in this software by approximately 35 million tkm (ton kilometer). Apart from the diesel fuel usage, the backfilling process also involves transport activity as a sub-process. Based on the data on Table 1, this transport activity and the diesel consumption as a fuel are counted. The calculation results approximately 3,483,000 Liter required in the backfilling process for all scenarios.

The next step, land preparation, covers limestone and diesel usage. However, the software database provides the limestone spreading activity as a unit process, which already includes fuel utilization and manpower. The lime in land preparation which is about 7.5 tons per hectare is spread over the ex-mining surface area. In the studied area, it equals to around 322.5 ton of limestone spread in the land preparation process, which is same for all assessed scenarios. It is used as a soil amendment for improving the physical and chemical structure of the soil. The soil pH-raising agent, which is $CaCO_3$, is also layered upon the mined soil as much as the limestone. Based on the backfilled land of a month, or about 43 hectares, the environmental burdens of each assessed scenario were examined. These burdens are analyzed based on the available database in the SimaPro software using the core and secondary data obtained by this study. Therefore, the needed data does not show the diesel unit and only indicates the total need of limestone for the total assessed area in hectares.

The following steps are distinct for each scenario. The revegetation scenario is continued with eucalyptus seedling, planting process, then land fertilizing. In the case of agriculture scenario, it follows with oil-palm seedling, oil-palm planting, fertilizing, protecting, and harvesting of fresh fruit from the oil-palm plantation. After the backfilling and land preparation, the following steps for the solar panel field scenario are construction and operation of the solar panel to generate electricity. All input and material as data for impact calculation purposes are required to be presented in the mass unit. Therefore, the data that is obtained as core and secondary data needs to be modified and computed to fulfil the software requirement.

### a. Revegetation (eucalyptus cultivation) scenario

On the backfilled pit-3 area of Banko Barat pit, around 7.74 hectares are planted with 8,599 eucalyptus trees. According to this core data, the secondary data are considered to determine the utilized soil, manure, and also used fertilizer. The seedling process requests nearly 2.40 kg of planting media per seed by considering that the percentage of required soil is equal to the manure percentage. Based on the eucalyptus fertilization dosage guideline that is released by the plantation and forestry agency, each plant requires TSP/SP-36, urea, and KCl in grams of 20; 80; and 30 respectively. In this scenario, the KCl is represented by the existence of K2O or inorganic potassium. Commonly, the potassium chloride as fertilizer contains K2O 60% (Winarna, Darmosarkoro, W., Sutarta, 2013). The required materials for revegetation scenario for 43 hectares backfilled area as the calculation basis are explained on the Table 2.

**Table 2.** Material/Process of Revegetation Scenario

| Material/process | Amount (Unit) |
|---|---|
| Soil for seedlings per plant | 55.42 ton |
| Manure for seedling per plant | 55.42 ton |
| Number of seeds/plants | 47,772 seeds/plants |
| Single super-phosphate | 0.96 ton |
| Urea | 3.82 ton |
| Inorganic potassium | 1.43 ton |

Source: Author Analysis, 2022 (analyzed based on data of PT. Bukit Asam, Tbk in 2019)

### b. Agriculture (oil-palm plantation) scenario

Data of oil palm tree seedlings are defined in the same quantity as the eucalyptus cultivation scenario, and so does the planting process. The seedling process requests approximately 2.4 kg of planting media per seed by considering that the percentage of required soil is equal to the manure percentage. Several fertilizers are applied for developing oil palm trees, including urea, single superphosphate, potassium chloride, and dolomite. The fertilizer dosage depends on the podzolic soil type of the mined land that has undergone leaching; so that the upper layer is light gray to yellowish and the lower layer is red or yellow.

**Table 3.** Dosage of Fertilizing Immature Oil Palm Plants in Podsolic Soil

| Plant age (months) | Type and dose of fertilizer (kg/plant) | | | | |
|---|---|---|---|---|---|
| | Zwavelzure Ammonium/ZA | Rock Phosphate/RP | Muriate of Potash/MOP | Kieserite/ MgO 25% | HGF-Borate |
| 0 | - | 0.50 | - | - | - |
| 1 | 0.10 | - | - | - | - |
| 3 | 0.25 | - | 0.15 | 0.10 | - |
| 5 | 0.25 | 0.50 | 0.15 | 0.10 | - |
| 8 | 0.25 | - | 0.35 | 0.25 | 0.02 |
| 12 | 0.50 | 0.75 | 0.35 | 0.25 | - |
| 13 | 0.50 | - | 0.50 | 0.50 | 0.03 |
| 20 | 0.50 | 1.00 | 0.50 | 0.50 | - |
| 24 | 0.50 | - | 0.75 | 0.50 | 0.05 |
| 28 | 0.75 | 1.00 | 0.75 | 0.75 | - |
| 32 | 0.75 | - | 1.00 | 0.75 | - |
| Total | 4.35 | 3.75 | 4.50 | 3.70 | 0.10 |

Source: Darmosarkoro, 2014

According to Darmosarkoro (2014), it has a heavy texture, and lumpy structure because of the clay. In addition, it also has a low level of permeability, organic matter, base saturation, and pH, which is about 4.2 – 4.8. Different dosage is applied to an unready and ready-toharvest oil palm tree monthly. Oil palm trees can be harvested from the age of 3 to 25 years after planting (Winarna, Darmosarkoro, W., Sutarta, 2013). The fertilizer dosage was determined distinctly according to its age, which is classified to immature and mature oil palm plants. The use of ZA can be replaced by urea with 0.47 conversion, while the rock phosphate is equal to SP-36 or SP-18 with 2 conversions. MOP is equal to KCl with $K_2O$ 60% content and kieserite/MgO 25% can be replaced by dolomite/MgO 18% with 1.4 conversion.

**Table 4.** Dosage of Fertilizing Mature Oil Palm Plants in Podsolic Soil

| Plant age (years) | Type and dose of fertilizer (kg/plant) | | | |
|---|---|---|---|---|
| | Urea | SP-36 | Muriate of Potash/MOP | Kieserite |
| 3 - 8 | 2.00 | 1.75 | 1.50 | 1.50 |
| 9 - 13 | 2.50 | 2.75 | 2.25 | 2.00 |
| 14 - 20 | 1.50 | 2.25 | 2.00 | 2.00 |
| 21 - 25 | 1.50 | 1.50 | 1.25 | 1.50 |

Source: Darmosarkoro, 2014

Protecting agents such as herbicides and pesticides are utilized on the plantation. The pesticide and insecticide are applied to the oil palm plantation as much as 3,150 kg and 2,600 kg per hectare respectively (Siregar, 2015). For the harvesting process, the data is analyzed based on the available database in the software. The required materials for agriculture (oil-palm plantation) scenario for 43 hectares backfilled area as the calculation basis are explained on Table 5.

**Table 5.** Material/Process of Agriculture Scenario

| Material/process | Amount (Unit) |
|---|---|
| Soil for seedlings per plant | 6.59 ton |
| Manure for seedling per plant | 6.59 ton |
| Number of seeds/plants | 5,676 seeds/plants |
| NPK | 1.45 ton |
| Dolomite | 649.53 ton |
| Urea | 471.35 ton |
| Single super-phosphate | 1,081.28 ton |
| Potassium chloride | 468.27 ton |
| Boric oxide | 0.57 ton |
| Insecticide | 63.50 ton |
| Pesticide | 75.37 ton |

Source: Author Analysis, 2022 (analyzed based on data of PT. Bukit Asam, Tbk in 2019)

### c. Solar panel field

Detailed data on the construction and operation processes in developing solar panel fields were obtained from the literature, then analyzed in accordance with the software database. It includes establishing the multi-Si type of photovoltaic plant in an open ground area and also generating electricity. Around 1.5 – 2.3 hectares of solar power is able to generate approximately 1 MWp by considering the geographic condition and construction equipment (USAID, 2010). By acknowledging this source, the total generated electricity by photovoltaic plants for 43 hectares is approximately 28 MWp.

Based on the data that are compiled in the life cycle inventory phase, a life cycle impact assessment is performed using the ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A method by including the long-term emission. The endpoint indicator shows the environmental impact on three higher aggregation levels. The research aims to have a whole description of environmental damage caused by all scenarios. Therefore, this method was chosen since the endpoint method follows the consequences of certain emissions until it causes damage related to human health, biodiversity, and resource scarcity.

Designated units are applied in describing the environmental damage. Disability-adjusted life years (DALYs) have been used to quantify endpoint indicators of the human burden of disease in life cycle assessment (Kobayashi et al., 2015). According to Golsteijn (2019), it takes into account the years lost to premature death and expresses the reduced quality of life due to illness in years as well. Aside from this, the damage related to biodiversity is represented in species.yr which means the species loss over time that is commonly used in quantifying the damage. In addition, the damage related to resource scarcity is indicated by USD 2013. In the end, to compare all the damage of each scenario, the normalization step is performed to synchronize the result because of the various unit of each damage.

### *3.2. Cost and Benefit Analysis*

Five indicators are executed for assessing the economic cost and benefit of all scenarios. In analyzing the scenarios, the investment efficiency is calculated by comparing total benefit to total investment as a form of return-on-investment indicator. Because of the difference between benefit and cost, the net present value of each scenario is measured by subtracting the investment present value from discounted cash flow. Therefore, the ratio of project benefits versus project costs is also calculated to clarify the calculation. Moreover, it needs to specify the payback period to identify the required time for the total discounted cost to be surpassed by the total discounted benefits. Furthermore, the internal rate of return needs to be computed which refers to the annual rate of growth that an investment is expected to generate. It is calculated when the NPV value is equal to 0. These indicators are computed by referring to the following equations.

$$Return\ on\ Investment\ (ROI) = \frac{Total\ benefit}{Total\ investment} \times 100\% \tag{1}$$

$$Net\ Present\ Value\ (NPV) = \left[\sum \frac{B_i}{(1+d)^i}\right] - \left[\sum \frac{C_i}{(1+d)^i}\right] \tag{2}$$

$$Benefit - Cost\ Ratio\ (BCR) = \frac{\left[\sum \frac{B_i}{(1+d)^i}\right]}{\left[\sum \frac{C_i}{(1+d)^i}\right]} \tag{3}$$

$$Payback\ Period\ (PP) = \frac{Total\ investment}{Cash\ flow\ per\ year} \tag{4}$$

$$0 = NPV = \left[\sum \frac{C_i}{(1+IRR)^i}\right] \tag{5}$$

## 4. Results and Discussion

### *4.1. Life Cycle Analysis*

Life cycle impact assessment, as the main step to evaluate the obtained data, delineates impact contribution of all materials, activities, and also processes that form the scenario. It is applied to all designated scenarios to create product system trees that figure the main process which evokes the most significant damage toward human health, ecosystem and biodiversity, as well as damage toward resource scarcity. The green boxes represent the materials that are included in the process, while the yellow boxes display all involved processes and the blue boxes figure initial material or process and the outcome of the scenario. The redline thickness pictures on how significant the process or material in contributing the impact. The greater thickness indicates the more crucial impact that releases because of a particular process. Each process in the revegetation scenario is assessed to determine the respective impact value based on impact category. From transport to eucalyptus fertilized land, the revegetation scenario includes 15 processes or materials as input for the software analysis. The assessment provides detailed impact per process or material for all damage categories, including human health, the environment, and resources.

The assessment of revegetation scenario results on the backfilling process as the most process that causes environmental degradation, compared to other processes. It results that around 97% of the total environmental damages are caused by the backfilling process. This is pictured by the widest red lines on Figure 4, while the other processes have minor impact on the environment.

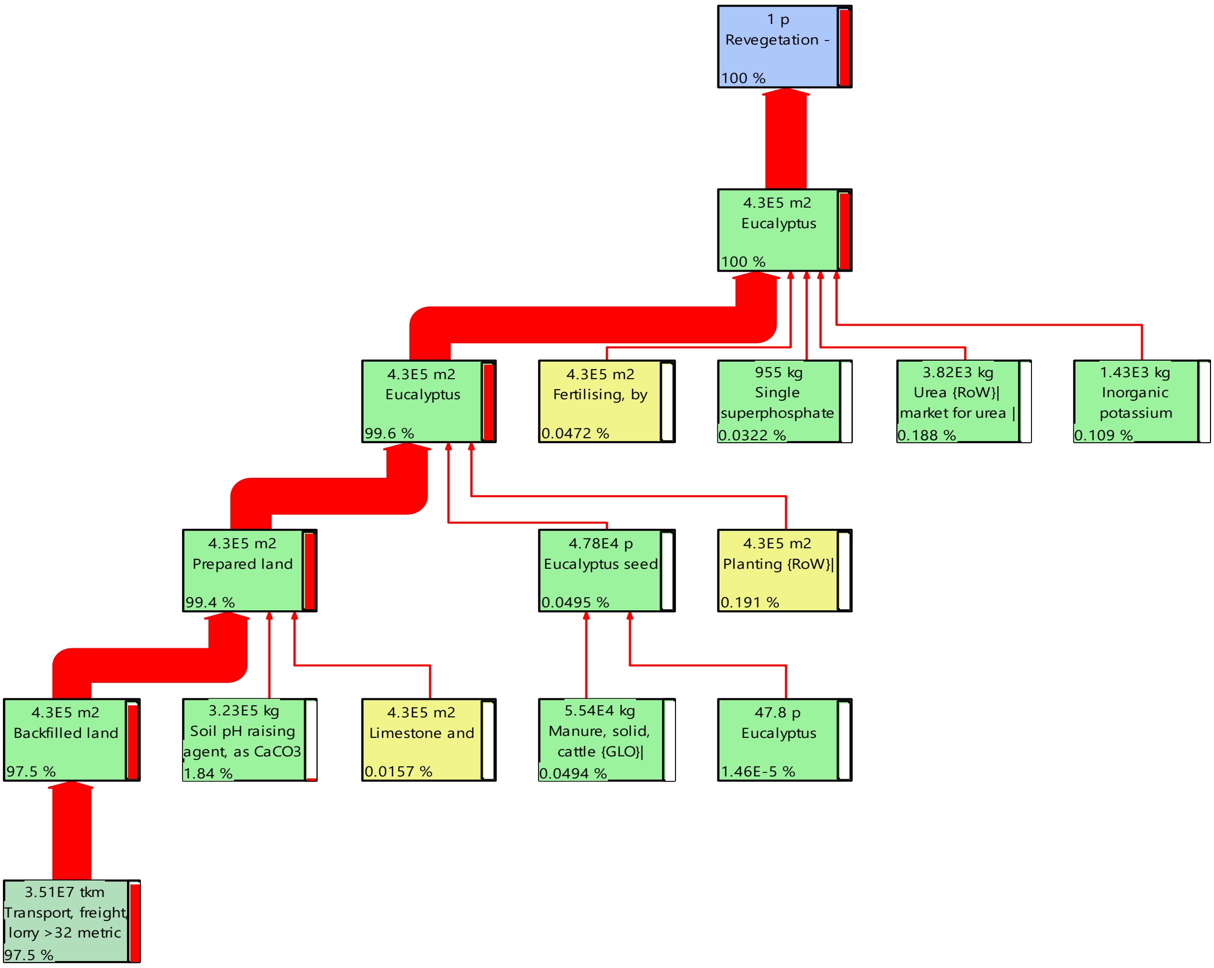

**Figure 3.** Product System Tree of Revegetation Scenario

Source: Author Analysis, 2022

In case of scenario 2, the analysis gives the most significant process that affects the environment to backfilling process as well, which is the same process carried out in the revegetation scenario. The assessment explain that the process contributes roughly 37% of the whole environmental damage caused by the entire agricultural (oil-palm plantation) scenario. Aside from overburden transport, insecticide use accounts for approximately 23% of total impact and pesticide use accounts for nearly 12% of total impact.

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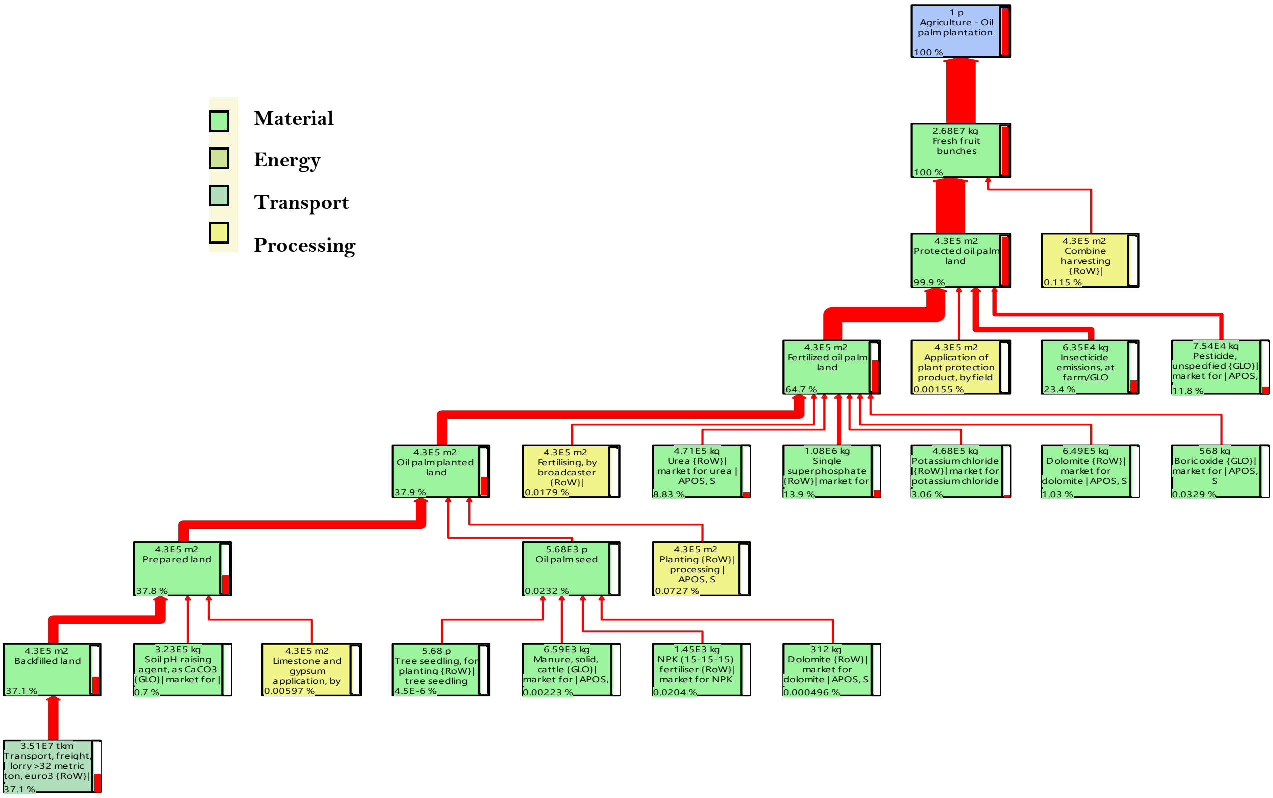

**Figure 5**. Product System Tree of Agriculture Scenario

Source: Author Analysis, 2022

According to Figure 6, solar panel field construction and electricity generation, among other processes in this scenario, generate significant environmental damages. Nearly 96.6% of total environmental impact is emitted by the electricity generation process. However, the backfilling and land preparation process is not considered to have a significant environmental impact because it contributes less than 3.36% of total emissions caused by the solar panel field scenario.

The details quantitative data for environmental impacts that are caused by all assessed scenarios are represented on Table 6. The measured impact categories include global warming; human toxicity; fine particulate matter formation, ozone formation, as well as its depletion; radiation; acidification, eutrophication, ecotoxicity, water consumption, resource scarcity, and also land use.

The impact categories have distinct units respectively. Therefore, the normalization step is examined so that the impact values can be compared. Figure 7(a) depicts the details normalization graph per impact category for the revegetation scenario, while Figure 7(b) shows the normalization graph per damaged category for all of the three scenarios.

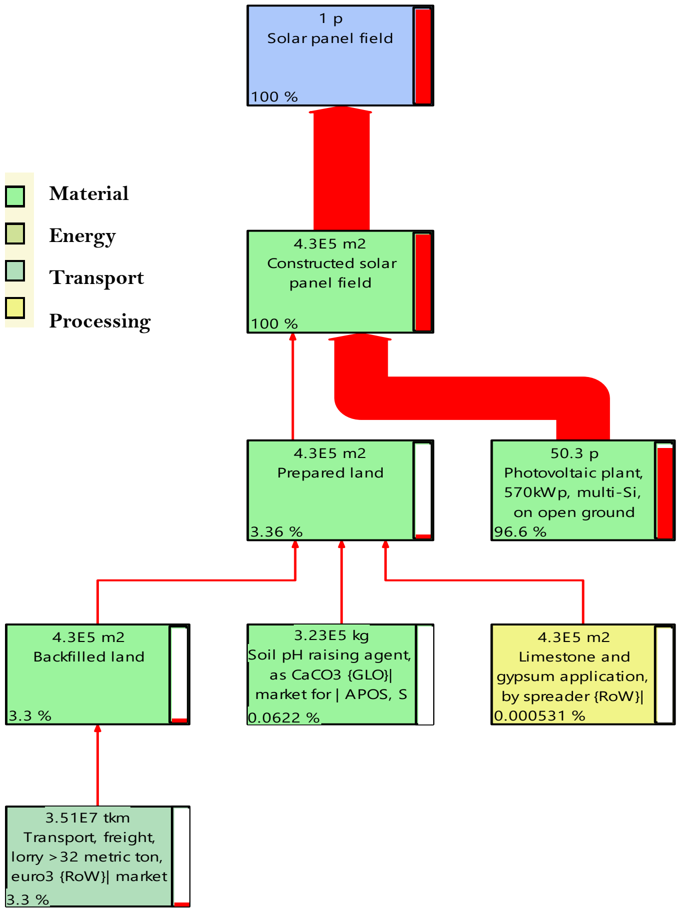

**Figure 6.** Product System Tree of Solar Panel Field Scenario

Source: Author Analysis, 2022

**Table 6.** Environmental Impact of All Assessed Scenario

| Impact category | Unit | Revegetation | Agriculture | Solar Panel Field |
|---|---|---|---|---|
| Global warming, Human health | DALY | 3.12E+00 | 5.44E+00 | 6.34E+01 |
| Stratospheric ozone depletion | DALY | 6.93E-04 | 2.33E-03 | 1.61E-02 |
| Ionizing radiation | DALY | 5.87E-04 | 1.61E-03 | 4.19E-02 |
| Ozone formation, Human health | DALY | 2.17E-02 | 2.83E-02 | 1.78E-01 |
| Fine particulate matter formation | DALY | 3.67E+00 | 7.59E+00 | 9.18E+01 |
| Human carcinogenic toxicity | DALY | 4.10E-01 | 1.03E+00 | 3.67E+01 |
| Human non-carcinogenic toxicity | DALY | 5.33E-01 | 6.26E+00 | 3.94E+01 |
| Water consumption, Human health | DALY | 1.02E-02 | 1.21E-01 | 3.02E+00 |
| Global warming, Terrestrial ecosystems | species.yr | 9.42E-03 | 1.64E-02 | 1.91E-01 |
| Global warming, Freshwater ecosystems | species.yr | 2.57E-07 | 4.49E-07 | 5.22E-06 |
| Ozone formation, Terrestrial ecosystems | species.yr | 3.13E-03 | 4.09E-03 | 2.64E-02 |
| Terrestrial acidification | species.yr | 2.83E-03 | 6.14E-03 | 6.44E-02 |
| Freshwater eutrophication | species.yr | 4.61E-04 | 1.59E-03 | 2.90E-02 |

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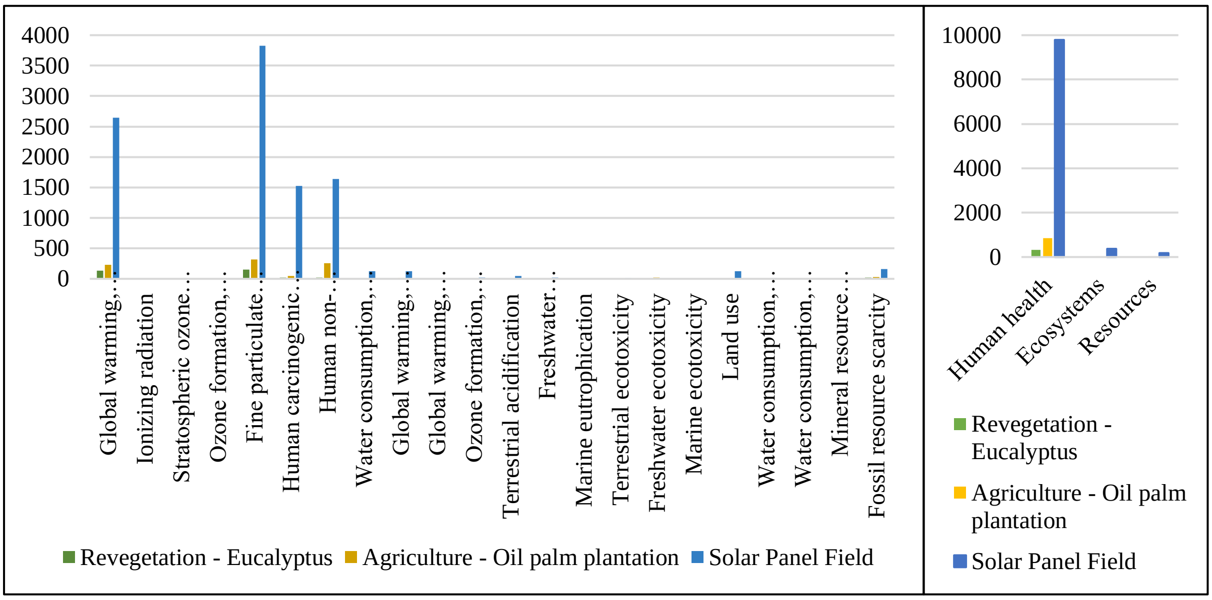
| Impact category | Unit | Revegetation | Agriculture | Solar Panel Field |
|---|---|---|---|---|
| Marine eutrophication | species.yr | 3.99E-08 | 5.58E-07 | 8.06E-06 |
| Terrestrial ecotoxicity | species.yr | 8.90E-04 | 2.82E-03 | 1.92E-02 |
| Freshwater ecotoxicity | species.yr | 3.79E-05 | 2.61E-02 | 7.78E-03 |
| Marine ecotoxicity | species.yr | 1.20E-05 | 1.68E-03 | 1.60E-03 |
| Land use | species.yr | 2.54E-03 | 3.32E-03 | 1.92E-01 |
| Water consumption, Terrestrial ecosystem | species.yr | 7.10E-05 | 7.58E-04 | 1.93E-02 |
| Water consumption, Aquatic ecosystems | species.yr | 7.66E-09 | 5.05E-08 | 1.29E-06 |
| Mineral resource scarcity | USD2013 | 1.34E+03 | 1.42E+04 | 1.97E+05 |
| Fossil resource scarcity | USD2013 | 5.03E+05 | 7.53E+05 | 4.53E+06 |

Source: Author Analysis, 2022



(a)

(b)

**Figure 7**. Comparison of Environment Impact for All Scenarios (a) per Impact Category, (b) per Damage Category

Source: Author Analysis, 2022

### *4.2. Cost and Benefit Analysis*

The assessed scenarios demonstrate very distinguished results in all cost-benefit analysis (CBA)'s indicators. In the case of revegetation, the mining company only receives a tax deduction once, at the start, for the amount equal to the total cost. As a result, the payback period is infinite and ROI or return on investment is infinite because the investment is thoroughly compensated. According to the analysis, the agricultural investment efficiency (oil-palm plantation) is around 156%, with net present value and benefit-cost ratios of around 160,507 and 1.02, respectively. Furthermore, the solar panel field scenario is estimated to yield nearly 4.5% ROI. Furthermore, the net present value is calculated to be USD 68,892,388 and the benefit-cost ratio is calculated to be 0.59. Furthermore, the agriculture (oil-palm plantation) and solar panel field scenarios will be able to pay back the investment 8 and 22 years after the scenario is initiated, respectively.

**Table 8.** Economic Analysis of All Assessed Scenario

| Indicator | Scenario | | |
|---|---|---|---|
| | Revegetation (eucalyptus cultivation) | Agriculture (oil-palm plantation) | Solar panel field |
| Return on investment/ ROI | 100.00% | 156.07% | 4.49% |
| Net present value/NPV | -5,987,269 | 160,507 | 68,892,388 |
| Benefit-cost ratio/BCR | 1.00 | 1.02 | 0.59 |
| Payback period/PP | - | 8 years | 22 years |
| Internal rate of return/IRR | 8.56% | 12.20% | 4.64% |

Source: Author Analysis, 2022

### *4.3. Environmental Impact*

The environmental assessment results in the land backfilling process as the major process that causes environmental damage, particularly for revegetation and agriculture scenarios. It generates at least 97% of the total environmental damage caused by the revegetation scenario. Aside from this, the process shares about 37% of the total environmental damage generated by the whole processes of the agriculture (oil palm plantation) scenario. Mostly, it emerges because of the vehicles and heavy machinery activities and expensed diesel fuel used for transporting the overburden to backfill the mined area's basin. For the solar panel field scenario, the greatest environmental damage is caused by solar panel field construction and electricity generation which emit roughly 96.6% of the total environmental impact. It becomes a prominent process since the construction process of a photovoltaic plant requires significant material, fuel, and labor to establish the plant.

Comparison of each scenario using the software obtains an expected result in identifying the environmental impact of all scenarios. The revegetation is found to generate the lowest environmental impact among assessed scenarios by contributing several damages, which are 323 points or equal to 7.8 DALY to human health, 13 points or equal to 0.02 species.yr to biodiversity, and 18 points or equal to 504,091 USD2013 to resources scarcity. Besides, the solar panel field scenario is defined as the greatest environmental impact by emitting 9,777 points or equal to 234 DALY to human health, 372 points or equal to 0.6 species.yr to biodiversity, and 168 points or equal to 4,729,707 USD2013 to resources scarcity. Though the solar panel field scenario contributes the highest impact, it emits fewer impacts, compared to the existing power plant generation process, which is a coal power plant. Aside from this, the agriculture scenario gives a slightly higher environmental impact than the revegetation scenario, by discharging certain damages, which are 854 points or equal to 20.5 DALY to human health, 43 points or equal to 0.06 species.yr to biodiversity, and 27 points or equal to 766,839 USD2013 to resources scarcity.

The application of the agriculture scenario in the coal-mined area contributes a main advantage in developing oil palm plantations. The common oil palm plantation begins its operation by clearing the forest area to prepare cultivation land. It is clear that this activity causes a significant loss of the ecosystem of the forest. Utilization of ex-mining areas as the oil palm cultivation land cut off this harm. However, agriculture (oil palm plantation) is considered to alleviate biodiversity loss as an effect of common oil palm plantations and diminish $CO_2$ emissions as it is a form of the cultivation process. Therefore, the usage of coal-mined land for oil palm plantations gains necessary merits for the environment.

### *4.4. Economic Cost and Benefit*

In the case of the revegetation scenario, tax deduction as a financial benefit for the mining company is only gained once at the beginning with the amount as much as the total cost. Therefore, the payback period is uncountable and the return on investment is 100% since the investment is fully compensated. Based on the analysis, the investment efficiency of the agriculture (oil palm plantation) is about 156% with the net present value and benefit-cost ratio around 160,507 and 1.02 respectively. Besides, the solar panel field scenario is assessed to result in nearly 4.5% of ROI. Moreover, the net present value is calculated as USD 68,892,388 and the benefit-cost ratio is examined as 0.59. In addition, the agriculture (oil palm plantation) and solar panel field scenarios will be able to pay back the investment for 8 years and 22 years respectively after the scenario initiation.

## 5. Conclusion

The result of the study indicates that the environmental impact of post-mining activities in the mined area in Tanjung Enim Mining Site could be assessed using Life Cycle Assessment (LCA) that is conducted through ReCiPe 2016 Endpoint (H) V1.06/World (2010) H assessment methods by SimaPro software. Besides, the cost-benefit analysis is also appropriate to be applied for computing the several economic indicators that denote the financial benefit and loss. Based on the designated methods and considered conditions, the following conclusions are generated. Backfilling process is the most significant process in revegetation and agriculture scenarios that generate the highest environmental impact among other processes. In the case of the solar panel field, the construction process of the photovoltaic plant is the most prominent one. The revegetation is found to generate the lowest environmental impact among assessed scenarios by contributing several damages, which are 323 points or equal to 7.8 DALY to human health, 14 points or equal to 0.02 species.yr to biodiversity, and 18 points or equal to 504,091 USD2013 to resources scarcity. An enormous environmental impact is emitted by the solar panel field scenario among other assessed scenarios. Aside from this, the agriculture scenario discharges a slightly higher environmental impact than the revegetation scenario. Though it is not the lowest one, the agriculture scenario is considered to alleviate biodiversity loss as an effect of common oil palm plantations and diminish $CO_2$ emissions as it is a form of the cultivation process. Though the revegetation scenario contributes small environmental damage, the gained benefit from this scenario is the lowest one. However, the revegetation forms a forest and acts as carbon storage to provide negative CO2 emissions. Aside from this, solar panel field scenario results in abundant environmental impacts. Nevertheless, the scenario considerably decreases the emission from the common power plant that is generated by coal.

## References

BNI. (2021). *Corporate Presentation 1Q2021*. 4.

Daryanto, W. M., & Samidi, S. (2018). Measuring the financial performance of enterprises under ministry of energy and mineral resources (EMR) an Indonesia experience. *International Journal of Engineering and Technology(UAE)*, *7*(3). https://doi.org/10.14419/ijet.v7i3.21.17086

Directorate of Agriculture India. (2007). *Cultivation of Oil Palm*. 6.

Golsteijn, L. (2019). Interpretation Of Metrics: DALYs And Damage To Human Health. *Pré*, 2–3.

Gunamantha, M., & Sarto. (2012). Life cycle assessment of municipal solid waste treatment to energy options: Case study of KARTAMANTUL region, Yogyakarta. *Renewable Energy*, *41*, 277–284. https://doi.org/10.1016/j.renene.2011.11.008

Hendryx, M., Islam, M. S., Dong, G. H., & Paul, G. (2020). Air pollution emissions 2008–2018 from Australian coal mining: Implications for public and occupational health. *International Journal of Environmental Research and Public Health*, *17*(5). https://doi.org/10.3390/ijerph17051570

Ivanova, S., Vesnina, A., Fotina, N., & Prosekov, A. (2022). An Overview of Carbon

Footprint of Coal Mining to Curtail Greenhouse Gas Emissions. In *Sustainability (Switzerland)* (Vol. 14, Issue 22). https://doi.org/10.3390/su142215135

Kamenopoulos, S., & Agioutantis, Z. (2021). The Importance of the Social License to Operate at the Investment and Operations Stage of Coal Mining Projects: Application using a Decision Support System. *Extractive Industries and Society*, *8*(2). https://doi.org/10.1016/j.exis.2020.05.019

Kobayashi, Y., Peters, G. M., Ashbolt, N. J., Shiels, S., & Khan, S. J. (2015). Assessing burden of disease as disability adjusted life years in life cycle assessment. *Science of the Total Environment*, *530–531*, 120–128. https://doi.org/10.1016/j.scitotenv.2015.05.017

Liu, X., Li, L., & Yang, Y. (2023). Development status of coal mining in China. *Journal of the Southern African Institute of Mining and Metallurgy*, *123*(1). https://doi.org/10.17159/2411-9717/1506/2023

Nasir, M., Bakker, L., & van Meijl, T. (2023). Environmental Management of Coal Mining Areas in Indonesia: The Complexity of Supervision. *Society and Natural Resources*, *36*(5). https://doi.org/10.1080/08941920.2023.2180818

Report, S. (2021). *Εκθεση Βιωσιμοτητασ 2021 Sustainability Report 2021*. 1–72.

Shi, F., Cao, H., Wang, C., & Yao, C. (2020). A system dynamics model for ecological environmental management in coal mining areas in China. *International Journal of Environmental Research and Public Health*, *17*(6). https://doi.org/10.3390/ijerph17062115

Siregar, K. (2015). Review of Life Cycle Assesment of Biodiesel in Indonesia. *Jurnal Rona Teknik Pertanian Unsyiah.*, *November 2014*.

Stobierski, T. (2019). How to do a Cost-Benefit Analysis & Why it's Important. *Havard Business Review*, 2.

USAID. (2010). *Solar power plant*. 1–7.

Vo, T. L., Nash, W., Del Galdo, M., Rezania, M., Crane, R., Mousavi Nezhad, M., & Ferrara, L. (2022). Coal mining wastes valorization as raw geomaterials in construction: A review with new perspectives. In *Journal of Cleaner Production* (Vol. 336). https://doi.org/10.1016/j.jclepro.2021.130213

Winarna, Darmosarkoro, W., Sutarta, E. . (2013). *Teknologi Pemupukan Kelapa Sawit. Prosiding Lahan dan Pemupukan Kelapa Sawit*.

Xiao, W., Chen, W., & Deng, X. (2021). Coupling and coordination of coal mining intensity and social-ecological resilience in China. *Ecological Indicators*, *131*. https://doi.org/10.1016/j.ecolind.2021.108167

Yang, L., Birhane, G. E., Zhu, J., & Geng, J. (2021). Mining Employees Safety and the Application of Information Technology in Coal Mining: Review. In *Frontiers in Public Health* (Vol. 9). https://doi.org/10.3389/fpubh.2021.709987