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Life Cycle Assessment a Coal Mining in East Kalimantan

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ABSTRAK

Sebuah penelitian Life Cycle Assessment yang bertujuan mengidentifikasi dampak lingkungan dari proses penambangan batu bara telah dilakukan. Cakupan proses meliputi land clearing hingga coal barging (cradle to gate). Unit fungsional yang digunakan adalah produksi 1 ton batubara. Data inventori dalam penelitian ini bersifat site specifik yang dikumpulkan dari sebuah perusahaan pertambangan yang berlokasi di Kalimantan Timur selama kurun waktu September 2022 hingga Juni 2023. Analisis dampak dikarakterisasi dengan memakai metode ReCiPe 2016 midpoint (H) dengan bantuan perangkat lunak OpenLCA v.2.0.2. Dari analisis dampak diperoleh bahwa operasi pertambangan batubara yang dikaji berpotensi menghasilkan Fine Particulate Matter Formation (0.122 kg PM2.5 eq), Global Warming (73.28 kg CO2 eq), Terrestrial Acidification (0.4114 kg SO2eq), Ozone formation-human health and Ozone formation-terrestrial ecosystems (0.54 kg NOx eq), Land Use (4.42×10-4 m2a crop eq), dan Water consumption (11.44 m3). Potensi Particulate Matter Formation dan potensi Global Warming umumnya terkait proses pemindahan material dan konsumsi air disebabkan oleh proses pengangkutan batubara. Dari penelitian ini ditemukan bahwa proses pengupasan tanah penutup merupakan hotspot lingkungan dari proses penambangan batu bara karena memberikan potensi dampak yang paling besar dari seluruh proses yang ada.

ABSTRACT

A Life Cycle Assessment study aimed at identifying the environmental impacts of a coal mining process has been carried out. The scope of the process includes land clearing to coal barging (cradle to gate). The functional unit used is the production of 1 ton of coal. The inventory data in this research is site specific, collected from a mining company located in East Kalimantan during the period September 2022 to June 2023. Impact analysis was characterized using the ReCiPe 2016 midpoint (H) method with the help of OpenLCA v.2.0.2 software. From the impact analysis, it was found that the coal mining operations studied have the potential to produce Fine Particulate Matter Formation (0.122 kg PM2.5eq), Global Warming (73.28 kg CO2eq), Terrestrial Acidification (0.4114 kg SO2eq), Ozone formation-human health and Ozone formation-terrestrial ecosystems (0.54 kg NOx eq), Land Use (4.42×10-4 m2a crop eq), and Water consumption (11.44 m3). The potential for Particulate Matter Formation and Global Warming is generally related to the process of moving materials and water consumption caused by the process of transporting coal. From this research, it was found that the overburden stripping process is an environmental hotspot for the coal mining process because it has the greatest potential impact of all existing processes.

1. INTRODUCTION

Despite Indonesia's National Energy Policy under Government Regulation No. 79/2014 that sets a target of increasing the share of new and renewable energy to 23% in the primary energy mix by 2025, the use of coal as a non-renewable energy resource remains dominant. In the press release of the Ministry of Energy and Mineral Resources of the Republic of Indonesia, numbered 026.Pers/04/SJI/2023, the government stated that the coal production target for this year is 695 million tons, with a projected domestic demand of 177 million tons and 518 million tons for export. In Indonesia, coal mining industry predominantly employs the open-pit mining system. The process of open-pit coal mining involves stages such as land clearing, soil removal, drilling and blasting, material removal, coal getting, coal hauling, coal crushing, coal barging until to transshipment the customers. Most of these processes rely on heavy equipment that consumes fuel as its energy source (Darpawanto et al., 2022; Yuniarto & Amalia, 2022). During material transportation using heavy equipment, the generation of dust on the road can impair visibility and pose risks to respiratory health (Dontala et al., 2015; Wang et al., 2019). In addition to dust-related concerns, several other significant environmental effects significantly impact the surroundings. These include deforestation, alteration to ecosystem, soil subsidence, various forms of pollution (water, soil, air, noise, thermal, and radioactive), blasting impacts, and spontaneous combustion. Also, local

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ecologies and communities within proximity to mining activities are often directly or indirectly affected (Asr et al., 2019; Monteiro et al., 2019). One approach to assess the environmental impacts from industrial activities is Life Cycle Assessment (LCA). LCA is defined as a compilation and evaluation of material and energy flows, as well as the potential environmental impact of a product's life cycle. The result of LCA guided decision making processes for developing alternative programs that support sustainability. The uses of LCA as a comprehensive methodology in environmental accounting in Indonesia have been gaining significant attention during the last decade (Valdivia et al., 2021; Wiloso et al., 2019). With regards to coal mining process, several LCA studies have been carried out. Most of these LCA studies have the goal in studying or evaluating the potential impact of the operation, identify and find improvement to reduce the environmental impact, and controlling the activity in order to increase company performance using cradle-to-gate scope with the functional unit of 1 ton of coal production (Burchart-Korol et al., 2016; Darpawanto et al., 2022; Firdausy et al., 2022; Roy et al., 2023; Tampubolon et al., 2021; Tao et al., 2022; Yuniarto & Amalia, 2022; L. Zhang et al., 2018). The result of the review study shows that the most impactful category is the Global Warming Potential (GWP) which mostly comes from the use of heavy equipment during its operation. Other impact categories are vary from acidification, fossil depletion, eutrophication, and human toxicity.

This study focuses on the operation of an open pit coal mining located in East Kalimantan (hereafter named as PT X). Being one of the mining companies in Indonesia, this company is urged to take action under the country's Green Growth Policy. One of the steps is by participating in the PROPER Program (Ahmad et al., 2019; Chaklader & Gulati, 2015). PROPER stands for *Program Penilaian Peringkat Kinerja Perusahaan dalam Pengelolaan Lingkungan Hidup* which literary means a program administered by the government for assessing and ranking companies on their environmental management. Following the updated PROPER regulations in 2021, LCA is one of its critical tools for assessment. As a part of the efforts to attain green ranking, they are required to conduct Life Cycle Assessments (Astuti, 2019; Handayani & Hanaseta, 2022). However, since the LCA method is relatively new approach to environmental management system in Indonesia, this study serves as a model for such assessment for the company in question. Hence, the objective of this study is to identify and quantify the environmental impacts of a coal mining process the Life Cycle Assessment methodology.

2. METHOD

This study is quantitative research following the standard guidelines of SNI ISO 14040:2016 about Life Cycle Analysis – Principal and Framework **Figure 1**. There are four main phases of LCA under this framework framework, starting from Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), to Interpretation. The data used in the Life Cycle Inventory Analysis was obtained directly from a coal mining company in East Kalimantan. The duration of this study spanned from September 2022 until June 2023. Data analysis for Life Cycle Impact Assessment was characterized using the ReCiPe 2016 midpoint (H) method with the help of OpenLCA v.2.0.2 software (Huijbregts et al., 2017; Kiemel et al., 2022).

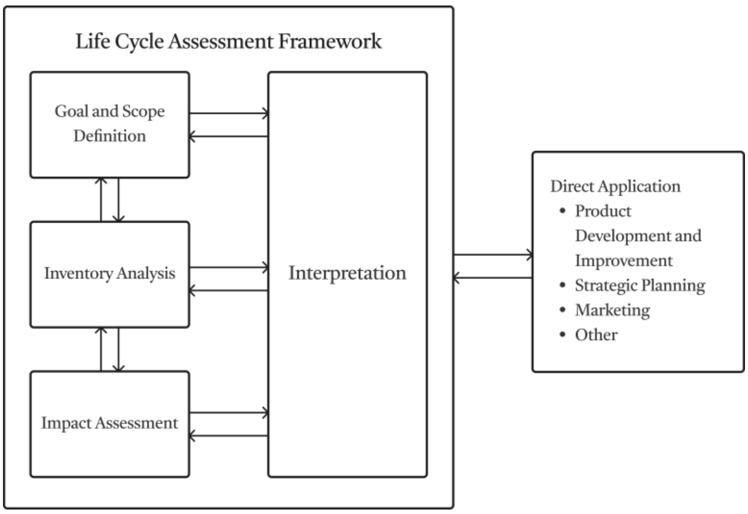

Figure 1. The Framework of LCA Based on SNI ISO 14040:2016

In determining the goal and scope of this study, a literature study and field observation were carried out. Literature study at this stage was to ensure that the research results are in accordance with the existing literature based on sources from books, scientific papers, and others as a reference and research support. Field observations were conducted in order to understand the business flow of the coal mining process to ensure the compatibility of the research theme to be carried out, supported with consultation and discussion with experts in the field. At this stage, it was possible to define the goal, scope, and functional unit used to define the reference unit of a product system. Inventory analysis describes the flow of matter and energy in coal mining activities. The data for this study was collected directly from the company's record consisting of inputs and outputs from raw materials, energy, and emissions produced by each process unit. In the input data, the required data are fuel, water, and chemicals. Then in the output data, there are products, waste, and emissions from all components of the production system. Which consists of required raw material, fuel used, coal production, waste production, land use, explosive material, data of overburden removed, company innovation, revegetation need, etc.

After the inventory analysis was completed, the Life Cycle Impact Assessment (LCIA) was carried out. This stage includes the activities of selecting the category of impact and characterization. It also can carry out normalization, grouping, and weighting if needed according to the goal and scope. LCIA process is done by connecting inventory data with impact categories specified on staged goal and scope determined before. The calculation for LCIA study in PT X will be done by using openLCA, this is a free and open-source software tool. This study uses thre database provided in OpenLCA and characterization factors from ReCiPe 2016 midpoint (H) with the aid of OpenLCA software v.2.0.2. This stage is the last stage in the LCA, the result analysis from impact assessment will help answer the problem identification of this study. At the Interpretation stage, the results of the LCI and LCAI are analyzed and discussed in order to identify and improve the process by givinf recommendations to reduce the environmental impact of the study. Things to be identified are the potential environmental impacts based on ReCiPe 2016 midpoint (H), the environmental hotspots, and a comparison of the potential environmental impacts from similar studies in other places.

3. RESULT AND DISCUSSION

Result

Goal and Scope Definition

The objective of this study is to identify the potential environmental impact and the hotspots of Coal Mining, PT X in East Kalimantan. Using LCA as the tool, a quantified result of the environmental impact will help provide a comprehensive understanding of the impact of used raw materials use, energy consumption, emission, and waste generated throughout its life cycle, which will be useful for the company and the public audience to design the improvements needed in the operation of coal production to reduce the impacts.The scope of this LCA study covers the land-clearing process until the end of the coal production process – coal barging. This scope is reffered to as cradle-to-gate. The functional unit used in this study is the production of 1 ton of coal. The data used during the inventory is site-specific data gathered from PT X during the year 2022.

Life Cycle Inventory

Through a field observation complemented with an interview with the management of PT X, the coal mining process of PT X can be modeled in a linked flow **Figure 2**. The coal mining process in PT X is an open-pit system. This system will open a large enough field and create a big hole, known as pit. In general, open-pit mining begin with land clearing. All vegetation in the upper layers including threes, shrubbery, grassland, and other materials on the surface need to be removed from the mined land. At this stage the process needs tools to support the land clearing process such as saws, bulldozers, and excavators, in addition to transporting workers to the site, there is also a light vehicle (LV). Most of the heavy equipment in coal mining needs fuel as an energy resource to operate. Once all the vegetation in mined land has been cleared, the next layer to remove is top soil. Soil is a precious non-renewable resource that contains high nutrient content. Later the soil will be reused for revegetation as a form of accountability of the mining company. Before the backfilling process, the soil will be stored in chosen area or pit before backfilling named Bank Soil. After soil, there is overburden material (OB Rock). To dredge OB rock there are two option depending on the hardness and thickness of OB rock. The blasting material is placed in the borehole. Blasting normally be held during daylight hours or rest hours to ensure the worker's safety. After blasting, the OB rock will be excavated by an excavator and then transported by a dump truck (HD truck) to the disposal place, later it will used again for backfilling.

Coal getting is the main process of coal mining, this process is to dig the coal that has been exposed after the removal of topsoil and OB rock. The exposed coal seams emit fugitive emissions such as Methane (CH_4) and Carbon dioxide (CO_2). These emissions come from the geological process, Methane (CH_4) and Carbon Dioxide (CO_2) remain trapped in coal seams until it is exposed. Coal getting is operated using a combination of excavators and dump trucks. Before the coal is mined, the excavator does not directly excavate the coal bed, but there will be coal cleaning. This process is to clean the coal from the remains of contaminating material. The contaminating material consists of soil and OB rock residues, then other material in the form of material agents (surface water, rainwater, and slurry) will be cleaned using a water pump and transferred to a temporary pond, and then discharged to the wastewater treatment plant. After raw coal is loaded into dump truck, it will be hauled to the ROM stockpile or Coal Processing Plant (CPP). Coal hauling is the transportation of raw coal using dump truck to the CPP. In the CPP, double-trailer dump truck will dump the raw coal to the crusher. Coal crushing is the process of breaking coal from a large size into smaller size. The crusher will crush the raw coal into the requested size, the coal is also sprayed with water to reduce the dust content in the coal. Then the crushed coal is transferred with a barge loading conveyor (BLC) to the barge. Then in coal barging, the coal in the barge will be carried with one or two tugboats. Up to this, all of the activity need fuel to operate the heavy equipment. Other than that, there are also utility activity that consist of Soil and Overburden Material Storaging, Backfilling and Revegetation, Wastewater Treatment Plants, and Utility Provide Activity.

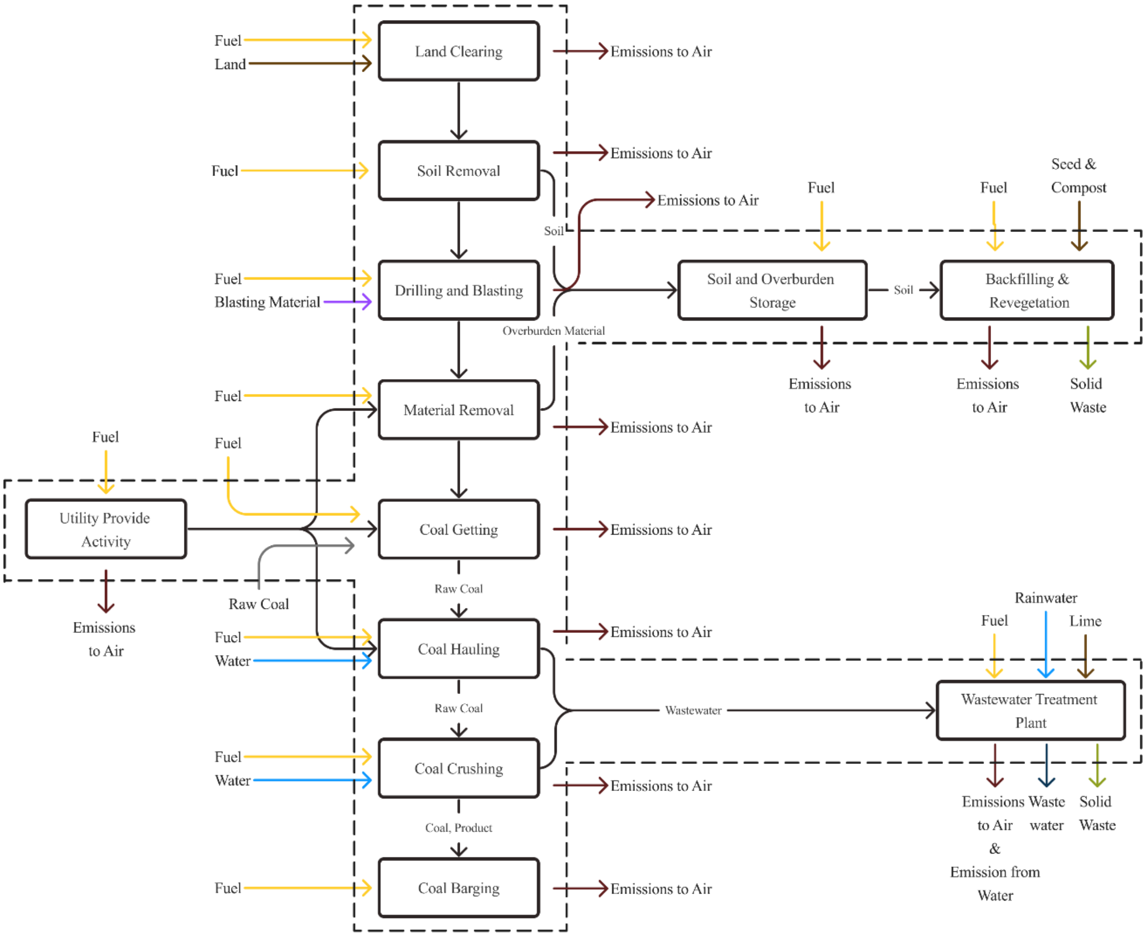

Figure 2. Product Flow System Diagram with Input and Output Flows

The Input flows of this study consist of energy consumption, substances from the earth, and water consumption. Energy consumption in mining operations is the largest contributor to each unit process. In PT X East Kalimantan, the energy sourceuses Biodiesel (B30) fuel in accordance with regulation from Ministry of Energy and Mineral Resource number 12 year 2015. The principle of Biodiesel is a mix of diesel fuel and biodiesel in optional ratio. For example, B30 fuel is a mix of 70% diesel fuel and 30% Biodiesel (Özener et al., 2014; Y. Zhang et al., 2021). Most of the consumption of fuel was used for heavy equipment such as excavator, dump truck, dozer, ripper, etc. To calculate the energy consumption, the average volume of the B30 consumption was converted into an energy unit following the Guideline of

Conducting Greenhouse Emission Inventory by the Ministry of The Environment. Output flows consist of coal product, solid waste, emissions to air, emissions from water, and wastewater volume. The air emissions in this study were derived from fuel consumption. The emissions from fuel combustion are consist of Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Nitrogen oxides (NO), and Sulfur dioxide (SO_2). These emissions are determined based on the numerous emissions analyzed in the literature review and are consider the most impactful direct emissions from fuel combustion. To obtain the quantified result of emissions emitted from the energy consumptions, the data need to be calculated by the conversion value. The calculation is based on the emission factor multiplied by the fuel consumption of each unit process. Emission factors for biodiesel fuel conversion are using emission factors from scientific paper and data on Heavy Duty Vehicle Table 1.

Table 1. Emission Factors of Fuel

Substance	B30 (ton/kiloliter)	Biodiesel (B100)	Diesel	Unit
CO2	1.49178	1.17573	0.074	Kg/MJ
NO	0.00904	0.00841	0.001	Kg/MJ
CH4			0.000006	Kg/MJ
N2O			0.000003	Kg/MJ
SO2	0.0113			

Source: (Wijono, 2017; IPCC, 2006)

For fugitive emissions, the calculation is based on the Intergovernmental Panel on Climate Change (IPCC) guidelines for fugitive emissions in surface coal mining. Since there are no specific emissions factors available in Indonesia, this calculation will use the Tier 1 method, which concludes emissions from the mining process and post-mining (may be released during handling, transportation, and handling). The Tier emissions are taken from the IPCC for Fugitive Emissions**,** this allows the calculation using readily available data and standardizde factors. The guideline recommended, that if there wasn't specific evidence for the low/high depth overburden, it is recommended to use the average emissions. The overall results of the Life Cycle Inventory collected of input and output data for 1 ton of coal production can be seen in **Figure 3**. This inventory data will be processed further on the Life Cycle Impact Assessment (LCIA) to be characterized into their corresponding potential impacts.

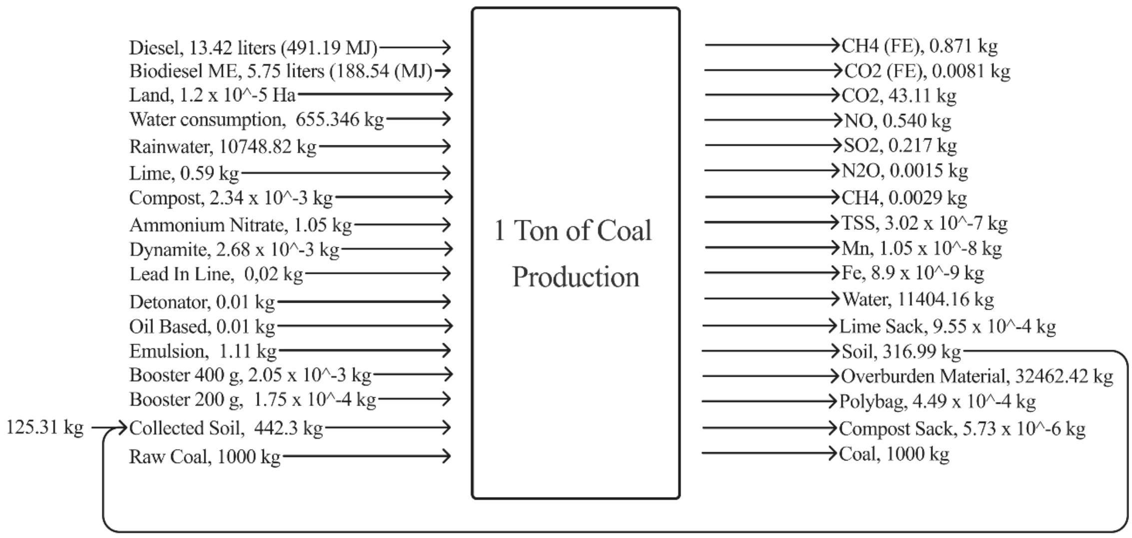

Figure 3. Mass Balance of Coal Mining Operation

Life Cycle Impact Assessment (LCIA)

In Life Cycle Impact Assessment the first stage is classification, the purpose is to classify all material, energy, and emissions that have been identified in inventory based on environmental impact categories. As it has been described in Section 2: Method, impact categories in this study are based on ReCiPe 2016 midpoint (H). According to ReCiPe 2016 midpoint (H), the inventory data covers impact categories that consist of Fine Particulate Matter Formulation, Global Warming, Land Use, Ozone formation-human Health, Ozone Formation-Terrestrial ecosystems, Stratospheric Ozone Depletion, Terrestrial Acidification, and Water Consumption. The connection between inventory data and impact categories is shown in Figure 4. With the help of OpenLCA v.2.0.2 software, the characterization result of the impact assessment was obtained as presented in Table 2.

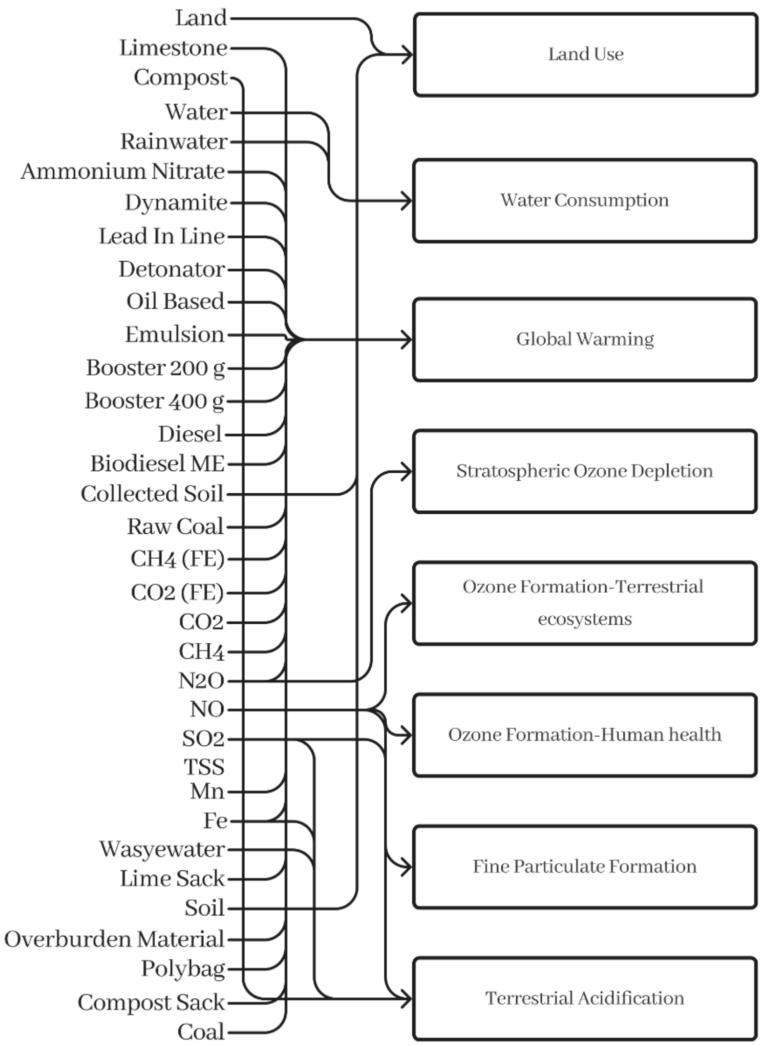

Figure 4. Classification of Impact Categories with Inventory data

Table 2. Impact Assessment of 1 Ton of Coal Production Based on ReCiPe 2016 Midpoint (H)

No	Impact Categories	Measure	Unit
1	Fine particulate matter formation	0.12233	kg PM2.5 eq
2	Global warming	73.28	kg CO2 eq
3	Land use	0.0004416	m2a crop eq
4	Ozone formation, Human health	0.54	kg NOx eq
5	Ozone formation, Terrestrial ecosystems	0.54	kg NOx eq
6	Stratospheric ozone depletion	0.0000165	kg CFC11 eq
7	Terrestrial acidification	0.4114	kg SO2 eq
8	Water consumption	11.437	m3

Discussion

The Global Warming Potential (GWP) in this study accounts for 73.28 kg CO_2eq per ton of coal, which consists of Carbon dioxide (57%), Methane (42%), and Dinitrogen oxide (0.56%). This GWP mostly comes from excavation to remove soil, overburden, and collect coal particularly during the material removal process. Compared to other studies, the GWP value in this research is considered average, if compared to other coal mining studies around the world but considering the scope of study is in Indonesia, the GWP value is quite high. The GWP value closest to this study in Indonesia is referred to, where the GWP is reported at 49.9 kg CO_2 eq (Darpawanto et al., 2022; Yuniarto & Amalia, 2022). The result of the review study shows that the most impactful category is Global Warming Potential (GWP), with the hotspot activity identified in material removal. The significant impact on material removal is attributed to fuel consumption, resulting CO_2 emissions emitted around 102.807.44 Ton CO2 eq. Another study, that has the closest value is found in from China studying Opencast Coal Mining, with GWP value around 73.3 kg, primarily CO_2 eq, resulting from mining stage (Tao et al., 2022; L. Zhang et al., 2018). The Terrestrial Acidification Potential (TAP) in this study accounts for 0.4114 kg SO_2eq per ton of coal. This potential mainly comes from atmospheric deposition of inorganic substances that cause acidity from emissions such as nitrogen oxide (NO), sulfur dioxide (SO_2) and ammonia (NH_3). The result it is shows the fraction of total impact from terrestrial acidification is mainly from Nitrogen Oxide (47%) and Sulfur Dioxide (53%). Compared to another study, this TAP is considered heavier than other study. For 1 ton of coal production in another study only produced between 0.036–0.377 kg SO_2eq.

High ozone concentration leads to Ozone formation related to human health potential and Ozone formation related to terrestrial ecosystems. These potentials account for Nitrogen Oxide (NO) and mostly come from material removal because of fuel combustions. Another important environmental impact potential is Land Use which represents a specific loss on land transformation due to this activity. The coal mining of 1 ton of coal requires an equivalent annual crop land area of 4.42×10^{-4} m^2. Last, water consumption discusses the use of water whether it being dispose, evaporated, incorporate to product, and transferred. The water consumption influence around 11.73 m^3. According to impacts analysis, it is obvious the major potential of environmental impact of coal mining are global warming. Global warming occurs because of the emissions released from fuel combustion. In inventory, the largest input data is from energy input, which indirectly affects the emissions. The Point of view from the process is shown the use of heavy equipment requires a large quantity of fuel. In this study, PT X East Kalimantan used Biodiesel-30 as a source of fuel, to find out the heating value of fuel consumption this study used several references to get precise data on energy consumption. According to the report it displays the largest emission contribute in the inventory. Carbon dioxide take account around 98%, the rest emissions sequentially are NO, SO_2, CH_4 , and N_2O. The entire process of Coal mining always used fuel as the source of energy. In the process there are several heavy equipment required to support the operation, most likely the hydraulic trucks and excavators are the biggest contributors, with a total of around 300 units. To excavate the OB ruck and coal there are a few factors that influence it, these factors can affect fuel consumption in terms of thickness, slope, distribution, shape, and condition (Hibatulloh et al., 2022; Sasmito & Rindawati, 2021). Besides that, the distance between the excavated area and the disposal area affects the fuel consumption. Not only that methane emissions from coal seams take account around 42% of global warming potential.

Therefore, improvement opportunities for this issue need to be considered. From the founding it is essential to reduce the level of CO_2 in the air, this emission came from fuel combustion therefore it is important to find improvement in this area. Based on previous research, the use of fuel consumption depend on heavy equipments productivity, to optimize and reduce fuel consumption, heavy equipment needs to assessed regulary and increase the productivity of each equipments (Himawan et al., 2020; Ramadhani et al., 2022). Reducing the distance in coal mining are also could suppress the fuel consumption. According to previous research one of the alternative ways are to utilize alternative fuel by increasing biodiesel consumption until biodiesel-100, the biodiesel option such as Fatty acid methyl ester (FAME), Dimethyl Ether (DME), Hydrotreated Vegetable Oil (HVO), Biogas, or other liquid natural gas (Breuer et al., 2021; Syarifudin & Syaiful, 2019). Using these alternative fuels can fully reduce CO_2 and SO_2 emissions, even though only apply partially to other harmful emissions. There are also clean technologies that can be applied in coal mining which is switching articulated trucks to fuel cell-electric trucks that could reduce CO_2 emissions by 13.55 % and NO_x by 29%. Other than that implement clean technology in coal mining such as dust suppression and mobile methane flare to reduce methane emissions (Laing et al., 2019; Lederwasch & Mukheibir, 2013). Further research on the implementation of clean technology in the field needs to be conducted to assess it more thoroughly and identify best practices for cleaner technology. Support in funding or investment, as well as government support, is also important. Moreover, research on clean technology in coal mining needs further development. Currently, there are limited findings on clean technology in scientific papers, with most of them being general reviews of clean technologies.

4. CONCLUSION

From the study, the results showed that the potential impacts of coal production from cradle to gate include Fine Particulate Matter Formation, Global Warming, Terrestrial Acidification, Ozone formation-human health and Ozone formation-terrestrial ecosystems, Land Use, and Water consumption. This form of energy supply causes harmful impacts on the environment, In order to reduce the environmental impact, coal mining need to optimize heavy equipment productivity, regularly assess and improve equipment, and reduce distance.n Other than that, alternative transitions to clean energy and decarbonization are increasing biodiesel rate, fuel cell-electric trucks implementation, dust suppression, etc. Government involvement in regulation and funding research in the development and implementation of clean technologies in coal mining.

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