CHEMICAL ENGINEERING TRANSACTIONS

VOL. 106, 2023

A publication of AIDIC
The Italian Association
of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Peck Loo Kiew, Hon Huin Chin

**ISBN** 979-12-81206-05-2; **ISSN** 2283-9216

DOI: 10.3303/CET23106049

# Environmental Performance of Three Coal Ash Management Strategies in a Copper Mine Site Using Endpoint Impact Category

Joni S. Adiansyah*

Postgraduate School of Environmental Science, Universitas Muhammadiyah Mataram, Indonesia
Mine Engineering Department, Universitas Muhammadiyah Mataram, Indonesia
joni.adiansyah@ummat.ac.id

The copper mine sites in Indonesia usually manage their power plant to fulfill energy demands. Two main types of power plants that operate in mine sites are coal-fired power plant and diesel power plant. The operation of these two power plants would generate the wastes that potentially pollute the environment. This study focuses on coal-fired power plant operations that produce two common types of waste: fly ash and bottom ash. A 160 MW coal-fired power plant operated by a mine site was taken as a case study. The fly ash and bottom ash (FABA) are managed using three strategies, namely landfilling, shipment to the third-party, and internal utilisation. This study aims to assess the endpoint damage category of each strategy applied. A life cycle assessment (LCA) approach was used to compare those strategies using SimaPro software. The ReCiPe (Hierarchical) endpoint damage category method that consists of three elements, namely human health, ecosystems, and resources, was applied. The functional unit (FU) was one ton of FABA managed by a mining company using three different strategies. The result showed that the lowest endpoint impact was the FABA utilisation management strategy with the following values: human health ($8.59 \times 10^{-6}$ DALY), ecosystems ($2.05 \times 10^{-8}$ species.yr), resources (0.888 USD2013), and the highest endpoint impact was generated by FABA shipment to third party strategy due to fuel diesel consumed, hauling material distance, and landfill disposal management. The environmental hotspot is mainly generated by diesel fuel consumption of vehicles and vessels that are being operated by those three strategies. Fuel efficiency, hauling and transporting route options, and road alignment design should be considered to improve the environmental performance of those three FABA management strategies.

## 1. Introduction

The mining industry is one of the industries that have a significant contribution to Indonesian local and national revenue. The total revenue from the mining sector in 2021 was approximately 28.01 trillion (Meilanova, 2021), with a total of employees hired about 95,666 people (BPS, 2022). Based on the Indonesian Statistical Bureau (BPS, 2022), the total mining productions (minerals) for five mineral commodities were as follows copper concentrate (3.4 Mt), gold (78.9 t), coal (614 Mt), tin (52.5 t), and nickel ore (65.5 Mt).

Indonesia is listed as the biggest ten coal producer worldwide, where coal contributes to 44 % of total electricity generation through coal-fired power plants (WorldAtlas, 2023). The coal-fired coal plant capacity is recorded at about 36.96 GW or 52 % of the total electricity capacity in Indonesia, and the coal-fired power plant operates in some mining industries, including Weda Bay industrial park, Konawe industrial park, and Nanshan industrial area (Fajrian, 2022).

The availability of coal as an energy source has created dual impacts on Indonesia associated with economic and environmental impacts. The electrification rate reached 99 % (ESDM, 2021) is one of the supporting variables for Indonesian economic growth. The operation of coal-fired power plant generates waste in the form of fly ash and bottom ash. The conventional method commonly applied by mine sites to manage the fly ash and bottom ash (FABA) is using a landfilling method by dumping FABA into a landfill equipped with a liner and wastewater treatment facility. The other management strategies for FABA are transporting to the licensed third-

Paper Received: 15 June 2023; Revised: 8 September 2023; Accepted: 19 September 2023
Please cite this article as: Adiansyah J.S., 2023, Environmental Performance of Three Coal Ash Management Strategies in a Copper Mine Site Using Endpoint Impact Category, Chemical Engineering Transactions, 106, 289-294 DOI:10.3303/CET23106049

party with a waste management facility and internal utilisation for supporting mining activity (Adiansyah, 2022). Some studies on FABA utilisation were found including FABA for reclaiming abandoned mining (Dube, 2020), FABA for clay mine rehabilitation (Suloshini et al., 2020), FABA for cement substitution (Rutkowska et al., 2021), FABA for brick mixing material (Yousuf et al., 2020), and FABA for soil amendment (Ukwattage et al., 2013). None of those studies analyse the environmental performance of FABA utilisation using life cycle assessment point of view. The environmental impact assessment using life cycle assessment allow for the mine site to identify the environmental hotspot of the FABA management strategy applied. This study aims to estimate the environmental performance of three possible FABA management options in the following aspects: human health, ecosystem, and resources. The innovation strategy for improvement would also be presented.

## 2. Methods

The life cycle assessment (LCA) is divided into four steps (ISO, 2006). The first step is to determine the goal and scope and followed by data collection (life cycle inventory). Data gathered, both primary and secondary, will be further accessed in the life cycle impact assessment stage, and the last step is result interpretation. The following section is detailing the four steps of the LCA study.

### 2.1 Goal and Scope

As an energy supply for mine operations, a copper mine site operates a 160 MW coal-fired power station. Total fly ash and bottom ash (FABA) generated by coal-fired power plant are around 10,000 t/y with three FABA management options used, including landfill disposal, shipping to third parties, and internal utilisation. In this study, the internal utilisation is focused on the mining road-base. This study is aimed to assess the environmental performance of FABA management strategies in three damaging indicators: human health, ecosystem, and resources. The functional unit was 1 t of FABA managed by a copper mine site using landfilling scenario, shipment to third party scenario, and internal utilisation scenario. The cradle-to-grave system boundary was applied. Some assumptions have been developed for the application of LCA in this study as follows 1) The total distance for shipping the FABA to the nearest port of the third-party treatment facility is assumed to be 613 km using google maps, 2) Transportation vessel of FABA to third party uses a barge and adopted from Ecoinvent database – Transport, barge, diesel-powered/US, 3) Ecoinvent database with tkm (ton kilometer) unit was applied for truck hauling that transporting FABA from coal-fired power plant to some dedicated locations, 4) Electricity uses a dataset from Ecoinvent that represents the production of high-voltage electricity in an average lignite power plant. The Lignite is used as a representant for brown coal, which includes sub-bituminous coal and lignite according to the definition of the IEA electricity information 2014 (IEA, 2014).

### 2.2 Life cycle inventory

The data inventory is the second step to collect and quantify the output and input data associated with the defined system boundary. Data inventory is the critical part of LCA study because it will affect the impact assessment results. In an LCA study, data inventory stage is usually presenting the data associated with both foreground and background processes, including materials and energy to/from the system as well as the transportation of materials and energy required by site operations. These types of data could be obtained from a database, i.e., Ecoinvent and actual activities for the coal ash management scenario, as discussed in the following subsection.

### 2.2.1 Coal ash (FABA) landfilling

Coal-fired power plant operation generates two primary wastes (fly ash and bottom ash) due to coal combustion activity. Fly ash is collected in the bag house filter and vacuumed by a vacuum blower into the fly ash silo, while bottom ash that falls into the bottom of the boiler will be collected using the bottom ash submerged chain conveyor. A dump truck (DT) will regularly transport FABA generated into a coal ash landfill facility about 1 km away from a coal-fired power plant. A dozer is being operated in the coal ash landfill facility to maintain the grade of the coal ash stockpile and its supporting facilities, including drainage and access road. The coal ash landfill is also equipped by wastewater treatment plant (WWTP) to process the leached water generated by the coal ash landfill. A detail of the boundary system is presented in Figure 1.

### 2.2.2 Coal ash (FABA) shipment to the third party

An 8,000 t of FABA was regularly transported to the third-party receiving port that 163 km away from the mine site. A dump truck with 5 t capacity and a loader were two equipment that operated for loading and hauling FABA from the landfill to the coal barge vessel. During the unloading process in the coal barge vessel, two heavy equipment, dozer and excavator, were being operated to adjust the FABA stockpile slope to avoid FABA spillage into the sea during the journey to the third-party receiving port. A water sprinkler for dust suppression purposes was also installed and operated during the unloading process in the coal barge vessel. Business process boundary of FABA shipment to the third-party, include the FABA treatment is presented in Figure 2.

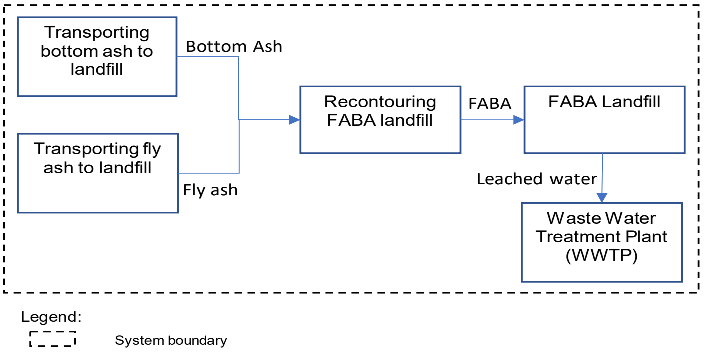


*Figure 1: Flow diagram and system boundary of FABA landfilling management strategy*

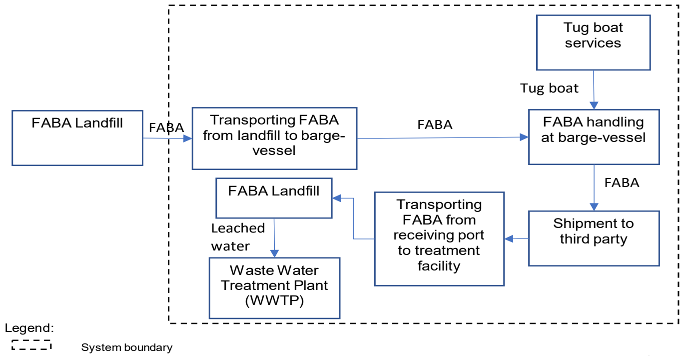


*Figure 2: Flow diagram and system boundary of FABA shipment to the third-party management strategy*

### 2.2.3 Coal ash (FABA) utilisation

Coal ash has an alkali characteristic with a pH ranging from 8-9 as mildly alkaline to 11-13 as strongly alkaline (bhatt el al., 2019). Some following studies were found on how to utilise coal ash, as presented in the introduction section. One possible opportunity is mixing the coal ash with mine acid soil and using it as mine course-based road layer. This utilisation creates benefit for mine operations associated with reducing the volume of acid soil and coal ash managed on-site. A dump truck with 20 t capacity and loader were two equipment that operated for loading and hauling of FABA from the landfill to the mine area where the FABA road-base project was being conducted. There were three main treatments that should be applied for FABA as follows: 1). Mixing FABA and acidic soil with 1:1 composition mix where an excavator and loader were required in this process stage, 2). Spreading the mixed material as a road-based layer where the dozer and road grader would be operated during this process stage, 3). Compacting the road-based layer with 8 t vibrator compacter as presented in Figure 3.

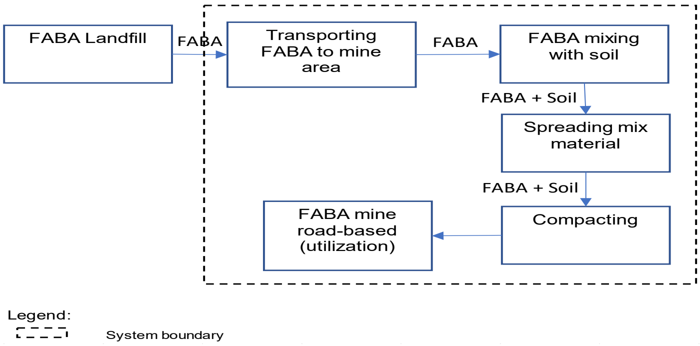


*Figure 3: Flow diagram and system boundary of FABA utilisation management strategy*

The material input and output of those three FABA management strategies are presented in Table 1 where diesel consumption for operating the equipment was identified as the primary material required by all FABA management strategies.

*Table 1: Data inventory for FABA management scenario*

| Business Process | Unit | Input | Output | Remark |
|---|---|---|---|---|
| FABA landfilling | | | | |
| Transporting bottom ash to landfill | tkm | - | 1,600 | hauling by truck |
| Recontouring landfill | kg | 3,188 | - | diesel fuel |
| | $m^3$ | 3.50 | - | water for dust suppression |
| Transporting fly ash to landfill | tkm | - | 6,400 | hauling by truck |
| Recontouring landfill | kg | 3,188 | - | diesel fuel |
| | $m^3$ | 3.50 | - | water for dust suppression |
| Wastewater treatment plant | kg | 1,472 | - | sulfuric acid – $H_2SO_4$ |
| | kWh | 200 | - | electricity |
| FABA shipment to the third-party | | | | |
| Transporting FABA to barge | tkm | - | 6,400 | hauling by truck |
| | kg | 446 | - | diesel fuel |
| FABA handling | kg | 1,870 | - | diesel fuel |
| | $m^3$ | 2.00 | - | water for dust suppression |
| Tug boat services | kg | 1,275 | - | diesel fuel |
| Shipment to the third-party | tkm | - | 4,904,000 | barge vessel |
| FABA unloading at the receiving port | kg | 1,870 | | Diesel fuel |
| Transporting FABA from receiving port to the treatment facility | tkm | - | 5,680,000 | hauling by truck |
| Wastewater treatment plant | kg | 1,472 | - | sulfuric acid – $H_2SO_4$ |
| | kWh | 200 | - | electricity |
| FABA utilisation | | | | |
| Transporting FABA to the mine area | tkm | - | 176,000 | hauling by truck |
| | kg | 446 | - | diesel fuel |
| Mixing FABA with soil | kg | 3,324 | | diesel fuel |
| Spreading mixed material | kg | 2,435 | | diesel fuel |
| Compacting | kg | 238 | | diesel fuel |

## 3. Results and Discussion

This section presents the last two stages of life cycle assessment: life cycle impact assessment and interpretation.

### 3.1 Life cycle impact assessment

Three damage categories are generated from a life cycle impact assessment that applies a ReCiPe method. Those damage categories are human health, ecosystem, and resources. Human health damage category uses Disability-Adjusted Life Years (DALY) as a metric to measure the gap between ideal situation and standard life expectations (Golsteijn, 2018). Ecosystem damage category applies species.yr as a metric to estimate species loss during a year (Manzo et al., 2018). Resources damage category uses USD2013 as a metric to represent the cost required for mineral and fossil resources in the future (Huijbregts et al., 2016).

As shown in Table 2, the FABA shipment to the third-party scenario generates the highest damage impact compared to the other two waste management strategies and FABA utilisation strategy contributes a lower impact on damage categories (human health, ecosystem, and resources).

*Table 2: Environmental impact comparison of FABA management scenario*

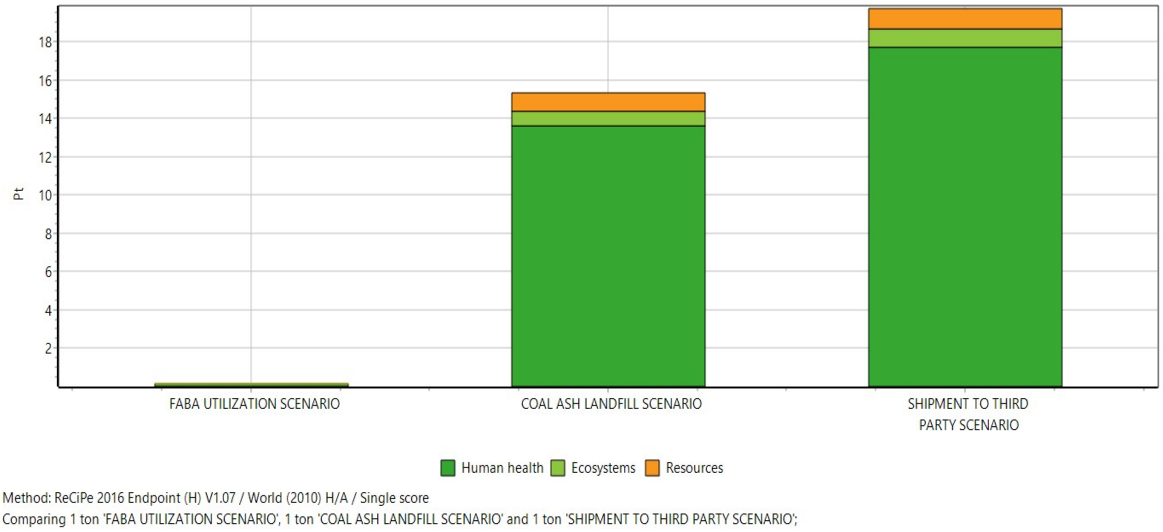
| Damage category | Unit | FABA landfilling | FABA shipment | FABA utilisation |
|---|---|---|---|---|
| Human health | DALY | 0.000814 | 0.00106 | $8.59 \times 10^{-6}$ |
| Ecosystem | Species.yr | $2.96 \times 10^{-6}$ | $3.56 \times 10^{-6}$ | $2.05 \times 10^{-8}$ |
| Resources | USD2013 | 129 | 147 | 0.888 |

A challenge to identify which category has the greatest impact on FABA Management Strategy was created by a comparison of units between these categories of damage. In order to obtain the total environmental damage under the ReCiPe method, as set out in Table 3, the categories of damages shall be weighted.

*Table 3: Weighted environmental impact of FABA management scenario*

| Damage category | Unit | FABA landfilling | FABA shipment | FABA utilisation |
|---|---|---|---|---|
| Human health | Pt | 13.60 | 17.70 | 0.143 |
| Ecosystem | Pt | 0.801 | 0.962 | 0.0055 |
| Resources | Pt | 0.920 | 1.05 | 0.0063 |

As shown in Figure 4, the total impact of FABA shipment to the third-part scenario produces 19.7 Pt at the endpoint level and is recorded as the highest damage scenario. The FABA landfilling scenario is the second environmental impact contributor, with 15.30 Pt damage at the endpoint level. The lowest impact generation is coming from the FABA utilisation scenario with 0.155 Pt damage at the endpoint level. The further treatment that is conducted in the third-party facility is assumed to be as landfilling system, and the comparison impacts of those three scenarios as presented in Figure 4.



Method: ReCiPe 2016 Endpoint (H) V1.07 / World (2010) H/A / Single score
Comparing 1 ton 'FABA UTILIZATION SCENARIO', 1 ton 'COAL ASH LANDFILL SCENARIO' and 1 ton 'SHIPMENT TO THIRD PARTY SCENARIO';

*Figure 4: Total impact categories of FABA management scenario at the endpoint level*

The environmental hotspots of those three FABA management strategies are presented in Table 4. Most of the environmental hotspots are coming from loading, hauling, transporting activity, and landfill management. These activities consume diesel fuel and emit some gases into the environmental air ambient. The FABA landfilling strategy environmental hotspot is generated by residual material that is landfilled and contributes about 99 % of the total environmental impact generated.

*Table 4: Process contributor analysis of FABA management scenario*

| Damage category/ process contributor | FABA landfilling | FABA shipment | FABA utilisation |
|---|---|---|---|
| Human health | Residual material landfill (99.6 %), diesel at market (0.14 %) | Residual material landfill (76.4 %), transport freight (23.2 %) | Transport freight (88.8 %), diesel at market (11.2 %) |
| Ecosystem | Residual material landfill (99.8 %), diesel at market (0.09 %) | Residual material landfill (83.1 %), transport freight (16.6 %) | Transport freight (89.2 %), diesel at market (10.8 %) |
| Resources | Residual material landfill (99 %), diesel at market (0.32 %) | Residual material landfill (87.1 %), transport freight (12 %) | Transport freight (61.5 %), diesel at market (38.5 %), |

### 3.2 Limitation

The study has many limitations associated with a local database library and publicly available data for treatment processes in the third-party. Utilisation of the ecoinvent database is one of the strategies to develop this study. This limitation may create less reliability and accuracy results of the impact assessment. This study excludes the credits of ash utilisation from the displaced materials that otherwise would have been used.

## 4. Conclusions

The mining industry is one of the industries that use coal-fired power plant as the main electricity generator. Currently, the coal-fired power plant dominates the total electricity capacity in Indonesia by approximately 52 % of the total electricity generated. The coal combustion in the coal-fired power plant generates two types of waste: fly ash and bottom ash (called FABA), which require further management to avoid environmental pollution. Three common FABA management strategies are landfilling, shipping to third-party for further treatment, and internal utilisation. Based on the endpoint damage category analysis, the lowest environmental impact associated with human health, ecosystem, and resources to manage 1 t of FABA was FABA's internal utilisation strategy (mine road based-course project) and followed by FABA landfilling strategy and shipping the FABA into third-party outside the mine site. Two main environmental hotspots are generated: diesel fuel consumption of vehicles and vessels that are being operated, and management of landfill used for FABA disposal. Fuel efficiency, hauling and transporting route options, and road alignment design should be considered to improve the environmental performance of those three FABA management strategies.

### References

Adiansyah, J.S., 2022, Carbon Emission Reduction using Waste Management Strategy Approach for Improving a Mine Site Environmental Performance, Chemical Engineering Transactions, 97, 157–162.

BPS, 2022, Mining Statistics of Non-Petroleum and Natural Gas 2017-2021, Jakarta, Indonesia.

Dube, S.K., 2020, Strategic Plan for Ash Disposal in Abandoned Mines filled with Acid Mine Drainage, International Journal of Scientific and Research Publications, 10, 709-717.

ESDM, 2021, Capaian Kinerja Ketenagalistrikan 2020, Rasio Elektrifikasi Capai 99,20 %, Ministry of Energy and Mineral Resources <www.esdm.go.id/id/media-center/arsip-berita/capaian-kinerja-ketenagalistikan-2020-rasio-elektrifikasi-capai-9920> accessed 6.8.2023.

Fajrian, H., 2022, Kapasitas PLTU Batubara Global Turun 13 % pada 2021, RI malah Naik 9 %, Katadata <www.katadata.co.id/happyfajrian/berita/> accessed 6.8.2023.

Golsteijn, L., 2018, Interpretation of Metrics: DALYs and damage to human health <www.pre-sustainability.com/articles/metics-interpretation-daly-and-damage-to-human-health/> accessed 6.8.2023.

Huijbregts, M.A.., Steinman, Z.J.., Elshout, P.M.., Stam, G., Verones, F., Vieira, M.D.., Hollander, A., Zijp, M., Zelm, R., 2016, ReCiPe 2016 A Harmonized Life Cycle Impact Assessment Method at Midpoint and Endpoint Level. Leiden.

IEA, 2014, Electricity Information 2014. International Energy Agency (IEA), Paris, France.

ISO, 2006, Environmental Management - Life Cycle Assessment - Principles and Framework ISO 14040, Geneva, Switzerland.

Manzo, S., Dong, Y., Miraglia, S., Salling, K.B., 2018, How the inclusion of Life Cycle Impacts affects transport cost-benefit analysis. European Journal of Transport and Infrastructure Research. 18, 372–388.

Meilanova, D.R., 2021, PNPB Sektor Mineba Tahun Depan Dipatok Lebih Rendah, Ekonomi Bisnis <www.ekonomi.bisnis.com/read/20210816/44/1430333/pnbp-sektor-minerba-tahun-depan-dipatok-lebih-rendah> accessed 6.10.2023.

Rutkowska, G., Chalecki, M., Żółtowski, M., 2021, Fly ash from thermal conversion of sludge as a cement substitute in concrete manufacturing, Sustainability,13, 1-14.

Suloshini, S., Ranathunga, A.S., Kulathilaka, S.A.S., Gunawardana, W.B., Mapa, M.M., 2020, Utilization of Bottom Ash for Clay Mine Rehabilitation. In: Proceedings of the 11th International Conference on Sustainable Built Environment, Kandy, Sri Lanka.

Ukwattage, N.L., Ranjith, P.G., Bouazza, M., 2013, The use of coal combustion fly ash as a soil amendment in agricultural lands (with comments on its potential to improve food security and sequester carbon). Fuel 109, 400–408.

WorldAtlas, 2023, The Top 10 Coal Producers Worldwide, World Atlas <www.worldatlas.com/articles/the-top-10-coal-producers-worldwide> accessed 6.8.2023.

Yousuf, A., Manzoor, S.O., Youssouf, M., Malik, Z.A., Sajjad Khawaja, K., 2020, Fly Ash: Production and Utilization in India-An Overview, Journal of Materials and Environmental Science, 11, 911–921.