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Carbon footprint comparison of three different mine tailings management using a life cycle assessment approach

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Abstract. One of the potential risks in the mining operation is tailings management. Some environmental incidents occurred were associated with tailings. This paper investigated the carbon footprint of three different mine tailings management using life cycle assessment (LCA) and The Australian indicator set method was applied to assess the carbon footprint. Those three different mine tailings management were tailings paste (OPT 1), thickened tailings (OPT 2) and OPT 1 improvement. The extended strategies for OPT 1 were also proposed by improving flotation technology and introducing renewable energy sources (OPT 1A-G). These strategies changed fine coal segregation technology from column flotation to stack cell (OPT 1A) and substituted fossil fuels to renewable energy with the various reduction percentage of 10%, 30%, 50% (OPT 1B-G). The results of the analyses show that OPT 1 generated the highest carbon footprint compared to the base case scenario (OPT 2). Replacing column flotation with stack cell contributed to the reduction of carbon footprint by 18%. The renewable energy (the wind and solar) utilization of 10%, 30%, and 50% affected vary on the carbon footprint reduction from 24% to 44%.

1. Introduction

Mining operations consist of various stages including mining, processing and dewatering plant, and tailings management. Those stages create some impacts that might be harmful to human and environment such as air emissions, water pollutions, and land-use change [1] [2]. Processing plants produce two types of materials which have economic value and non-economic value. The by-product, known as tailings, consists of small quantities of minerals or metals, chemicals, organics, and process water [3] [4]. Jones and Pöggendorf [5] revealed that the mining industry generated around 14 billion tonnes of tailings during 2010. The large volume of tailings can create a massive environmental footprint and severe environmental impacts. There were 237 environmental pollution cases worldwide associated with tailings from 1917 to 2009 [6]. A proper tailings management is required to minimize the mine tailings impacts. A good tailings management could lead to the social license to operate.

Coal mining generates tailings from fine coal recovery process. Fine coal commonly has particle size ranges between -1.0 mm and -0.5 mm, and represents 10-20% of the total Coal Handling Processing Plant (CHPP) feed [7] [8]. The fine coal recovery can increase the saleable coal produced by mine site. In another hand, this processing generates tailings, increases energy consumption, and requires more land for disposal area. Therefore, the proper selection for mine tailings management strategy is required to reduce the environmental impacts and increase benefits value.



2. Method

The life cycle assessment (LCA) is used to analyze the carbon footprint generated by two mine tailings management strategies. Based on [9] that LCA is defined as a technique to assess the environmental aspects and potential environmental impacts of a product, process, or service throughout their cycle process, i.e. cradle-to-grave. LCA can also assist stakeholders in identifying opportunities to improve the environmental performance, selecting the relevant environmental performance indicators, and promoting environmental awareness of a company [9]. There are four interrelated steps in LCA method, namely goal, and scope of the project, data inventory, life cycle impacts assessment, and interpretation.

The hypothetical situation in a coal mine was selected to describe the carbon footprint generated by mine tailings management. One coal open-pit mine site that has production capacity of 20 million tonnes per annum (Mtpa) of Run-of-mine (ROM) was taken as a case study. Two technologies applied were DCT (Deep Cone Thickener) and HRT (High Rate Thickener). These technologies increase the tailings mass percent solids up to 50% (tailings paste), and 30% (thickened tailings). The coal-fired power plant supplies the mine site electricity demand.

There were two main scenarios of mine tailings management with seven variations assessed (Table 1). These scenarios were tailings paste (OPT 1) and thickened tailings (OPT2). Some variations of OPT 1 were developed by introducing two components: stack cell flotation and renewable energy. Detailed scenario variations were as follows:

- Scenario 1A (OPT 1A): using stack cell flotation in segregation stage;
- Scenario 1B (OPT 1B): using stack cell in segregation stage and introducing 10% of solar energy (PV);
- Scenario 1C (OPT 1C): using stack cell in segregation stage and substituting 30% of fossil fuel with solar energy (PV);
- Scenario 1D (OPT 1D): using stack cell for segregating fine coal and tailings, and utilizing 50% of solar energy (PV);
- Scenarios 1E-G (OPT 1E-G) have similar specifications as OPT 1B-D, but the type of renewables installed was wind power.

Table 1. Mine tailings management scenario

Components	Scenario								
	1	1A	1B	1C	1D	1E	1F	1G	2
Column flotation	√	-	-	-	-	-	-	-	√
Stack cell flotation	-	√	√	√	√	√	√	√	-
Deep cone	√	√	√	√	√	√	√	√	-
Thickener	-	-	-	-	-	-	-	-	√
Renewable Energy	-	-	√	√	√	√	√	√	-

3. Result and Discussion

The goal of this study is to determine management options for fine coal tailings management. One ton of fine coal concentrate slurry generated by flotation cells was defined as the functional unit. Flotation tank had 40% recovery and required 50.855 tons of fine coal slurry to produce 1 ton coal concentrate slurry.

3.1 Inventory analysis

Two main materials involved (input and output) are presented in Table 2. Tailings paste scenario generated the highest electricity consumption contributed by column flotation (85%) and thickened tailings (12.9%). The introduction of new technology (stack cell flotation) into OPT 1 can reduce almost 50% of total energy usage. This technology has different aeration and sparging system compared to column flotation that consumes more energy as presented in [10]. Therefore scenarios 1A-G consumed the lowest energy compared to other scenarios.

Table 2. Materials inventory

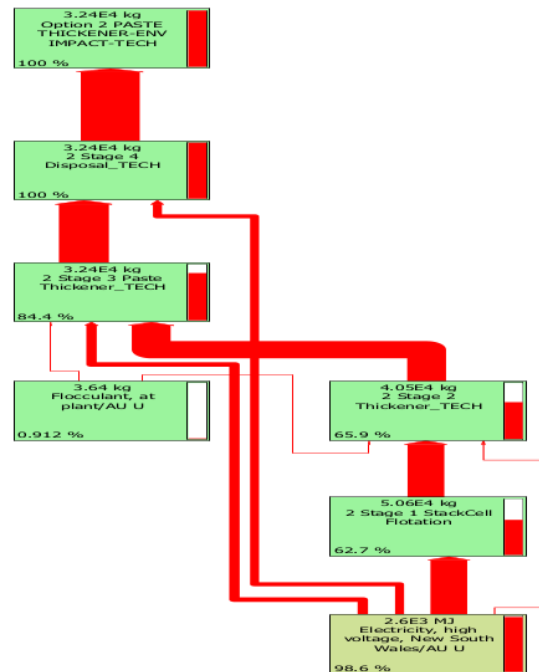
Material	Unit	Scenarios		
		Tailings Paste (#1)	Tailings Paste with stack cell flotation (#1A-G)	Thickened Tailings (#2)
Total Electricity	kWh	1,016.6	597.45	887.2
Flotation		864.5	455.3	864.5
Thickener		20.75	20.75	20.75
Underflow pump		0.2	0.2	1.9
Deep cone thickener (Paste)		131.2	131.2	-
Chemical	kg	8.3	8.3	5.8

Sources: Kohmuench *et al.* [10]; Adiansyah *et al.* [11]; Kohmuench *et al.* [12]; QCC [13]; Sanders [14]

The combinations of these data (Table 2) were analyzed in life impact assessment (LIA) stage to calculate their contribution to carbon emissions as shown in Figure 2.

3.2 Impact assessment

The main contributor to the carbon footprint was energy consumption both for operational and pumping energy. The operational activity consumed energy ranged between 597 to 1,000 kWh, while the pumping activity consumed 1,05 kWh electricity average. In tailings paste scenario (with technology improvement), for example, the coal-fired power plant as the main energy source contributed to more than 90% of total global warming impact (see Figure 1).

**Figure 1.** Environmental impact hotspots

There are two strategies adopted to reduce the global warming impact as follows:

1. Using stack cell flotation which uses the blower for aeration supply and agitator method.
2. Substituting fossil fuel energy source with wind and solar power sources where these two renewable energies have high intensity at the mine site area.

3.2.1 Carbon footprint comparison

A total of nine different scenarios from mine tailings management were evaluated during the impact assessment phase as shown in Figure 2. The scenario that produced the highest carbon footprint was OPT 1, which used paste technology and 100% fossil fuel energy. OPT 1 generated 28% higher carbon footprint compared to the base scenario (OPT 2).

Replacing column flotation with stack cell flotation (OPT 1A) resulted in a decreased carbon footprint of 18% compared to OPT 2. Two main parameters combination, namely technology improvement and substituting fossil fuel energy with renewable energy, generated significant effect to the number of carbon dioxide equivalent (CO₂-e) emitted. As seen in Figure 2, this strategy was able to reduce the carbon footprint by 24%, 33%, and 43% for OPT 1B, 1C, and 1D, respectively. The results also indicated that increasing of 20% renewable energy utilization (from OPT 1B to OPT 1C) generated 150% CO₂-e reduction.

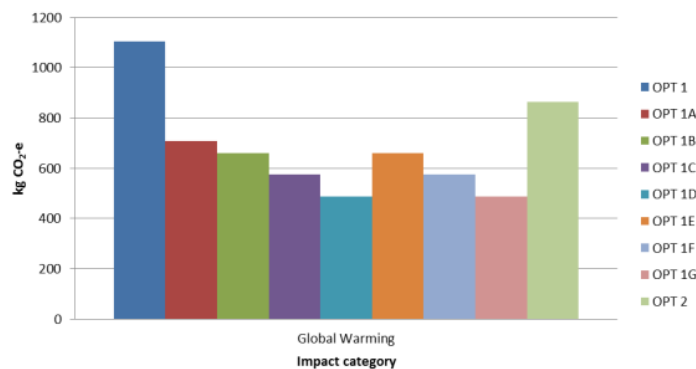


Figure 2. Carbon footprint

The analysis produced similar results for other scenarios (OPT 1E-G). Different type of renewable energy used did not provide significant differences in the results.

4. Conclusion

There are various strategies in coal mine tailings management, including tailings paste, and thickened tailings. Selection of technology used in tailings disposal method affects the amount of energy consumption. This also correlates with the carbon footprint generated.

This paper indicates that tailings paste strategy combined with technology improvement, and renewable energy provides a low carbon footprint compared to the base scenario (thickened tailings). Another advantage of using this strategy is a higher land-use reduction for tailings disposal area due to the less water content in transported tailings. Further analysis of land-use and economic aspects is required for creating a better sustainability performance of mine tailings management.

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