Journal of Environmental Management 199 (2017) 181–191

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Application of a life cycle assessment to compare environmental performance in coal mine tailings management

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ARTICLE INFO

Article history:
Received 18 October 2016
Received in revised form
1 February 2017
Accepted 16 May 2017

Keywords:
Life cycle assessment
Thickened tailings
Tailings paste
Belt filter press
Environmental impacts
Land use

ABSTRACT

This study compares coal mine tailings management strategies using life cycle assessment (LCA) and land-use area metrics methods. Hybrid methods (the Australian indicator set and the ReCiPe method) were used to assess the environmental impacts of tailings management strategies. Several strategies were considered: belt filter press (OPT 1), tailings paste (OPT 2), thickened tailings (OPT 3), and variations of OPT 1 using combinations of technology improvement and renewable energy sources (OPT 1A–D). Electrical energy was found to contribute more than 90% of the environmental impacts. The magnitude of land-use impacts associated with OPT 3 (thickened tailings) were 2.3 and 1.55 times higher than OPT 1 (tailings cake) and OPT 2 (tailings paste) respectively, while OPT 1B (tailings belt filter press with technology improvement and solar energy) and 1D (tailings belt press filter with technology improvement and wind energy) had the lowest ratio of environmental impact to land-use. Further analysis of an economic cost model and reuse opportunities is required to aid decision making on sustainable tailings management and industrial symbiosis.

1. Introduction

Coal is utilized in many countries worldwide as a fossil fuel. Globally, the utilization of coal is 3.4 and 3.8 times higher than use of oil and natural gas, respectively (Osborne and Gupta, 2013). In total, coal supplied 29% of the world's primary energy in 2013 (Thomas, 2013). As illustrated in Table 1, the significant contribution of coal is at least in part due to its widespread geological distribution and to the large reserves, estimated to be around 860 billion tonnes.

These numbers indicate that coal-based industries have an important contribution to make to a country's development, not only in developed but also in developing countries. In Australia, for example, more than 64% of electricity generated comes from coal, 21.3% from natural gas, 7.2% from hydropower, and 4.4% from windpower (World Nuclear Association, 2013). In another example, Indonesia, a developing country, aims to generate 35,000 MW of electricity over the next five years, with coal-fired power plants contributing 55% of the total power generated (Perusahaan Listrik Negara, 2015). The demand for coal, currently led by the BRIC (Brazil, Russia, India, and China) economies, is predicted by Osborne and Gupta (2013) predicted to increase more than 50% between 2013 and 2030. Coal processing is needed to produce saleable coal to meet market demand, as run-of-mine (ROM) contains both coal and gangue mineral impurities. These processes, which include comminution, classification, concentration, and dewatering, take place in a coal handling and preparation plant (CHPP). An inevitable outcome of this processing is the production of tailings.

Coal tailings, also referred to as fine coal rejects, are produced from fine coal processing. The classification of fine coal is based on particle size in the range 0.15 mm–1.0 mm. Fine coal processing represents about 10–20% of the CHPP feed (Honaker et al., 2013; Kumar et al., 2014). This fine coal processing generates around 30% reject material, consisting of both coarse rejects and fine rejects (tailings). This means that 0.6–1.2 million tonnes per annum (Mtpa) of tailings are generated by coal mine sites with 20 Mtpa of ROM. Failure to manage tailings effectively can increase mining operation cost and result in severe environmental damage and human health consequences (Adiansyah et al., 2015; Kossoff et al.,

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http://dx.doi.org/10.1016/j.jenvman.2017.05.050
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Table 1
Distribution of proved coal reserves.

Location	Reserves (billion tonnes)	Percentage (%)
Europe/Eurasia	304.4	35.4
Asia Pacific	264.9	30.8
North America	245.1	28.5
Middle East/Africa	32.7	3.8
South America	12.9	1.5

Source: BP Statistical Review of World Energy in Thomas (2013).

2014; Zhengfu et al., 2010). Good planning is therefore required to prevent and identify impacts that might occur as a result of mine tailings management. Life Cycle Assessment (LCA) is one of the tools that could be utilized to achieve these objectives.

Although the application of LCA in mining is not as widespread as in some other fields (e.g. agriculture or food), some mining LCA studies can be found in the literature. The goals of these LCAs vary and include evaluating the environmental impact of two different alternative technologies for the disposal of mineral mine tailings (Fernandez-Iglesias et al., 2013), comparing the environmental impact of belt conveyors and off-highway trucks in surface mining (Erkayaoğlu and Demirel, 2016), identifying the environmental profile of gold production in terms of embodied energy and water, greenhouse gases, and solid waste (Norgate and Haque, 2012), reviewing the LCA methodology used in the mining industry (Awuah-Offei and Adekpedjou, 2010), underground mine development to the post-closure phase (Reid et al., 2009), and estimating land use equivalent factors in mining operations (Spitzley and Tolle, 2004). Results have been presented in the literature covering various minerals including bauxite (Bovea et al., 2007), copper (Memary et al., 2012), iron ore (Ferreira and Leite, 2015; Haque and Norgate, 2015), nickel (Mistry et al., 2016), and coal (Burchart-Korol et al., 2016; Ditsele and Awuah-Offei, 2012). Recent literature, however, has not considered LCA and land-use impacts of different coal tailings management. This study attempts to fill this gap and discover the novelty of environmental and land-use impacts in coal mine tailings management.

The aim of this study is to compare the environmental performance/impact of different mine tailings management strategies, and to evaluate the magnitude impact of land-use change. To achieve these objectives, three mine tailings strategies and five improvement strategies were selected and applied at a coal mine site located in New South Wales (NSW) Australia. The potential impacts of each of these strategies were analyzed using SimaPro with two impact methods: the Australian Indicator and ReCiPe (Simapro manual PRe Consultants, 2008). The analysis of land-use impact was based on the method developed by Spitzley and Tolle (2004) and Milà I Canals et al. (2007).

2. Methodology

2.1. Base case and scenario definition

The case selected is an open pit mine that is projected to extract about 20 million tonnes per annum (Mtpa) of ROM coal and operate for 20 years. Four scenarios were developed in order to compare the potential impacts of different tailings management strategies, as shown in Table 2. These scenarios seek to reduce the volume of water transported in tailings by increasing the percentage of solids. Scenario 3 is the base case scenario, with the highest percentage water content. The use of tailings paste was selected for Scenario 2, with the percentage solids increasing to 50% compared to Scenario 3. Scenario 1 involves tailings cake, with the lowest percentage water content. Scenario 1 was also subject to an additional technology improvement of the flotation system, as shown in Table 2. Two systems were replaced, namely the aeration and sparging technologies that could decrease energy consumption in a flotation tank, as noted in Kohmuench et al. (2010). Altered mechanical dewatering systems were applied to achieve the final water content prior to disposal. The four scenarios are described in section 2.3.1.

2.2. Goal and scope

The objectives of this study were to develop an inventory of different tailings management scenarios, to assess and compare the environmental impacts of each tailings management scenario, and to determine the associated land-use impacts. In addition, the most sustainable management option for fine coal tailings management was also to be determined. The functional unit (FU) is defined as 1 tonne of fine coal concentrate slurry generated by flotation cells.

2.3. Life cycle inventory (LCI)

A life cycle inventory (LCI) considers the input and output of a product throughout its life cycle (ISO 14044). In this study, the product was fine coal concentrate slurry from flotation cells which also generates tailings as a by-product. This section describes the system boundary and operation of each scenario, the data sources, and some of the main assumptions of this study.

2.3.1. System boundary and description

The LCA system boundary mainly consists of three stages: segregation of fine coal, mechanical dewatering, and tailings transportation. Fig. 1 shows the life cycle stages, with each of the

Table 2
Coal tailings management strategies for each scenario.

Scenario	Segregation	Mechanical dewatering	Tailings transport
1. Tailings with 65% solids 1.A Tailings with 65% solids – flotation technology improvement	Flotation column cells with additional of frother and collector.	#1. Thickener with additional of anionic flocculant; #2. Belt press with additional anionic and cationic flocculants.	Transported by truck to the tailings disposal area.
2. Tailings with 50% solids	Flotation column cells with additional of frother and collector.	#1.Thickener with additional of anionic flocculant; #2. Paste thickener with an additional anionic flocculant.	Pumping to the tailings disposal area.
3. Tailings with 30% solids	Flotation column cells with additional frother and collector.	Thickener with additional of anionic flocculant.	Pumping to the tailings disposal area.