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Research article

A comparative life cycle assessment of material handling systems for sustainable mining

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ABSTRACT

In this comprehensive LCA comparison study, main objectives are to investigate life cycle environmental impacts of off-highway mining trucks and belt conveyors in surface mining. The research methodology essentially entails determination of the functional unit as 20,000 tons/day coal production transported for 5 km distance. After the system boundary was selected as the entire life cycle of material handling systems including pre-manufacturing of steel parts and plastic components, manufacturing, transportation, and utilization data was compiled from equipment manufacturers and the Eco-invent database. Life cycle impact categories for both material-handling systems were identified and the developed model was implemented using SIMAPRO 7.3. Climate change and acidification were selected as major impact categories as they were considered to be major concerns in mining industry. Although manufacturing stage had a significant impact on all of the environmental parameters, utilization stage was the hotspot for the selected impact categories. The results of this study revealed that belt conveyors have a greater environmental burden in climate change impact category when compared to the trucks. On the other hand, trucks have a greater environmental burden in acidification impact category when compared to the belt conveyors. This study implied that technological improvement in fuel combustion and electricity generation is crucial for the improvement of environmental profiles of off-highway trucks and belt conveyors in the mining industry. The main novelty of this study is that it is the first initiative in applying LCA in the Turkish mining industry.

1. Introduction

Increasing rate of energy demand has generated consequent global environmental problems recently. Therefore, defining environmental impacts of continuous utilization of finite energy resources in a quantitative way is crucial more than ever. Coal, as a primary energy source, is now faced with increasing environmental constraints both in mining and utilization. It is vital to ensure that coal is mined and is used in an economically efficient and ecologically sustainable manner, particularly in developing countries and regions as Turkey. The regulations are not binding parties completely and cost related to environmental monitoring is still not considered as a cost driver in decision making. Total share of coal in Turkey's electricity production is stated to be as approximately 26%, so it is obvious that coal mining has a crucial role when compared to other energy resources (Ministry of Energy and Natural Resources 2014). In February 2009, Turkey became signatory to the Kyoto Protocol, and therefore, has to come up with policies for cleaner development supported by external sources of finance. Implementing new technologies in every stage of coal industry and targeting reduction of emissions is obligatory in Turkey's future.

In addition to this, increasing awareness about global warming, ecobalance, and sustainability forces decision makers to manage production in accordance with accepted international standards. In this regard, LCA has become a vital tool to implement a systematic approach for evaluating environmental impacts of products and systems in their entire life cycle. LCA is a powerful tool to assist economical analysis as well as decision making in any production process including mining where ultimate pit limits could also be enhanced by sustainable development measures (Adibi et al., 2015).

This paper presents LCA comparison of material handling alternatives that could be the most energy intensive operation with higher environmental load in surface mining. In the scope of this study, 23 off-highway trucks and eight belt conveyors were

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compared for 20,000 tons/day production capacity using LCA.

1.1. LCA applications in mining industry

LCA has been applied in various industrial fields, however, there have been limited applications completed in the mining industry. Financial aspects of LCA in Polish mining industry were one of the first attempts to introduce LCA as a decision support system in mining (Goralczyk and Kulczycka, 2004). Non-measureable effects of LCA were stated as improved credibility and decreased competition for a company. In this study, LCA was defined as a tool that should be supported with a financial analysis and potentially advantageous for equivalent projects to be evaluated by economic means. Economies of scale for surface coal mining is stated to have a significant role in impact assessment together with geological conditions that influence operation (Ditsele and Awuah-Offei, 2012).

In order to compare technically equivalent projects or equipment, inventories about material, energy inputs, and emissions were prepared for various industrial fields. Data availability is a major concern in LCA as it might be highly confidential for mining companies (Durucan et al., 2006). High level modeling of mining operations might result in complexity, as there are simultaneously occurring sub-activities. The developed database was based on flexible object-relational code, allowing modification and update of unit processes without disturbing overall model structure. Using primary sources of data is not always possible so publicly available databases should be encouraged in every country to provide easily accessible environmental data.

Another country that prepared its national LCA database and started to use this sustainable approach in mining industry is Mexico, a worldwide leader in silver production. Environmental management and life cycle approach in the Mexican mining industry was studied and the role of this approach was indicated by stating the systematic observation of processes for potential impacts, reducing operating cost, and improving efficiency (Suppen et al., 2006). In this study, lack of archive data about production and industrial process for small- and medium-scale companies enforced focusing on a large-scale operation.

Mining industry requires operation of massive and expensive heavy-duty machines and equipment. In selection of these machines and equipment, primary factors considered include operating and capital investments, and productivities. A LCA comparison of mechanical and electrical drive trucks was implemented to identify stressor categories and air emissions in a medium-scale mine in terms of global warming potential (GWP) and acid rain precursors (ACP) (Demirel and Düzgün, 2007). The authors also applied multi-criteria decision analysis to develop a decision support tool for mine managers, environmental policy makers, and mine owners. It was concluded that electric drive trucks were found to be less environmental friendly in ACP and mechanical drive trucks were found to have higher impact on GWP.

Use of LCA in the mining industry and research challenges were also studied and pointed out the two-fold relevance (Lesage et al., 2008). The authors stated that mining industry has a role providing the LCA community with primary environmental impacts metals. On the other hand, mining industry can use LCA in order to evaluate environmental impacts of mining activities and identify hotspots. Mining is an industry with numerous upstream and downstream processes that is preferably scaled down for LCA studies due to low availability of data. Regardless of such challenges, recent research focusing on sustainability in mining, minerals, and energy point to a confident approach towards synergies between policy makers and the mining industry (Moran et al., 2014).

Large corporations that operate on multiple locations lead mining industry in assessing environmental impact and reporting on sustainability. However, aggregated numbers and generalized statements that internalize sustainability are considered as misleading the community and should be improved by focusing on scale-based frameworks across geographic dispersion (Fonseca et al., 2014). Mine sites close to protected areas where threatened species and habitats exist might require a more specific approach compared to reporting frameworks. Decision-support tools utilized at the planning phase of mining projects could aid in quantitatively defining environmental impact indicators and communicating with stakeholders (Marnika et al., 2015). Energy generation is a sector that is commonly in relation with stakeholders and is criticized for its debatable sustainability potential. Countries that are heavily depending on fossil fuels for energy generation, such as Turkey and Poland, need to investigate environmental performance of mining and other downstream processes in detail. LCA studies conducted on energy generation in these countries are challenged by the lack of data representing mining activities and encourage research in this field (Lelek et al., 2015).

Creating national electricity mixes that cover alternative sources has been discussed for many years. Lignite, commonly stated as a comparably less environmental friendly option, forms the majority of available resources in Turkey followed by natural gas that has to be imported. Increasing the share of natural gas in Turkey's electricity generation is an option that has to be investigated in detail as its impact in categories, such as GWP, is lower whereas ozone layer depletion would become a critical measure (Atilgan and Azapagic, 2015). LCA studies related to electricity generation commonly focus on impact categories including GWP and acidification potential, similar to this study, as majority of impacts originate from combustion of fuels in power plants that are partially represented by high quality data (Brizmohun et al., 2015). There are also challenges in using a standardized terminology in impact assessment for defining mineral resource input (Drielsma et al., 2016) and critical raw materials indicating the necessity to review existing impact categories about mining (Mancini et al., 2015). Recycling, not studied in the scope of this research, also has a relation to mineral resources and has to be investigated according to the technology utilized in order to understand the GWP of metal recovery (Allegrini et al., 2015).

2. Comparison of off-highway trucks and belt conveyors using LCA

The complex and interindustry structure of mining creates a challenging system to model for LCA purposes. Lack of a broad framework specifically defined for LCA studies in mining results in missing sensitivity and uncertainty analysis (Awuah-Offei and Adekpedjou, 2011). Data representing mining processes are rarely covered in available LCI whereas raw material used to manufacture equipment and energy consumption of machinery is an essential part of environmental data sources. Main stages of LCA (ISO, 2006) are followed to compare material haulage systems in surface mining and point out major environmental loads.

2.1. System boundaries of off-highway trucks and belt conveyors

Adopting ISO 14044 guidelines (ISO, 2006), system boundaries were determined according to the available data and the scope of the study. A comprehensive life cycle inventory of air emissions associated with freight transportation in the US pointed out the importance of using a whole dataset instead of tailpipe emissions, which underestimate the life cycle impact of vehicles (Facanha and Horvath, 2006). Eco-invent database is stated to be providing a