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Case history of environmental impacts of an Indonesian coal supply chain

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ABSTRACT

Coal will continue to be the most demanded energy source worldwide, which highlights the importance of better understanding current practices and environmental impacts of this industry. Indonesia is the largest coal exporter in the world, but studies evaluating the environmental impacts of the coal industry in this country are missing in the literature. A case study of the Indonesian coal supply is evaluated by using attributional life cycle assessment (LCA) techniques to develop inventory data and to evaluate greenhouse gas (GHG) emissions, depletion of fossil fuels (DFF), and water consumption associated with the production of coal from mining to the consumer's gate. Five scenarios are evaluated to identify opportunities for improvement. Material and energy inputs are inventoried through site visits and surveys, with complementary data added from the literature. Three pits producing sub-bituminous coal are evaluated where the processes of mining, coal transport to local and international markets, administrative operations, and water treatment are analyzed. Results are normalized by the functional unit defined as the energy content in the produced coal (expressed in GJ). Total GHG emissions are 4021 g CO_2e/GJ, DFF is 39 MJ/GJ and water consumption is 41.5 L/GJ or 2 L/GJ if recycled water is considered. Mining operations are the largest source of GHG emissions and DFF, with overburden removal and transport responsible for more than one third of these impacts. Fugitive methane release and sea transport to international customers also have a significant impact on GHG emissions and DFF respectively. The energy return on investment (EROI) is 25.9 at the delivery point and 42 at the mine mouth indicating that this is a net energy producing operation. Alternative scenarios show that GHG emissions and DFF could be significantly reduced by increasing biodiesel content in the fuel mix of ground operations and by transporting overburden with a conveyor.

1. Introduction

Global energy consumption increased 48% in the past 20 years and is expected to increase by 6% over the next 30 years (U.S. EIA, 2016). Fossil fuels account for 82% of the global energy supply and are expected to remain as the predominant sources of energy worldwide (U.S. EIA, 2016). Coal is more abundant and less expensive fossil fuel (1–2 US$/GJ) relative to oil and natural gas (3–12 US$/GJ) and is a preferred fuel source for electricity generation when available (MIT, 2007). Indonesia is the largest coal exporter globally, with most of its production shipped to India and China (U.S. EIA, 2015). Despite that coal consumption is expected to provide a lower percentage of the global energy demand until 2040, total energy consumption is expected to increase globally, leading to a net increase in overall coal consumption. By 2040, coal production is expected to increase from 171 to 208 billion GJ, with China and India the largest consumers (U.S. EIA, 2016). Consequently, Indonesian production and distribution of coal will become increasingly important in the context of the global energy supply. The growth in coal production poses environmental challenges worldwide. More than 30,000 million metric tons (Mt) of carbon dioxide-equivalents (CO_2e) were emitted from fossil fuels in 2011, with coal contributing 44% of these global greenhouse gas (GHG) emissions. Projections show the same trend for the next 30 years (IEA, 2016).

Studies that evaluate the sustainability of coal production focus on combustion for electricity generation. Whitaker et al. (2012) review and harmonize 53 studies that evaluate GHG emissions of

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coal-based electricity worldwide and find that mining is the second source of total emissions after coal combustion. Widder et al. (2011) report that mining and transportation of coal are major sources of GHG emissions in U.S. coal-fired plants, and that fugitive methane (CH_4) constitutes one-half of these mining emissions. Restrepo et al. (2015) describe a LCA of underground coal mining in Brazil and find that more than 70% of GHG emissions are attributed to the production of coal, 13% to electricity consumption, and the rest from the use of diesel, material inputs, and infrastructure. Liang et al. (2013) describe different coal power generation technologies in China and report that ultra-super-critical coal power generation results in the lowest GHG emissions and that coal combustion is the major GHG emitter followed by the coal mining stage.

Coal-combustion technologies for electricity generation are already mature, limiting strategies that seek to reduce GHG emissions during combustion. Weldu and Assefa (2016) evaluate alternatives for coal-fired power generation in Canada and report that co-firing coal with wood pellets reduces GHG emissions, but increases overall costs. Carbon capture and storage (CCS) and carbon capture and utilization (CCU) have arisen as technologies intended to reduce the environmental impacts of coal-fired power plants. CCS is expensive and still developing (Jaramillo et al., 2007) and the environmental benefits of CCU vary widely depending on the utilization method. Cuéllar-Franca and Azapagic (2015) find that GHG emissions can be reduced by using mineral carbonation and by using CO_2 to produce chemicals, but increased when using CO_2 to produce algae for biodiesel. In general, GHG emissions from CCS are lower than CCU, but other environmental impacts such as ozone depletion or acidification are higher.

There is potential to improve the sustainability of coal by targeting the mining stage as it is the second source of GHG emissions. However, previous studies evaluating the coal mining stage use average emission factors due to the lack of availability of more detailed data, combine coal with other industries, or focus on alternative impact categories. Bernhardt et al. (2012) evaluate the pollution or rivers from surface coal mining runoff in the Central Appalachia region, and Palmer and Hondula (2014) evaluated the impact of current compensatory mitigation of coal mining on aquatic natural resources. Fugiel et al. (2017) conducted a LCA of the mining sector in European countries, but aggregated the mining impacts of coal, petroleum, natural gas, metal ores and other mining activities making it difficult to evaluate coal mining individually. Moreover, as mining methods and practices are sensitive to site-specific characteristics, applying the results from one mine to another is difficult. With Indonesia being the most important coal exporter in the world, studying the characteristics and environmental impacts of the mining industry in this country is important. This study develops cradle-to-gate life cycle inventory (LCI) data and evaluates GHG emissions, depletion of fossil fuels (DFF), and water consumption associated with the production and transportation of coal by evaluating a case study of one of the most important coal mining industries in Indonesia.

Between 2002 and 2012, primary energy consumption in Indonesia grew by 44% with coal providing most of this growth (IEA, 2016). The Indonesian government encourages coal in the power sector due to abundant domestic supply. Coal is expected to provide approximately half of the energy capacity in the future (U.S. EIA, 2015). Indonesian coal comes mostly from Sumatra and East and South Kalimantan, where the top six miners account for 75% of the total production (Harrington and Trivett, 2012).

Indonesia has a major role in reducing GHG emissions as a highly populated country and Non-Annex I Party to the United Nations Framework Convention on Climate Change. In 2009, the Indonesian government committed to a 26% reduction in GHG emissions by 2020, the largest commitment made by any developing country (Ministry of Environment Republic of Indonesia, 2010). Further reductions of 41% were committed contingent on the availability of international support. To achieve the targeted reductions, all sectors, including energy production, are part of the Indonesia's National Action Plan for Reducing Greenhouse Gas Emissions, which reinforces the importance of quantifying and identifying the GHG emission sources and other environmental sustainability metrics related to Indonesian coal production.

2. Methods

The evaluated open pit mining operation produces nearly 56 million Mt of coal per year, of which 87% is destined for power generation and 11% for cement manufacturing. As shown in Fig. 1, three pits are operated in the South Kalimantan region to produce a sub-bituminous coal with moderate energy content (16.8–21.0 MJ/Mt) that is low in sulfur, ash, and nitrogen (Table S1). Three types of coal are produced by blending coals from the three mine pits (P1, P2, and P3) and are classified according to their chemical composition and calorific value. Calorific values are 21.9 MJ/kg coal for P1, 20.6 MJ/kg coal for P2, and 17.6 MJ/kg coal for P3. The largest pit (P1) also serves as the center of all operations including mining, engineering, administration, and accounting. Processing operations start at the pits where coal and overburden are extracted, loaded, and hauled with off-highway mining trucks. Coal is hauled to a crushing and blending facility to reach specifications on particle size and calorific value and then transported in barges along the Barito River. Approximately, 20% of the produced coal is sold to local power companies, mainly in the Paiton region, and 80% is transported to a floating facility, where coal is loaded to ships and transported to international costumers. Administrative and water treatment activities are carried out alongside these processes.

Attributional LCA techniques and the SimaPro software are used to calculate and keep track of GHG emissions, DFF, and water consumption through each step of coal production for an assumed time unit of one year (Pre-Consultants bv, 2014). Fig. 2 describes all unit-processes (smallest processes inventoried for analysis) included in the system boundaries of the study from mining operations (processes that happen within the boundaries of the mining pits) to transportation of coal to the consumers gate (i.e. power plants and cement industries). Thermochemical conversion of coal is not included in the boundaries of the study. Embedded energy and GHG emissions from the production of material and energy inputs (i.e. diesel and chemicals) are included in the boundaries; however, the production of capital goods (i.e. machinery and buildings) is excluded as the contribution of capital goods to the outputs has been shown to be marginal (Jain et al., 2014; Whitaker et al., 2012).

2.1. Environmental sustainability metrics

GHG emissions, DFF, and water consumption are expressed per GJ of energy contained in coal arriving at the international port destinations. GHG emissions come from on-site fuel combustion, embedded emissions in energy and material inputs (e.g. the emissions associated with the manufacturing of diesel, which include all processes from the extraction of petroleum until diesel is used at the mining operation), and fugitive CH_4 emitted from the mine surface and post-mining stages. Characterization factors for nitrous oxide (N_2O) and methane (CH_4) are assumed to be 298 kg CO_2e and 25 kg CO_2e based on the CML 2001 method for a 100 year time horizon.

DFF is defined as the sum of fossil energy directly consumed on-site operations and embedded in the production and delivery of