Assessment of environmental impacts of coal mining in Lakhanpur Opencast Project of Ib Valley Coalfield, Odisha using Life Cycle Assessment (LCA) model

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Abstract

Introduction: Coal as the primary fuel for the fossil fuel energy sector, is gradually and slowly being replaced by eco-friendly "Green Energy'. In this scenario, it is very much important on the part of coal industry to orient itself to remain relevant in the energy sector in a sustainable manner.

Coal mining provides almost 59% of coal as a source of electricity generation in India. It involves different activities to produce coal. There have been increasing concerns over environmental problems associated with extraction and use of coal. At present, coal mining industries are trying to make assessment of their activities which affect the environment, in order to identify appropriate corrective measures to improve environmental sustainability of their processes and products. Here, the aim of study was to understand the effect of mine characteristics on cradle-to-gate life cycle environmental impacts of coal mining in Lakhanpur OCP of Ib Valley Coalfield of Odisha.

Methods: The functional unit was defined as "one tonne of processed coal" at the mine gate. The relative mass-energy-economic value method, with some modification, was used to scope the product system. Data were collected from mine in person, from environmental impact statements, coal mining permit applications, government reports, published literatures and relevant websites. Life cycle impact assessment(LCIA) included here classification and characterization but no normalization, grouping, or weighting, to avoid ambiguity. In this work, mid-point characterization models were preferred over damage-oriented (end-point) characterization models because of their high levels of uncertainties. The LCIA also includes sensitivity analysis.

Results & Discussion: LCA is a perfect and prominent tool for comparison of various systems based on the impacts. So, more mines are needed to be included in the study and thereby compared further based on impacts. More impact categories could be considered for study to address more resource inputs and emissions to air, water and ground. Impact categories which are used for study in LCA studies for coal mining product usage should be included as possible in the study to reduce LCI data gap for the products.

Keywords: **Coal, Green Energy, Mining, Mine gate, Life Cycle Assessment(LCA), Life Cycle Impact Assessment(LCIA)**

I. INTRODUCTION

Coal generates about more than half (57.3% as in June,2018) of the electricity used in India (Ministry of Power, GOI, 2018) and India stands as the third largest electricity producer in the world. Projection up to 2020 predict that increases in coal consumption for electricity generation, will result in an annual coal production growth rate of about 8.8% (Coal requirement in 2020: A Bottom-up Analysis by Anurag Sehgal, Rahul Tongia, Abhisek Mishra). Apart from electricity generation, coal happens to be the main fuel stock in other industrial processes such as steel making, cement production, and paper making.

Open cast coal mining operations account for about three fifth (60% in 2017-18) of total coal production in India. Opencast Mining methods are important for coal extraction as they are very much amenable to higher productivity compared to underground mining systems.

In the present scenario, in spite of importance of coal, there have been increasing concerns over environmental problems associated with extraction and use of coal. Coal mining has severe impacts on water, land, abiotic resources and also climate conditions which is caused by Greenhouse Gas(GHG) emission. Though, we have other problems related to coal such as acidification, photochemical oxidation, etc., but the former impacts are considered to be major impacts for coal mining process. Life Cycle Assessment (LCA) provides systematic and quantifiable measure for assessing environmental burdens of products and processes occurred.

II. Life Cycle Assessment(LCA)

Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support. Reliable LCA performance is crucial to achieve a life-cycle economy. This is a comprehensive tool for quantifying and interpreting environmental impacts of a product or service from the cradle to grave. However, depending on the nature and intended purpose of an LCA study, the boundaries of the system under study may be modified appropriately resulting in either a cradle-to-gate or gate-to-gate assessment.

III. RELATED WORKS

Many LCA works have been done on the complete life cycle of coal (cradle-to-grave), where whole extraction process is considered as a black box. Very few LCA studies have been conducted on the main mining process (cradle-to-gate approach). The limited number of mining LCAs undermines the many life cycle inventories that have been developed, since every product system consumes the products of mining directly or indirectly (e.g., by utilizing electricity produced by coal-fired power plants). In spite of the low application of life cycle thinking to decision making in the mining industry, some examples of mining LCA studies can be found in the literature (Awuah-Offei et al. 2008a, b; Bovea et al. 2007; Durucan et al. 2006; Mangena and Brent 2006; Spitzley and Tolle 2004; Suppen et al. 2006). In fact, the lack of LCI data on coal mining has been cited as one of hindrances to the accuracy of LCI data. A search on the International Journal of Life Cycle assessment gives only 23 results with "coal mining" which reflects the relatively low application of LCA studies in coal mining or even in mining industry.

IV. OBJECTIVE OF PRESENT STUDY

Life Cycle Assessment (LCA) provides systematic and quantifiable measures for assessing environmental burdens of products and processes occurred. Many LCA work studies have been done on coal use but particularly in electricity generation which contains the assessment relating to the data on coal from mine gate to power generation. But the coal mining stage [from cradle- to-gate] has been neglected. This situation has resulted in incomplete assessment of sustainability of coal extraction/mining and use. This study is undertaken to prepare a Life Cycle Inventory of energy, water and land usage for various processes in Lakhanpur Opencast Project of Ib Valley Coalfield of M/s Mahanadi Coalfields Ltd. and to estimate cradle-to-gate environmental impacts of the mining process per functional unit from the inventory analysis calculations.

IVA. LOCATION & ACCESSIBILITY

Lakhanpur Opencast Project is under Lakhanpur Area of M/s Mahanadi Coalfields Limited and is situated in Jharsuguda District of Odisha. It is located in the southern part of Ib Valley Coalfield about 8 KM south of Belpahar Railway station of S.E.C. Railway on the Howrah- Mumbai main line. The mine is at a distance of 4k.m. from the Chief General Manager's office and 5k.m. from the Bandhabahal colony. National Highway No-200 connecting Sambalpur – Raipur (C.G.) via-Jharsuguda is passing through Belpahar Town is at about 7k.m. from the mine. National Highway No-42 passing through Jharsuguda, a Junction of SEC Rly is about 30 k.ms. from the Mine. The highest and lowest elevations of the area under report are 250 m and 198 m above mean sea level respectively. The location map of Lakhanpur Opencast Project in Ib Valley Coalfield is given at figure 1 & 2.

Fig. 1: Part plan showing Jharsuguda district

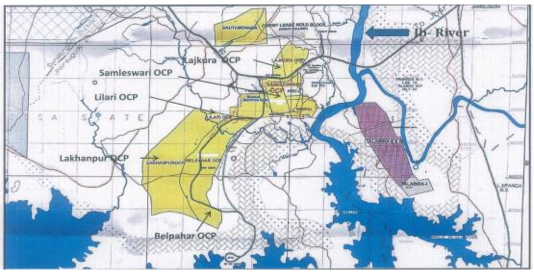

Fig. 2: Part plan showing mines of Ib Field, Jharsuguda district

Govt. of India has approved Lakhanpur OCP on dated 22.01.1992 with two Advance Action Plans of Lakhanpur OCP after Phase-I and Phase-II was approved by G.O.I on 22.01.1992 by the coal company to expedite project construction. The date of opening of the project and starting of OB removal is 03.10.1992 and starting of coal production is 22.02.1993.

IVB.GEOLOGY

Lakhanpur OCP is developed in sector-III of Belpahar Block, covering an area of 20 square km and has an estimated reserve of 945 MT coal in three seams - Lajkura seam, IB seam and Rampur seam. Out of the three seams only the Top seam i.e. Lajkura seam is quarriable and the other 2 seams are deep seated and will be mined in future by 30MTY Integrated Project.

IVC.GEOMINING CHARACTERISTICS

The strike length of the mine is 6km and along the dip it is 300m to1200m. Average thickness of the workable Lajkura seam varies from 25 to 32 m. Along the strike length, the mine is divided into five quarries namely Quarry-1, 2, 3, 4 and 5 to reduce the dumper lead and to increase simultaneous backfilling capacity.

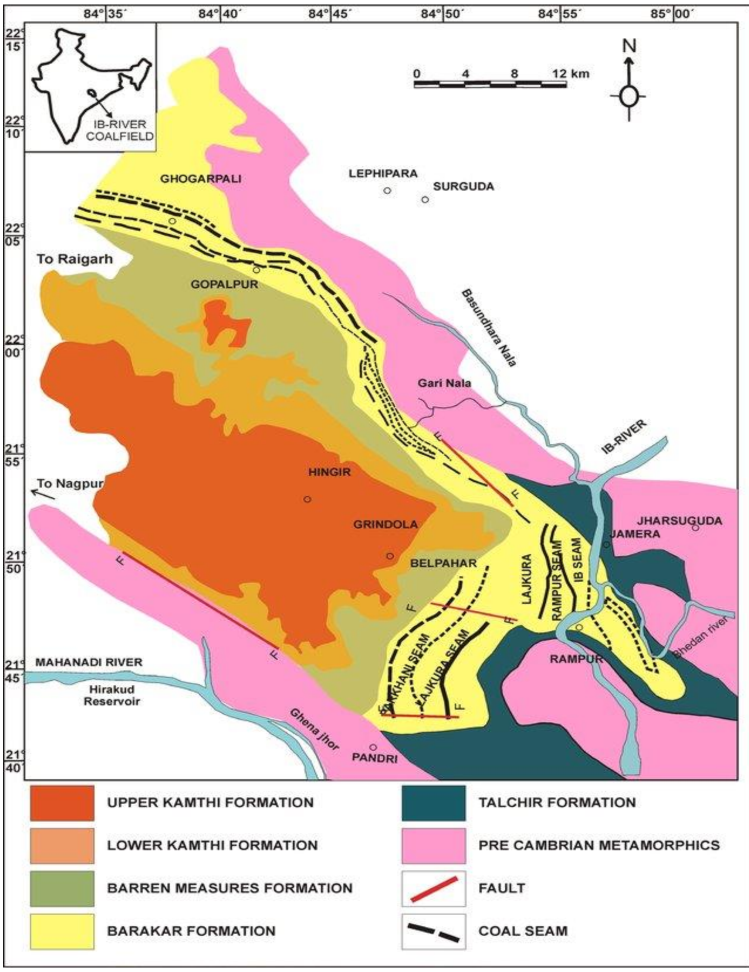

Fig.3: Geological plan of Ib Field

IVD.METHOD OF WORKING

The Mine is worked by Departmental Shovel – Dumper Combination to remove Overburden with EKG & BEML hydraulic shovels &backhoes, TATA-1200 hydraulic shovels and 100 Te, 60 Te & 50 Te Dumpers at Quarry 4. From 21.10.2009, a contract had been awarded for OB Outsourcing and presently Quarry 1, 3&5 are being worked by OB Outsourcing. The coal is won by deploying Surface Miners (six contractual and one departmental.) which provides -100 mm size coal and Tipper and Pay Loader combination of E.S.M companies, private contractors and Project Affected People (PAP) for loading and transportation to sidings and stock.

Fig.4: Mine Plan of Lakhanpur OCP

Table.1: Coal & OB Production of Lakhanpur OCP

Year	COAL(Te)	OBR(Cu.M)
2009-10	13061129	8853015
2010-11	14010559	15310857
2011-12	14999987	14910553
1012-13	14999990	18131557
2013-14	14999996	19356162
2014-15	18400762	15682764
2015-16	18196221	15159567
2016-17	18749950	35744943
2017-18	20723892	36470504

V. METHODOLOGY ADOPTED

A complete system flow of coal mining from cradle-to-gate of the mine is prepared. System boundary for LCA is selected. An appropriate functional unit is selected. Life Cycle Inventory(LCI) on resource inputs and emissions for production of coal in Lakhanpur Open Cast Project is prepared. The life cycle impacts for categories of energy-use, water-use, land-use, resource depletion, climate change is assessed.

VA. SYSTEM BOUNDARIES

To collect all the data for the entire unit processes connected to coal is impractical because of resource and time limitations. As a result, the system boundaries for the LCA had to be scoped to ensure a manageable volume of data within the constraints of available resources. Since the system under study is a cradle-to-gate system, the unit processes include drilling, blasting, excavation, loading and hauling of coal to the mine gate as shown in Fig.5. The processes downstream of mining, such as coal processing, transportation of coal to places for use, the use of coal and disposal of any end waste products, such as fly ash are being excluded from the system boundaries. While selection of system boundaries, care had been taken that the critical environmental flows in the life cycle of coal were not excluded.

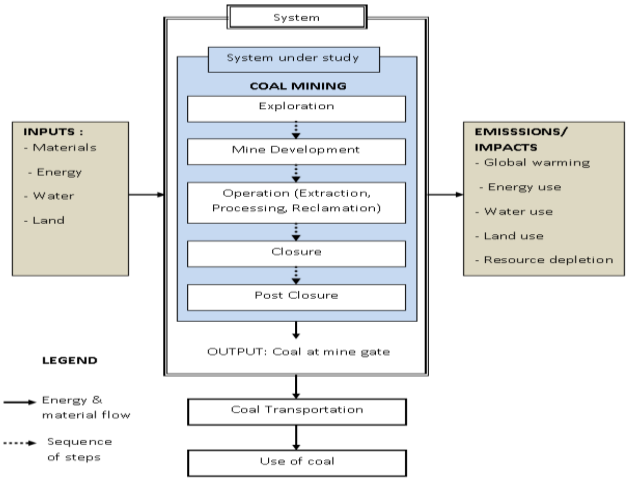

Fig.5: System Boundary in the Cradle-to-Gate Life-Cycle Assessment of Coal

VB. FUNCTIONAL UNIT

Functional unit is a defined fundamental unit which forms as a basis for impact assessment in any product processes or services. A functional unit can be energy-based, mass-based, currency based, processed output based, etc. A mass based functional unit is easy to work with since mining companies typically report their reserves and production information on the basis of mass. Also, the practice in coal mining industry is that material inputs, waste products and economic information are expressed on the basis of a unit mass of product [typically a Tonne (Te)]. Applying a mass-basis provides clarity, easy comparability of LCA results and also allows for scaling of results over any production scale or time period based on interest. The functional unit for this study was defined as, 'One Tonne of coal produced at the Mine Gate'. This choice of functional unit ensures consistency with the functional units used in many other coal LCA studies.

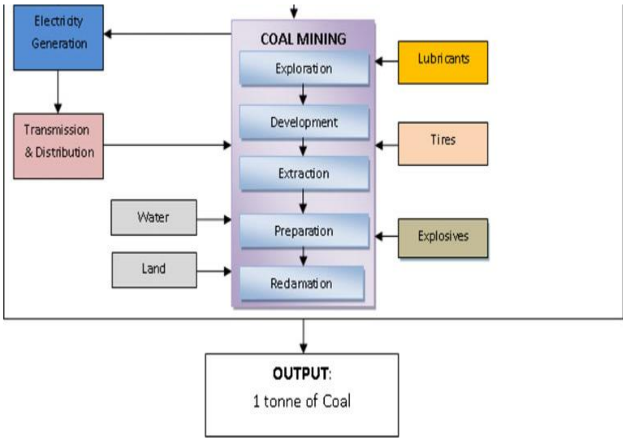

Fig.6: Functional Unit in product system of Opencast Coal Mining

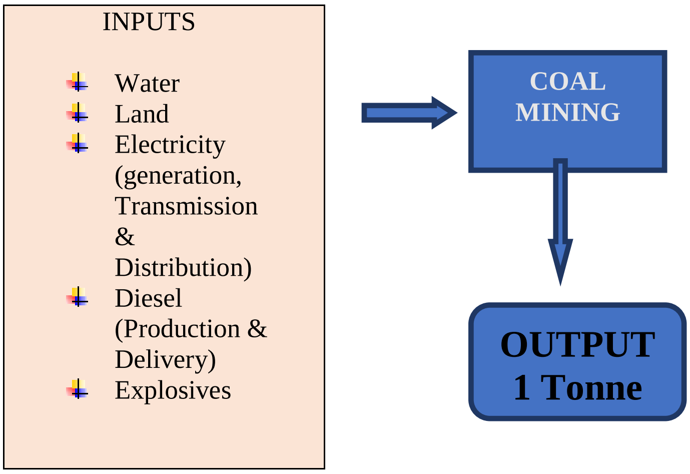

Fig.7: Inputs & Functional Unit in Final System boundaries considered for this LCA study

VC. LIFE CYCLE INVENTORY (LCI)

Life Cycle Inventory (LCI) analysis involves creating an inventory of flows from and to nature for a product system. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water. In this study basic inputs are Water, Land, Electricity (Generation, Transmission and Distribution), Diesel (Production & Delivery) and Explosives.

VCI. WATER USE

Water consumption data for each process was collected and classified into industrial/ mining and other domestic purposes. The data was collected in an aggregated figure but not broken down according to uses in mines.

VCII. LAND USE

Amount of Coal Reserves, Overburden and Lease holding details of land acquired by mine was collected. Break-up of the total lease hold area according to the conceptual plan was prepared. Land use calculations for the life cycle inventory analysis were determined by dividing the total land area that is likely to be disturbed throughout the life of a mine (land already disturbed by construction of facilities and coal extraction, plus coal resources areas that are yet to be disturbed) by the total reserves for the mine. Year wise disturbing and reclamation data was collected to calculate Land Occupation Impact (LOI).

VCIII. USE OF ELECTRICITY AND OTHER FUELS

Data was collected on each unit of machinery used for coal mining processes of the project/mine. Rated Gross power, Min-Max fuel consumption for diesel operated machinery, operating rated power for electrical machines was acquired. Total diesel consumption and total electricity consumption was measured to calculate the amount of fuel use/energy use per tonne of coal produced (Functional Unit). High- Speed Diesel is used which has calorific value of 10,670 Kcal/kg. Delivery of diesel to the mine is carried out by M/s Indian Oil Corporation Ltd.(IOCL) tankers from Sambalpur, Odisha. The Abiotic resource depletion for fuel use can be assessed from the distance of delivery for the fuel from well to mine gate. Similarly, resource depletion for the electricity generated can be assessed for E-Resource mix of electricity generation data of Indian Power plants. The amount of emissions of CO_2 can be calculated from the emission factors, oxidation factors of the respective fuel.

VCIV. EXPLOSIVES

Site Mixed Emulsion or Site Mixed Slurry explosives which contain Ammonium Nitrate - Fuel Oil (ANFO) as main explosive component are used. Energy content of ANFO is MJ. Powder Factor (Kg of explosive/ Te of material) was collected. Four different powder factors were maintained in the mine as for three different types of overburden removal operations and for blasting coal. The amount of energy of explosive in MJ can be calculated per tonne of coal produced. The amount of CO_2 released from the explosive during blasting is also calculated to assess climate change impact.

VI. RESULTS & DISCUSSIONS:

Lakhanpur Opencast Project operated by M/s Mahanadi Coalfields Ltd. a subsidiary company of M/s Coal India Limited was considered for data collection in this study. This project is under the administrative control of Ib Valley Area of M/s Mahanadi Coalfields Ltd. situated at a distance of 30 KMs by road from Jharsuguda town and 90 KMs from Sambalpur where Company's Corporate Office is located. Proved reserve of coal was estimated to be 123.41 M. Te.

VIA. LIFE CYCLE IMPACT ASSESSMENT(LCIA)

The inventory results are translated to contributions to the selected environmental impact categories. Land Use, Water Use, Energy Impacts, Climate Change Impact, Abiotic Resource Depletion Impacts are the considered impact categories.

VIAI. LAND USE IMPACT

Characterizing land use impact from the transformative perspective such as changes in quality, productivity and

biodiversity is complex and not recommended particularly in this case as for the lack of the respective data before the start of mining and current data. In this project, life cycle land use impacts were assessed from the occupancy perspective in which the area of land occupied and duration of occupancy. At Lakhanpur Opencast Project, though the land is reclaimed in small amounts regularly year wise, no part of land is being released from the lease hold.

Land Occupation Impact (LOI) = Area of land under Lease x (Total number of years until the release of lease or until land is restored to its original quality)/ total reserves in Te.

Balance mineable reserves as per data collected is 123.41 Million Te. Total lease hold area for the project purpose is 1444.00 Ha and 49.855 Ha is for residential purpose. The further project life is estimated to be 6years as per 21 MTY extension project report which was prepared during 2014-15. Lease for land was obtained in 1989. After the complete removal of coal, an estimated time of 5 years is considered for complete reclamation of land area and restoration of land to its original quality. Number of years from obtaining of lease hold to its release is considered to be 31+5 = 36 years.

Total mining lease hold area = 1444.00Ha. Total balance mineable reserves = 123.41 Million Te. LOI = 14938550*36/123410000 = 4.3577 m^2 – year/ Te of coal produced.

VIA II. WATER USE IMPACT

There are no characterization methods standardized in LCA methodology for the water use impact category. The amount of water consumption from the inventory analysis phase per tonne of coal was used as an indicator for water usage impact. The total Water consumption per day is calculated to be 3974.9576 m^3 (Peak demand) including domestic and drinking purposes. Average coal production per day considering 360 working days in a year is 57,566.366 Te. The water use impact was determined to be 69.05 Liters per Te of coal produced.

Production Capacity as per consent order	21.00 MTPA
Environmental Clearance from MoEF	Environmental Clearance for 21.00TY obtained vide letter No: J11015/391/2012-1A.11 (M),dtd.28/02/2018
Year of Establishment	1991
Mineable reserve	358. 58 M. Te
Project life	25 + 6 YEARS AS PER 21.00MTY EXPANSION REPORT
Active Mine area	9,95,574 m^2
Total mining leasehold area	1444.00 Ha
Total Cost of the project	1074.17Cr.
Stripping Ratio	2.34
Area covered under plantation	149.665 Ha.
Coal Production in FY 2017-18	20723892.00Te

Table-2: Details of Lakhanpur Opencast Coal Project

VIA III. ENERGY USE

In this category, total energy used in the mine from cradle to gate for production of 1 Te of coal is assessed. Total energy includes energy consumption by machinery comprising diesel usage and electricity consumption and energy usage during blasting in the form of explosives. Net calorific value for HSD in India is in the range of 10100 – 10300 Kcal/Kg approximated to 10,670 Kcal/Kg.

Total annual HSD consumption from the inventory analysis calculations is measured to be 35,893,781 liters.
HSD fuel consumption per Te of coal = 35,893,781/20723892 = 1.732 Litre/Te
Net calorific value for HSD is 10670 Kcal/Kg.

Density = 0.8263 Kg/Litre

Net Fuel energy consumption/tonne = 1.732*0.8263*10670= 15,270.39 Kcal=64.136 MJ

Total annual electricity consumption is 14,693,239.428KWh = 52,475,855.10 MJ [1KWh=3.6 MJ]

Electricity consumption per tonne of coal is 2.532MJ =0.709 KWh

From the inventory analysis calculations, the energy content of explosives used per tonne of coal = 3.2049 MJ

The total energy usage per one Tonne of coal = 69.671MJ

Table 3: Energy usage calculations

CONTENT	QUANTITY
Annual HSD consumption	35,893,781 Litres
HSD cons. per Te of coal	1.732 Litres
Net Fuel energy cons. per Te of coal	63.934 MJ
Annual electricity cons.	52,475,855.10 MJ
Electricity cons. per Te of coal	2.532 MJ
Explosive energy per Te of coal	3.2049 MJ
Total energy use per Te of coal	69.671MJ

VIA IV CLIMATE CHANGE

Climate change impact is assessed from the amount of Greenhouse gas emissions added to the atmosphere per ton of coal produced. GHG emissions mainly considered for an LCA study are CO_2, CH_4. Coal bed methane emissions occupy a heavier portion in GHG emissions, but it has not been included in this study due to lack of availability of respective data. Carbon dioxide emissions from the equipment utilizing HSD and electricity are calculated. CO_2 emissions from the explosives during blasting are also accounted for.

(a)Emissions from electricity consumption

CO_2 emissions from electricity consumption are estimated based on the emission factors and oxidation potential as per statistics given by International Energy Agency (IEA). IEA table gives CO_2 emissions by an emission factor (EF) as $[CO_2]_{g/KWh}$ = 912.

CO_2 emissions from electricity cons.= $[CO_2]_{g/KWh}$ * Average electricity (per Te of coal)
(consumption per Te of coal) = 912*0.71=0.647Kg CO_2/Te of coal

(b)Emissions from HSD consumption

CO_2 emissions from HSD consumption of the machinery can be calculated with the respective CO_2 emission factor given from Intergovernmental Panel on Climate Change (IPCC) tables. As per IPCC tables, the carbon content for the HSD fuel is averaged to be around 85% by weight with being implied that Indian fuel consumption comprises of 18.7% of Indian crude and 81.3% of imported crude components. 1Kg of HSD = 0.85 Kg of carbon = 0.85 x 44/12 x 0.99kg of CO_2

CO_2 emission factor diesel = 72.97 kg/MJ of energy consumption (for HSD). CO_2 emissions from HSD consumption = 72.97 * 63.934 = 4665.2639 kg of CO_2/Te of coal =4.66Te of CO2/Te of coal.

(c)*Emissions during blasting:* From the inventory analysis results, the total CO_2 emissions from explosives are summed up to be 0.13 Kg/Te of coal.

Abiotic Resource	Amount used to generate 1 kWh of electricity	Amount used per Te of coal (1.11 kWh)	ADP-CML 2001	ADP(g Sb- eq.)
Coal	0.4717 Te	0.5235	0.00671 kg Sb-eq./ kg	3.512685
Natural Gas	0.0002862833 m^3	0.000317 m^3	0.0187 kg Sb-eq./m^3	0.005928
Crude oil	0.07 Gallons	0.0003 kg	0.0201 kg Sb- eq./kg	0.00603

Table 4: Abiotic resource depletion potential calculations

Table 5: CO_2 Emissions calculations

Type	Unit emissions	Total CO_2 emissions
High Speed Diesel	72.97 Kg/MJ	4.67 Te
Electricity	0.912 Kg/KWh	0.647 Kg
Explosives	0.17 g/gram of ANFO	0.13 Kg

VIA V ABIOTIC RESOURCE DEPLETION

The abiotic resource depletion impact indicators relate life cycle inputs to the extraction of minerals and fossil fuels. The Center of Environmental Science of Leiden University (CML) has developed characterization factors called Abiotic Depletion Potentials (ADP) for different minerals and materials including energy sources. The ADPs are based on mid-point modeling and a standard of ‘kg antimony equivalent/kg resource extraction’.

Abiotic Resource Depletion = $\sum (ADP_i x\ m_i)$ Where;

ADP_i is the Abiotic Depletion Potential of resource i

m_i is the quantity of resource i extracted to provide inputs for the life cycle system.

The resource depletion potentials were characterized with respect to fossil fuels such as coal, natural gas and crude oil only which comprises the major percentage of resources utilized for electricity generation in India.

Crude oil which is used for the delivery of fuel from mine well to the gate of mine should also be accounted. HSD is delivered to the mine from Sambalpur which is at a distance of 90 km from the mine gate using oil tankers of capacities 18kl and 12kl.

VIA VI DATA QUALITY AND UNCERTAINTY

CH_4 emission from coal bed forms a major portion of Greenhouse Gas (GHG) emissions leading to climate change. Lack of CH_4 emission data has been a major drawback for this study. Lack of data representing the coal processing plant led to not including the process in the system boundaries. When mine specific data was not available, data obtained from various other reports and studies was included in this study. Maximum amount of work has been put to avoid uncertainties in data or Life Cycle Inventory analysis calculations.

VII CONCLUSIONS

Based on the study, the following conclusions are drawn:

The following conclusions are drawn from this work:

- The potential land use impact, assessed from the perspective of land occupation has been calculated to be 4.3577 m^2 - year/tonne of coal.
- The life cycle water use impact for the production of coal from surface mining has been determined to be 69.05 liters per tonne of coal produced.
- The potential energy use impacts including electricity, diesel and explosives aggregated amount to 69..67 MJ. Energy content of explosives used contributed the largest share of energy use impact.
- Whereas, CO2 emissions from electricity consumption and explosive utilization amounted to be 0.647kg/te and 0.13kg/te of coal respectively.
  CO_2 emission from HSD consumption alone is calculated to be 4.66 Te /Te of coal.
- Abiotic resource depletion potentials for the resources involved in electricity production which is consumed in mine have been evaluated.

VIII RECOMMENDATIONS FOR FUTURE WORK

The followings are the recommendations for future works:

- LCA is a perfect and prominent tool for comparison of various systems based on the impacts. So, more mines needed to be included in the study and thereby compared further based on impacts.
- More impact categories could be considered for study to address more resource inputs and emissions to air, water and ground. Impact categories which are used for study in LCA for coal mining product usage should be included as much as possible in the study to reduce LCI data gap for the products.

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