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# Quantification of Environmental Impacts of Coal Mining in Lajkura Opencast (Surface) Mine of IB Valley Coalfield of Odisha, India Using Life Cycle Assessment (LCA) Model

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**ABSTRACT - Purpose: In the present scenario, coal is the major fossil fuel in India. It will remain as major contributor of energy in the country because of its abundance and it is cheaper also. But there is problem of environmental degradation due to coal mining. In order to deal with environmental problems, industries including mining industries use the Environmental Management Systems (EMSs)-14001. Coal mining especially opencast mining creates much more adverse impacts on environment. Life Cycle Assessment (LCA) is the appropriate tool to evaluate the environmental performance taking into relative mass-energy-economic value (RMEE) method. In the research work, five opencast coal mine projects of Ib Coalfield are considered for evaluation of the environmental performance of each mine to get a comparative study with water use, land use, energy use, abiotic resource depletion, and change in climate. This study aims to assess the effect of mine activities on environment through cradle-to-gate Life Cycle environmental impacts in Lajkura Opencast(surface) Mine of Ib Valley Coalfield of Odisha on the abovementioned environmental parameters. Similarly, same study is in progress for other coal mine projects as indicated above.**

**Methods: The research work used the general principles of the ISO 14040-49 series Life Cycle Assessment (LCA) standards, modifying them as and when required. The functional unit is defined as "one tonne of coal processed coal" at the end of the production cycle, i.e., mine gate. The relative mass-energy-economic value method, with certain need-based modification, is used to scope the intended product system. Data are collected from mine in person, from environmental impact statements, coal mining permit applications of the company, government reports like coal ministry, energy ministry, published literatures including national and international journals, and relevant websites of the company. Life Cycle Impact Assessment (LCIA) includes classification and characterization only, normalization, grouping, or weighting, being untouched, to avoid ambiguity. In this work, mid-point characterization model is preferred over damage-oriented (end-point) characterization model due to their high levels of uncertainties. Besides, the LCIA embraces sensitivity analysis.**

**Results and discussion: For the studied mine, life cycle potential water use impact is 133.41 litres/tonne of coal produced at the mine gate. The potential land use and energy use has been assessed to be 5.271 $m^2$ -year/tonne and 128.72 MJ/tonne respectively. $CO_2$ emissions from HSD consumption alone is 8.67 Kg/tonne of coal, whereas, emissions from electricity consumption and explosives is 1.532 Kg and 0.154 Kg respectively. Impacts due to land use depend mainly on land for coal mining activities and the prevailing climatic conditions of the region.**

**Conclusions & recommendations: LCA can be used as a perfect and prominent tool for comparison of various systems based on the environmental impacts. So, more opencast coal mines are required to be included in the study, thereby comparing the environmental impacts of impact categories considered in the study. More impact categories could be considered for study to address more resource inputs and emissions to air, water and land.**

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***Keywords: Abiotic Resource Depletion, Coal Mining, Climatic Change, Energy use, Land use, Life Cycle Assessment (LCA), Water use.***

## I. INTRODUCTION

Mining provides most of the raw materials for industrial processes and products and is an essential part of the world economy. Coal, as fossil fuel, contributes about 59% of the electricity generation in the country as shown in Fig.1. Indeed, coal mining plays an important role in the energy security of India. Bulk production of coal is done by open cast method of mining. Despite the importance of coal, there have been increasing concerns over environmental problems associated with extraction and use of coal, as knowledge and understanding of impacts and processes on the environment have grown. In order to deal with environmental problems at their sites, mining companies are increasingly adopting environmental management systems such as the *ISO 14001* - Environmental Management System (EMSs). A key requirement of ISO certified EMSs is continual improvement, which can be better managed with life cycle thinking [15],[16],[17],[18],19] & [20]

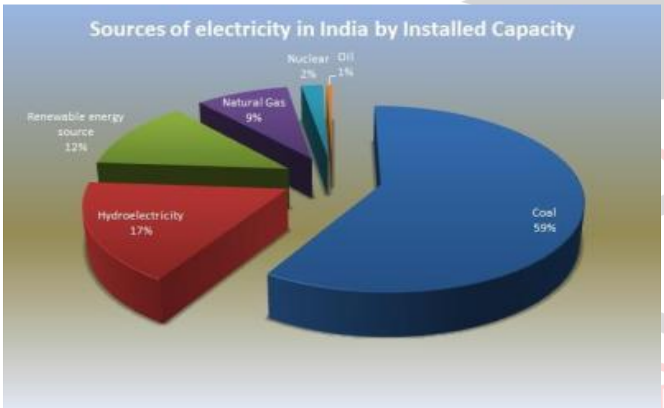


Fig.1: Sources of electricity in India by installed capacity [24]

There are various tools for assessing the environmental performance of systems, and these include, Environmental Impact Assessment, Ecological Footprint, Risk Assessment, Ecological Risk Assessment, Material Flow Analysis and Life Cycle Assessment [3].One of important and environment friendly tools that is used to achieve sustainable development by ensuring installation and operation of major industries and projects is “Life Cycle Assessments (LCAs)”. Although the early development of Life Cycle Assessment (LCA) methodology dates back to the end of the 1960’s, in the context of the environmental assessment of packaging options, it is in the 1990’s that its methodological development really took off. It was identified at the World Summit on Sustainable Development in 2002 as one of the science-based approaches that could help guide policy aimed at improving the products as well as services provided, while reducing environmental and health impacts. In LCA studies, the mining system is often represented as a black box, not lending itself to the interpretation of the different processes used in coal and minerals production. The limited number of mining LCAs may be due to the lack of life cycle thinking in the industry.

## II. LIFE CYCLE ASSESSMENT (LCA)

Life Cycle Assessment (LCA) is a tool for the systematic evaluation [Fig.2] of the environmental aspects of a product or service system through all stages of its life cycle. LCA model 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 [Fig.3] of the system under study may be modified appropriately resulting in either a cradle-to-gate or gate-to-gate assessment.

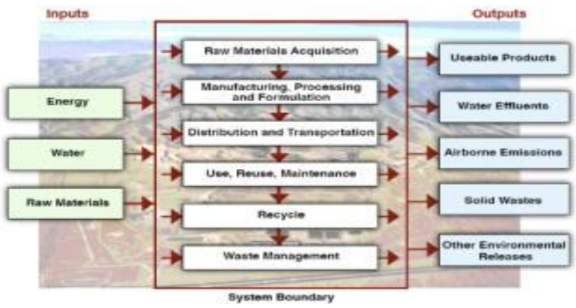


Fig.2: Phases of LCA

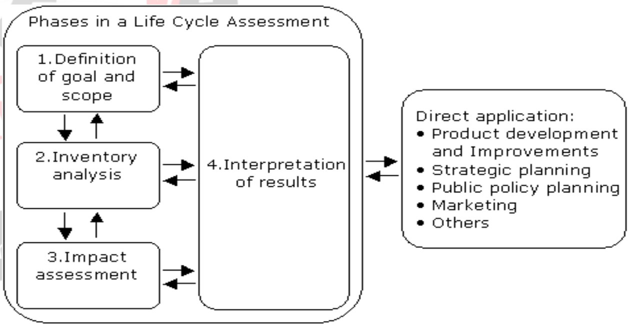


Fig.3: Generic LCA Model

## III. BACKGROUND OF LCA

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 LCA study in coal mining undermines many a life cycle inventories, which have been developed, since every product system consumes the products of mining directly or indirectly. 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 [1],[2],[4],[8],[9],[10] & [11].

## IV. OBJECTIVE OF STUDY

The purpose of the study is to prepare a Life Cycle Inventory of energy, water and land usage for various

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processes of Lajkura Opencast Project and to quantify cradle-to-gate environmental impacts of the mining process per functional unit from the inventory analysis calculations. Further, this study will include more numbers of opencast projects of Ib Coalfield for quantification of environmental impacts due to coal mine activities for obtaining a comparative value for decision making, which project stands where on different desired parameters [14].

## V. ENVIRONMENTAL IMPACTS OF COAL MINING

The usual impact categories [7] & [13] that are considered in LCA studies performed before this decade, are global warming, ozone depletion, human toxicity, fresh water aquatic eco toxicity, acidification and eutrophication potential impacts [21]. Additionally, land-use, water-use, and energy-use impacts are also suitable for mining LCA [8], [9] & [10]. While including abiotic resources depletion in their LCA study of mining recognized that the former methods are inadequate for an LCA study on mineral extraction process [8]. Hence therefore many a LCA studies have considered Energy-Use, Land-Use, Water-use, Climate change as the prominent environmental impact categories for the mining processes of minerals including coal.

### 5.1.ENERGY-USE

Optimum use of raw materials as well as efficient use of energy resources is very much crucial for the sustainability of coal mining and mining in general. Energy use has always been accounted for LCA [3], but many often it was only addressed to the point of inventory compilation and determining environmental system flow. It is essential to focus on energy use as an impact so that issues of energy efficiency is well in case of coal mining. Energy sources, including electricity and diesel, are important inputs to mining [5] and make up the highest component of mining costs. Given that coal mining processes involve using fossil fuels, either directly or indirectly through electricity, whose supply is not infinite, it is important to understand the energy profile of the coal mining industry.

### 5.2.LAND-USE OR LAND DISTURBANCE

Surface or opencast coal mining, affects large areas of land and habitats [6] & [12], and this is one of the reasons, often coal mining being opposed by environmental pressure groups and communities also. The land impacted by surface coal mining is typically reclaimed contemporaneously with mining to allow the de-coaled land for post-mining uses as it was before the mining. However, land use impacts in coal mining are believed to be crucial, important and the dominant contributor to changes in all aspects of global diversity [5]. The large surface area disturbances due to surface coal mining, makes this impact even more severe.

### 5.3. WATER-USE

Coal mining involves the use of water for dust suppression on haul roads, coal transport road, coal handling plant, washing plant and domestic purposes. The quantity of water used in coal mining can be high depending on processes involved [6]. The potential for water depletion in some areas makes it very vital to evaluate the water use impacts for coal mining in such areas. Therefore, it needs to develop effective strategies for water- use management to curtail the wastage of water.

### 5.4. CLIMATE CHANGE

Greenhouse Gas (GHG) emissions associated with coal mining includes methane from coal strata, and carbon dioxide and nitrous oxide from the use of fuels in coal mining operations [23]. To control GHG emissions as per the recommendations of those set in Paris Climate change conference, 2015; it is required to pursue a comprehensive strategy.

## VI. METHODOLOGY

The following steps are included in the methodology of the study:

a. To prepare a complete system flow of coal mining from cradle to gate of the mine.
b. To select a system boundary for LCA.
c. To select an appropriate functional unit.
d. To prepare the Life Cycle Inventory on resource inputs and emissions for production of coal in the mine.
e. To assess the environmental impacts due to energy-use, water-use, land-use, and use of other resources.
f. To compare environmental performances and explore the sources of differences in performances.
g. To suggest improvement measures to address source of impacts.

The different steps of methodology and model development have been further elaborated while describing the environmental parameters with suitable units of measurement.

## VII. STUDY SITE

Lajkura opencast project has been chosen as the study site. It is a coal mining project and the second oldest opencast coal mine of Ib Coalfield of Gondwana formation.

### 7.1. LAJKURA OPENCAST PROJECT

Lajkura Open Cast Project [Fig.4 & 5] of M/s Mahanadi Coalfields Limited has been considered for data collection for this study. This project or mine of capacity one Million Tonne per annum, was sanctioned by the Government of India in August 1983. The production of coal was started from 1984-1985. The target of Coal for the year 2016-2017 is 2.50 M Te and the target of OB is 7.350 $Mm^3$. At present Lajkura OCP is running with the capacity 4.5 MTY in the expansion area for 29 years life as on date 01.04.2009 (as per 2.5 MTY Project Report).

### 7.2. MINE DETAILS

The following are details geo-mining parameters of the Lajkura Opencast Project. The details of coal production and other relevant information of the mine is shown in Table-1.

1. Name of the seam (Main) : LAJKURA SEAM
2. Thickness of the seam : 18 to 23mtr
3. Full dip : 1 in 23, N-$70^0$ W

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4. Maximum quarry depth : 159 m
5. Average stripping ratio : 1:3.40 (Highest in MCL)
6. Grade of Coal : "G-13"
7. Targeted capacity :4.5 M. te
8. Date of opening of mine : 07.08.1984
9. Crossing point of Lajkura seam : $135^0$C
10. Quarry Area :2554400 $m^2$ or 255.44Ha
11. Target of OB :9 $Mm^3$
12. Coal target : 4.5 MT
13. Incubation period : 90 days.

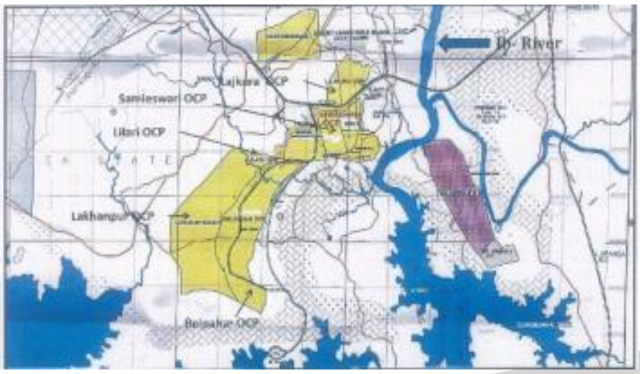


Fig.4: Part plan showing mines of Ib Field.

Fig.5: Mine Plan of Lajkura OCP

Table-1: Details of coal production and other relevant information of Lajkura OCP

| | | |
|---|---|---|
| Production capacity as per consent order | 1.00 MTPA, 2.50 MTPA, 4.50 MTPA | |
| Environmental Clearance from MoEF | Environmental Clearance for 4.5 MTY obtained vide letter No: J-11015/423/2008-1A. II (M), 12.03.2013 | |
| Year of Establishment | 1985 | |
| Coal reserve | 69.40 M Te | |
| Project life | 29 years | |
| Excavated mine area during 2018-19 | 70,000 $m^2$ | |
| Total mining lease area | 721.29 Ha | |
| Quarry excavation area | 255.44 Ha or 2554400 $m^2$ | |
| Total Cost of the project | 465.88 Cr. | |
| Stripping Ratio | 3.40 | |
| Area covered under Plantation | 322.13 Ha. | |
| Powder Factor | Location | P.F |
| | OB | 2.35 |
| | Coal | 5.12 |
| Actual Production | Year | Coal Production in Te. |
| | 2012-13 | 900,000 |
| | 2013-14 | 28,90,000 |
| | 2014-15 | 25,00,000 |
| | 2015-16 | 18,90,000 |
| | 2016-17 | 29,00,000 |
| | 2017-18 | 45,00,000 |
| | 2018-19 | 45,00,000 |

## VIII. FUNCTIONAL UNIT

Functional unit is a defined fundamental unit which forms as a basis for impact assessment. A functional unit can be energy-based, mass-based, currency based, processed output based, etc. A mass based functional unit is easy to work in coal mining as mining companies typically report their reserves and production information on the basis of mass. Moreover, the practice in coal mining industry is the material inputs, waste products and economic information, expressed on the basis of a unit mass of product (typically a tonne). Therefore, the functional unit for this study is defined as, 'One tonne of processed coal at the mine gate'. This choice of functional unit ensures consistency with the functional units used in many other coals LCA studies also.

## IX. SYSTEM BOUNDARY

The area or region, in which, the mining activities takes place to produce is considered as the system, which is enclosed by the system boundaries. To collect all the data for the entire unit processes connected to coal extraction, is not practical because of resource and time limitations. That is why; the system boundaries for the LCA had to be scoped to ensure a manageable volume of data within the ambit of availability. Since the system, under study is a cradle-to-gate system, the unit processes are drilling, blasting, excavation, loading and hauling of coal up to the mine gate. The processes downstream of mining, such as 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 [Fig.6], care has been taken such that the critical environmental flows in the life cycle of coal is not excluded.

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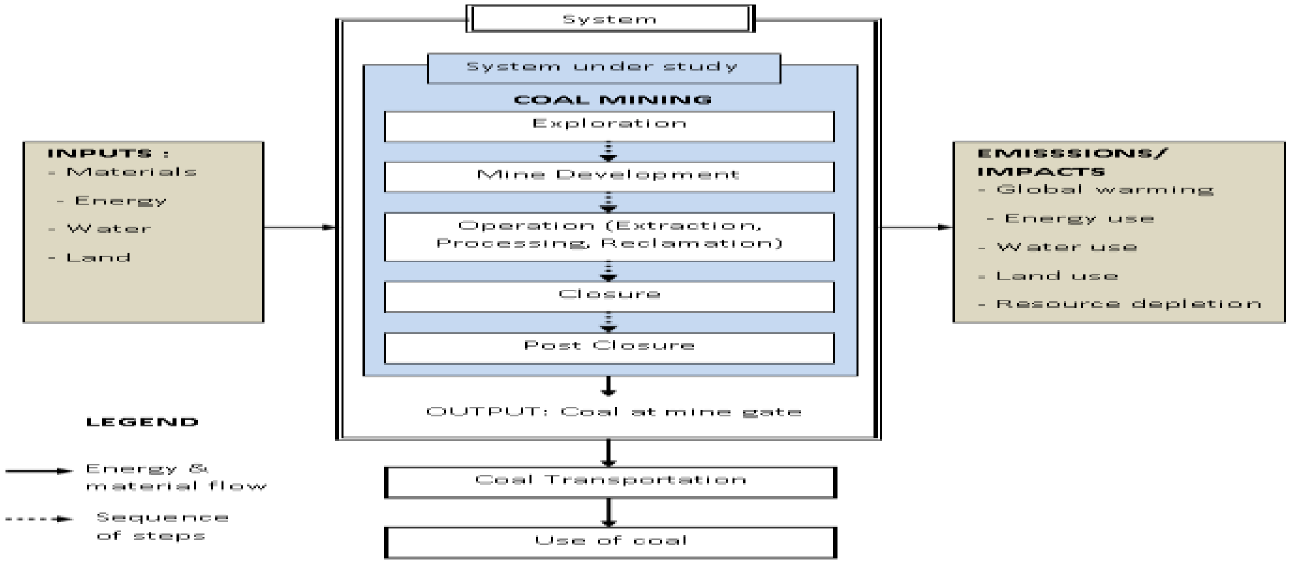


Fig.6: System Boundary & Functional Unit in product system of Opencast Coal Mining

# X. LIFE CYCLE IMPACT ASSESSMENT

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.

## 10.1. 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 are assessed from the Occupancy perspective in which the area of land occupied and duration of occupancy. The de-coaled land in Lajkura OCP is reclaimed in small amounts regularly year-wise, but no part of land is yet released from the lease hold.

### 10.1.1. 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 tonnes. Total proved reserves as per data collected is 69.40 M Te. Total lease hold area for the project purpose is 721.29Ha and 56.95 Ha for basic infrastructures and residential purpose. The further project life is estimated to be 8 years as per 2.5/4.5 extension project report which was prepared during 2015-16. Lease for land was obtained in 1984.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 42+5=47 years.

Total mining lease hold area = 778. 24 Ha. = 7782400 $m^2$

Total mineable reserves = 69.40 M. Te= 69400000 Te

***LOI = 7782400*47/69400000 = 5.271 $m^2$ – Year/ Te of coal produced***

## 10.2. WATER USE IMPACT

The quantity of water consumed is calculated from the inventory to produce one tonne of processed coal, which is an indicator for water usage impact.

Table.2: Water consumption calculation (2018-19)

| Sl. No. | Industrial/Mining | Kilo-Litres (Cu. M.)/Day |
|---|---|---|
| 1 | Dust suppression: Haul Road, Coal Transport Road, CHP, Siding | 1070 |
| 2 | Fire fighting | 122 |
| 3 | Surface Miner operation | 29.50 |
| 4 | Workshop | 52.50 |
| 5 | Others | 14.10 |
| 6 | Domestic | 379.50 |
| | Total (in Kilo litres /day) | 1667.60 |
| Water consumption per tonne of coal production during 2018-19 is 133.41 litres with 4.5 M. Te of coal production during 2018-19 | | |

The total water consumption per day is calculated to be 1667.60 $m^3$ (peak demand) including domestic and drinking purposes. Average coal production per day considering 360 working days in a year is 4500000 Te/360= 12500 Te. The water use impact was determined to be 1667.60 x 1000/12500= 133.41 liters per tonne of coal produced.

## 10.3. ENERGY USE

Total energy used in the mine from cradle-to-gate for production of 1 tonne of coal is assessed. It includes energy consumption by machinery comprising diesel usage and electricity consumption, energy usage during blasting in the form of explosives.

Net Calorific value for HSD in India is in the range of 10,100–10,300 Kcal/Kg approximated to 10,670 Kcal/Kg.

Total annual HSD consumption from the inventory analysis calculations is measured to be 11,475,000 liters. HSD fuel consumption per tonne of coal = 11,475,000/4500000 = **2.55 Litre/Tonne**. Net calorific value for HSD is 10670 Kcal/Kg. Density = 0.8263 Kg/Litre

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Net Fuel energy consumption/tonne = 2.55*0.8263*10670= 22,482.38 Kcal=94.4260 MJ

**[1Kcal=0.0042 MJ]**

Lubricating energy consumption/tonne=0.66*0.8263*10670= 5819.00 Kcal=24.4396 MJ

Total annual electricity consumption is 27.2159 TJ Electricity consumption per tonne of coal is 4 MJ.

From the inventory analysis calculations, the energy content of explosives used per tonne of coal = 128.7169 MJ.

***The total energy usage per one tonne of coal = 128.7169 MJ***

Table.3: Energy usage calculations

| Raw Materials (Fuel/Energy) | Quantity |
|---|---|
| Annual HSD consumption (l/Te) | 11,475,000 litres |
| HSD cons. per tonne of coal | 2.55 litres |
| (a)Net Fuel energy cons. per tonne of coal | 94.4260 MJ +24.4396 MJ |
| Petrol cons. litre per tonne of coal | NIL |
| Lubricants cons. litre per tonne | 0.66 litre |
| (b)Net lubricant energy cons. per tonne of coal | 24.4396 MJ |
| Annual electricity consumption | 7559972.22 kWH= 27.2159 TJ |
| (c ) Electricity cons. units per tonne of coal | 1.68 kWH=6.048MJ |
| Annual explosives consumption | 4090500 Kg |
| Explosive consumption kg per tonne of coal | 0.909Kg |
| (d)Explosive energy per tonne of coal | 3.8033 MJ |
| Total energy use per tonne of coal | **128.7169 MJ** |

### 10.4. CLIMATE CHANGE

Climate change impact is assessed from the amount of Greenhouse gas emissions added to the atmosphere per tonne 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.

**Emissions from HSD consumption & Lubricants**: $CO_2$ 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 = 0.85Kg 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 * (94.4260 +24.4396) = 8673.579 Kg of $CO_2$/tonne of coal

**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 tonne of coal)

(consumption per tonne of coal) = 912 * 1.68 = 1.532 Kg $CO_2$/ tonne of coal

**Emissions during blasting:** From the inventory analysis results, the total explosives consumption explosive per tonne of coal production is 3.8033 MJ, which emits 0.154 Kg of $CO_2$.

Table 4: $CO_2$ emissions calculations

| Type | Unit emissions | Total $CO_2$ emissions |
|---|---|---|
| High Speed Diesel | 72.97 Kg/MJ | 8673.579 Kg |
| Electricity | 0.912 Kg/KWh | 1.532 Kg |
| Explosives | 0.17 g/gram of ANFO | 0.154 Kg |

### 10.5. ABIOTIC RESOURCE DEPLETION

The abiotic resource depletion impact indicators are related to life cycle inputs to the extraction of minerals and fossil fuels. The ADPs are based on mid-point modeling and a standard of 'kg antimony equivalent/kg resource extraction'.

Abiotic Resource Depletion = $\sum (ADP_i \times m_i)$

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 are characterized with respect to fossil fuel such as HSD oil only which comprises the major percentage of resources utilized for coal mining in India.

Table-5: Abiotic resource depletion potential evaluated

| Abiotic Resources | Amount used per tonne of coal (1.11 kWh) | ADP-CML 2001 | ADP(g Sb-eq.) |
|---|---|---|---|
| HSD Oil | 0.0003 kg | 0.0201 kg Sb-eq./kg | 0.00603 |

HSD 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 70 Kms from the mine gate using oil tankers of capacities 18 KL and 12KL.

## XI. SENSITIVITY ANALYSIS

Sensitivity analysis was conducted to identify significant unit processes and assumptions, and their effects on the LCA results. This analysis was carried out for energy use, resource depletion and climate change impacts. Sensitivity

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analysis is important for these because of the many unit processes which contribute towards the potential impacts, and the various assumptions that could affect the overall results. Some of the parameters used in the characterization of land use impacts do not lend themselves to variation. For instance, the coal resource area that can potentially be affected by coal extraction cannot be changed without changing the coal reserves, and changing the area disturbed by development of facilities would only be reasonable if it is accompanied by a change in the scale of production.

## XII. DATA QUALITY AND UNCERTAINTY

CH4 emission from coal bed forms a major portion of Greenhouse gas emissions leading to climate change. Lack of CH4 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. Maximum amount of work has been put to avoid uncertainties in data or Life Cycle Inventory analysis calculations.

## XIII. CONCLUSION

In the above study based on cradle-to-gate assessment of coal mining, the land use impact, water use impact, energy use impact as well as abiotic resource depletion impact are quantified as under.

The water use impact for the production of coal from surface mining has been calculated to be 133.41 liters per tonne of coal produced. The potential land use impact, assessed from the perspective of land occupation has been calculated to be 5.271 $m^2$- year/tonne of coal. The potential energy use impacts including electricity, diesel, lubricant and explosives aggregated amount to 128.7169 MJ. Energy content of explosives used contributed the largest share of energy use impact. $CO_2$ emission from HSD and lubricants consumption alone is calculated to be 8673.579 Kg of $CO_2$/tonne of coal. Whereas, emissions from electricity consumption and explosive utilization amounted to be 1.532 Kg and 0.154Kg respectively. Abiotic resource depletion potentials for the resources involved in coal production, which is consumed in mine have been evaluated as 0.0003kg.

## XIV. RECOMMENDATIONS FOR FUTURE WORK

a. More impacts category needs to be quantified for cradle-to-gate assessment in coal mining to facilitate pin pointing to produce unit tonne of processed coal.

b. LCA helps to perform sensitivity analysis in order to identify major changes that can be applied to the system of mining.

c. More opencast mines are required to be included to have comparison on the same set of environmental impacts in the same coalfield.

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