

Model for Life Cycle Sustainability Assessment of Coal Based Electricity Generation in India

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Abstract

Purpose: This study evaluates the environmental efficiency of coal-based electricity generation in India. The study further proposes a new paradigm of life cycle assessment model named CEEPA - Coal Electricity Environmental Performance Assessment (CEEPA).

Methods: Life cycle assessment methodology has been used to quantify the impacts of electricity generation from coal. An emission revision model based on pollution and waste produced and its effect categories were proposed after an analytical comparison between three coal-fired thermal power plants in different regions of the country.

ReCiPe method was used to conduct the assessment in this study. Software SimaPro was used for LCA analysis. The study was carried out “from cradle to gate” and the functional unit was 1 KWh electricity at the consumer level

Results: The total Global Warming Potential (GWP) values for the three power plants (PP1, PP2 & PP3) are 1,100 g CO₂eq/kWh, 1,287 g CO₂eq/kWh and 898 g CO₂eq/kWh respectively. PP1, PP2 uses Indian coal for electricity generation which is supplied domestically and later sent to the grid, whereas PP3 uses Indonesian coal.

Conclusion: The evaluation performed in this study illustrate the latest environmental assessment situation for various technologies in power generation. It also provides an opportunity to suggest areas for possible improvements in the existing electricity generation system based on the quality and quantity of coal used. The empirical findings indicate that the production of coal-based electricity generation has a substantial effect on the use of natural resources, the environment and human health. The implementation of high-efficiency low emission coal-fired power plants is the first step along a pathway to near-zero emissions from coal with carbon capture, use, and storage.

1 Introduction

Electricity is an essential requirement for the economic development and well-being of a developing economy such as India, which has a population of 1.2 billion and an area of 3.29 million km² and is the world's second-most populous country in the world (Burke et al., 2019). In recent decades, the Indian energy sector has undergone significant transition and expansion. (Ghosh, 2002; Ghali and El-Sakka, 2004; Fankhauser and Jotzo, 2018). Currently, it is the third-largest power producer, fourth-largest user, and ranks fifth in capacity. Maintaining a stable supply of energy for a nation like India is at the centre of the scheme, as it breeds hi-tech solutions providers and is pushing rapidly towards digital transformation with cashless payment as the priority of the current governance. (Shukla et al., 2007; Inani and Tripathi 2017; Halawa et al., 2018). Despite this national agenda, it is worth noting that about 50 million rural households in India still lack access to electricity (Singh and Sundria, 2017). While India is accelerating its economic growth measures electricity demand continues to rise, backed by future ideas to increase capacity by constructing new large coal-based power plants for electricity generation. In the

energy deprived rural regions, several microgrid energy solutions are being offered in various modes such as solar, bio-digester, and similar alternatives. These micro-grids will subsequently be connected to larger low-carbon power plants, thus diverting away from coal-fired electricity production into a sustainable energy future.

The Indian government ratified the Paris climate change agreement with the United Nations on 2 October 2016 with the goal of addressing climate change and energy security problems in a reasonable way for smooth economic growth. It has been agreed to comply with the nationally determined contribution (NDC) of emission by 30 - 35%, and further curb CO₂ emission to produce 40% of cumulative electric power from clean energy sources by 2030.

Therefore alternative energy solutions for producing power such as wind and solar can be used for electricity generation as they are increasingly moving from sources of fossil fuel.

2 The Electricity Scenarios In India

2.1 Coal quality in India

Naturally Indian coal has high ash content but low sulphur content as well. Owing to its low price worldwide supply, fast transport whole has a long tradition of being the most widely used fuel in the world to produce energy from thermal power plants, but the biggest drawback of using coal to generate electricity is the emission from its combustion (Lewis and Nocera, 2006).

Research estimates that coal will continue to be the key source of fuel for electricity generation in India in the view of the abundant coal reserves providing cheap and consistent electricity sources (Malik et al., 2020; Yang and Urpelainen, 2019). The indigenous coal received by the power plants is generally sub-standard with low gross calorific value (GCV about 300kcal/kg) and high ash content (around 35-40%). The coal, as received on-site also has different consistency, size, moisture content and also contains non-coaly materials such as shales, stones, metallic tram iron parts (Bauduin et al., 2011).

The typical range of quality of Indian coal is given below:

- Gross calorific value: 45000-3000 kcal/kg
- Ash: 34 - 45%
- Moisture: 6-15%
- Volatile matter: 20-25%

But additional technological processes can be employed to improve coal quality and reduce its ash content (Bhattacharyya, 1994).

The components of the course sample are presented in Table 1. Anthracite, bituminous, and sub-bituminous type of coal are mostly found here. Just the southern part of the country includes a few

lignite deposits (Mishra, 2004).

2.2 Need for the study and importance to future research

In India, electricity generation based on coal has been at the forefront because of its abundant availability and guaranteed reliability. Since the 1970s coal-based power plants have dominated the electricity generation sector. In addition, India's energy stability, based on the projections of domestic coal reserves to sustain its rising economy, is also projected to be improved by increased use of domestic coal (Chikkatur & Sagar, 2006; Shahzad and Yousaf, 2017). The Indian coal market was previously dominated by the state post nationalization of 1973; and has been slowly revamped since the early 1990s, but still, remains heavily under the control of the central government (Shukla et al., 2007). Coal-fired power plant capacity in India is estimated to double between 2012 and 2022 contributing to nearly 75% of generation capacity (Bhushan et al., 2015).

The definition of sustainability limits for the process is relevant given the environmental context and the continuing progress of coal-based electricity generation in India. For example, electricity generation is a resource-intensive operation with a huge amount of water demand and it seems to be a major challenge with the current water crisis (Gupta, 2002; DeNooyer et al., 2016). Its environmental footprint is further exacerbated because fossil fuels pollute the atmosphere when burned, and they have other adverse environmental effects on the air that we breathe.

The major thermal power pollutants are particulate matter (PM), sulphur dioxide (SO₂), and oxides of Nitrogen (NO_x). The Ministry of Environment and Forest and Climate Change (MoEFCC) has imposed strict environmental standards on coal-fired thermal power plants working revised in December 2015 to encourage reductions in PM, SO_x, NO_x, and Mercury emissions. Environmental challenges have significant effects on climate change and last but not least; the social and political threats associated with the availability of electricity (Holdren, 1991). In the current scenario it is important to evaluate the environmental implications of the process of electricity generation using the latest technologies and simultaneously explore prospects for change at different stages of generation. Further work in this direction is required because due to its abundant availability and affordability, coal will be used in India as fuel for electricity generation for the next few decades. A reliable supply of sustainable electricity is an imperative prerequisite for a smooth growth curve, considering the fact that India is in an accelerated development phase. Another reason to pursue further research in that direction is to find new coal-based electricity generation methods and technologies with reduced environmental impacts.

3 Literature Review

Sustainability assessment of electricity generation has been a topic of great interest in recent years. While most of the researchers focused only on a specific type of pollution or environmental impact, some of them also highlighted studies in their assessment of a wider group of problems. In-depth literature

review was undertaken with the primary focus on experiments based on an LCA approach for the electricity generation process.

While analysing a product or any process the LC approach takes all the elements from cradle to grave into account. The system boundaries define the scope of analysis including the upstream processes, input materials, emissions, and downstream processes.

For the research, an intensive literature review was conducted; we did not find any current electricity model focused on life cycle as evaluation method (Table 2). This paper emphasizes on the various phases in the coal-fired electricity generation process.

A comprehensive environmental evaluation of coal mining activities and energy generation process based on lignite in Turkey from the extraction stage to the power plant gate was carried out using the life cycle assessment methodology (Burchart-Korol et al., 2016; Şengül et al., (2016). This assessment was further supported by Lelek et al., (2016)

as evidence of sustainable development in the field of energy systems, considering energy consumption as a major factor in this process even during the 1960s to 1970s

Ou et al., (2016) explained that while LCA of electricity generation has gained importance; only a few papers acknowledged the analysis of water use. Therefore, they focused mainly on water use in coal and natural gas-based power plants including research on variability due to fuel type and supply strategy, and designs for power plant and carbon capture and storage. They also considered uncertainties at different points, including the distribution of electricity, which is a key reason for inadequate electricity generation due to the insufficient consumption monitoring system and negative environmental impacts. Compare to other nations, this negatively results in higher coal usage but less power generation (Agrawal et al., 2014). Although the current model and the findings provided in this study are based on the data collected from India's coal-fired thermal power plants, it covers the standardized process and steps involved in the process of generating electricity globally. The model is developed considering the numerous factors at various stages of electricity generation.

The main purpose of this study was to develop a life cycle assessment model for coal-fired electricity generation. The impacts on the environment were quantified and divided into multiple categories. This model is constructed based on primary data for the electricity generation process in India.

4 Data Collection And Methodology

The life cycle assessment approach was adopted to estimate the environmental impacts of coal extraction from the earth to produce energy to meet the demands of human life and finally to investigate various strategies for managing solid waste produced by the electricity generation process (Vendries et al., 2020). Figure 2.presents the steps included in the study.

4.1 Data sources

Data from three power plants were obtained all of which are considered in this study.

The Ecoinvent database was also utilized as the background data in line with the Indian conditions. The author obtained primary data for this study directly from the power plants through personal visits.

This included the input data as well as the output results as provided by the concerned authorities. Data sources such as scholarly literature, secondary information like government and industrial reports were also used. The power plants included in the study account for substantial generation of electricity and are among India's largest electricity-generating companies. The author conducted personal visits to the power plant to collect primary data from the site.

When comparing the results the similarity in the electricity generation capacities of the selected powerplants provided an equivalence platform, as the results must be comparable (Mohammadi et al., 2015).

4.2 Power plants selected for the study (Geographic coverage)

The electricity producers included in the study account for major electricity generation in the country and are the principal electricity producing companies in India as shown in figure 3. The selected power plants truly represent the coal-fired electricity generation scenario of India.

Convenience sampling is a non-probability sampling technique that was used to select the power plants in this study. This method was adopted for data collection to reach power plants to participate in the study as it was simple, inexpensive, and made data acquisition possible. Indian coal (high ash) is blended with imported coal (higher grade) to form a proportion depending on the state of the facility, the configuration of the boiler, the final application of the mixed coal, as well as a plant operators personal knowledge.

4.3 Goal and scope definition

As shown in figure 4 the first step of conducting an LCA study is to identify the goal of the process. This goal of this study is to conduct the environmental assessment using a Life cycle assessment (LCA) approach for three coals fired thermal power plants in India. The research presented here is carried out for a cradle-to-gate life cycle assessment for electricity generation. It encompasses the phases of the life cycle from the mining of coal up to the disposal of ash. Inventory data on coal mining was collected using the average interventions of coal mining in India.

4.4 Functional unit

Generally, LCA studies classify various means of obtaining the same function to establish legitimate decorum of similarity while comparison. LCA studies are based on quantitative analysis the outcome of which are assessment results. Therefore, careful defining the functional unit is a very critical aspect (Hauschild, 2005). As the purpose of this study was to conduct a life-cycle inventory of electricity generated from coal, 1 KWh electricity at the consumer level is defined as the functional unit of this study in all phases.

4.5 Define System boundaries

This research addressed all the key steps in coal-fired electricity generation beginning with the mining of coal, transportation of coal, processing, combustion, and waste management/disposal. An approach that uses process-chain analysis related to the types of fuels used in each process enables all such emissions to be completely accounted for, even when they occur outside the national borders (Dones et al., 2003).

This study is based on an assessment of thermal power plants only in India. The analysis for emissions related to the construction and demolition of the plant or any other infrastructure was excluded from the system boundary (figure 5.)

The purpose was to measure the current emission rate and propose a model for coal fired electricity generation. The major inputs included raw materials, water consumption, and energy requirements. The resulting outputs present the waste generated leading to solid, liquid and air pollution (Spath et al.,1999).

4.6 Life cycle inventory (LCI):

After determining the purpose and scope, the next step is to identify and quantify the materials and emissions crossing system boundary (Clift et al., 2000) by developing a Life Cycle Inventory (LCI). The LCI is a methodology for estimating resource usage and the amount of waste flows and emissions caused by the life-cycle as defined in the scope (Gutiérrez et al., 2010) or otherwise attributable to it.

The latest data should be collected for conducting an LCA study (Hellweg and I Canals, 2014). Existing literature, data collected from the site and expert consultation through Delphi method have verified the emission and resource categories (Dones et al., 2005; Kanan et al., 2007).

In this analysis SimaPro 8.0.1 (PRé Sustainability) was used for assessment in this study. SimaPro is a professional platform that facilitates easy modelling and assessment of complex processes and resources in a meaningful way. It measures the various environmental impacts to allow the sustainability performance assessment which can leverage solutions product on process improvement. Here we have used the ReCiPe method to perform the analysis so that the results can be observed both at the midpoint and endpoint stages.

5 Interpretation And Results

Life cycle impact assessment (LCIA) is an important phase of the LCA methodology as it facilitates categorization of the environmental impacts linked with the products or process (Praene and Rakotoson, 2017). While the method of life cycle assessment of coal-based electricity generation is more or less universal it is a demanding challenge to recognise the variation between technology in different countries and it was coupled with the variation in the quality of coal.

In accordance with the guidance provided by ISO14044 (ISO 2006) standards, allocation has not been considered here. As this is a cradle to gate study, the system boundary includes the phases only until the generation of electricity (Martínez et al., 2009). The final phase of the LCA process is Life cycle interpretation.

The two main objectives of life cycle interpretation as defined by the International Organization for Standardization (ISO) are:

- To analyze outcomes, reaching conclusions, describing limitations and making recommendations based on the results of the preceding phases of the LCA and transparently disclosing the outcomes of the interpretation of the life cycle;
- To provide an easily understandable, complete, and consistent presentation of the findings of an LCA study, according to the goal and scope of the study.

Electricity generation from coal-fired thermal power plants in India produces the largest amount of CO₂ per unit of energy released by combustion. The findings of this analysis include the environmental impacts of the selected coal-fired thermal power plants using the ReCiPe method from the cradle to gate perspective.

5.1 Global Warming and climate change potential:

The Global Warming Potential (GWP) is measured in kg CO₂ equivalents per kWh of electricity generation. The total GWP for the three power plants (PP1, PP2 & PP3) is 1,100 g CO₂eq/kWh, 1,287 g CO₂eq/kWh and 898 g CO₂eq/kWh respectively as shown in figure 6. PP1, PP2 uses Indian coal for electricity generation which is procured locally, while PP3 uses imported Indonesian coal. It is clearly evident from the findings that imported coal has lowered GHG emissions compared to thermal power plants running primarily on Indian coal.

Murray and Lopez (1996) originally investigated the DALY-concept for the World Health Organisation which Hofstetter (1998) later introduced into LCA. Evaluation of the adverse effects (damage) on human health using the concept of 'Disability-Adjusted Life Years' (DALY) when implementing a Life cycle assessment approach (Norris, 2006; Kobayashi et al., 2015; Arvidsson et al., 2016). As illustrated in Figure 7. the disability-adjusted life years (DALY) at three geographical locations in India for coal based

electricity generation is presented. The estimation from PP1 shows 4.00E-07 DALY per kWh, PP2 shows 4.20E-07 DALY per kWh and PP3 that uses imported coal shows that total human health impact is 2.90E-07 DALY per kWh of electricity generation (from upstream and combustion processes) due to climate change.

5.2 Comparison with existing Literature

The life cycle assessment results from this study were used to perform a comparative assessment of emissions reported from other countries as presented in figure 8. Only one LCA study for coal-fired electricity generation conducted in India was found and therefore power plant which is used for comparison with our results. The results obtained in this study have been compared with international studies from Japan, Thailand, U.S., Turkey, Europe, U.K., Pakistan Netherlands, and Mauritius.

CO₂ emissions from PP2 (India) are the highest and the emission observed from Turkey is at the minimum.

The higher global warming potential of the Thermal Power Plant in India is evident from the use of coal with high ash content with old technology which does not provide optimum efficiency.

This study listed various impact categories such as ecotoxicity, climate change, ozone depletion, acidification potential, photochemical oxidation based on inventory data for life cycle assessment.

The data assessment produced characterization results related to the relevant data on eutrophication potential and acidification potential as shown in Figures 9 and 10 Emissions towards GWP are expressed in kilogram of CO₂ equivalents as shown in fig. 11

Figure 11 presents the GWP in kg CO₂ equivalents per kWh of electricity generation. The total GWP (upstream and combustion processes) due to coal thermal power plants is 876 g CO₂ eq/kWh and 987 g CO₂ eq/kWh, respectively, whereas around 526g CO₂ eq/kWh from combustion imported coal PP3, respectively. The results show that Indian coal has higher global warming impacts from GHG emissions when compared to imported coal.

NO_x causes damage to vegetation and aquatic life through acid rain. It is also a precursor for photochemical smog contributors (Ozone, PAN, HNO₃) in troposphere which causes damage to the human respiratory system as it affects Ozone (O₃) balance. NO_x can contribute to eutrophication and influences ecosystem by nutrient overload. The Photochemical Ozone Creation Potential of coal electricity generation are presented in Figure.12

5.3 Summary and suggestion for each power plant

5.3.1 Power plant – Chhattisgarh (PP1):

PP1 is a conventional power plant running on low load factors at an efficiency of just 30%

(net efficiency, higher heating performance - HHV). It operates on the old pulverized coal technology which is the most commonly used alternative for coal-firing in India as well as globally.

PP1 primarily uses Indian coal for power generation, which has high ash content that contributes to the creation of huge quantities of fly ash. The plant management and authorities are working to divert this waste to other sectors where it can be used as raw material, such as cement and bricks manufacturing industry. Gigantic heaps remain stacked up, even after extensive efforts to regulate the tremendous quantity of fly ash generated.

This power plant was built before 1980. Because of the age of the power plant, reconstruction and upgrade is a cost-effective choice to increase its performance.

Retrofitting would boost the setting of the plant and add to the existing capacity of power generation at an additional cost.

5.3.2 Power plant – Bihar (PP2):

All the units of PP2 have adopted subcritical technology which can produce power at an efficiency of about 33%. The power produced here covers the demands of the northern, western, eastern, and north-eastern regions of India. Though Sub-critical technology has been in service for a while now; through renovation, modernization measures, there is a scope to improve the efficiency and performance of these plants. As a large quantity of fly ash is generated here, the authorities initiated the process of making fly ash bricks at the power plant site itself. This intervention led to the implementation of a local government policy that is mandatory to use of ash bricks prepared, within a 100-kilometer radius from the power plant site. Only fly ash bricks which minimise the use of traditionally prepared bricks should be used for large national highway building schemes and other developmental projects.

5.3.3 Power plant – Mumbai (PP3):

PP3 is located Eastern suburbs of Mumbai and has an installed capacity of 1580 MW. This unit of capacity 500MW was installed in the mid-1980s which can run on gas or oil. Due to the decline in the supply of gas this unit is only placed into service when demand rises urgently or unexpectedly. While this is currently, a standby unit the company expects to be able to use it in the normal stable generation of electricity.

It is a subcritical thermal power plant supporting the regional grid. The coal is sourced for this plant is sourced entirely from Indonesia. A regulated system for the management of sulphur oxide the flue gas desulfurization (FGD) unit and an electrostatic precipitator is installed for control of particulate matter.

PP3 has a well-defined environment policy and management system in place. The parent company has established a Corporate Safety, Health & Environment Department (C-SHE) that is responsible for all environmental and safety activities in the company.

In the supercritical unit improved efficiency is observed as it utilises higher temperature and pressure, lower fuel consumption per unit of energy, and decreased greenhouse gas (GHG) emission. The reduction in CO₂ emissions units would be between 8- 10 percent. Lower fuel consumption has a direct effect on reducing other emissions as well. Supercritical units operate above critical point parameters at 225.56 kg/cm² and 374.15⁰C, where the density of water is the same as that of steam. Also, the latent heat is zero at this point, restricting the development of steam-water mixed-phase resulting in reduced fuel heat input. It is implied that subsequent attempts should be made to prepare for more advanced and effective ultra-supercritical technology.

6 Model - Coal Electricity Environmental Performance Assessment (Ceepa)

An comprehensive literature analysis was undertaken, but no LCA model for the electricity generation was identified. In order to construct the proposed model, other existing LCA models for waste management and road development were used as a reference (Birgisdóttir et al., 2007).

The model for Coal Electricity Environmental Performance Assessment (CEEPA) is presented as Figure no. 11. The key subject of the model are emission and waste generation (variables) and their impact categories. Variables and selected impact categories have been used to propose the model in this study. SimaPro software was used to analyze the data collected from the three power plants and the model was developed based on the results obtained from the impact categories.

A systematic literature analysis of studies from different countries for life cycle assessment of electricity generation from coal is the main basis of the development of this model.

The emissions and environmental impacts from these studies were noted. Assessment of coal-fired power plants from India was conducted using the LCA approach. The results obtained from this assessment were combined with the observations extracted from the existing literature to develop the set of total outputs of coal-fired electricity generation in India.

The model was developed taking into consideration the following points: -

6.1 Resource inputs:

The inputs in this section include the overall resources, raw material, natural resources, fuel consumed, and other chemicals utilized in the process of electricity generation. Coal is the main fuel burnt for the

generation of electricity. It is mined from the earth; before the fuel is burnt in the furnace it undergoes further refining (pre-treatment).

Environmental emissions and waste:

Environmental emissions are classified as emissions to the atmosphere, waterborne emissions, and solid wastes. The data about plant emissions was collected from the environmental departments in the power plants.

6.2 Atmospheric Emissions:

Carbon dioxide, carbon monoxide, nitrogen oxides, and particulate matter, and sulfur oxides are the most common sources of emissions to the air.

6.3 Waterborne Emissions:

After the wastewater undergoes treatment it still contains an average quantity of toxins which is discharged from industries and other receiving water bodies. Amongst the various parameters tested for waterborne emission the most common ones are dissolved solids, suspended solids, biological oxygen demand (OD), chemical oxygen demand (COD), acid, chromium, and ammonia.

6.4 Solid Wastes:

This segment covers waste generated from various sources in a solid form which is diverted to landfills or follows a disposal trend of incineration. Examples of main solid wastes pollutants generated from the coal-fired electricity production process are fly ash by burning coal, slag, and particulate matter from the combustion of fossil fuel that is captured by the control devices for air pollution.

All the emissions from coal-fired electricity generation have been included in this section. These variables are direct emissions from the power plants. These are also called midpoint indicators.

6.5 Impact categories:

Here the midpoint indicators were categorized to the environmental impact chain up to final impacts, which are then classified under human health damage, damage to nature, and damage to the human environment.

The following impacts have been analyzed from the process of electricity generation from coal-based power plants.

- Fossil fuel depletion
- Land-use change
- Ecotoxicity
- Human toxicity
- Climate Change (Human Health and Ecosystem)
- Particulate Matter emissions
- Photochemical Oxidants
- Eutrophication
- Waterborne toxicities
- Ozone Layer Depletion
- Acidification

CEEPA (Coal Electricity Environmental Performance Assessment) - LCA model proposed for a coal-fired thermal power plant in India.

7 Significance Of The Findings:

The findings obtained from the life cycle assessment methods provide a larger picture of the environmental degradation that, if effective measures are not taken would be exacerbated over time. This research can serve as a benchmark for policymakers and other researchers to analyze the environmental effects of coal-fired electricity generation and comparative analysis. This result indicates that coal-fired thermal power plants are responsible for introducing better and cleaner technology to minimize particulate matter and greenhouse gas emissions by strictly complying with the clean air Act by the Ministry of Environment and Forest (MoEF). It's worth noting that the electricity generating companies believe that the mandate clean air act provides no incentives for their efforts of pollution reductions, so it would be highly desirable to imply a tax on real-time emission which will be a motivating factor to foster clean energy generation.

In a rapidly industrializing economy such as India, it is important to note that electricity demands are raising every day with the shift in living standards and the integration of the existing energy-deprived regions into electrified villages. We will see massive investments in solar and wind energy generation systems; coal is still the king and will continue to be a major fuel for electricity generation for at least a few more decades to come. The projection of the environmental impacts in this study creates an opportunity to attempt pricing the carbon emissions which will also improve the health impacts due to coal based electricity generation.

7.1 Limitation of the proposed model

This study is an attempt to provide a model for the life cycle assessment of electricity based on data from Indian power plants. The overarching objective of this research was to develop a framework model for the LCA process of coal-fired electricity generation as described in the beginning. The key steps in the electricity generation process have been identified including the input component factors that shape the basic framework, the output emissions, and the waste produced as well as the direct impact on the categories. This paves the way for prospective researchers to investigate LCA of coal-fired electricity generation through numerical simulations that have not been executed with the current proposed model.

8 Recommendation

The study indicates that coal-based electricity generation has significant impacts on natural resource consumption, environment and surrounding ecosystem, and human health. For all future coal fired power plants, high generation, low emission preparation and set up should be mandatory for construction along route to near zero emission

The findings from this study demonstrate that all stages of the process of the overall process of electricity generation have significant environmental impacts. Coal mining requires a lot of water in addition to atmospheric pollution, natural habitat degradation, and social-economic damages. The combustion of coal for the generation of electricity is a water-intensive process that also leads to environmental pollution and the release of toxic gashes compounds in the atmosphere.

India needs to shift aggressively towards cleaner technologies like Supercritical (SC) and ultra-supercritical (USC) systems of thermal power generation.

8.1 Government initiatives to improve the efficiency of coal based Thermal Power Plant in India

Several steps have been taken by the government to improve the efficiency of coal based thermal power plants & improve the air quality in the vicinity of these plants. The supercritical technology has been made mandatory for all the upcoming Ultra Mega Power Projects (UMPPs). Intensive efforts are being invested towards research and development to enhance the targeted efficiency and viability of Advanced Ultra Supercritical Technology (A-USC) with a 10% improvement over the supercritical unit. About 7751.94 of outdated and obsolete units have already been superannuated to replace older inefficient coal-fired thermal power plants by super critical units till date. In addition to this, a policy of automatic transfer has been initiated by the Government of India (Ministry of Coal), for the Letter of Assurance (LOA)/Coal linkage (granted to old plants) to new (proposed) super-critical units. The BEE (Bureau of Energy Efficiency) launched the Perform Achieve and Trade (PAT) scheme under the National Mission on Enhanced Energy Efficiency according to which 154 thermal power stations are individually targeted for improving efficiency. Particulate matters (Fly ash) from flue gases are captured by the installation of a high-efficiency Electrostatics Precipitator (ESP). Low NO_x burners are installed for

reducing NO_x emission from flue gases. Tall stacks (275 meters) help dispersion of flue gases and thereby controlling SO₂ emission by reducing the concentration of polluting gas at ground level (Ministry of Power, GOI, 2017). The Coal Electricity Environmental Performance Assessment (CEEPA) model presented in this study is based on a single score method that encourages assessment from multiple angles of various ecological impacts and can therefore serve as a realistic guide for policy makers and public administrators. From recent research conducted by Narula et al., 2017, it emerges that the Indian government mainly considers affordability as a major factor in electricity generation over environmental sustainability. Government should support accelerated installation of Supercritical power plants, the implementation of which has already been demonstrated in India through funding allocation. Forsyth, 2007 has illustrated the importance of technology transfer along with the incentivization and reformation of formal policy mechanisms such as the Clean Development Mechanism (CDM). Clean coal, as well as carbon capture and storage, are highly recommended for the quality of Indian coal; therefore, investment in technology development, R&D should be prioritized.

9 Conclusion

As a developing country, India needs to assess the viability of its energy market to help change and introduce the most feasible options for the future. In an attempt to contribute towards this goal, the current study presents a sustainability assessment of the electricity generation from power plants in India, considering few major power plants and electricity technologies currently operating in the country.

Approximate estimation of the quality and quantity of coal reserves and mapping of the uncertainties would be useful to estimate the productivity of power generation and waste handling leading to improved energy planning.

The building of a more efficient power plant means, the transition from subcritical to supercritical and Ultra-supercritical Technology. Among various other strategies for reducing CO₂ emissions in the electricity sector introduction of carbon capture storage will help to cope with related challenges. Clean coal technologies are highly recommended for the quality of Indian coal; therefore investment in technology development, R&D should be prioritized. Integrating low carbon technology options with the current study by calculating the appropriate weightage of different sources of fuel for electricity generation would facilitate the estimation of Sustainable Energy.

Declarations

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- Conception or design of the study: BS, SU
- Data collection: BS
- Data analysis and interpretation: BS, SU
- Drafting the article: BS
- Critical revision of the article: SU
- Final approval of the version to be published: BS,SU
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Tables

Table 1: CONSTITUENTS OF COAL	
Constituent	Percentage
Carbon	38-60
Volatile matter	1-36
Silicon oxide	3-43
Aluminum oxide	45-63
Iron oxide	15-36
Calcium oxide	2-20
Magnesium oxide	Trace-12
Trace magnesium oxide	Trace-5
Ash	3-60
Sulphur	0.3-8.3
Phosphorous	Less than 0.5
Source: Mishra, 2004	

Table 2: Literature review table for coal-fired electricity generation

Sr. No	Author	Research Gaps & Future Work
1	Mishra, (2004)	This article has a limited focus and this highlights the radioactivity effects. In India several papers look only at a specific phase. So a comprehensive LCA research in this area has not been done.
2	Ruether et al., (2004)	Accurate estimation of GWP for construction and mining as well for stack emissions are important to estimate life cycle GHG emissions.
3	Rebitzer et al., (2004)	If combined with life cycle costing (LCC), which can be most efficiently based on LCA, though is not elaborated in this paper, two of the three pillars of sustainable development, environment, and economics, are represented.
4	Chinh et al., (2007)	This paper emphasizes only on the inventorization of air emissions from coal-fired power plants. Gap emerging is that the focus is only on procurement and scoping impact assessment and improvement has not been carried out in this study.
5	Di et al, (2007)	The main limitations are related to the LCA methodological approach, especially data quality and collection, time boundaries, and process modeling. There is a need for global guidance to guarantee an efficient allocation of resources and to help ensure reliable quality data. To address this need, it is essential to develop credible LCAs databases that have uniform data requirements to allow consistent modeling and reliable decision support.
6	Koornneef et al., (2008)	At present only pilot projects have been carried out in India, once the technology is substantially commercially viable, similar research should be explored in India.
7	Chopra, (2009)	The energy requirement for production and dismantling, material and energy requirement for maintenance of the infrastructure, and waste processing and recycling after dismantling has not been included in the study due to data limitation. Data limitations comprise mainly uncertainty and absence of data on the effect of CO ₂ capture on important emissions to the atmosphere.
8	Zhang and Cheng(2009)	Similar studies on low carbon technologies associated to LCA are missing in the Indian context
9	Schreiber et al., (2010)	In order to reduce the emissions due to fossil fuels, next level of technologies such as Integrated Gasification Combined Cycle (IGCC) combined with Carbon Capture and Storage (CCS) could play an important role. Similar LCA studies explain the impacts of implementation of these technologies should be carried out in India.
10	Santoyo-Castelazo et al.,(2011)	Basic LCA data regardingCO ₂ pipeline and storage site have been extracted from the literature . The focus is only on CO ₂ emissions but NO _x , SO _x , CFCs and airborne inorganic particles such as fly ash, soot, and other trace gas species should also be studied.

13	Masanet et al., (2013)	No complete LCA has been performed yet on coal combustion power plants with CCS, with important gaps identified in terms of the consideration of parts of the supply chain, alternative technologies and potentially important impact categories
14	Agrawal et al., (2014)	Focuses only on climate change impacts on human health.
15	Bouman et al., (2015)	Depending on timeframe and scope, there are examples of detailed inventories in which fugitive emissions are addressed on a component-specific level that could be adapted to specific conditions.

Table 3: Life Cycle inventory for coal fired power generation - Average of the three power plants

Input	Unit	Total
Coal	kg	376.63
Limestone	kg	3.18
Diesel	kg	2.97
Electricity	kWh	46.22
Water	kg	4368.36
Output	Unit	Total
N	kg	0.04
P	kg	0.02
CO ₂	kg	698.73
SO ₂	kg	19.3
NO _x	kg	3.01
N ₂ O	kg	1.43
CH ₄	kg	2.01
TSP	kg	43.11
COD	kg	11
BOD	kg	0.12
SS	kg	0.17
Soild waste	kg	10.39
Flyash	kg	103

Figures

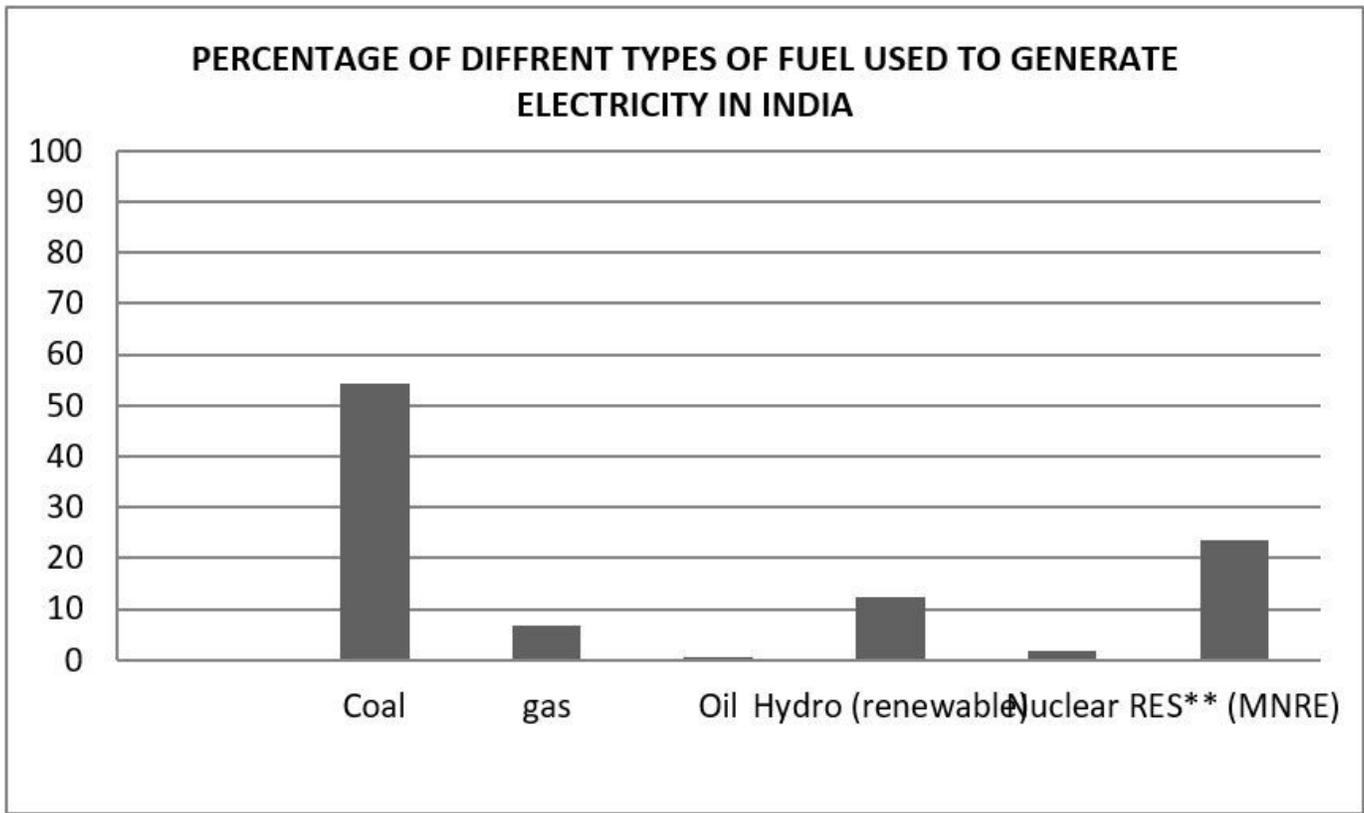


Figure 1

Fuel wise electricity generation in India Source: Central Electricity Authority (CEA), 2020

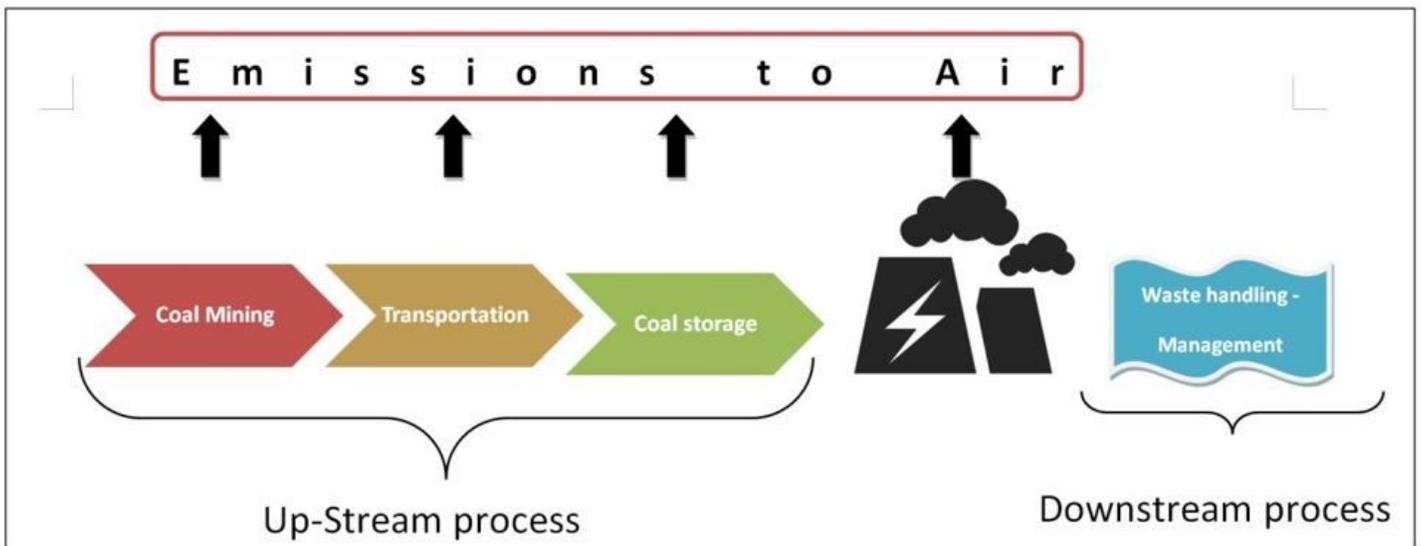


Figure 2

Steps in the process of coal fired electricity generation

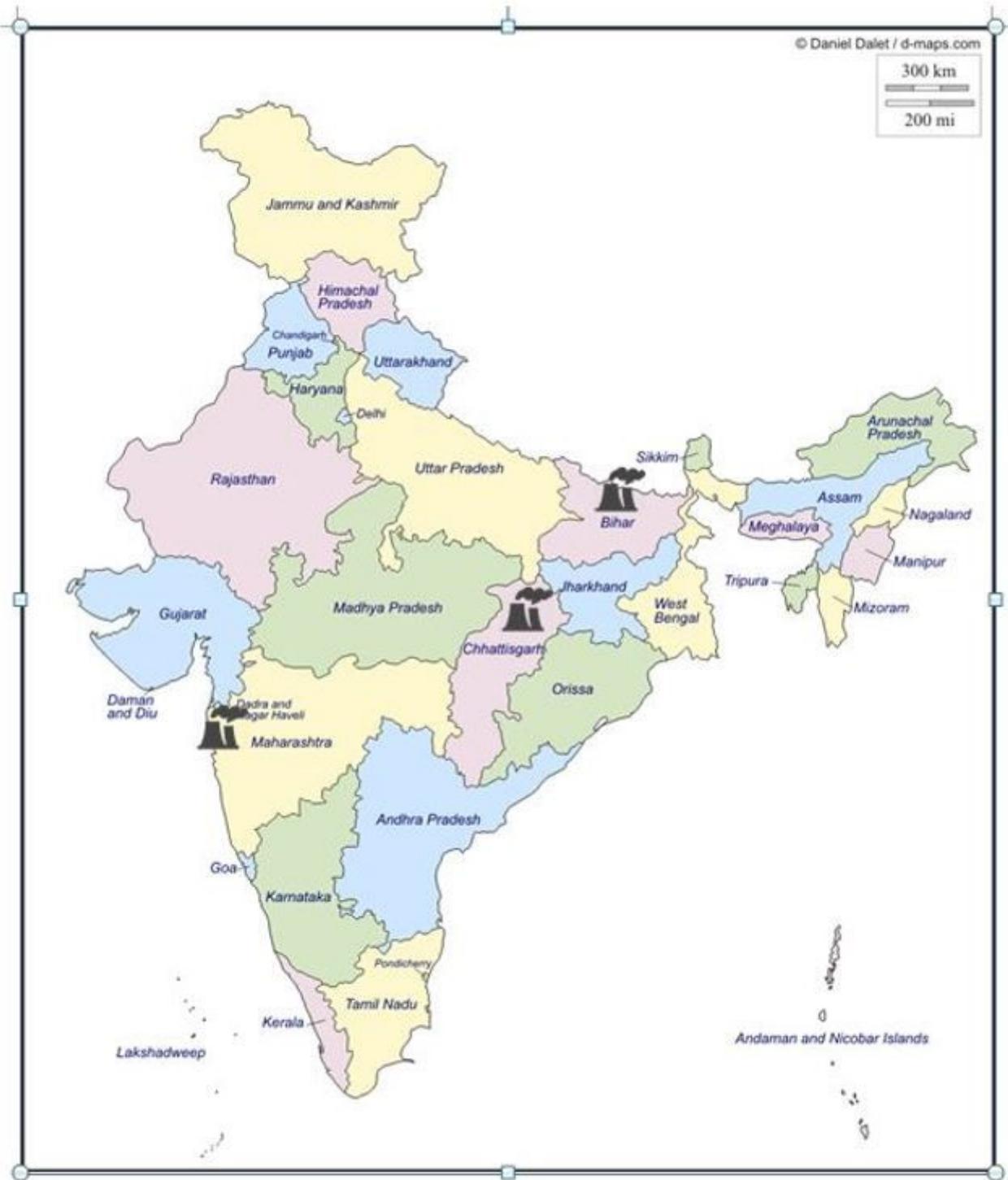


Figure 3

Location of power plants selected for the study Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

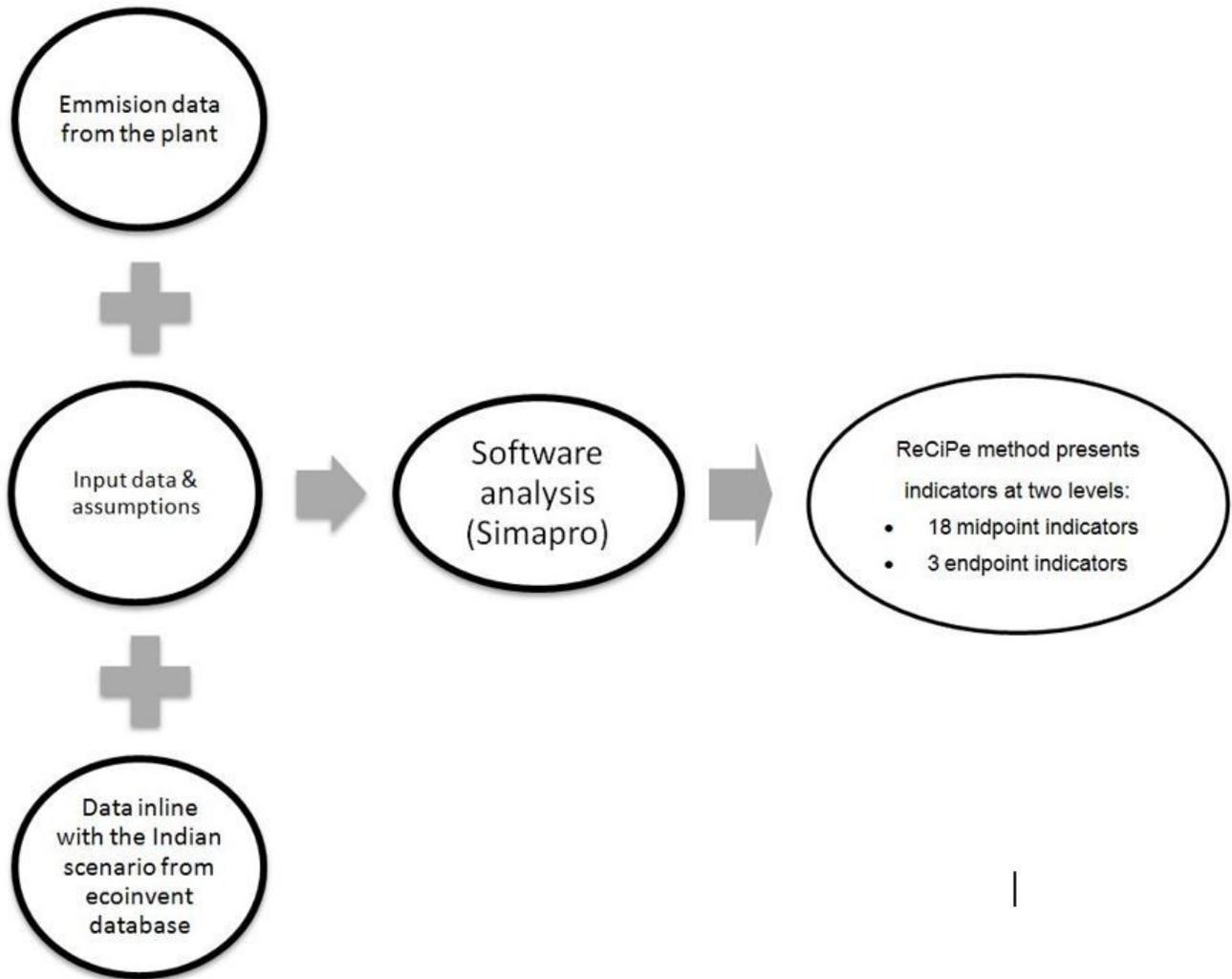


Figure 4

Diagram showing methodology procedure of the assessment

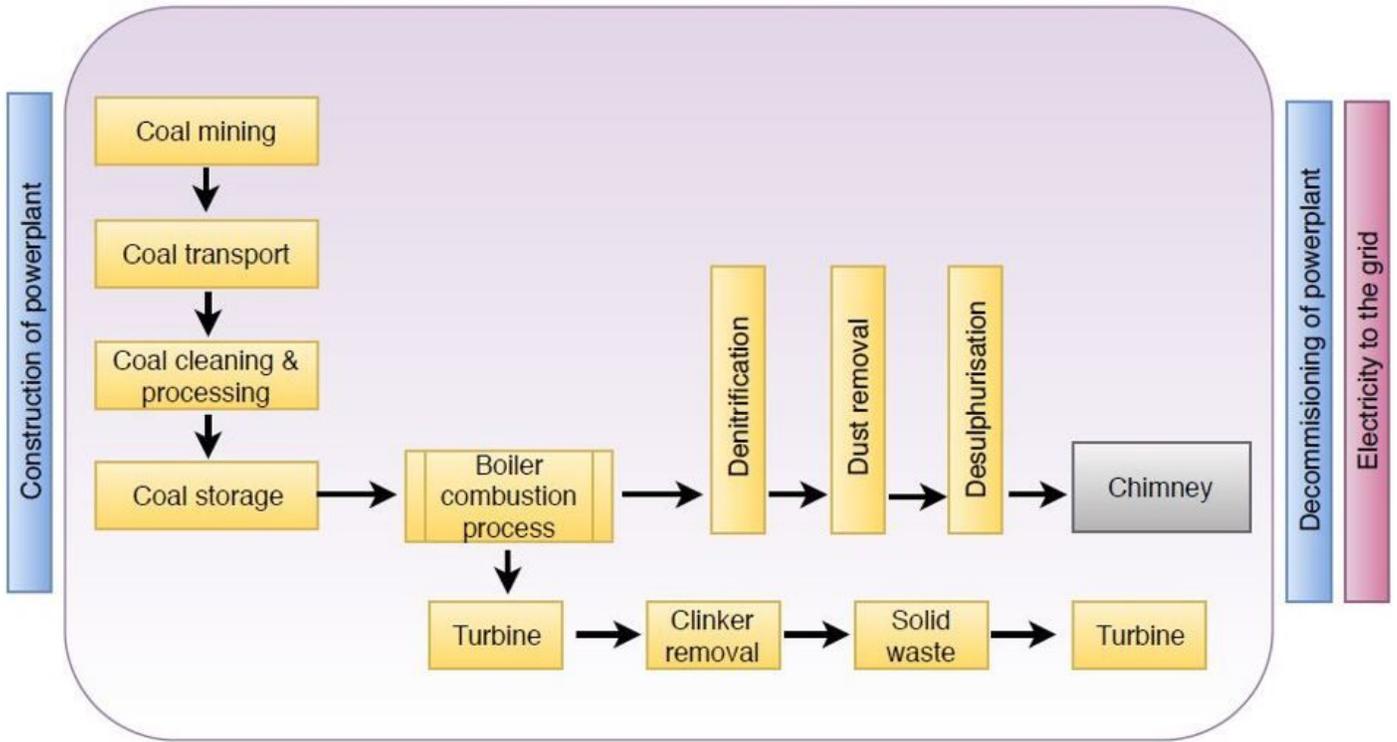


Figure 5

System boundary for LCA of coal-based electricity generation

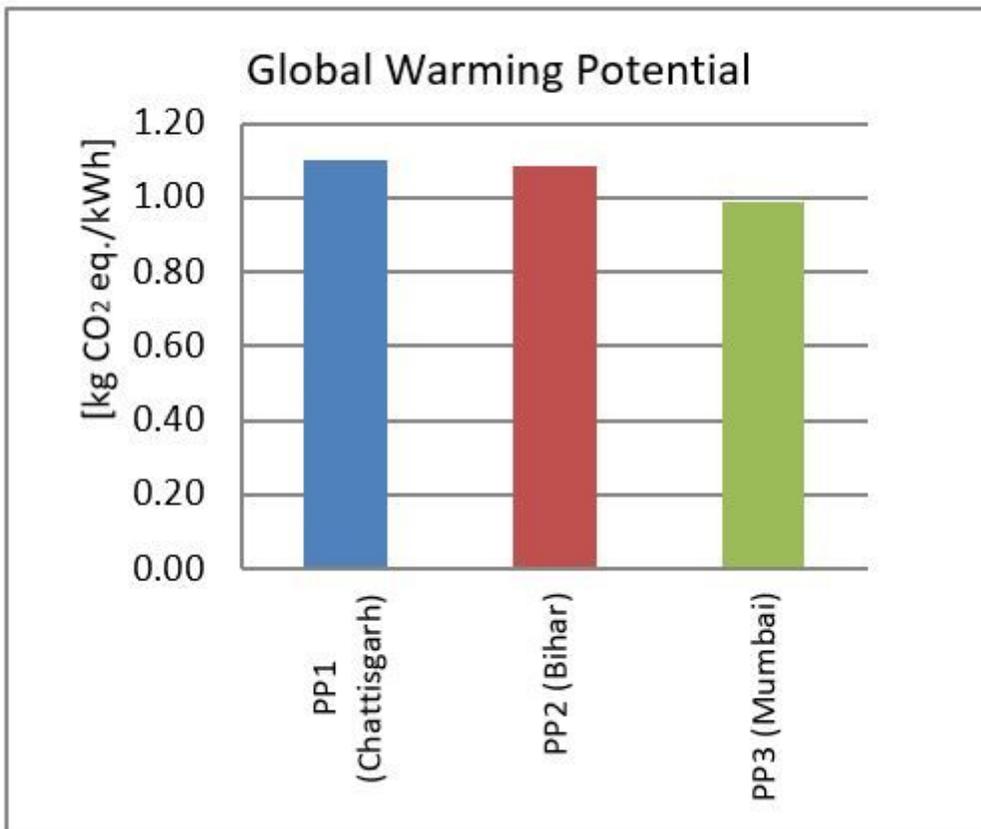


Figure 6

Global warming potential of 1kWh electricity generated in coal fired thermal power plant

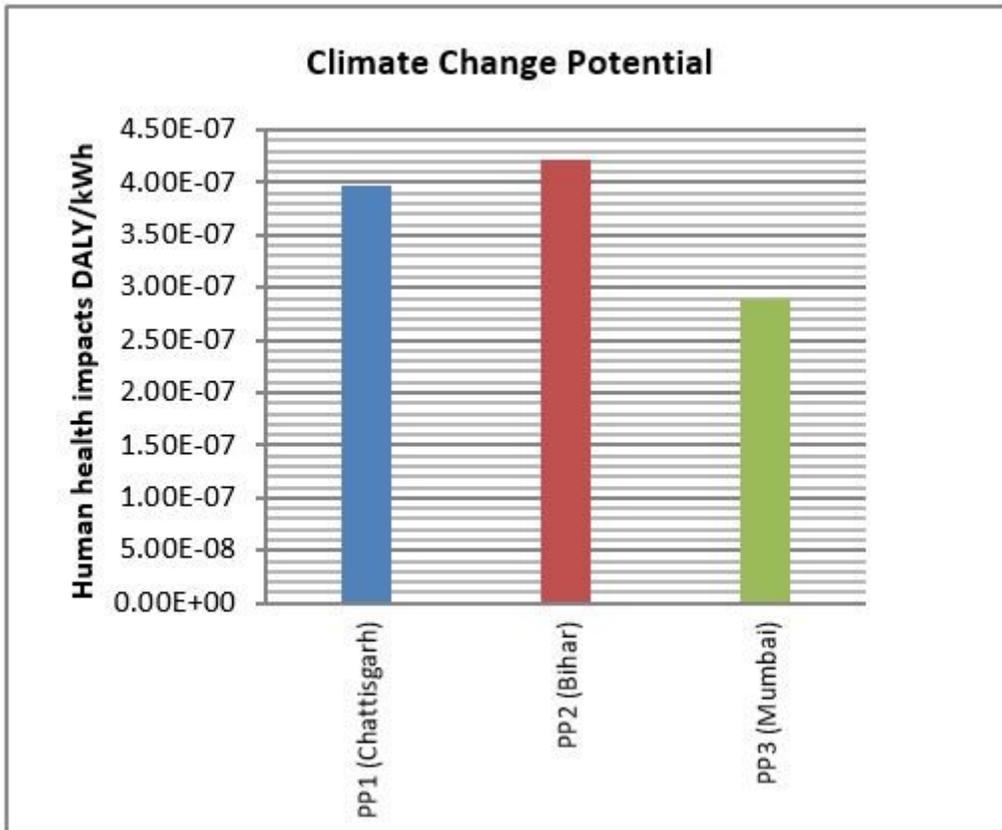


Figure 7

Climate change impacts on Human health (DALY) for 1kWh electricity generation

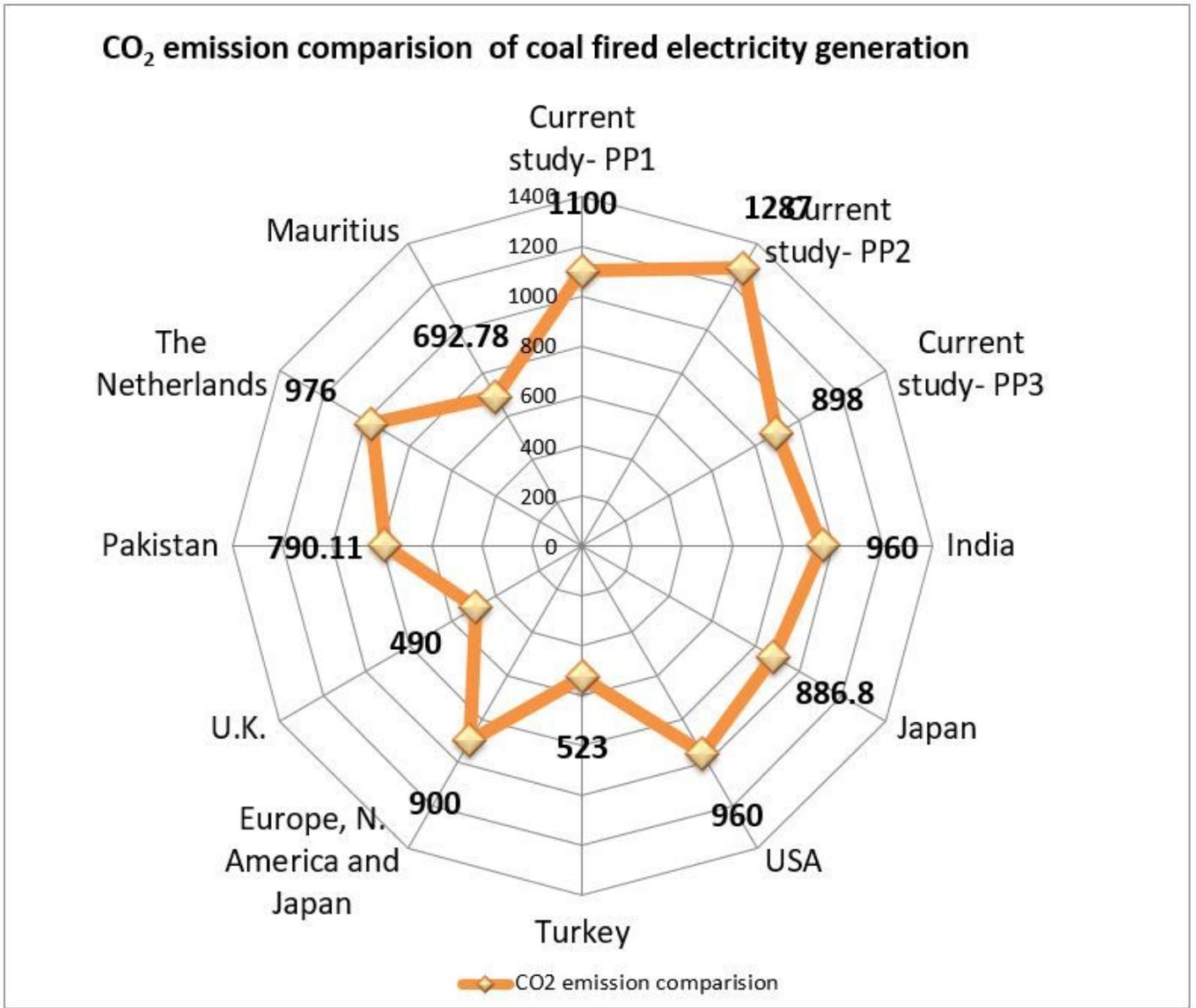


Figure 8

CO₂ emission comparison between countries

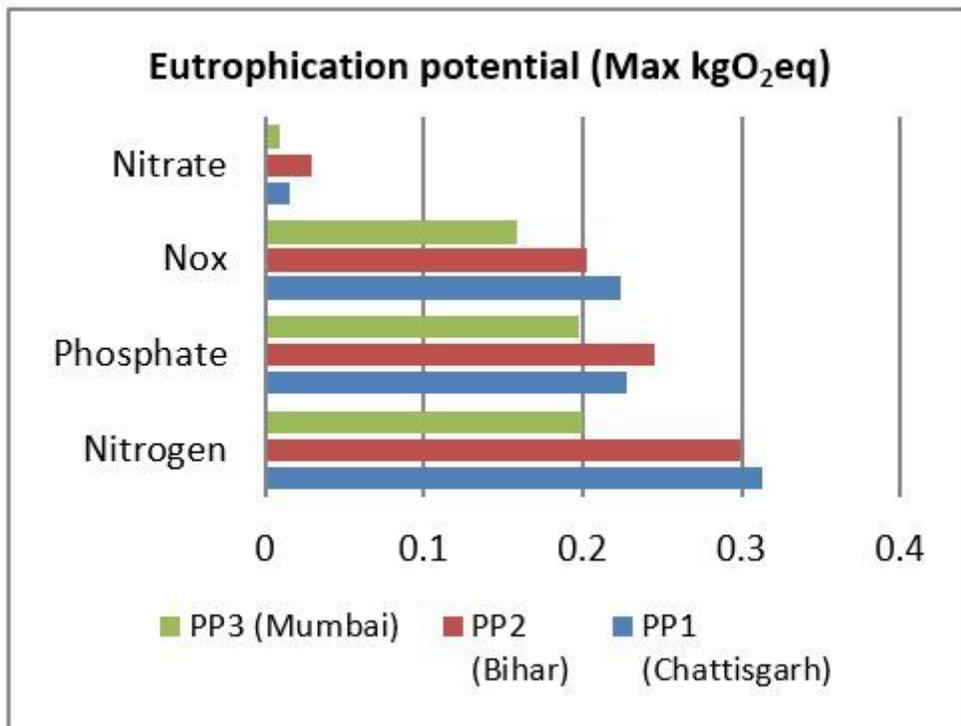


Figure 9

Eutrophication Potential of coal electricity generation

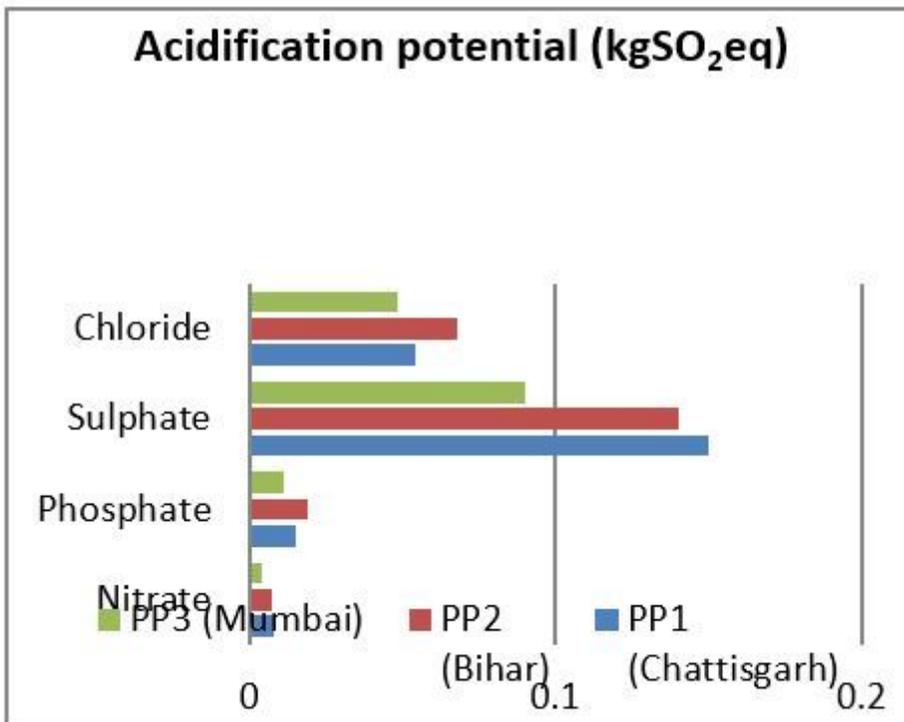


Figure 10

Acidification Potential of coal electricity generation

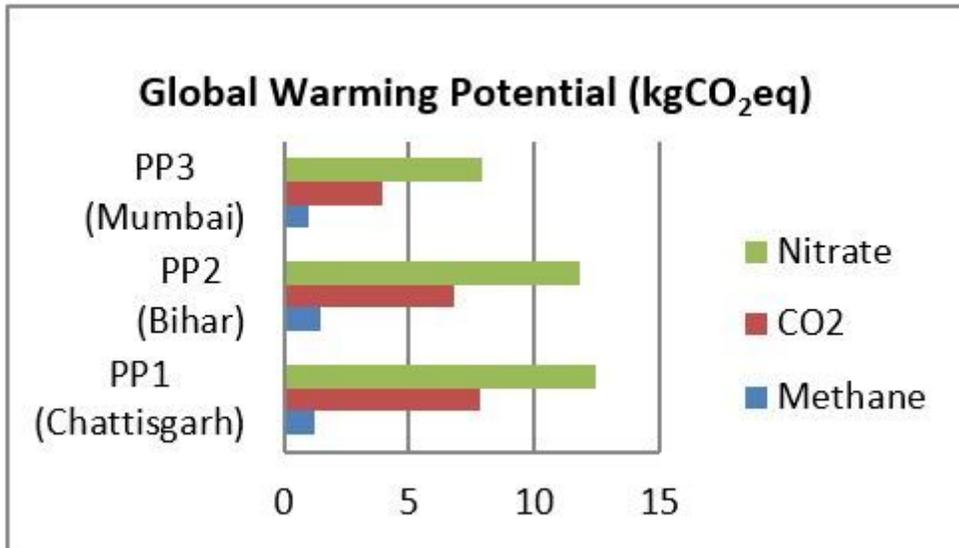


Figure 11

Global Warming Potential of coal electricity generation

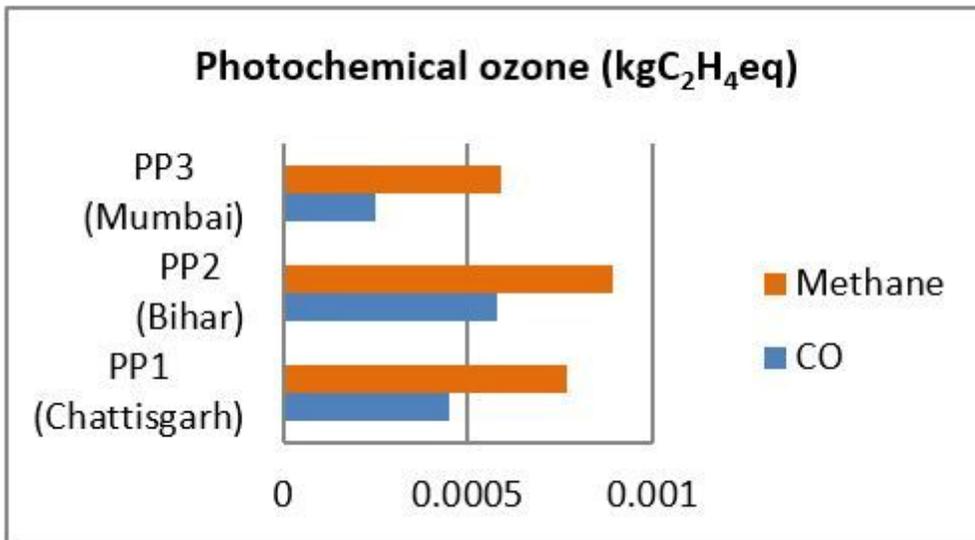


Figure 12

Photochemical Ozone Creation Potential of coal electricity generation

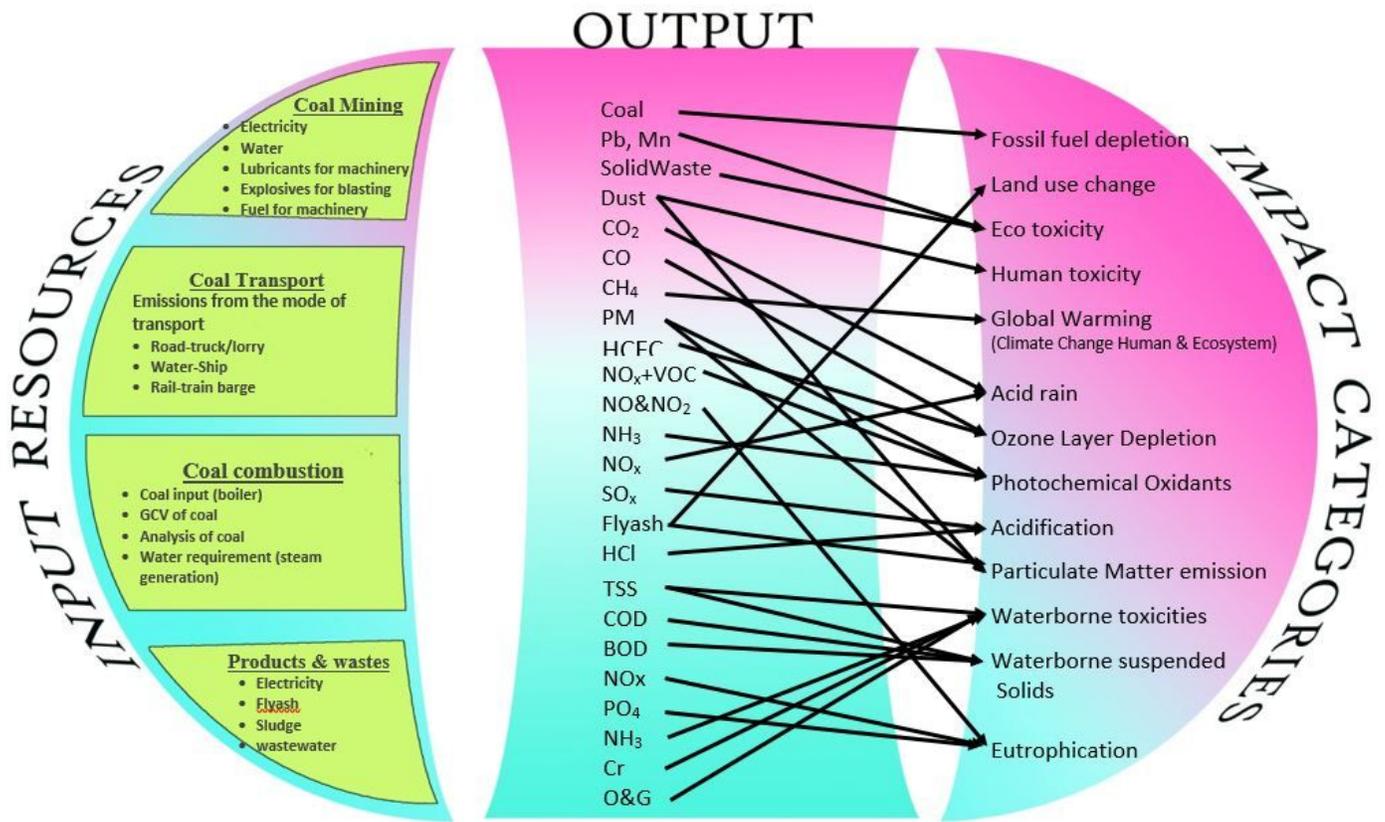


Figure 13

LCA model proposed for coal-fired thermal power plant