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Research on Quantifying Carbon Footprints in Indian Coal Mines and Exploring Pathways to Carbon Neutrality

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Abstract: ***The use of coal as the main energy source presents serious problems for environmental sustainability and carbon emissions, particularly in developing nations like India that are growing quickly. The purpose of this study is to calculate the carbon footprint of coal mining activities in India and assess practical routes to carbon neutrality. A thorough evaluation of coal mining's effects on climate change and regional ecosystems is necessary, as it accounts for almost 50% of India's total CO2 emissions [6] [1].***

Keywords: Carbon Footprint, Indian Coal Mines, Carbon Neutrality, Web-based Application, Greenhouse Gas Emissions, Sustainability, Clean Technologies, Afforestation Offsets, Carbon Credits, Emission Calculation Algorithms.

I. INTRODUCTION

With more than 50% of the country's electricity coming from coal and almost 50% of its total carbon dioxide (CO2) emissions coming from it, coal's importance as an energy resource is still widely recognized in India's economy [6] [3].

The problems caused by coal mining are becoming more serious as India tries to strike a balance between environmental sustainability and economic growth. In addition to increasing greenhouse gas emissions, the extraction and burning of coal has a significant negative influence on human health and local ecosystems. According to studies, the emission of harmful compounds from coal mining operations can cause soil erosion, water contamination, and negative health impacts [6].

Coal mining operations must embrace sustainable practices and look into ways to become carbon neutral given the urgent need to combat climate change and lower carbon footprints worldwide. The goal of carbon neutrality is to achieve a net-zero carbon footprint by using sustainable practices, like afforestation and the use of renewable energy sources, to sequester or offset the same amount of carbon that is emitted [4, 2, 6]. In order to do this, the Indian government has launched a number of initiatives, such as the National Action Plan on Climate Change (NAPCC) and pledges to adopt renewable energy, that are intended to encourage the use of clean technologies and lower emissions in the coal industry [5].

Despite these endeavors, a thorough comprehension of the carbon emissions linked to coal mining and the efficacy of possible mitigation tactics is still lacking. By calculating the carbon footprint of coal mining activities in India and determining workable routes to carbon neutrality, this study seeks to close this gap. This study will evaluate the present state of carbon emissions from coal mining through in-depth data analysis and look at a number of tactics, including joint ventures, carbon capture and storage (CCS) technology, and agricultural carbon sequestration.[4], [2], [5].

II. BACKGROUND

Historically, coal has been a vital component of India's energy sector, contributing about 50% of the nation's electricity production [6] [3]. This dependence on coal can be attributed to its cheap cost as compared to alternative energy sources and its widespread availability. But as the negative effects of coal mining on the environment become more obvious, there is a pressing need to have these conversations about how sustainable this energy source is.

The utilization and mining of coal have a substantial impact on the emissions of greenhouse gases, specifically carbon dioxide (CO2). India's coal industry accounted for about half of the country's CO2 emissions in 2021, highlighting the critical need for efficient emissions reduction plans[6]. Additionally, there is a strong correlation between coal mining activities and serious environmental damage, such as deforestation, water pollution, and land degradation.

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According to studies, mining operations frequently upset the surrounding ecosystems, which results in a decline in biodiversity and the pollution of water bodies with heavy metals and other contaminants.

The health effects of coal mining are not limited to the mining areas; elevated levels of exposure to air and water pollution have been associated with a number of health problems, including as cancer and respiratory disorders. Moreover, methane (CH4), a strong greenhouse gas that aggravates climate change, is released as a result of coal mining[6]. These difficulties have raised questions about whether coal can continue to be a sustainable energy source in the long run and the necessity of switching to greener alternatives.

Acknowledging these problems, the Indian government has launched a number of initiatives to lower carbon emissions and encourage sustainable coal industry practices. The government's intention to lessen the environmental effects of coal is demonstrated by programs like the National Action Plan on Climate Change (NAPCC) and pledges to boost the percentage of renewable energy sources [4],[2] [5]. However, a thorough grasp of the present emissions situation and the possibility of putting in place workable routes to carbon neutrality are prerequisites for these policies' efficacy. The coal industry has a significant possibility to achieve carbon neutrality, which is defined as reaching a net-zero carbon footprint by balancing emitted carbon with an equivalent quantity sequestered or offset [6].

Adopting renewable energy technology, putting carbon capture and storage (CCS) systems into place, and improving carbon sinks through afforestation are some ways to reach carbon neutrality.

This research aims to investigate these pathways while quantifying the carbon footprint of coal mining operations in India, ultimately contributing to a more sustainable future for the nation.

III. LITERATURE REVIEW

A. *Carbon Emissions from Coal Mining*

Coal mining must be revisited when evaluating anthropogenic greenhouse gases such as CO2 and methane (CH4), as they are coal mining’s most significant emissions. It has been estimated by Sharma (2021) that coal mining contributes nearly half of the overall CO2 emissions in the country India. The processes of extraction and combustion of the fuels are known to cause excessive greenhouse gases emission which amplifies global warming. Kumar et al. (2022) further assert that methane emissions from underground coal mines could be up to 20 times more in terms of global warming potential than carbon dioxide over a hundred years implying that there are problems that need to be solved as a matter of urgency. Effective monitoring and quantification of these emissions however, is quite crucial as studies have shown, to comprehend their implications on climate change and their control thereafter.[6]

B. *Environmental Impacts of Coal Mining*

The adverse effects of incinerating coal on the environment cannot be reduced to just the carbon emissions. Moreover, mining activities can also cause serious ecological damage endangering local ecosystems and water bodies. Mishra et al. (2022) have reported that the extraction of coal directly impacts the land as it directly changes the land use pattern causing loss of forest cover and endangering the wildlife [3]. In addition, the by-products of mining activities in isolation may be toxic enough to pollute drinking water to the nearby residents [6]. The net effect of such changes in the environment is significantly drastic, resulting to ecological disturbance for great periods of time.

C. *Sustainable Mining Practices*

Sustainable practices are more and more accepted as the answer to the threats that the coal mining presents to the external environment. Singh et al. (2023) recommend the use of green mining technologies, like bio-reclamation and other best management practices, so that the environmental impacts are reduced to a bare minimum [4],[2]. Furthermore, there is a need to make use of eco-friendly energy sources like wind and solar.

IV. RESEARCH OBJECTIVE

The coal mining activities practiced in India will be evaluated in terms of understanding the effect of these activities on the emissions of GHGs and the steps that can be taken to ensure that they will be able to achieve zero emission targets. The study objectives can be defined as follows:

A. Estimation of Carbon Emissions:

To estimate possible carbon emissions of coal mining phases such as coal extraction, transportation, and combustion , this objective seeks to give a full account of emissions that can be expected from such mining activities in different countries in India over her various regions.

B. Analysis of Environmental Effects:

To assess the environmental consequences of coal mining on the regional population and wildlife. This includes assessing land transformation, water pollution, health impacts of coal mining, and arguing for more responsible approaches in these activities [6].

C. Definition of Low Carbon Strategies:

To scope and evaluate all possible strategies and technologies in coal mining sector that would assist in achieving carbon neutrality. This would include looking at whether carbon capture and storage implemented, energy sources are renewable or looked into afforestation [4],[2] [5].

D. Evaluation of the Policies and their Suggestions:

To examine current policy measures and their applicability in fostering sustainable coal mining strategies. This objective will aim at provision of guidelines on how to strengthen these polices in relation to low by saving center and even in matters of active community participation [5] [6].

V. METHODOLOGY

The methodology in this project has stages and it provides precautions for the proper development and implementation of the application.

A. Research & Requirement Gathering

The first step of the process requires wide-ranging investigational research. This is done to understand the principles and rules in the calculation of carbon emissions. It also embraces the study of emission factors, source data on mining activities and the carbon foot printing analysis resources on the internet. In order to understand the needs for the development of the application, we held interviewed several different groups of people including the governments, environmentalists and coal mining organizations.

B. System Design

System design phase is also concerned with building the application's architecture. This entails working on deep data flow diagrams, determining system users and their roles, backend and frontend system formulation. The user interface is simplified ensuring ease of data entry and report generation by the user. The React.js (for the frontend) and Node.js with Express (for the backend) technologies are chosen for their adaptability as well as their capacity to scale.

C. Emission Calculation Algorithms

The core of the emission calculation algorithm is based on standard methodologies for quantifying carbon emissions. These methodologies use predefined emission factors that represent the average amount of CO_2 emitted per unit of activity. The formula for calculating emissions is generally expressed as:

Formula 1:

$$\text{Emission} = \text{Activity Data} \times \text{Emission Factor}$$

Where:

- Activity Data: Refers to the data related to specific coal mining operations such as fuel consumption, electricity usage, or distance traveled by vehicles.
- Emission Factor: A coefficient that quantifies the emissions associated with a particular activity (e.g., kg of CO_2 per liter of diesel consumed). These factors are sourced from national or international databases (like IPCC Guidelines for National Greenhouse Gas Inventories).

A. Algorithm: Emission Calculation

1) Input**:**

- Activity Data (A)**:** The total quantity of activity, such as energy consumption (in GJ) or amount of fuel used (in tons).
- Emission Factor (E)**:** The amount of CO2 produced per unit of activity (e.g., kg of CO2 per GJ or ton).

2) Process**:**

- Multiply the activity data by the emission factor.

Emission=A×E

3) Output

- Total Emissions (kg CO2)**.**

B. Example:

If 1000 GJ of energy is used and the emission factor is 94.6 kg CO2/GJ, the total emissions would be:

Emission=1000×94.6=94,600kg CO2.

Example Calculation:

If a coal mine consumes 100,000 liters of diesel fuel for its transportation activities, and the emission factor for diesel fuel combustion is 2.67 kg CO_2 per liter, the carbon emissions would be calculated as:

Emission = 100,000 liters × 2.67 kg CO_2/liter = 267,000 kg CO_2

This formula can be applied to different activities like electricity consumption (Scope 2 emissions) or transportation (Scope 3 emissions). The sum of emissions from various activities provides a comprehensive carbon footprint for a given time period.

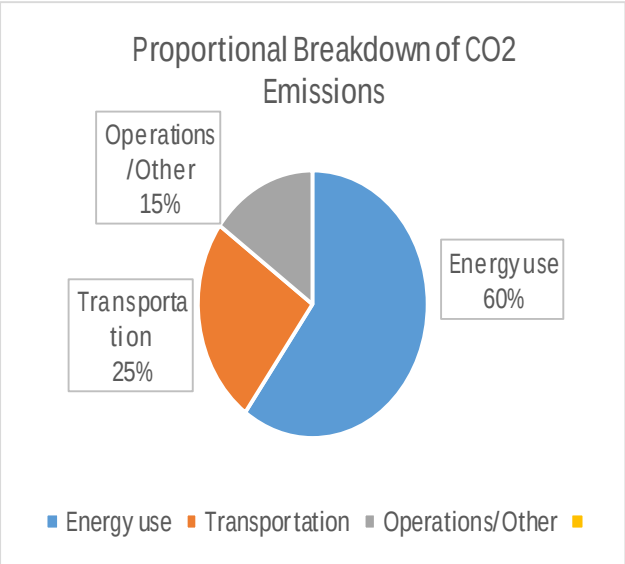
VI. RESULT

It is expected that the outcomes of this study will greatly contribute to understanding the different aspects of coal mining in India including the carbon emissions resulting from it, effectiveness of the existing policies and possible ways toward achieving carbon neutrality. The results will be organized by the following sections: Techniques and strategies for measuring existing or potential carbon emissions

A. Quantification of Carbon Emissions

•Emission Baseline Establishment- The study shall establish a detailed carbon emissions baseline from coal mining activities, incorporating coal extraction, loading, and other mining operations as well as coal transportation and burning related activities. Preliminary data gives an indication of the fact that coal mined emits around 50% of the total CO2 emissions in the country [6] [1].*Sector-Specific Emissions*: Detailed emissions data will be segmented by region and mining type, highlighting variations in carbon output based on operational practices. Initial findings suggest that underground mining emits more methane compared to surface mining, necessitating targeted mitigation efforts [6].

FIGURE 1. PROPORTIONAL BREAKDOWN OF CO2 EMISSIONS



B. Environmental Impact Assessment

1) Ecological and Health Impacts: The report examines the environmental effects of coal mining, addressing issues such as land abuse, water pollution, and potential dangers to the region's inhabitants. The preliminary research shows that the spread of such diseases as lungs and another type of cancer is directly related to the processes involved in mining [6].
2) Community Perspectives: Stakeholders are expected to provide qualitative information on the issues raised, including the effects of coal mining on the environment and health,[5][6] which will contribute to the understanding of the social impacts of coal mining.

C. Pathways to Carbon Neutrality

Opportunities and Challenges for Carbon Capture and Storage The results will determine the prospects of introducing CCS technologies in coal mines in India from the technical and economic points. The time emission simulations demonstrate the capability of reducing emissions by 20-30% when CCS technology is adopted, depending on the operational scope and systems in place for the mining exercise [4],[2].

Potential of Renewable Energy: The study will also investigate the prospects for the incorporation of renewable energy in coal mining operations. It is expected that such findings will demonstrate that emissions when changing from conventional fuels to solar and wind energy will be greatly reduced, with some reports indicating cases where energy-related emissions were reduced by as much as 50% [4],[2] [6].

D. Policy Effectiveness and Recommendations

1) Evaluation of Current Policies: The study will evaluate critically the existing policies that are put in place to counteract the impacts of carbon emissions in the coal sector. Some of the preliminary findings indicate that, although some targeted policies have been effective, there are significant discrepancies concerning implementation and outreach [5] [6].
2) Actionable Recommendations: On the Strength of the findings, the research will also put forward concrete recommendations to improve existing policy frameworks including how to engage the stakeholders and address some of the challenges such as sustainable coal mining practices [6] [5].

E. Contribution to Sustainable Development Goals

Where Global Goals come into play: The outputs will present how improved management of coal mining related carbon emissions will assist India in meeting its obligations under the Sustainable Development Goals (SDGs) especially Goal 13 (Climate Action) and Goal 15 (Life on Land) [6] [5].

VII. DISCUSSION

This research lays out fundamental aspects concerning the carbon footprint of coal mining activities in India and emphasizes the need to confront the environmental and social consequences. The results show that coal mining is one of the sources responsible for greenhouse gases emissions and hence there is an urgency on the need to curb the effects of change in climate.

A. Carbon Emissions Implications:

Given the absence of a measurable increment in intensity or level of activities performed, setting an emission baseline is vital if targeted actions are to be implemented effectively. Emissions quantification indicates large variation for several mining activities and methods, with underground workings emitting much more methane than surface operations, rather than the other way round [6]. This clearly begs the need for focused campaigns which will target different mining processes.

B. Effects on the Environment and Local Communities:

The environmental impact assessment indicates not only the devastation of local environments but also negative health implications for populations located near coal mines. The connection between health problems and mining activities makes it imperative for mining to be done responsibly and companies to be held accountable for their activities. The community's views collected through questionnaires and interviews also show the dissatisfaction from the residents due to environmental destruction and the ineffective policy intervention in alleviating the problem [5][6] .

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C. Pathways to Carbon Neutrality:

The assessment of potential pathways to carbon neutrality, especially those involving the integration of CCS or renewable energy, serves as a guide to the coal mining industry. The results indicate that CCS may be capable of reducing emissions to a great extend, whilst the shift to renewable energy sources would not only have an environmental benefit in terms of the carbon emissions, but zThese initiatives are important in ensuring compliance with the global climate change obligations and fulfilling the national sustainable development objectives.

D. Policy Recommendations:

The study examines the weaknesses of contemporary policies and emphasizes the significance of the implementation phase of the project and policies including the communities. It is suggested that, the existing policies, which include the sustainable indicators, stakeholder engagement, and their evaluation, should be improved to promote responsible mining [6] [5]. In addition, the mining sector can be made more responsible through the inclusion of sustainable development goals within the mining practices.

VIII. CONCLUSION

The present investigation brings to the fore the enormous carbon footprint to be associated with coal mining activities in India and the urgent need for mitigation measures and how research has shown that coal production is an important activity in generation of energy and yet it has significant social and environmental influences.

This study makes it possible to understand better both the existing challenges and the available opportunities especially in addressing the carbon emissions from the coal industry. Strategy formulated towards carbon zero emissions inclusively addresses the CCS utilization and the use of alternative energy sources seeks to address the carbon mining effects.

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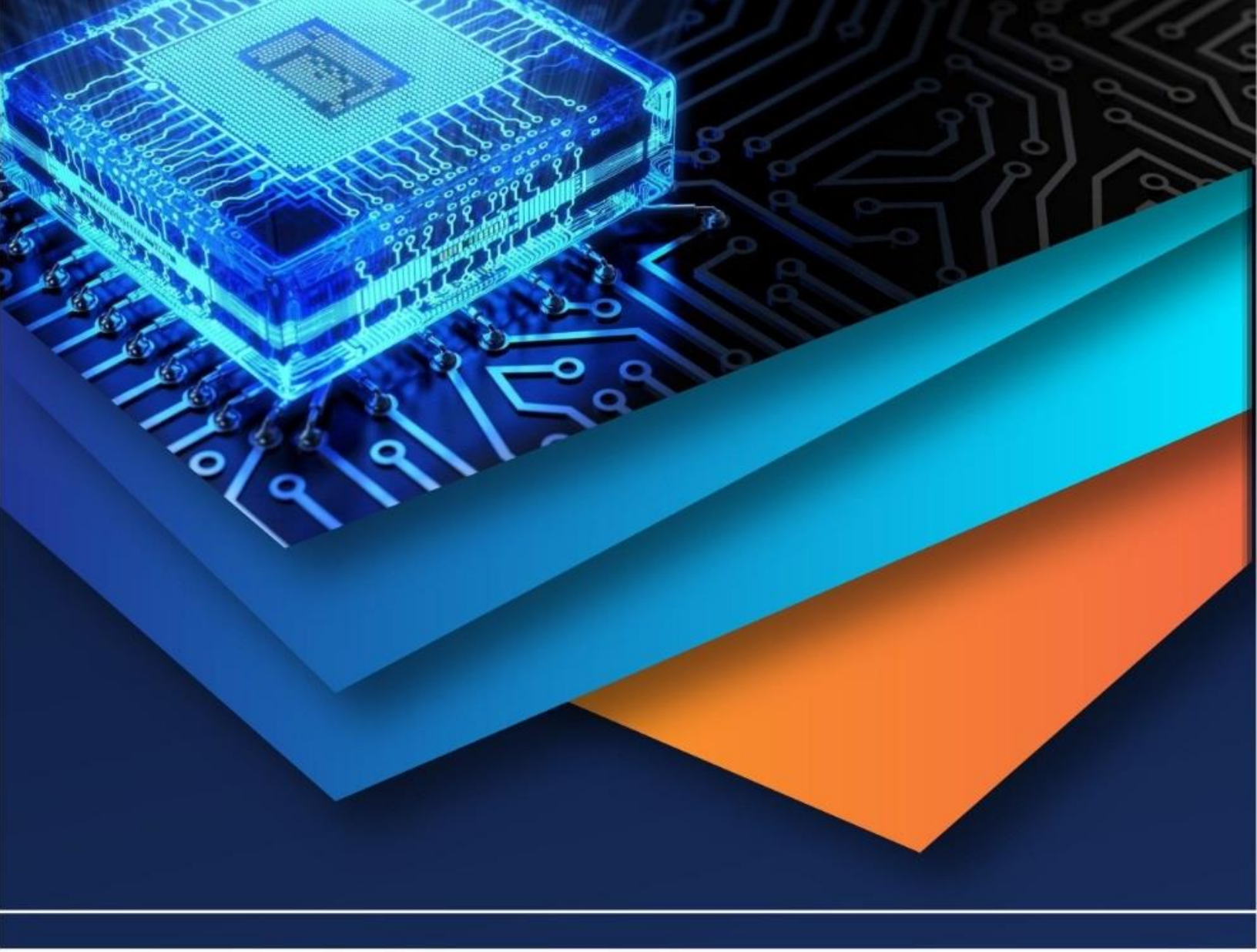

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