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Research Article

Climate Impact and Decarbonization Pathways of Indian Steel Manufacturing: A Comparative Case Study of Bokaro Steel Plant and Jindal Steel & Power

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Abstract

This study explores how steelmaking affects climate change and public health by comparing two major Indian manufacturing hubs: Jindal Steel & Power (JSPL) and SAIL's Bokaro Steel Plant (BSL). Making steel is energy-intensive and releases large amounts of carbon dioxide (CO_2), sulfur dioxide (SO_2), and particulate dust. Bokaro Steel Plant relies on traditional blast furnace technology, with current emissions releasing around 2.46 tonnes of CO_2 per tonne of crude steel, causing severe local air pollution and public health burdens. In contrast, Jindal Steel utilizes direct reduced iron (DRI) and coal gasification, while actively testing carbon capture technology and green hydrogen integration to cut carbon intensity down to 2.0 tCO_2/tCS by 2030 and achieve net-zero emissions by 2047. The study demonstrates that while private plants are adopting low-carbon innovations, traditional public plants like Bokaro need urgent technological upgrades such as cleaner gas filters, top pressure recovery, and hydrogen power—to protect public health and help India meet its national climate goals.

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1. INTRODUCTION

Steel is the fundamental backbone of modern global infrastructure, urban development, and industrial growth. However, the iron and steel industry is one of the most energy-intensive and carbon-heavy industrial sectors, contributing approximately 7% to 9% of global direct fossil fuel emissions. In India, where rapid economic expansion and urban development drive heavy demand under national initiatives such as Make in India, the steel sector holds a critical role but currently accounts for roughly 12% of total national greenhouse gas (GHG) emissions.

The environmental footprint of steel manufacturing extends beyond macro-level global warming to localized ecological and public health crises. Legacy blast furnace operations release significant quantities of criteria air pollutants including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and fine particulate matter ($PM_{2.5}$/PM_{10}) into regional airsheds, causing respiratory morbidity and adverse environmental impacts in industrial belts.

India's national climate commitment targets net-zero carbon emissions by 2070. Reaching this milestone demands an aggressive structural transformation of its heavy manufacturing foundation. This paper presents a comparative environmental and decarbonization analysis between a legacy state-owned enterprise, the Bokaro Steel Plant (operated by SAIL), and a private sector pioneer, Jindal Steel & Power (JSPL). By evaluating their emission benchmarks, operational technology profiles, and transition pathways, this study highlights key strategies necessary to align Indian steel production with sustainable climate goals.

2. METHODOLOGY & ANALYTICAL FRAMEWORK

This study employs a comparative case-study methodology utilizing secondary quantitative data, official corporate sustainability filings, environmental audit reports, and national policy frameworks:

- **Site Selection & Technology Routes:** A comparative analysis of Bokaro Steel Plant (BSL) in Jharkhand, operating via the traditional Blast Furnace–Basic Oxygen Furnace (BF-BOF) route, versus Jindal Steel & Power (JSPL) facilities in Angul and Raigarh, utilizing Direct Reduced Iron (DRI), Coal Gasification, and Electric Arc Furnace (EAF) systems.
- **Key Performance Metrics:** Evaluation of carbon intensity (measured in tonnes of CO_2 per tonne of crude steel tCO_2/tCS), criteria air pollutant loads (SO_2 and particulate matter emissions), energy efficiency metrics, and planned technology roadmaps toward net-zero targets.

3. Technology Profiles & Emission Benchmarks

The operational profiles and environmental metrics of Bokaro Steel Plant and Jindal Steel & Power reveal stark differences in energy dependency, carbon output, and decarbonization timelines.

Feature / Metric	Bokaro Steel Plant (SAIL)	Jindal Steel & Power (JSPL)
Primary Process Route	Blast Furnace – Basic Oxygen Furnace (BF-BOF)	DRI – Coal Gasification / Electric Arc Furnace (EAF)
Primary Energy Source	Coking Coal & Metallurgical Coke	Non-coking Coal, Syngas, Grid Electricity
Current Carbon Intensity	~2.46 tCO_2 / tCS	~2.10 - 2.25 tCO_2 / tCS
2030 Carbon Target	~2.20 tCO_2 / tCS	2.00 tCO_2 / tCS
Target Net-Zero Year	2070 (Aligned with National Goal)	2047
Decarbonization Levers	Coke dry quenching, top pressure recovery, scrap blending	Coal gasification with CCUS, Green Hydrogen integration, renewable power

4. Environmental and Health Impacts

4.1 Carbon Footprint & Global Climate Drivers

The substantial disparity in carbon intensity between the two manufacturing models stems directly from their chemical reduction mechanisms:

- **Bokaro Steel Plant (BF-BOF Route):** Relies heavily on high-grade imported coking coal. In traditional blast furnaces, carbon acts as both the thermal energy source and the primary chemical reducing agent for iron ore. The reduction reaction produces massive volumes of carbon dioxide:

  $$Fe_2O_3 + 3C \rightarrow 2Fe + 3CO$$

  $$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

  Consequently, Bokaro's operational carbon intensity remains elevated at approximately 2.46 tCO_2 per tonne of crude steel (tCO_2/tCS), well above the global industry average of ~1.89 tCO_2/tCS.
- **Jindal Steel & Power (DRI-CG/EAF Route):** JSPL employs a synthesis gas (syngas) route derived from coal gasification, producing a mixture rich in hydrogen (H_2) and carbon monoxide (CO):

  $$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$

  By shifting a portion of the chemical reduction workload to hydrogen and melting sponge iron within Electric Arc Furnaces powered increasingly by grid-connected renewable energy, JSPL maintains a significantly lower carbon emission profile.

4.2 Local Air Quality and Public Health in Industrial Belts

Beyond greenhouse gas emissions, traditional steelmaking releases localized atmospheric pollutants that pose direct risks

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to public health in surrounding communities. Industrial regions around Bokaro and Jharkhand's mining-manufacturing corridors suffer from high ambient concentrations of criteria pollutants:

- **Sulfur Dioxide (SO_2):** Originating from high-sulfur coal combustion in coke ovens and thermal boilers. Un-desulfurized gases lead to ambient air deterioration and localized acid deposition risks.
- **Particulate Matter ($PM_{2.5}$ and PM_{10}):** Fugitive dust emissions from raw material handling, sinter plants, and blast furnace tapping contribute significantly to high PM levels, leading to chronic respiratory illnesses, reduced lung function, and cardiovascular conditions among regional residents.

5. Pathways to Decarbonization: Comparative Analysis

5.1 Legacy Upgrades: The Bokaro Imperative

For traditional public-sector integrated plants such as Bokaro Steel Plant, modernizing legacy infrastructure represents the immediate baseline priority:

- **Flue Gas Desulfurization (FGD):** Retrofitting FGD installations across sinter plants and captive thermal units to capture up to 90% of atmospheric SO_2 emissions.
- **Waste Energy Recovery:** Expanding Coke Dry Quenching (CDQ) and Top Pressure Recovery Turbines (TRT) to capture high-temperature waste heat and generate clean internal power.
- **Scrap Blending:** Increasing the recycled steel scrap ratio in Basic Oxygen Furnaces to lower hot metal (pig iron) demand per tonne of steel produced.

5.2 Next-Generation Technology: The Jindal Framework

- Private sector plants possess greater agility to pilot innovative technological pathways aimed at aggressive decarbonization targets:
- **Coal Gasification with CCUS:** Integrating Carbon Capture, Utilization, and Storage (CCUS) into existing coal gasification plants to isolate concentrated CO_2 streams before atmospheric release.
- **Green Hydrogen Transition:** Transitioning Direct Reduced Iron (DRI) reactors from syngas to 100% green hydrogen, produced via renewable-powered water electrolysis.
- **Net-Zero 2047 Target:** Pioneering a strategic roadmap to reach 2.00 tCO_2/tCS by 2030 and full carbon neutrality by 2047, coinciding with India's centenary of independence.

6. POLICY RECOMMENDATIONS & CONCLUSION

To successfully transition the national steel sector toward low-carbon operations without sacrificing industrial competitiveness, targeted policy interventions are essential:

1. **Green Steel Procurement Mandates:** Establish public procurement quotas requiring minimum percentages of certified low-carbon steel in national infrastructure and construction projects.
2. **Targeted Subsidies for CCUS & Green Hydrogen:** Provide capital expenditure grants and production-linked incentives (PLI) for hydrogen electrolysis and carbon capture installations at legacy public plants like Bokaro.
3. **Indian Carbon Market Enforcement:** Enforce robust emissions cap-and-trade mechanisms under the Carbon Credit Trading Scheme (CCTS) to penalize high carbon intensity (>2.2 tCO_2/tCS) while rewarding early decarbonization leaders.

7. CONCLUSION

This comparative study demonstrates that while state-owned facilities like Bokaro Steel Plant form the historical foundation of India's industrial backbone, their dependence on conventional blast furnaces imposes high carbon intensity and localized health burdens. Conversely, private enterprise initiatives like Jindal Steel & Power illustrate that combining Direct Reduced Iron, coal gasification, CCUS, and planned green hydrogen integration offers a feasible path toward radical decarbonization. Accelerating technological modernizations across public facilities while scaling green hydrogen in private operations is vital for protecting public health and fulfilling India's climate ambitions.

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