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Productivity and Environmental Performances: Analytical Study across Major Public Sector Steel Plants in India

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ABSTRACT
This study conducts an empirical investigation of public sector prominent steel plants in India: SAIL DSP Durgapur, SAIL BSP Bhilai , SAIL BSL Bokaro, SAIL RSP Rourkela , SAIL ISP Burnpur, and overall Steel Authority of India Limited (SAIL). The analysis seeks to examine the connection between production and environmental management strategies by utilizing many performance indicators from 2001 to 2023. This report emphasizes the necessity for India to greatly increase its steel manufacturing capacity and tackle environmental concerns, as the country's steel consumption is expected to reach 720 million metric tons by 2050. The analyzed key indicators include Coke rate, BF productivity, Specific Energy, Specific Water Consumption. The study utilizes suitable econometric techniques to thoroughly comprehend the sustainability and effectiveness of these steel facilities. The results emphasize the significance of implementing cutting-edge technologies and sustainable methods to fulfil future requirements while reducing environmental consequences.

Keywords: Steel industry, Environmental indicators, Sustainability, Econometric analysis, Technological adoption.

JEL Classifications: L61, Q52, O13

1. INTRODUCTION

Steel is a highly important and useful material for engineering and building worldwide. While India does not produce all of its steel domestically, it can satisfy its substantial steel demand by importing it, facilitated by enhanced communication technologies, decreased international freight expenses, and simplified international trade. India possesses enormous reserves of coal and iron ore, giving it a distinct advantage in the production of steel. India, although it ranks as the third-largest steel importer in the world, cannot depend entirely on imports due to its increasing demand for steel. The nation's steel needs stand at around 120 metric tons annually, expected to reach the yearly production goal of 720 metric tons by 2050.

The consequences of India's increasing steel production are substantial. India's current annual steel production is approximately 120 metric tons. To achieve its goal for the year 2050, the country needs to augment its production capacity by more than 600 metric tons. While steel industries in industrialized nations such as the USA, UK, France, Japan, and China see moderate growth, India emerges as a lucrative market for steel makers and suppliers of raw materials. Nevertheless, the Indian steel industry is susceptible to environmental degradation threats, even though it has the capacity for recycling. The World Steel Association suggests using the Life Cycle Assessment (LCA) methodology to tackle these challenges. This approach assesses possible environmental effects at every stage of the steel product's life cycle, encompassing reuse, recycling, and disposal phases. Assessing the environmental impact of the steel sector requires the evaluation of emissions from steel plants, their current usage, and the use of technology that decrease energy consumption. This method is crucial for a comprehensive evaluation.

Steel recycling can result in substantial savings in coal, iron ore, and limestone. Recycling a metric ton of steel waste can preserve around 740 kilograms of coal, 1400 kilograms of iron ore, and 120 kilograms of limestone. Recycling steel products and minimizing CO2 emissions can help mitigate greenhouse gas (GHG) emissions. Implementing internal industry techniques, such as utilizing steel-making slags, can effectively mitigate emissions without causing any negative impact on the environment. According to a 2012 research by the Centre for Science and Environment (CSE) in Delhi, the current environmental condition of the Indian steel sector is unsatisfactory, despite its potential in long-term . Steel industry in India is subject to regulation under Ministry of Environment and Forests, Government of India. The Environmental Protection Act (EPA) and the Environmental Protection Rules and Regulations, enforced by the Ministry of Environment and Forests, Government of India. Iron and steel industry are required to acquire government licenses from the EPA to develop new iron and steel plants or make substantial expansions to existing ones. Steel plants are required to establish pollution control facilities and adhere to regulations regarding water, air, and noise pollution. These regulations are enforced by pollution control boards.

Fuel expenses pose a considerable obstacle for numerous integrated steel factories in India, since their consumption rates tend to surpass those of foreign facilities. This issue is caused by the high consumption of power , the use of old equipment, operational procedures, and the high costs of coal and iron ore mining. Nevertheless, the implementation of technological advancements, the efficient exploitation of waste heat, and the enhancement of input quality are progressively diminishing the need for power in steel plants. Technological improvements have a direct impact on energy and environmental conservation in Indian steel factories. Steel factories are tackling energy and environmental concerns by implementing technical advancements and embracing energy-efficient and eco-friendly technology. The government facilitates these enhancements through a range of mechanisms, such as the National Action Plan on Climate Change (NMEEE), UNDP-AUSAID-MOS Steel Project, NEDO Model Projects with the Government of Japan, Global Superior Energy Performance Partnership (GSEP), and guidelines on Corporate Responsibility for Environmental Protection (CREP).

Considering above initiatives, it is imperative to analyze the comprehensive sustainability of the Indian steel sector, which has not received sufficient investigation. Our main goal is to find the relatioship steel production and environmental performance in steel plants in India. The special focus of study concentrate on Public sector integrated steel plants, namely SAIL DSP Durgapur, SAIL BSP Bhilai , SAIL BSL Bokaro, SAIL RSP Rourkela , SAIL ISP Burnpur, and overall Steel Authority of India Limited (SAIL). We analyze the production and environmental performance of the plants, specifically looking at coke rate per ton of hot metal production, blast furnace productivity per metre cube, specific energy consumption per ton of crude steel, and specific water consumption per ton of crude steel. We use suitable econometric techniques to conduct empirical analysis of the data collected between 2001 and 2023.

2. Brief Descriptions of Selected Steel Plants in the Study

2.1. Steel Authority of India Limited (SAIL)

Hindustan Steel Limited (HSL) was set up on 19th January 1954 for managing a steel plant that was coming up at Rourkelain Orissa. Thereafter other three integrated steel plants came under HCL. Steel Authority of India Limited (SAIL) was formed on 24th January 1973 as a holding company for the plants replacing HSL.SAIL is now (2023) India’s one of the largest and the world’s 20th largest steel producer with an annual turnover of over Rs. 100000cores. The company has a high level of vertical integration and it is self-sufficient in iron ore. It produces both basic and special steel products for different uses as well as for exports. The company’s main steel products include flat products, structurals, rail products, etc. SAIL has five integrated steel plants at Durgapur, Bhilai, Rourkela, Bokaro and Burnpur, with a total production capacity of more than 21 million tonnes of crude steel per annum. In addition, there are three steel plants at Salem, Durgapur and Bhadravati, which produce special steels and alloy steels and a plant at Chandrapur producing ferro-alloys.

Table 2.1: Overall SAIL Production Performance in Million Tons

Year	Hot Metal	Crude Steel	Total Saleable Steel
2014-15	15.41	13.91	12.84
2015-16	15.72	14.28	12.38
2016-17	15.7	14.5	13.9
2017-18	16	15	14.1
2018-19	17.5	16.3	15.1
2019-20	17.5	16	15.1
2020-21	16.6	15.2	14.6
2021-22	18.7	17.4	16.9
2022-23	19.4	18.3	17.2
2023-24	20.5	19.2	18.4

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

SAIL is a manufacturer of both standard and specialized steels that find use in many sectors such as home construction, power generation, automotive manufacturing, engineering, railway infrastructure, and defense industries. The company produces and markets a diverse range of steel products, which include hot rolled and cold rolled sheets and coils, galvanized sheets, railway products such as wheel and Axle, Rails, electrical sheets for electrical applications, New structural steels, plates, bars, and rods, as well as stainless steel along with other alloy steel.

SAIL has recently initiated ambitious development plans intending to augment its production capacity from the existing 21 million tonnes per annum (MTPA) to 50 MTPA by 2030. This growth is a component of a deliberate effort to enhance its market standing and fulfil increasing domestic and global demand. In addition, SAIL is making investments in environmentally friendly technologies to decrease carbon emissions. This includes the implementation of renewable energy sources and improved waste management methods. These endeavours are in line with worldwide sustainability patterns and India's dedication to diminishing its carbon emissions.

2.2. SAIL BSP: Bhilai Steel Plant

SAIL BSP Bhilai, a prominent entity in the Indian Steel Industry, is situated in Bhilai, Chhattisgarh. It is one of SAIL's flagship unit committed to excellence. The facility was founded in 1955 as a result of a bilateral agreement between the Government of India and the USSR. SAIL BSP is pioneer in the production of steel rails for railways, steel plates for different application, and various other steel products. Bhilai Steel Plant produces by-products from its coke oven unit during production of Metallurgical coke for blast furnace application from its Coal Chemical recovery facilities. The SAIL BSP Bhilai has achieved the prestigious distinction of winning the Ministry of Steel 'Prime Minister's Trophy for the best-

Table 2.2: SAIL BSP Bhilai Production Performance in Million Tons

Year	Hot Metal	Crude Steel	Saleable Steel
2014-15	5.1	4.8	4.3
2015-16	5.3	5.1	4.2
2016-17	5	4.7	4
2017-18	4.3	4.1	3.7
2018-19	4.8	4.4	3.7
2019-20	4.8	4.5	4
2020-21	4.6	4.2	4
2021-22	5.3	4.9	4.7
2022-23	5.4	5.2	4.8

2023-24	6	5.7	5.2

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

Integrated steel plant in India for long eleven consecutive years. The plant have the capability to manufacturer heavy steel plates, railway steel requirements, and structural application steel. SAIL BSP Bhilai is the exclusive provider of India's longest train tracks, which measure over 260 meters (850 ft.) in length. The Steel Plant is capable of manufacturing both merchant products and wire rods as per market demand. The inauguration of a new Universal Rail Mill, costing Rs 1200 crore, took place at SAIL's Bhilai Steel Plant on January 22, 2017. SAIL has begun commercial production of the world's longest single rail, measuring 130 meters, from the new Universal Rail Mill. The addition of the new URM will increase BSP's rail production capacity to two million tons per year. This mill will have the highest production capacity for rails of any one location worldwide.

The Bhilai Steel Plant (BSP) has lately accomplished notable milestones, such as achieving a record production of 5.7 million tonnes of crude steel in 2023, the biggest amount ever produced since its establishment.

2.3. SAIL DSP: Durgapur Steel Plant

This plant was built up with British assistance in West Bengal. The Plant started iron production on26th December 1959. The plant produces Wheel and Axles mainly for Indian Railways. The other products being Light and Medium Sections, Merchant products, Blooms and Billets. The present capacity of the plant is 2.6 million tonne of hot metal per annum. DSP produces finished product only around 45% of total saleable steel. TMT bars, light & medium structural and Wheel & Axle are its main finished products. Merchant Mill produces TMT bars of different sections in variety of grades like EQR, HCRM, Rock Bolt, 500S, 500B CRS, 550D etc with Green Pro Certification from Confederation of Indian Industry (CII). All the production units of the plant are covered by ISO 9001:2000 certification.

The Plant utilizes the CO-BF-BOF process for steel production. Following the latest modernization in the 1990s, several new facilities have been incorporated. These include two newly reconstructed coke oven batteries, CDI in Blast Furnaces, three Ladle Furnaces, one Bloom caster, one bloom-cum-round caster, and a new state of the art Medium Structural Mill (MSM) for producing next generation structural steel. The Plant is positioned to achieve nearly 100% crude steel production using the Concast route of steel production. The one of flagship unit of DSP is its Wheel and Axle Plant, which specializes in manufacturing forged wheels and axles specifically for the Indian Railways. The wheels undergo testing with International Standards .

Table 2.3: SAIL DSP Production Performance in Million Tons

Year	Hot Metal	Crude Steel	Saleable Steel
2014-15	2.3	2.1	2
2015-16	2.2	2	1.9
2016-17	2.3	2	1.9
2017-18	2.5	2	1.9
2018-19	2.6	2.2	2.1
2019-20	2.5	2.2	2.1
2020-21	2.3	2.1	2
2021-22	2.4	2.2	2.1
2022-23	2.6	2.3	2.2
2023-24	2.6	2.3	2.2

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

Over time, the company has developed many types of wheels as per the requirement of the Indian Railways.The plant has recently inaugurated a new medium structural mill, which will enhance its capability to manufacture structural steel products utilized in building and infrastructure projects. DSP is allocating resources towards environmental sustainability initiatives, such as implementing air pollution control systems and implementing strategies to minimize water usage in its operations through Zero Liquid Discharge (ZLD).

2.4. SAIL BSL: Bokaro Steel Plant

Situated in the coal belt of Jharkhand, this plant also was set up with Russian collaboration. Commissioning of the first Blast Furnace was done on 2nd October 1972. This plant is mainly for the flat products like hot and cold rolled sheets and coils, Slit coils and galvanized sheets. The special features of the plant are its Universal Slabbing Mill and 2000 mm continuous Hot Strip Mill, one of the fastest of its type in the world. Some of the special steel products of the plant are SAILCOR, SAILMEDS, SAILRIM, HRNO,SAILMA, WTCP, BSL-46 etc.

The modernization or expansion of Bokaro Steel Plant incorporated additional features, such as two twin-strand slab casters and a Steel Refining Unit. The Steel Refining Unit of Bokaro Steel Plant was launched on September 19, 1997, and the Continuous Casting Machine was inaugurated on April 25, 1998. The initial design of the Bokaro Steel Plant focused on the production of various flat products, including Hot Rolled Coils, Hot Rolled Plates, Hot Rolled Sheets, Cold Rolled Coils, Cold Rolled Sheets, Tin Mill Black Plates (TMBP), and Galvanised Plain and Corrugated (GP/GC) Sheets.

Table 2.4: SAIL BSL Production Performance in Million Tons

Year	Hot Metal	Crude Steel	Saleable Steel
2014-15	4.2	3.8	3.4
2015-16	3.7	3.4	2.6
2016-17	3.4	3.2	3.4
2017-18	4	3.7	3.5
2018-19	4.2	3.8	3.6
2019-20	4.1	3.7	3.4
2020-21	3.8	3.4	3.2
2021-22	4.3	3.8	3.8
2022-23	4.5	4.1	3.8
2023-24	4.7	4.3	4

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

Furthermore, the factory supplies robust raw materials to many contemporary engineering industries such as vehicle manufacturing, LPG cylinder manufacture, pipe and tube fabrication, as well as barrel and drum manufacturing, among others.

Bokaro Steel Plant (BSL) has been constantly engaged in augmenting its production capacities and enhancing operational efficacy. BSL has inaugurated a state-of-the-art cold-rolling mill complex, aimed at improving the manufacturing of top-notch cold-rolled products. Furthermore, BSL is prioritizing digital transformation and automation to optimize operations and enhance efficiency. These activities are integral to BSL's goal to maintain competitiveness and adapt to the changing requirements of the steel market.

2.5. SAIL RSP: Rourkela Steel Plant

Situated in Orissa this plant was set up with a 1 million tonne per annum ingot capacity with German assistance. Pig iron production began in the plant on 3rd February 1959. This was the first plant in Asia to introduce Basic Oxygen Furnace (BOF) process at a time when this process was yet to receive recognition from the established steel producers at home and abroad. The plant produces a wide range of flat steel products like hot and cold rolled sheets, strips and narrow plates, galvanized plain and corrugated sheets, electrical steel sheets, tin plates and large diameters ERW and SW pipes. New units for producing Cold Rolled Grain Oriented (CRGO) and Cold Rolled Grain Not-Oriented (CRGNO) electrical sheets have come up.

Rourkela Steel Plant, often known as RSP, ranks first among Indian steel industries in various respects. RSP was the first steel factory in the country to use LD Technology in the steel business. Furthermore, RSP is now the

exclusive steel factory and the solitary unit within SAIL that uses the continuous casting method to make all of its slabs. This strategy is both economical and focused on ensuring high quality. RSP supplies silicon steels to India's power sector and high-quality pipes to the oil and gas sector. The RSP is the only plant under SAIL that can manufacture silicon steels. In addition to this, RSP also manufactures flat and tubular items, as well as a wide range of advanced coated products.
RSP, or Rourkela Steel Plant, has experienced substantial transformations, similar to other steel factories in India. The plant has undergone a significant refurbishment and expansion project. Following its modernization and extension, the facility has successfully increased its production capacity for hot metal, presently reaching 4.5 million tonnes. The plant's crude steel production capability has experienced a significant increase per year to 4.3 million tonnes.

The production of Saleable Steel is projected to rise to around 5.0 million tonnes from the current annual output of 4.2 million tonnes, In addition to the enhanced production capacity, RSP's modernization and expansion initiative has also yielded other benefits. For instance, RSP has experienced an expansion in its consumer base, an improvement in product quality, a reduction in expenditure, an increase in labor productivity, an enhancement in economies of scale, and an improvement in market compatibility. Lastly, the plant's rigorous adherence to environmental regulations has resulted in decreased environmental deterioration.

Table 2.5: SAIL RSP Production Performance in Million Tons

Year	**Hot Metal**	**Crude Steel**	**Saleable Steel**
2014-15	3.1	2.9	2.5
2015-16	3	2.7	2.4
2016-17	3.1	2.9	2.7
2017-18	3.3	3.2	2.9
2018-19	3.8	3.7	3.3
2019-20	3.6	3.5	3.2
2020-21	3.8	3.5	3.2
2021-22	4.3	4	3.7
2022-23	4.3	4	3.8
2023-24	4.5	4.3	4.2

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

2.6.SAIL ISP: Indian Iron and Steel Company

IISCO was the proud owner of India's oldest unit that produced pig iron using contemporary processes. The operation was located in Kulti, on the banks of the Barakar River near Hirapur. The establishment of an open-top blast furnace in 1870 by Bengal Iron Works Co. (BIW), founded by James Erskine, marked the pioneering of iron manufacturing in India in 1875. In 1904-06, the same unit at Kulti played a pioneering role in introducing steel production in India using tiny open-hearth furnaces. In 1936, IISCO absorbed BIW and thereafter initiated steel production as a routine practice in 1939. In 1952, the Steel Corporation of Bengal (SCOB), which was established in 1937, was merged with IISCO. The combination of SCOB's Napuria Works with IISCO's Hirapur Works resulted in the establishment of the Burnpur Works of IISCO. In 1953 and 1955, the Burnpur Works had two simultaneous expansions, resulting in a boost in its production capacity to 1 million tonnes of ingot steel and 0.8 million tonnes of saleable steel. IISCO was brought under state ownership in 1972 and subsequently became a fully owned subsidiary of SAIL in 1979. The Indian Iron & Steel Company (IISCO), a subsidiary of SAIL, was merged with SAIL on February 16, 2006 and subsequently renamed as IISCO Steel Plant (ISP).

Table 2.6:SAIL ISP Production Performance in Million Tons

Year	Hot Metal	Crude Steel	Saleable Steel
2014-15	0.6	0.1	0.1
2015-16	1.4	0.9	0.9
2016-17	1.8	1.4	1.3
2017-18	2.1	1.8	1.7
2018-19	2.2	1.9	1.9
2019-20	2.5	2.1	2.1
2020-21	2.1	1.8	1.8
2021-22	2.4	2.2	2.2
2022-23	2.6	2.4	2.3
2023-24	2.7	2.5	2.4

Source: Annual Reports of Steel Authority of India Limited (SAIL) (www.sail.co.in)

A total of over 16,000 crores has been allocated for the modernization and expansion of IISCO. Following its refurbishment and extension, the factory has augmented its crude steel production capacity to around 2.5 million tons per year.

Recent enhancements comprise the implementation of a state-of-the-art sinter plant and the integration of energy-efficient methodologies, which are anticipated to amplify production and reinforce IISCO's dedication to sustainability.

3. Literature Review

Overview of the Steel Industry

Iron and Steel are being used by humans for about 6000 years. After industrial revolution in early 19th century the modern iron and steel industry started its functioning. The production and consumption of iron and steel was slow in earlier part of century but growth was faster after Second World War. Total production of crude steel in the world in year 1900 was 28.3 MT which rose to 850 MT in year 2000 and 1869 MT in year 2019(World Steel Association Data). World Crude steel production and consumption increased rapidly in last decade of 19th century and early 20th century led by China and other Asian countries.

3.1International Studies

P. D'Costa, (1999) examined the steel industries of Brazil, India and Korea. In all the three countries state led steel industry was started for industrialisation. The comparative study reveals that only Korea succeeded in maintaining investment momentum for rapid industrialisation. The weak bureaucratic industrial governance undermined the development of steel industry in India and Brazil. Korean steel industry technology was far more efficient due to greater autonomy and able to make technological superior steel plants. Due to incoherent Indian steel policy the growth of steel industry was slow.

J Ma (2000) analysed post economic reforms of China technical efficiency and Malmquist productivity indexes for 88 steel enterprises accounting for 72 % of China's steel industry's output for the period 1989–1997. The input variables used was labour, capital and energy. Output variables selected was gross output of the enterprise. The analysis was done based on size of the enterprise with respect to gross output in 1990 as small (less than 0.3 billion Yuan), medium (more than 0.3 and less than 1 billion Yuan) and large (more than 1 billion Yuan). The study reveals that the product structure of the enterprise had the highest impact on technical efficiency. The firms producing only finished steel had shown higher technical efficiency than others. The productivity of the china's integrated Iron and Steel industry improved over the period of study but more increase in productivity reported for medium sized organisation due to greater autonomy and flexibility in production.

Feng He (2013) study of Energy efficiency and productivity change of China's iron and steel industry brings out fact that the energy efficiency is about 61.1% for the period 2001-2008 mainly contributed by technical shift and scale efficiency growth. In this period annual productivity growth rate was 7.96% for the China's steel industry.

The study was based on variable, Net fixed assets, No. of employees, Energy as input , value added as desired output along with waste gas, waste water and solid waste as undesirable output. The methodology of study was based on Farrell (1957) efficiency measurement which consists of two components, Technical efficiency and Allocative efficiency. The study was focused on China's 50 steel company and their data for analysis. Energy efficiency analysis was done using DEA model and further divided into pure technical efficiency and scale efficiency. It identified the inefficient organisations using Energy saving potential analysis and got the production frontier, best practice enterprise for each year of study.

3.2 Indian Studies

Debnath R M (2014) studied the technical and scale efficiency of Indian iron and steel industry using Data Envelopment analysis (DEA). To analyse the relative efficiency input variable used are gross fixed assets, total energy cost, total no. of employee and current assets. The output variable of the study was income, sales, PBIT & PAT. As per the study the international norms of energy consumption is 4.5-5.5 giga calories per tonne of crude steel while Indian steel plants was only able to achieve energy consumption of 6.5-7.0 giga calories per tonne of crude steel. The study emphasise onoperation inefficiencies of public sector undertakings due locational and logistical disadvantages.

According to Vadde and Srinivas (2012) the labour productivity at comparable capacities for Indian companies Tata Steel and SAIL was less than 20% compared to best operating steel plants of POSCO and Nippon Steel. Findings of study was economics of scale plays a vital role in iron and steel industry. Old machinery of plants and inefficient technology were major roadblocks in improving productivity.

Chatterjee A, (2009) studied different aspects of Indian iron and steel industry from pre independence to early 21st century. The future of Indian iron & steel industry is very bright due to present very low per capita consumption compared to world average and potential of faster growth. The steel plants are working to reduce cost of steel production in integrated plants and achieving favourable results. Steel industry focus shifted to superior product quality, increased BF productivity, low specific energy consumption, higher labour productivity, and profitable product mix.

Shivamaggi, (1968) analysed the Wages, Labour productivity and cost of production for seven important industries including Iron and Steel industry. They studieddataon quantity and value of gross output, materials and fuels consumed, net value added, for employment, man-hours worked and wage for the period 1951-61. The important observation from the exploratory exercise was improvement in labour productivity was attributed to increase in fixed capital per unit of labour and improvement in management decision making.

Dastur (1972) highlighted the importance of Iron and steel industry for industrial development of India. He analysed post independence creation of steel capacity and government development initiatives. According to the study India need to invest in construction of large capacity steel plants along with expansion of existing units to fulfil growing need of steel in the country. The cost of capital was very high for the steel industry and cost of equipment was also high for installation of new capacity. The analysis focused on cost consciousness for Indian iron and steel industry to bring down the cost of production through improved technology, preventive maintenance, and management decision making techniques.

Kumari, (1993) analysed for the period 1971 -to 1987-88the productivity in public sector enterprise covering 11 industry, which were -steel, minerals and metals, coal, chemicals, power, petroleum, heavy engineering goods, medium and light engineering goods, transportation equipment, consumer goods and textiles. The study measured total factor productivity and partial factor productivity for different public sector manufacturing industries over a time period. For measuring total factor productivity, Kendrick Index, Solow Index and Divisia Index were used. It identified the areas needed to improve productivity by expansion of public sector enterprises and more efficient technologies for generation of economies of scale.

Ghosh, (1994) studied the Indian steel industry and compared SAIL and Tata Steel with global standard in steel industry. The emphasis was to reduce the cost of production using the required investment in technological up gradation. He highlighted the process inefficiencies of Indian steel plants for high cost of production. According to the study public sector undertaking SAIL should be provided adequate resources for technical up gradation so that it becomes productive and competitive in steel industry.

The steel industry in India has played a crucial role in the country's industrial development. Agarwal and Singh (2018) state that the industry has progressed from an early stage to become the second-largest global producer of raw steel. The rise is propelled by ample resources, policy backing, and rising domestic demand. The authors emphasize the significance of government initiatives, such as the National Steel Policy 2017, which intends to reach a capacity of 300 million tonnes by 2030-31, with a focus on sustainable practices and technical developments.

Environmental Performance and Sustainability Research on the ecological consequences of steel manufacturing has been a crucial focus. In this study, Kumar et al. (2020) examine the implementation of Life Cycle Assessment (LCA) in Indian steel mills, with a focus on its significance in mitigating greenhouse gas emissions and improving resource efficiency. The study emphasizes the incorporation of Life Cycle Assessment (LCA) into operational plans as a means to reduce environmental degradation and advance sustainability.

Sarkar and Bhattacharya (2019) examine the use of energy-efficient technologies in steel factories, highlighting substantial enhancements in energy efficiency and reductions in emissions. According to their research, the use of technological advancements, such as waste heat recovery systems and cleaner manufacturing practices, has improved the environmental performance of factories like Bhilai and Rourkela.

Technological Advancements andTechnological innovation is a fundamental and essential element for the steel industry's success. Gupta et al. (2021) analyze the modernization initiatives in facilities like Bokaro and Durgapur, emphasizing the influence of sophisticated manufacturing techniques and automation on productivity and quality. The study outlines the impact of investing in advanced facilities, including as continuous casting machines and high-pressure descalers, on improving production efficiency and product quality.

Economic Performance and Market Dynamics are typically, economic evaluations of the steel sector center on assessing production efficiency and market position. Bhatia and Roy (2017) conducted an empirical evaluation of production patterns in prominent Indian steel factories, establishing a correlation between these patterns and both market demand and global steel pricing. Their research demonstrates that factories such as SAIL and Bhilai have displayed resilience and adaptation in response to market shifts, thanks to deliberate expansions and diversification.

Verma and Patel (2020) examine the impact of integrated steel factories on regional economic development. Their research demonstrates the socio-economic advantages resulting from the establishment of steel mills in locations like Jharkhand and Odisha, encompassing the generation of employment opportunities, the enhancement of infrastructure, and the implementation of community welfare projects.

Current advancements and forthcoming possibilities of Contemporary research indicates an increasing emphasis on sustainability and digital transformation within the steel industry. Singh and Mehta (2023) analyze the application of digital technologies in industrial facilities such as Bokaro and IISCO, highlighting the advantages of data analytics and automation in improving production processes and facilitating decision-making.

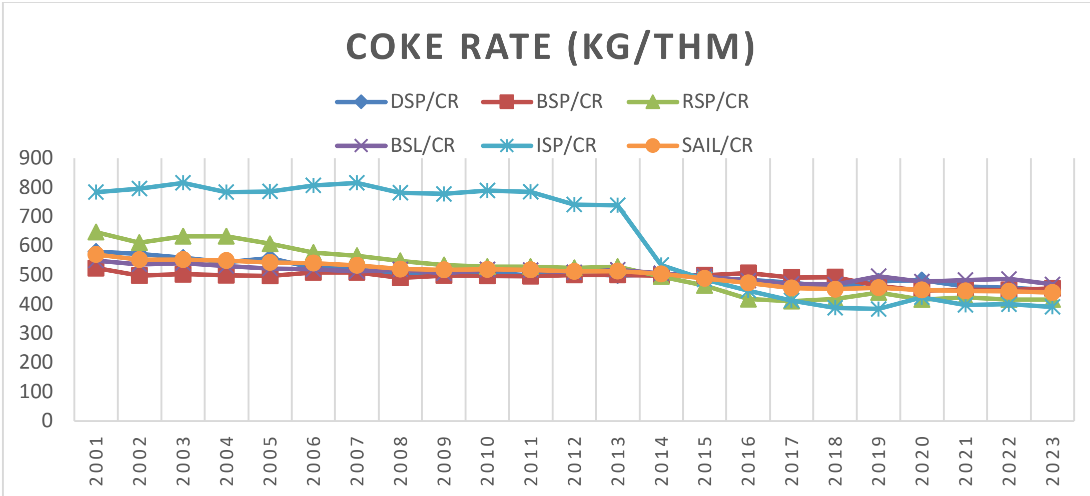
The future outlook of the Indian steel sector is intricately linked to global sustainability objectives and technical progress. Research indicates that the ongoing allocation of resources towards environmentally friendly technology and the implementation of circular economy concepts will be essential for preserving competitiveness and attaining enduring sustainability.

4. Notes on Economic and Environmental Indicators in the Steel Industry

4.1. Coke rate

The coke rate is a measure of the quantity of coke consumed per metric ton of hot metal generated in a blast furnace. In the Indian steel industry, it is crucial to attain a reduced coke rate to enhance cost-effectiveness and promote environmental sustainability. According to recent data, the average coke consumption in India is usually between 400 to 450 kg per ton of hot metal. However, some highly efficient factories have managed to attain rates as low as 350 kg. They are reducing the coke rate results in cost savings and a decrease in CO_2 emissions, as coke manufacturing is a highly carbon-intensive process. Basu et al. (2019) found that adjusting the coke rate can result in a decrease of 10-15% in production costs. The primary emphasis of research and development is to enhance the quality of Coke and integrate alternative reductants to accomplish these reductions.

Figure 4.1: Pattern of Coke Rate across Steel Plants

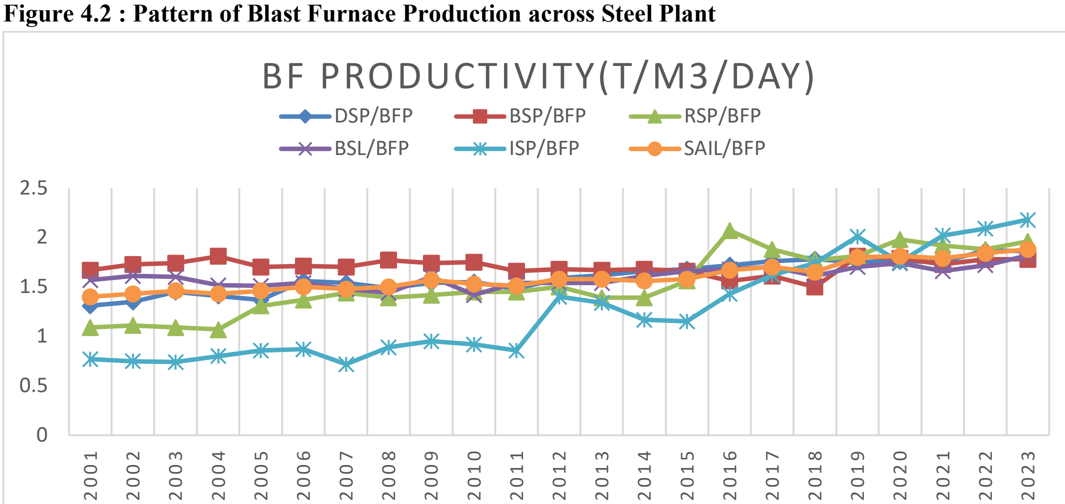


Source: Combined from Various Annual Reports of Ministry of Steel, Govt. of India

4.2 Blast FurnaceProductivity

The measurement of blast furnace productivity is determined by the daily output of hot metal, usually expressed in tons. Increased productivity is indicative of improved operational efficiency and reduced expenses per unit of production. The blast furnace productivity in India exhibits considerable variation, with contemporary furnaces producing rates as high as 2.5 tons of hot metal per cubic meter per day. According to Mehta and Das (2019), regular monitoring and process adjustment are crucial for maintaining high levels of productivity. Productivity is significantly influenced by factors such as the quality of raw materials, regular furnace maintenance, and efficient operational techniques.

Figure 4.2 : Pattern of Blast Furnace Production across Steel Plant

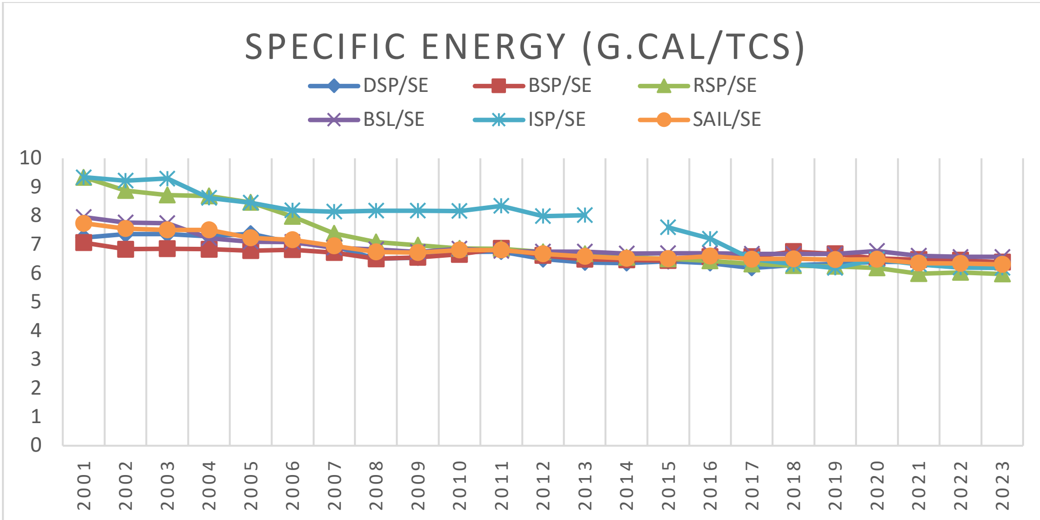


Source: Combined from Various Annual Reports of Ministry of Steel, Govt. of India

4.3. Specific Energy

Specific energy consumption is the measure of energy utilized for each metric ton of steel manufactured. This statistic is essential for evaluating the energy efficiency of steel production operations. In India, the amount of energy used per ton of crude steel ranges from 6 to 8 gigajoules (GJ). Sahu et al. (2020) propose that enhancing energy efficiency can result in significant financial savings and a decrease in environmental harm. To achieve these aims, it is crucial to deploy energy-efficient technology, such as improved electric arc furnaces and energy recovery systems.

Figure 4.3 : Pattern of Specific Energy across Steel Plants

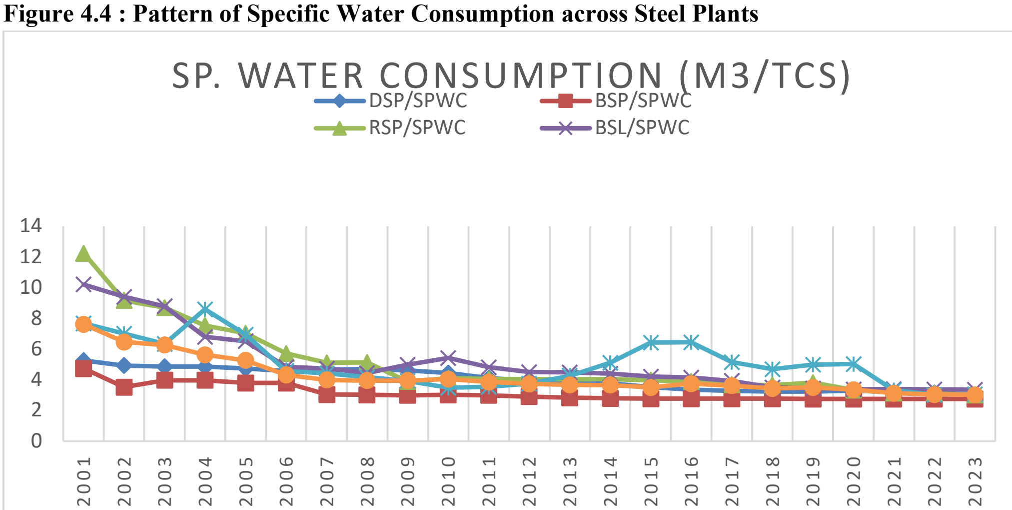


Source: Combined from Various Annual Reports of Ministry of Steel, Govt. of India

4.4. Specific Water Consumption

Specific water consumption is the precise measurement of water usage per metric ton of steel manufactured. Effective water management is crucial for ensuring sustainability, especially in countries with limited water resources. Water consumption in steel factories in India varies between 3 and 5 cubic meters per ton of steel. Patel and Joshi (2020) highlight the importance of implementing water recycling and reuse techniques to reduce water use. By incorporating closed-loop water systems and employing advanced treatment methods, the water footprint of steel manufacturing can be greatly diminished.

Figure 4.4 : Pattern of Specific Water Consumption across Steel Plants



Source: Combined from Various Annual Reports of Ministry of Steel, Govt. of India

5. Econometric Methodology

5.1. Panel Unit Root Tests

The problem of low statistical power in tests performed on individual time series data has led to a considerable increase in the use of unit root tests in panel data models. This study uses the unit root tests for panel data developed by Levin-Lin and Chu (LLC) (2002) and Im-Pesaran-Shin (IPS) (2003) in addition to the conventional unit root tests, which are the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test, to investigate the stochastic properties of the panel variables. Single time series unit root tests and panel unit root tests are not the same thing. The following equation represents the fundamental requirements of the panel unit roots Augmented Dickey-Fuller (ADF) test:

$$\Delta y_{it} = \rho y_{i,t-1} + \sum_{j=1}^{p_i} \eta_{ij} \Delta y_{i,t-j} + X'_{it}\delta + \varepsilon_{it} \tag{1}$$

LLC enables the independent separation of examination intermediation, time trend, residual, and self-reliance orders from the cross-section unit. However, it necessitates the generation of a sequence of time data that is independent, has a generic sample size, and exhibits the typical autoregressive behavior of order one, often known as AR(1) series, with general connectivity. Variable-specific differences in the order of lag for p_i shall be permitted. The appropriate order of lag is determined by allowing for the greatest lag order and then assessing the t-statistics for η_{ij}. Direct estimation of equation (1) does not yield the estimated value of the autocorrelation coefficient, ρ. The proxies for Δy_{it} and y_{it} should be standardized and devoid of deterministic components and autocorrelations. The estimation of the coefficient of autocorrelation is necessary.

5.2. Panel Cointegration Test

To examine the long-term cointegrating relationship between variables, we utilize the panel cointegration tests suggested by Pedroni (1999 and 2004). The Pedroni (1999) panel cointegration test is employed to assess the appropriateness of the test to be applied to the estimated residuals of the cointegration equation while normalizing the statistics of the panel with the correction terms. The test procedures utilize the estimated residual derived from the hypothetical equation of long-run regression in the following manner:

$$y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \ldots + \beta_{Mi} x_{Mi,t} + e_{i,t} \tag{2}$$

for $t = 1,..,T;\ i = 1,....,N;\ m = 1,\ ....,\ M,$

T denotes the temporal variation in the number of observations, N is the number of cross-sectional units utilized in the panel, and M represents the number of regressors. The term "intercept" in the given context refers to the specific value associated with members or parameters of fixed effects that vary across individual cross-section units. The same principle applies to both the slope coefficients and the temporal effects particular to members, $\delta_i t$.

Pedroni (1999 and 2004) has introduced test statistics for panel cointegration, specifically for the panel of heterogeneous and panel of heterogeneous group means. He has also provided definitions for these statistics for two distinct sets. Initial set comprises three statistics, namely, $Z_{\hat{v},N,T}$, $Z_{\hat{\rho}N,T\ 1}$ and $Z_{tN,T}$. These statistics are derived from pooling residuals and considering panel dimensions. The specific statistics are as follows:

$$Z_{\hat{v},N,T} = T^2 N^{3/2} \quad \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{11i}^2 \hat{e}_{i,t\ 1}^2 \tag{3}$$

$$Z_{\hat{\rho}N,T\ 1} = T\sqrt{N} \quad \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{11i}^2 \hat{e}_{i,t\ 1}^2 \quad {}^{1} \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{11i}^2 \left(\hat{e}_{i,t\ 1}\Delta\hat{e}_{i,t} \quad \hat{\lambda}_i\right) \tag{4}$$

$$Z_{tN,T} = \quad \tilde{\sigma}_{N,T}^2 \sum_{I=1}^{N}\sum_{T=1}^{T} \hat{L}_{11i}^2 \hat{e}_{i,t\ 1}^2 \quad {}^{1/2} \sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{11i}^2 \hat{e}_{i,t\ 1}^2 \left(\hat{e}_{i,t\ 1}\Delta\hat{e}_{i,t} \quad \hat{\lambda}_i\right) \tag{5}$$

Where $\hat{e}_{i,t\ 1}$ is the residual vector of the least square estimation of the equation (2) and the other notations are properly defined by Pedroni.

The second set of the above-mentioned statistics is based on the pooling of the residuals along with the between dimensions of the panel, which allows us for an autocorrelation of heterogeneous parameters across variables, can be expressed as follows:

$$\tilde{Z}_{\hat{\rho}N,T\ 1} = \sum_{i=1}^{N} \quad \sum_{t=1}^{T} \hat{e}_{i,t\ 1}^2 \quad {}^{1} \sum_{t=1}^{T} \left(\hat{e}_{i,t\ 1}\Delta\hat{e}_{i,t} \quad \hat{\lambda}_i\right) \tag{6}$$

$$\widetilde{Z}_{tN,T\ 1} = \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{e}_{i,t\ 1}^{2} \quad {}^{1/2} \sum_{t=1}^{T} \left(\hat{e}_{i,t\ 1}\Delta\hat{e}_{i,t} \quad \hat{\lambda}_i\right) \tag{7}$$

The above-mentioned statistics calculate the group mean of all individuals and conventional statistics of time series. The asymptotic distribution of all statistics can be represented by the following:

$$\frac{X_{N,T} \quad \mu\sqrt{N}}{\sqrt{v}} \Rightarrow N(0,1) \tag{8}$$

Where $X_{N,T}$ represents the corresponding form of the test statistics, whereas μ and v represent the mean and variance of the test respectively. In the case of the alternative hypothesis, the panel *v* statistics will diverge to the positive infinity. So, this is a one-tail test, where the large positive values will reject the null hypothesis of no cointegration relation between variables. The remaining statistics will move away to the negative infinity, which replies to the rejection of the null by large negative values.

6. Hypothesis and DataBase

Based onthe above-mentioned background, the basichypothesis, which is tobetestedto fulfillour purpose, which is to look at the dynamic inter-linkage between production and management of the environment measured by some suitable parameters in the case of Indian steel plants, categorized asfollows:

- *There is no inter-linkage between blast furnace productivity and various environmental parameters like energy consumption, coke rate, and water consumption.*

The analysis is restricted to five prominent public steel plants and overall SAIL, focusing on a period of from 2001 to 2023. The secondary data on the variables Blast Furnace (BFP) productivity per meter cube, specific Energy Consumption (SE) per ton of crude steel, Coke Rate (CR) per ton of hot metal, and Specific Water Consumption (SPWC) per ton of crude steel have been gathered from the annual reports of SAIL DSP Durgapur, SAIL BSP Bhilai , SAIL BSL Bokaro, SAIL RSP Rourkela , SAIL ISP Burnpur, and overall Steel Authority of India Limited (SAIL). The data for the variables collected in our study are in index form, as provided by the plants.

7. Empirical Findings

7.1. Panel unit root tests

Firstly, the stationarity of the panel data was assessed by conducting various unit root tests, including the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Im, Pesaran, and Shin (IPS), and Levin, Lin & Chu (LLC) tests. The factors being examined were Blast Furnace production (BFP), Energy Consumption (SE), Coke Rate (CR), and Water Consumption (SPWC). All of these variables showed non-stationarity at their respective levels, as indicated by negative test statistics that were not statistically significant at the 5% level. This implies that the null hypothesis, which assumes the presence of a unit root, cannot be disproven. This suggests that any disturbances to the variables will have long-lasting repercussions. Technically speaking, this implies that the series are integrated at a first-order level, denoted as I(1).

Estimated Statistics of Panel Unit Root Tests

Results of Panel Unit Root Tests at Level								
Variables	Constant				Constant and Trend			
	ADF Test	PP Test	IPS Test	LLC Test	ADF test	PP test	IPS Test	LLC Test
BFP	-0.89	-0.77	-0.92	-1.04	-0.73	-0.92	-1.06	-0.92
SE	-1.33	-1.29	-1.22	-0.97	-0.94	-0.96	-0.84	-1.05
CR	-1.08	-0.91	-1.05	-0.85	-0.88	-1.01	-0.99	-0.92
SPWC	-1.01	-1.04	-1.41	-0.93	-0.97	-1.09	-1.02	-1.03
Results of Panel Unit Root Tests at First Difference								
BFP	-5.93*	-6.11*	-6.77*	-6.66*	-5.98*	-6.12*	-6.02*	-6.77*

SE	-6.04*	-7.03*	-6.29*	-6.51*	-6.23*	-5.91*	-6.03*	-6.14*
CR	-5.97*	-6.55*	-6.57*	-6.39*	-6.84*	-6.44*	-6.11*	-6.66*
SPWC	-6.11*	-6.12*	-6.33*	-6.28*	-6.77*	-6.15*	-6.47*	-6.58*

Source: Authors' own estimation by using E-views 8 (* indicates statistical significance at 5% level)

Nevertheless, the results underwent a significant transformation when the data was initially differentiated. The test statistics for all variables in the ADF, PP, IPS, and LLC tests were found to be significantly negative, with p-values < 0.05. This suggests that the variables have achieved stationarity. Consequently, by obtaining the first differences, the unit-roots were eliminated, rendering the variables appropriate for subsequent econometric modelling and analysis. From a technical perspective, this transformation is essential because it indicates that although the levels of BFP, SE, CR, and SPWC may exhibit a random walk pattern, their fluctuations do not, enabling a more reliable long-term study.

Put simply, the early statistics indicated that the production and consumption figures exhibited unpredictable patterns. Nevertheless, once the data was modified, it reached a state of stability, indicating that the fluctuations in these figures were more foreseeable as time progressed.

7.2. Pedroni Panel Cointegration Test

The Pedroni Panel Cointegration Test is a statistical method used to determine the presence of cointegration in panel data. The Pedroni panel cointegration test was used to examine the enduring links between the variables. This test assesses the cointegration of a set of non-stationary series, indicating if they exhibit a shared long-term trend. The findings indicated a notable presence of cointegration among the variables. The test statistics obtained from both within-dimension (panel statistics) and between-dimension (group statistics) analyses had significantly negative values, with p-values below 0.01. The panel rho-statistic, panel PP-statistic, and panel ADF-statistic all provided evidence to reject the null hypothesis of no cointegration.

Estimated Results of Pedroni Panel Cointegration Test

Within Dimension				
Test Statistics	Individual Intercept		Individual Intercept and Constant Trend	
	Statistic	Prob.	Statistic	Prob.
Panel rho-Stat	-2.96*	0.01	-3.03*	0.00
Panel v-Stat	-3.11*	0.00	-3.27*	0.00
Panel PP Stat	-3.02*	0.00	-3.08*	0.00
Panel ADF Stat	-2.99*	0.01	-3.22*	0.00
Between Dimension				
Group rho Stat	-3.77*	0.01	-3.96*	0.00
Group PP Stat	-4.02*	0.00	-4.11*	0.00
Group ADF Stat	-4.66*	0.00	-4.09*	0.00

Source: Authors' own estimations using E-views 12

These data indicate that there is a consistent and lasting balance between BFP, SE, CR, and SPWC. In technical terms, this means that any temporary differences between these variables are eventually adjusted, ensuring a stable long-term connection. These findings have significant ramifications for policy and management in the steel industry, as they demonstrate that environmental issues such as energy consumption and water usage are inherently connected to production levels, and they tend to change in tandem over time.

Put simply, this implies that the production levels of steel and the consumption of energy and water are intricately connected in the long term. The interconnectedness of different areas implies that modifications in one area will inevitably impact the others, underscoring the necessity of integrated resource management to uphold efficiency and sustainability.

7.3. Environmental and Production Performance Indicators

The study extensively examined the performance indicators of public sector prominent steel plants from 2001 to 2023. It specifically focused on metrics such as Coke Rate (Kg/THM), Energy Consumption, and Water Consumption. The investigation indicated a consistent decrease in coke rates, indicating enhanced efficiency and technological progress. As an example, the Durgapur Steel Plant (DSP) decreased its coke consumption rate from 580 kg/THM in 2001 to 449 kg/THM by 2023. This pattern remained constant in other plants, indicating the sector's endeavours to improve operational efficiency.

Likewise, there was a decrease in energy use across these plants. The decrease in energy consumption can be due to the implementation of more advanced technologies and improved energy management strategies. SAIL's endeavours in renewable energy and energy recovery technologies have a substantial impact in reducing energy consumption per metric ton of steel manufactured. This exemplifies the dedication of the sector to diminishing its carbon emissions and advancing sustainability.

The data shows a significant decrease in water consumption, suggesting advancements in water recycling and management techniques. For instance, the Internet Service Provider (ISP) has substantially reduced its water consumption over several years. These findings highlight the efficacy of environmental management measures and the beneficial influence of technology improvements in resource usage.

Put simply, steel plants are enhancing their operational efficiency by reducing their use of coke and energy in steel production, as well as improving their management of water utilization. This not only enhances the efficiency of steel production but also yields environmental advantages.

8. Conclusions from the Findings

The empirical investigation validated the connections between production and environmental management in the Indian steel sector. The findings offer strong evidence that when manufacturing processes are optimized alongside environmental considerations, it can result in enhanced operational efficiencies. The decreasing patterns in coke rate and energy consumption suggest improved operational efficiencies, which can be linked to the use of sophisticated manufacturing techniques and government programs aimed at encouraging sustainability in the steel industry. These measures are in line with the sector's objectives of decreasing its carbon emissions and enhancing the efficient use of resources.

From a technical standpoint, these findings indicate that although the variables are not stationary on their own, they have a shared long-term equilibrium relationship. This implies that any temporary deviations are eventually fixed. Policymakers can utilize these observations to formulate policies that promote technological advancements targeting sustainable steel manufacturing.

This study demonstrates that by optimizing their energy and water usage, steel mills may achieve resource conservation and enhance the efficiency of steel production. This underscores the significance of integrating production objectives with environmental stewardship to achieve a sustainable future. Policymakers should prioritize investments in modern technologies to enhance production efficiency in steel plants, thereby reducing energy consumption and costs. Additionally, promoting sustainable practices, such as recycling and the utilization of by-products like blast furnace slag, can significantly mitigate environmental impacts. Supporting regulatory frameworks that encourage innovation and investment in cleaner technologies will also foster a more sustainable steel industry in India.

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