A Brief Report

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India's Energy Transition:
An Inquiry into the Steel Industry and its Path to Sustainability

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Executive Summary

Industrialisation relies on metals, with steel as a key driver. In 2021, global steel production reached 2 billion tonnes, led by China, followed by India, Japan, and the USA. Steel plays an important role in the development of any industry, serving as a raw material and a vital component in industrial forward and backward linkages. In terms of forward linkages, steel is integral to various industries like automobile and construction, which affects their costs and production capabilities. Simultaneously steel is crucial for the production of machinery, equipment, and tools, forming the backbone of efficient manufacturing processes and facilitating industrial growth. Consequently, the availability, affordability, and quality of steel directly influence the performance and development of numerous sectors, making it an essential driver of industrial progress and economic prosperity.

Emissions from the steel industry worldwide, accounting for approximately 2.3 gigatonnes (Gt) of carbon dioxide annually, constitute a significant portion of global industrial emissions. In India, the steel industry is responsible for 24% of its total industrial emissions. This is due to the industry's heavy reliance on coal, which makes up about 85% of its energy needs. The global trend indicates an increase of 1 gigaton of annual carbon dioxide emissions, over the next three decades, mainly driven by growing steel demand in developing economies. In India, steel production predominantly employs three methods:

Induction furnace: A relatively more energy-efficient process that produces lower greenhouse gases. However, if the electricity used is generated from fossil fuels, it can still contribute to emissions.

Electric Arc Furnace: These are considered more environment friendly, compared to traditional blast furnaces, as they use scrap steel, reducing the need for iron ore extraction. The melting of steel scraps, however, does lead to some extent of emissions.

Blast Oxygen Furnace: This method is highly efficient in producing large quantities of steel, and it can use lower grade irons. However, it has a large environmental footprint due to its reliance on coal as it generates large amounts of slag and waste materials.

In India, the steel sector heavily relies on the coal industry, creating a symbiotic relationship between the two. Coal is one of the most important sources of energy for heavy industries like iron and steel. This dependence on coal has several positive outcomes such as promoting foreign investment, exports, and job opportunities, but also raises environmental concerns due to significant carbon emissions. An energy transition in the steel industry is vital to holistically achieve the sustainable development goals. The Ministry of Steel, Government of India, is actively working to reduce carbon emissions and environmental pollution in steel plants through its various schemes and regulations, focusing primarily on energy efficiency, renewable energy, material efficiency, green hydrogen, and CCUS (Carbon capture, Utilisation and Storage).

Using cleaner methods to produce steel,

Photo Credit: https://www.livemint.com/industry/energy/the-uphill-climb-to-liberalize-coal-11603030207632.html however, has some of its own negative implications:

Initial High Costs: Upgrading or replacing existing infrastructure and implementing new technologies may require significant capital investment, which could strain the finances of steel producers, potentially leading to higher steel prices.

Job Displacement: As coal demand decreases, coal mines may shut down or reduce operations, leading to layoffs or unemployment for coal miners and supporting staff.

Economic Disruption: Communities that are heavily reliant on coal can face economic disruption and a decline in local businesses when the mines close.

Technological Challenges: The development and implementation of clean steel production technologies can be technically challenging and may slow down the adoption of cleaner methods and require extensive research and development.

The Indian steel industry faces multiple challenges, including high energy consumption, limited access to quality coking coal, inadequate infrastructure, technological barriers, etc. Coking coal, essential for the industry, is predominantly imported due to limited domestic reserves, creating supply chain vulnerabilities and price volatility. These challenges, along with fluctuating coal prices, significantly impact the industry's profitability and influence the global investors' decisions.

Forecasting steel production is crucial for economic, environmental, and social planning as it facilitates efficient resource allocation, guides investment decisions, supports environmental planning. Accurate forecasts help governments and industries limit the probable negative effects on economic indicators such as employment, income, etc. In the context of cleaner steel production, these forecasts are crucial in transitioning to more sustainable practices while ensuring that the steel sector continues to play a vital role, especially in developing economies.

Key Findings

- The forecast indicates that annual steel production will more than double by 2040, aligning with the findings reported by the International Energy Agency (IEA). This reaffirms the potential for a substantial surge in steel production in India, implying increased coal consumption unless rigorous energy transition policies are implemented.
- Since India relies heavily on imported coking coal, a more than two-fold increase in steel production will proportionately impact the volume of imported coal, potentially having an adverse impact on India's Balance of Payments (BoP).
- The expense of importing coking coal to facilitate steel production is poised to become a substantial component of the total production expenditures, consequently undermining its cost competitiveness on the global stage. Furthermore, with rising demand, the cost of coking coal is anticipated to surge, compounding the overall production costs.
- If steel production increases through cleaner technologies, coal consumption will reduce, that can result in job displacement across coal related industries. A decline in coal production can lead to social disruption, as families and communities face uncertainty and potential migration as people seek new job opportunities elsewhere.
- The substantial rise in steel production would boost the need for raw materials, potentially impacting global commodity markets and intensifying resource competition.

The transition to alternative clean technologies for steel production in India is not only imperative for environmental sustainability but also offers a pathway to economic growth and innovation. To realise this transition, it is recommended that India embraces a comprehensive approach encompassing policy incentives for clean technology adoption, investments in research and development, and fostering collaborations between the government, industry, and research institutions. By balancing between the development of cleaner steel production methods while also mitigating the impacts on those dependent on the coal industry, India can position itself as a global leader in sustainable steel manufacturing, reaping long term benefits for the economy, environment, and society.

1 Introduction

Industrialization is driven primarily by the use of metals. The most crucial of the widely used metals is steel, which is considered as the backbone for the development of an economy. The per-capita level of steel consumption is an important growth indicator and any industrial economy is characterised by a high steel consumption. As of 2021, the world produced nearly 2000 million tonnes (Mt) of steel, over half of which was produced by China (1032.8 Mt) (*World Steel Association*, 2022). India is the second largest steel producer with a production of 118.1 Mt followed by Japan (96.3 Mt) and USA (86 Mt) (*World Steel Association, 2022*). Post independence, India looked to develop its primary, secondary and tertiary sectors simultaneously and thus steel, that is both a raw material and an intermediary product became one of the most important inputs as it connects all sectors through its forward and backward linkages. Effective labour costs and ample reserves of iron ore drive the growth of Indian steel production. However, India lags in the per capita steel consumption at 74 kg against the world per capita consumption of 228 kg (*Ministry of Steel*, 2021). Recently, the government of India has announced the Specialty Steel Production-Linked Incentive (PLI) scheme as well as sanctioned Rs. 70.15 crore to the Ministry of Steel. This continuous growth in the steel industry has improved the country's competitiveness on the global stage and has opened up opportunities for international investors to enter the Indian market.

The iron and steel industry currently emits 2.3 Giga tonnes (Gt) of Carbon Dioxide. This is expected to increase by 1 Gt in the next three decades as a result of the increasing demand from developing economies (*Energy Transitions Commission*, 2023). Steel industry is also the largest coal consumer, among the heavy industries, with coal accounting for 75% of its energy needs. In India, the sector is the largest CO_2 emitter from the industrial sector with a share of 24% in total industrial emissions (Mallett & Pal, 2022). Out of India's total greenhouse gas emissions, 9% is from the steel industry alone. India also relies heavily on coal for steel production with coal accounting for 85% of the sector's energy needs. An energy transition in the steel industry is vital to holistically achieve the sustainable development goals. Currently steel is mainly produced through two methods: the Blast Oxygen Furnace method and Electric Air Furnace which traditionally rely on fossil fuels. Another method is through electric arc furnaces which are relatively cleaner source of production and accounts for 30% of the steel produced across the globe. It however requires scrap metal which are not always available and also has certain restrictions in terms of quality required for some applications, such as in automotives. Although some developed countries have started producing steel from cleaner technologies, it is still a challenge for developing nations as cleaner steel costs more to produce.

It is also important to note that a large chunk of the Indian population is dependent upon coal. A transition in the steel industry, leading to a coal phase out will impact hundreds of thousands of people that are directly and indirectly dependent on the coal industry. It is therefore, necessary to explore the workings of the steel industry, the trends in its consumption and the impact of steel decarbonisation on the coal industry. The objective of this study is to present the current steel industry scenario of India, to forecast steel production and to assess the impact of changing steel production on coal industry as well as those dependent on the coal industry. We also present the steel production capacity in India and its production in the public and private sectors. An overview of the funds mobilised through Corporate Social Responsibility for public and environmental welfare is also presented. We then forecast the total steel production in the economy for the period of 2023-2040 using the autoregressive method (AR), explained in detail in section 4.3. Finally, we present appropriate recommendations for the steel industry to develop the roadmap for sustainable steel production.

2 The Indian Steel Industry

The Indian steel industry is the second largest steel producer in the world and the largest producer of sponge iron. Starting with a negligible presence in the global market, India went through several highs and lows while navigating its way to become one of the leading steel producing countries. In this section, we present the detailed setting of the industry starting with the history, production and capacity followed by the policy scenario and contributions to the welfare of the public and the environment.

2.1 Historical Perspective

India has been using steel since the ancient times; however, it was only during the late nineteenth century that steel production began using modern technology. Although attempts were made to establish iron and steel plants from the early 1800s, it was only through the establishment of Tata Iron and Steel Company (TISCO) in 1907 that the steel industry foundation was laid by Jamsedji Nusserwanji Tata in Jamshedpur. TISCO went on to become the largest steel producer in the entire British Empire by 1939 and is now among the top ten global steel producers (World Steel Association, 2022). Post independence, India witnessed a massive growth rate in the industry for two decades, which could not be sustained after the 1970s as a result of the economic slowdown. As a result of the liberalisation policies in 1991, this trend finally reversed and overall production increased with an entry of private players which further increased the total steel exports. Since then, India witnessed a continuous and exponential growth in the sector and is now a net exporter of steel and pig iron (Ministry of Steel, 2022). The historical timeline of the industry is depicted in Table 1.

Table 1: Historical timeline of the Indian steel industry

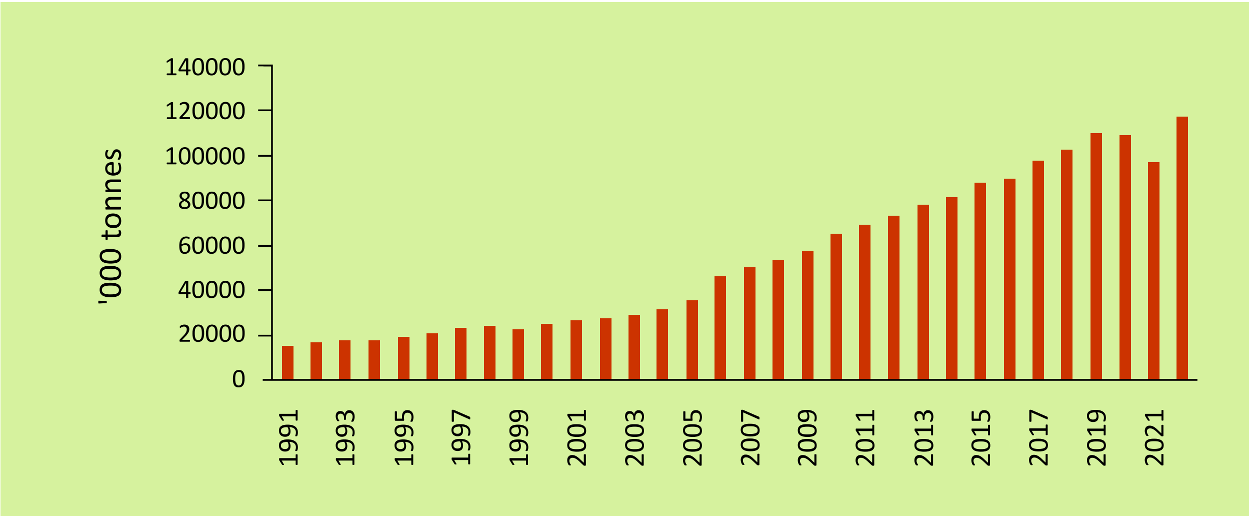
1808-1860	Early attempts to establish the iron and steel industry by the East India Company
1870	Establishment of Bengal Iron Works Company (later changed to Burrakar Iron Work and eventually acquired by Bengal Iron and Steel Company)
1875	Establishment of Bengal Iron and Steel Company (Changed to Bengal Iron Company Ltd in 1926)
1907	Establishment of Tata Iron and Steel Company
1919	Establishment of Indian Iron and Steel Company (IISCO)
1930	Bengal Iron Company merged with IISCO
1950	Three plants set up by The Hindustan Steel Limited
1973	Steel Authority of India (SAIL) launched
1991	Liberalisation of the iron and steel sector as per the New Economic Policy
1996-1997	Industrial decline due to economic slowdown
2002	Global industrial and economic revival
2005	National Steel Policy announced with the objective of establishing a modern and efficient industry standard
2005	India becomes one of the top ten global steel producers
2017	Revised National Steel Policy with a roadmap for long term growth
2018	India becomes the second largest crude steel producer

Source: Collated by Author based on information from various reputed sources

2.2 Capacity and Production

India had a steel production capacity of merely 1 MT till 1947. Post independence the capacity grew to nearly 15 MT in just a decade (Ministry of Steel, 2022). This was primarily the result of state ownership and the first three five-year plans when the government set up the Bhilai, Durgapur, Rourkela and Bokaro plants. Figure 1 presents the total steel production in India post liberalisation. The industry witnessed a slower growth rate in the first decade of the implementation of the New Economic Policy. This picked up pace post 2005 after the National Steel Policy was announced and has increased quite consistently other than FY 20 and FY 21 due to the Covid-19 pandemic.

Figure 1 Steel Production in India (1991-2022)



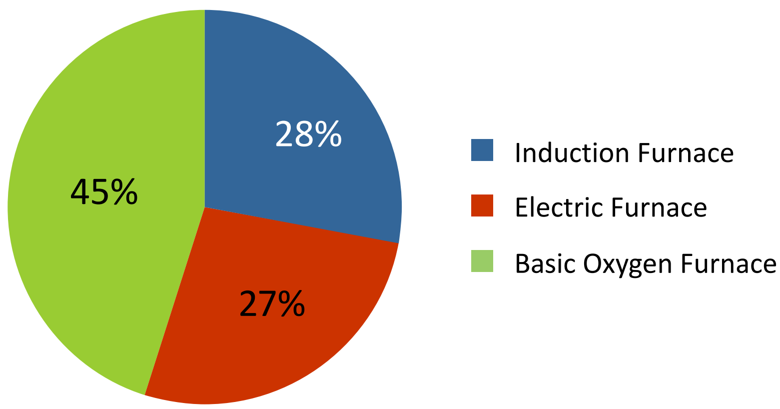
Source: India Steel Production, 2023

Steel is produced using primarily three methods in India:

- Induction Furnace: uses electric induction coil for operation
- Electric Arc Furnace: uses high current electric arcs to melt steel scraps
- Basic Oxygen Furnace: uses coal as the primary carbon bearing material to separate oxygen from iron ore

Although the first two methods use electric energy and not coal directly, they are still a source of emission in India as 72% of electric energy is generated from coal (*Central Electricity Authority*, 2023). Figure 2 depicts the share of each method of production.

Figure 2 Crude Steel Production Processes



Source: Ministry of Steel, 2022

India also leads in production of sponge iron and is a net exporter of pig iron. A large number of coal-based plants are set up in the coal rich states of the country for production of sponge iron contributing to 78% of total production. Table 2 presents the details of the sponge iron and pig iron production in India.

Table 2: Sponge iron and pig iron production in India (in Million Tonnes)

Production of Sponge Iron (Mt)

Year	2017	2021
Coal Based	23.28	30.60
Gas Based	6.22	8.42
Total	29.50	39.00

Pig Iron Domestic Availability (Mt)

Year	2017	2021
Production	6.89	5.88
Import	0.02	0.02
Export	0.67	1.41
Consumption	6.20	4.51

Source: Ministry of Steel, 2022

2.3 The Public and Private Sector in the Steel Industry

The private sector plays a crucial role in the growth of the Indian steel industry. The sector comprises of large-scale steel producers as well as small and medium scale units of sponge iron plants, mini blast furnace units, electric arc furnaces and cooling units, among others. The sector contributes substantially to the production of primary and secondary steel.

With a 33 million tonne annual capacity for crude steel, Tata Steel is one of the major global steel producers. Tata Steel operates Tata Steel BSL Ltd., and Tata Steel Long Products Ltd. in India, and together they have a combined manufacturing capacity of 20.6 million tonnes. Another integrated steel firm in India is JSW Steel Ltd., which has a 28 million tonne annual capacity with a single location steel producing facility which has capacity a 12 million tonnes. To ensure long term growth, JSW Steel places strong emphasis on research and innovation. Arcelor Mittal Nippon Steel (AM/NS) has created an integrated flat carbon steel producer in India with an annual capacity of 10 million tonnes and offers over 300 grades of steel. With a considerable global footprint, Jindal Steel and Power Company is another key participant in the Indian steel sector. For a more efficient and low-cost production, it uses backward and forward integration (*Ministry of Steel, 2022*). With an annual production of 1.1 million tonnes, Jindal Stainless Ltd. is India's largest stainless-steel producer. ESL Steel Ltd., an integrated steel producer in Jharkhand was founded in 2006 and was taken over by Vedanta Ltd. in 2018. The company's current annual capacity is 1.88 million tonnes per annum and produces TMT bars, wire rods, pig iron, among others, through its Sinter plants, coke ovens, blast furnaces and basic oxygen furnaces. JSHL is a fully integrated stainless steel mill in India with a capacity of 0.8 million tonnes per annum and provides high-end precision stainless steel products. It also produces high nitrogen steel for the defence industry (*Ministry of Steel, 2022*).

Table 3: Difference between Maharatna, Navratna and Miniratna status given to CPSEs

Maharatna	Navratna	Miniratna
To be eligible for the Maharatna status, a CPSE must already have Navratna status, be listed on the Indian stock exchange with a minimum prescribed public shareholding under SEBI regulations, have an average annual turnover, an average annual net worth, and an average annual net profit after tax of more than INR 25,000 crore, INR 15,000 crore and INR 5000 crores over the last 3 years respectively, and significant global presence.	To be eligible for the Navratna status, a CPSE must already have the Miniratna Category-I status and have a composite score of 60 or above in the six selected performance indicators: net profit, net worth, total cost of production, profit before interest, depreciation and taxes, capital employed, cost of services and cost of manpower.	Miniratna category I status is given to CPSEs that have a positive net worth, have made profit in the last 3 years and have a profit before tax of atleast INR 30 crores.Miniratna category II status is given to CPSEs that have a positive net worth and have been profitable for the last 3 years.

Source: Ministry of Heavy Industries, 2023

The Ministry of Steel has administrative control over seven central public sector enterprises (CPSE). The Steel Authority of India Limited (SAIL) is a Maharatna CPSE, has five integrated steel plants and three special and alloy steel plants in various locations across India. SAIL has research and development units, engineering, technology and safety organizations, a marketing, and distribution network coordinated by central marketing organisation. As of January, 2022, SAIL had a workforce of nearly 63,000 individuals, consisting of 10,632 executives and about 52,000 non-executives. Between April, 2021 and December, 2021, the workforce decreased by 2604 individuals (*Ministry of Steel*, 2022).

RashtriyaIspat Nigam Limited (RINL), a Navratna CPSE, is the corporate entity of Vishakhapatnam Steel Plant. The company operates one integrated steel plant in Andhra Pradesh and three mines in Andhra Pradesh and Telangana. Additionally, RINL has set up a Forged Wheel Plant in Uttar Pradesh to cater to the needs of the Indian Railways. As of December, 2021, RINL had a workforce of nearly 16,000 individuals consisting of 5258 executives and 10,670 non-executives. A reduction of 786 individuals was observed as compared to the previous year (*Ministry of Steel*, 2022).

NMDC Limited is a Navratna CPSE that explores minerals and develops mines for producing raw materials for the steel industry. It is a major iron ore supplier to the domestic steel producers and operates large mechanized iron ore mines Chhattisgarh and Karnataka. As of December, 2021 the manpower strength of NMDC was 5464 individuals.

MOIL is a Schedule-A Mini Ratna Category-I CPSE and the largest producer of manganese ore in India, with a share of 48% in domestic production. Recently MOIL received environmental clearance for prospecting in Kodegaon, Maharashtra, and is in the process of purchasing land for the mine and obtaining other statutory clearances. It has also identified manganese bearing areas in four districts of Madhya Pradesh for exploration. As of December 2021, the manpower strength of MOIL was 5802.

MECON Limited is a multidisciplinary design, engineering, consultancy, and contracting organization that specializes in metals and mining, energy, infrastructure and environmental engineering. They offer services for setting up projects from concept to commissioning and has a manpower of 1138 as of December, 2021.

MSTC Limited was established in Kolkata in 1964 and became a PSU in 1982-83. Initially it was responsible for importing various types of scrap but later diversified into providing e-auction/e-procurement services and trading division for the import and domestic sourcing of bulk industrial raw materials. It is largest government company in India in the e-commerce sector, providing standalone and neutral e-commerce services to various central and state government departments and private entities. As of December, 2021, the company had 318 employees.

KIOCL Limited is a Schedule-A Mini Ratna Category-I CPSE and was incorporated in 1976 to mine magnetite ore. The company currently sells iron ore pellets and foundry grade pig iron and is venturing into exploration of mineral deposits. The company has obtained environmental clearance for setting up a non-recovery coke oven plant and ductile iron spun pipe plant and is in the process of obtaining statutory clearances to mine iron and manganese ore. As of December, 2021, KIOCL had 709 employees (*Ministry of Steel*, 2022).

https://growmudra.com/news/details/90a6a3e4bf2f998638f0ea1bb15ed6f4/public-sector-steel-firms-clear-rs-692-crore-dues-to-msmes-in-may:-ministry

2.4 Public Welfare

The CPSEs have incurred expenditure on CSR initiatives in the areas of education, health, women's empowerment, sustainable income generation, access to water and sanitation systems, and environmental sustainability. SAIL helps 600 government schools by supplying mid-day meals and dry ration kits. Additionally, it operates 20 special schools in integrated steel plant locations for pupils in the Below Poverty Line category. In addition to partnering with the Government of Chhattisgarh to electrify health centres using solar power, NMDC has also started a skill development programme for tribal youth living close to its projects.

Ministry of Steel, SAIL, RINL, NMDC and other public sector businesses have taken action to adhere to the regulations of the Supreme Court to incorporate gender equality at workplaces. They have established committees to handle sexual harassment claims, provided maternity leaves and child care facilities, among other benefits. Mahila Samitis have also been established to encourage awareness of health, family planning and self-employment for female workers. They also provide women employees specialized training programmes in technical and management fields. Women in Public Sector (WIPS) cells have been formed to help women improve their networking skills. The number of women employed in the public sector steel companies range from 3.5% to 17% of their total workforce.

In terms of hiring and promoting employees, SAIL abides with the Presidential Directives on Reservation for Scheduled Castes and Scheduled Tribes. As of January, 2022, nearly 17%, 16% and 15% of SAIL's workforce are SCs, STs and OBCs respectively. SAIL's plants are located in economically underdeveloped regions that help in the economic advancement of those areas. Other companies such as RINL, NMDC, MECON, KIOCL and FSNL, among others also contribute to the welfare of the employees belonging to the weaker sections of the society by various measures such as granting scholarships to children, organizing workshops, setting up grievance redressal cells and sponsoring employees for training programs.


https://www.downtoearth.org.in/news/climate-change/cop27-report-sees-slight-rise-in-2022-global-emissions-highest-in-india-85928

2.5 Environment Management

The Ministry of Steel is actively aiding in the decrease of energy usage and carbon dioxide emissions while also taking measures to mitigate environmental pollution within steel plants through the implementation of a variety of programs and regulations. India is committed to achieving net zero emissions by 2070 as part of the Glasgow commitments. The Ministry of Steel has categorized their approach into five pillars, which includes energy efficiency, renewable energy efficiency, material efficiency, green hydrogen and CCUS (Carbon Capture, Utilization and Storage). The Ministry is also coordinating with stakeholders and government departments to push this transition as per the parliamentary committee meeting on transitioning towards low carbon steel and circular economy in the steel sector (*Ministry of Steel*, 2022).

The Ministry of Steel is focused on improving energy efficiency in the steel sector through the National Mission for Enhanced Energy Efficiency (NMEEE). NMEEE includes the Perform, Achieve, and Trade (PAT) scheme, a market based mechanism that certifies and allows trading of energy savings. The objective of the programme is to reduce energy consumption in 197 iron and steel plants, making it a major step towards energy efficiency in the sector.

The Japanese government, through their Ministry of Economy, Trade, and Industry, provides financial support for eco-friendly projects in India under the Green Aid Plan (GAP) administered by the Department of Economic Affairs. These are referred to as Model Projects, and cover diverse sectors, including steel, are supervised by NEDO (New Energy and Industrial Technology Development Organisation) in Japan. At COP-27 in Egypt, the Ministry of Steel hosted a session that focused on decarbonisation in the Indian steel industry. The event featured discussions and presentations by major steel industry players like JSW, TATA Steel, and SAIL, highlighting their strategies for reducing carbon emissions through technologies such as Green Hydrogen and Carbon Capture.

Photo credit: BLOOMBERG

2.6 Steel Production Policies in India

The National Steel Policy (NSP) 2017 aims to enhance the MSME sector, secure raw materials, reduce imports, and improve cost efficiency, with the goal of creating a globally competitive steel industry. The policy focuses on self-sufficiency in production, technology advancement, and the vital role of MSME steel plants in boosting capacity to support India's consumption driven growth while elevating productivity and quality. The Domestically Manufactured Iron and Steel Products (DMI&SP) Policy 2017 promotes the use of domestically produced iron and steel in government procurement. The policy covers 49 iron and steel products making it challenging for imported steel to compete in government contracts. The Steel Import Monitoring System (SIMS) introduced in 2019 is an online platform that requires pre-registration of proposed steel imports. It provides comprehensive information on steel imports occurring about two months in advance, which aids the industry in gaining a deeper understanding of the specific steel grades coming into the country, thereby facilitating the planning processes of domestic manufacturing. The Production Linked Initiative (PLI) Scheme, approved by the cabinet with an outlay of INR 6,322 crores, focuses on promoting specialty steel production. This scheme covers five categories of specialty steel used in various applications such as automobiles, pipelines, etc. The Government has also taken steps to address the high prices of vital raw materials in the manufacturing sector, which includes iron and steel. These measures include adjusting tariffs by eliminating import duties on materials like anthracite, coal, coke, and ferro-nickel, increasing export duties on iron ore and pellets, and introducing an export duty on pig iron. This resulted in a 15-25% reduction in steel prices. This was, however, reversed in November, 2022. The Steel Scrap Recycling Policy (SSRP) 2019 aims to establish metal scrapping centres in India for the processing and recycling of ferrous scrap, particularly from automobiles. The policy establishes a structured approach to ensure safe and eco-friendly collection, dismantling, and shredding of scrap metals, mitigating pollution and health risks (*Ministry of Steel*, 2022).

Source: https://economictimes.indiatimes.com/industry/indl-goods/svs/steel/

3 Energy Transition in Steel Industry

To address the challenges of energy security and climate change while simultaneously focusing on countries having to expand their energy requirements, a global and comprehensive technological transformation is vital. As an emerging nation, the major challenge for India is to attain substantial

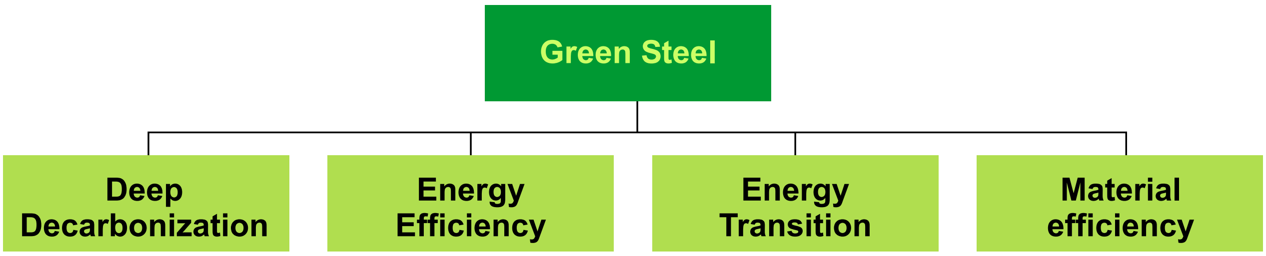
Figure 3 **Challenges in the Indian Steel Industry**

Source: Chatterjee, 2013

economic growth as well as enhancement in its energy security while eliminating excessive carbon emissions.For this, emphasis should be given to minimize carbon emissions in the major industrial fields, such as iron and steel industry since it contributes approximately 7% of global carbon emissions (Kim et al., 2022). Thus, decarbonization of the heavy industries is critical to ensure the industry's long-term viability.

Steel is considered as a critical component of energy transition and decarbonization because it is widely used in the production of turbines, solar panels, as well as electric cars (Kim et al., 2022). According to the report of Paris Agreement, climate-neutrality, and COP 26 commitments, each country must strive towards the goal of net-zero emissions and environmental sustainability. To accomplish the objective of carbon neutralization and to avoid the negative impact of climate change, lowering emissions particularly from steel industry must be an integral part of India's effort (Arens et al., 2021). Indian steel industry scenario and the drivers of green steel[1] transition is depicted in the figures 3 and 4. The factors that are responsible for a green transition in the steel industry are energy efficiency, energy transition, deep decarbonization, and material efficiency[2].

Figure 4 **Drivers of Green Steel Transition**



Source: Collated by Author

[1] Green steel refers to the production of steel without utilizing any carbon-intensive energy source.
[2] Material efficiency is the utilization of less material to produce a product which conserves resources and helps in waste management.

The Indian steel industry does face several challenges related to high energy usage, paucity of coking coal, conversion costs, poor infrastructure, technological barriers, and low labour productivity.The industry is heavily dependent on energy generated fromfossil fuels such as coal for various of processes of making steel such as iron ore processing, melting, and refining. The high energy requirement not only increases the cost of production but also poses as a challenge in terms of environmental sustainability.

Coking coal is used as a raw material in the steel industry, particularly for the blast furnace route. Since India has limited reserves of high-quality coking coal, it relies on imports from countries like Australia, Canada, and the United States. Highdependence on imported coking coal can lead to supply related challenges such asvolatility in price levels, and increased cost of production.

The conversion costsand the fluctuations in raw materialprices in the sector significantly impact the overall profitability of steel producers and ultimately affect the global investors'decision. Therefore, technological upgradation, such as adopting advanced steelmaking techniques and automation, can help improve productivity and reduce costs of production as well.

In India, the factors such as outdated production technologies, and inadequate skills contribute to lower labour productivity. Hence, labour productivity can be increased through skill development, efficient technology adoption, and process optimization which will increase global competitiveness and reduce production costs.

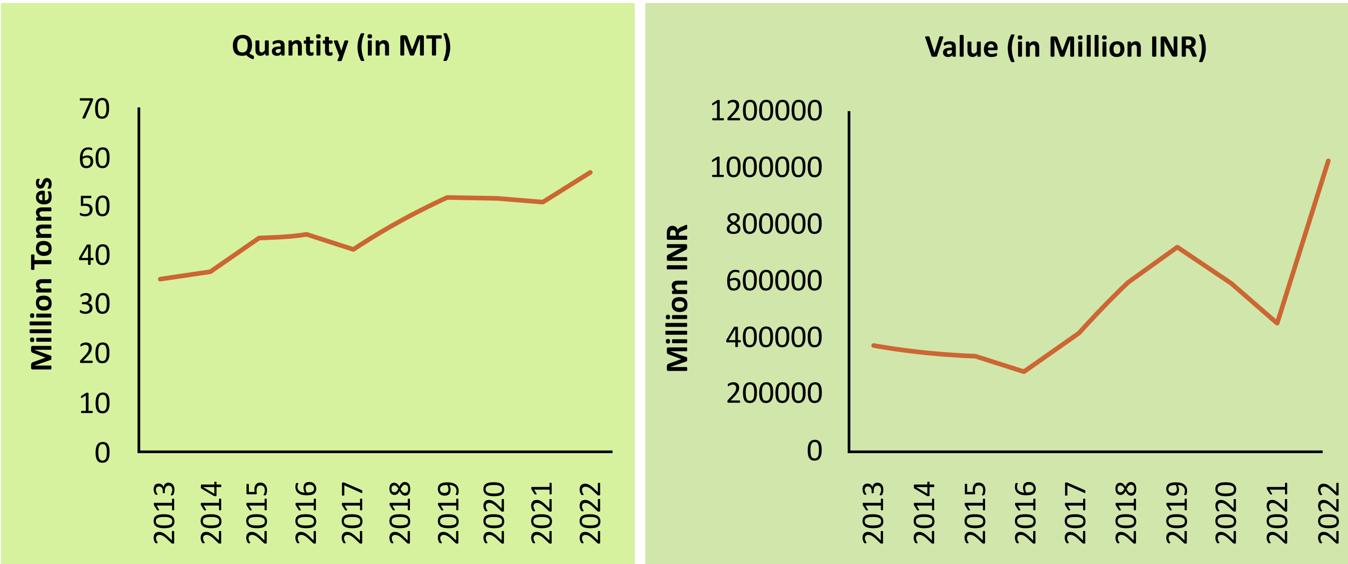
Infrastructure plays a vital role in the Indian steel sector. However, poor infrastructure can affect the competitiveness and profitability of steel producers.Efficient and large-scale infrastructure development projects are essential for facilitating international trade in steel products.

3.1 Steel Dependency on Coal

In India, steel sector is heavily dependent on coal industries; any influence on coal will have an impact on steel and vice-versa. Heavy industries such as, iron & steel are those industries which largely relies on coal for their energy needs. Coal is an important raw material for the steel industry, and the use of high-grade iron ore acts as a significant factor for the sector's performance. The coal sector is crucial to rising industrialization since it supplies fuel to fulfil the increasing need for energy.Though utilizing coal in steel industry promotes greater foreign investment, exports, and job opportunities, the major concern is that it emits huge amounts of carbon in the steel making process.

About 80% of the coking coal requirements are met through imports due to lack of availability of good quality coking coal. Considering that coking coal constitutes about 42% of the cost of steel production (*Ministry of Steel*, 2023), the Ministry of Steel is actively working to decrease the expenditure on coking coal imports through diversifying the sources of production. Figure 5 depicts the quantity and value of coking coal imported to India. It can be observed that even though the quantity of imports has increased by about 1.6 times, the value of imports has increase by 2.7 times, indicating an increase in overall imports as well as an accelerating cost of coking coal. This will further affect the output price leading to cost ineffectiveness in the steel industry.

Figure 5 **Quantity and Value of Coking Coal Imports (2013-2022)**



Source: Ministry of Steel, 2023

3.2 Measures Adopted for Decarbonization of the Steel Industry

Like every country, India is also committed towards achieving the target net-zero by the year 2070. The Ministry of Steel have come forward to achieve various short-run and long-run goals to accomplish the target of net-zero. In the short-run, Ministry of Steel has mainly focused on the utilization of green energies, BCCUS technologies, and green hydrogen (PIB, 2023). However, in the long-run, less use of coal in steel sector, solar energy usage, green hydrogen production and consumption, scrappage and recycling, improvement in energy efficiency, promotion of technological development, have been given importance (Öhman et al., 2022).

Various initiatives and projects related to steel sector are as follows: Green Steel Mission, Steel Scrap Recycling Policy (2019), National Solar Mission (2010), Perform, Achieve and Trade (PAT) scheme (2012), New Energy and Industrial Technology Development Organization (NEDO) Projects (Japanese Model), scrap processing plant, Hydro-pumped storage projects, Direct Reduced Iron- Blast Furnace (DRI-BF) Electric Arc Furnace route, use of Synthetic Gas or SynGas, increasing capacity of sinter plants (PIB, 2023). Apart from these initiatives, the main thrust areas that should be focused on are Pulverized Coal Injection (PCI), Solid Waste Management, Coke Oven Gas/Coal Bed Methane in blast furnace.

3.3 Steel Decarbonization Benefits

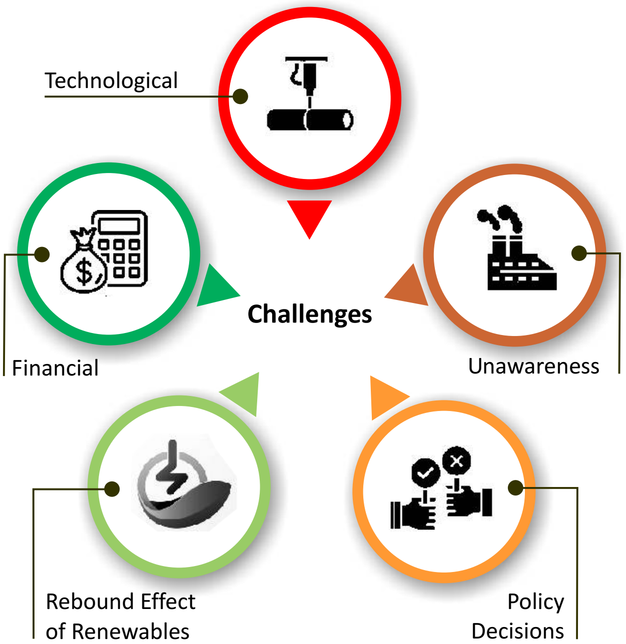
The advantages of decarbonizing the steel sector are measured in terms of energy savings, carbon cuts, monetary savings, societal gains, and environmental improvements.

- A paradigm shift in primary steel production, involving the implementation of innovative iron and smelt reduction technologies that permit the combination of low-carbon energy, use of hydrogens, carbon capture, usage, and storage (CCUS) techniques, use of renewables, etc.would help cut emissions in the longer-term (Öhman et al., 2022).
- There would be more financial savings as a result of less use of energy sources such as coal.
- The negative environmental impact of using fossil fuels, namely coal and natural gas, would be reduced.
- Steel recycling would decrease the use of resources and ultimately limitsthe growth of carbon emissions (Nechifor et al., 2020).
- Greater scrap steel recycling demand would encourage economic activity in which possibly would result in creating employment opportunities (Nechifor et al.

3.4 Challenges in Steel Industry Decarbonization

The usage of decarbonized steel is progressing but at a very slow rate, and most countries have not prioritized the adoption of decarbonized steel yet. The challenges related to the decarbonization of steel industry are as follows:

Figure 6 **Challenges to Decarbonization Faced by the Steel Industry**



Source: Collated by Author

Financial challenges: Since decarbonization processes are costly, the shift to a more sustainable steel industry is difficult. Investment in the climate neutrality projects is not sufficient in an emerging economy like India which makes the process of transitioning towards a green steel sector more complex.

Technological challenges: Adoption of modern technologies for decarbonization is crucial in a developing economy like India. Especially the technological constraints arise due to the unskilled labourers, technologically underdeveloped, use of traditional technologies, poor quality of technologies, poor innovation, lack of investment in R&D, etc.

Rebound effect of utilization of renewables: Every country is striving towards the goal of reaching net zero emissions. Decarbonization of key sectors is required to meet the target, which may be accomplished utilizing renewable energy sources. Renewables, such as solar and wind, on the other hand; require turbines and solar panels which is made of iron and steel. As a result, the use of renewables has a rebound impact in the economy.

Unawareness of decarbonization techniques: The steel sector is struggling to overcome obstacles due to a lack of awareness on decarbonization pathways in India.

Policy frameworks: For creating a green steel market and to facilitate the transition, the steel industry requires supportive policies and regulations. Government should encourage sustainable production, consumption, and processing of steel, provide financial incentives,and long-term commitmentswill help in accelerating the decarbonization efforts (Muslemani et al., 2021).

Addressing the above-mentioned challenges require collaboration with the major stakeholders, steel producers, governments, private sectors, and different research units. Additionally, increasing awareness among consumers about the adverse environmental impact of steel production and promoting sustainable practices can create market demand for decarbonized steel, further driving the industry towards a low-carbon future.

https://www.greenbuildermedia.com/blog/transforming-our-future-decarbonizing-steel

4 Forecasting Steel Production

4.1 Overview

According to a joint report by Word steel and the Indian Steel Association, the construction sector will be a key driver of steel demand across India. The government's efforts on infrastructure development will significantly boost the country's demand for steel. Furthermore, by encouraging the growth of industries through the 'Make in India' initiative, India aims to establish itself as a global centre for design and manufacturing. An increasing economic growth gradually shifts consumer preferences towards metal intensive items due to expansion in the manufacturing and construction sector (Crompton, 1999).

Forecasting steel production remains crucial as we transition to cleaner methods of steel production due to several reasons:

- Economic Planning: Accurate forecasting of steel production is essential for economic planning at both the national and regional levels. It assists governments in decision making and helps industries and businesses make appropriate decisions, including investment, resource allocation, and work planning.
- Resource Allocation: Forecasting guides the efficient allocation of resources, ensuring that the necessary infrastructure, raw materials, and energy sources are available to support steel production and associated industries.
- Employment Planning: Steel production is a significant source of employment. Accurate forecasts are vital for government and industries to anticipate labour force requirements.
- Trade and Export Planning: Steel is a major export and import commodity. Accurate production forecasts help countries formulate strategies to improve their balance of payments and competitiveness in the global markets.
- Investment Decisions: Investors in the steel industry rely on accurate forecasts to make informed decisions about where and when to invest. Accurate forecasts reduce investment risks and promote industrial growth.
- Environmental Planning: Accurate production forecasts are vital for environmental planning as they help in understanding and addressing the potential environmental impacts, including emissions, water usage and waste management.
- Infrastructure Development: The construction of steel mills, transportation networks, and energy infrastructure depends on anticipated steel production needs.
- Energy Planning: Given that steel production is energy-intensive, forecasting helps in energy planning, enabling government and industries to assess and secure the required energy sources, whether they are traditional or cleaner alternatives.
- Policy Formulation: Accurate production forecasts support policy formulations, including those related to energy, emissions reduction, environmental regulations, and industrial development. They help policymakers balance economic growth with sustainability.
- This section therefore focuses on forecasting the production of steel in India by using autoregressive (AR) forecasting technique. Based on information about past behaviour, an AR model predicts future behaviour, and is employed when there is a relationship between time series values. Only historical data is used in autoregressive modelling to forecast future behaviour. This is explained in greater detail in the next sub-sections.

4.2 Brief Review of Literature

The steel industry accounts for a significant portion of industrial energy usage and carbon emissions. By utilizing various econometric methods and forecasting analysis, several studies have predicted the future steel demands as well as shown the steel market scenario. Wårell, 2014 investigated the trends and developments of global steel consumption by employing the Intensity-of-Use methodology. The findings of the study implies that even though new technologies will lower steel consumption, the quick expansion and significant rise in demand for steel in developing nations will contribute to the steel market's sustained growth. Pauliuk et al., 2012 in a study for China, applied material flow analysis (MFA) and suggested that the supply of old steel scrap will expand significantly, and it might replace up to 80% of iron ore for steel production. In a similar fashion, Hu et al., 2010 investigated iron and steel demands and steel scrap for China. Using a modified IPAT model, Xuan & Yue (2016) have forecasted the steel production from 2010 to 2030 for China and suggested that encouragement of steel scrap recycling will help in natural resource conservation and ultimately lessens environmental deterioration. For Chile, Simsek et al., (2020) have forecasted energy demand, supply, and carbon emissions by utilizing a Long-range Energy Alternatives Planning System (LEAP) model in the study. The forecasting scenario showed that transport, mining, and other industrial sectors contributes more to emissions as compared to the transformation sector (power sector). Hence, suitable country-specific energy efficiency measures, and green energy provisions should be implemented in Chile. Kermeli et al., (2022) concluded that long-term energy models are required to lessen the industrial emissions. The International Energy Agency used its Stated Policy Scenario method to predict steel consumption in India till 2040. The results showed that the demand tripled between 2019 and 2040 due to massive urbanisation and demand for energy intensive building materials (*International Energy Agency*, 2021). The methodology, however, has certain limitations, such as, its lack flexibility in considering alternative scenarios or policy changes, potential under-estimation of technological innovations, lack of consideration for external factors and global trends, and insufficient exploration of energy transition scenarios, which may be essential for long term planning. Auto regressive forecasting, on the other hand is data driven and flexible, making it suitable for assessing trends beyond existing policies and providing real-time insights, while also considering external factors.

https://indianindustryplus.com/2019/11/08/steel-scrap-recycli

4.3 Methodology

We use monthly data from January, 1990 to November, 2022 and forecast steel production till December, 2040 (*India Steel Production*, 2023). The production of steel has been forecasted through a variety of methods such as (Privolos's*, 1987)* world iron ore model, VAR model used by Chen et al., (1991) and ARMA model used byIkram et al., (2016), among others. Autoregressive models are often employed to examine the behaviour of a variable over time, as they are based on the notion that current values depend on past values. For example, an AR(1) process bases the current value on the value that came before it and an AR(2) model will base the current value on the previous two values. Therefore, an autoregressive model of order p can be written as

$$y_t = c + \ _1y_{t-1} + \ _2y_{t-2} + \dots + \ _py_{t-p} + \ _t$$

where y is the variable, c is constant and b is the intercept.

The next step is to determine the optimal number of lags for the AR model. We do that with the help of the partial autocorrelation function (PACF) as it measures the direct effect of a specific time period with the current time period. This is depicted in Figure 7 and we observe that the PACF value is the highest at time period 13, which makes sense as we have monthly data, hence we develop an AR model of order 13.

Table 4 Stationarity Test

Variable	Order of differencing	ADF test statistic	Critical value at 5%	p-value	Result (Null Hypothesis)
Steel	Level	-2027	-3.421	0.583	Fail to reject
Production	1st difference	-7.175	-3.421	0.000*	Reject

*Significant at 5%, null hypothesis: unit root is present

To determine whether the series is stationary, we use the Augmented Dickey Fuller (ADF) test and the results are presented in table 4. The series is stationary at 1st difference.

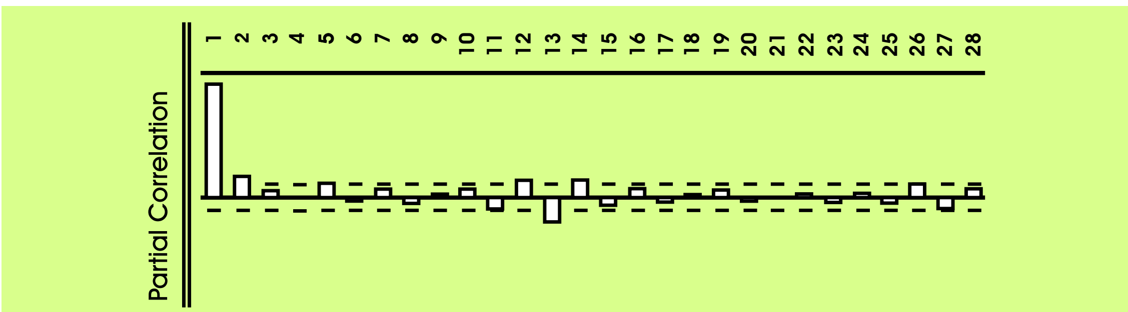
4.4 Results

Before proceeding with developing the model, it is important to check the stationarity of the time series, which requires the data to have a constant mean and variance over time.

Presence of a trend implies the series is non-stationary and must be transformed through differencing. For instance, the following equation transforms the variable using the first order difference:

$$y_t = y_t - y_{t-1}$$

Figure 7 Partial Autocorrelation Function (PACF)



Before proceeding to forecasting the time series, it is important to distinguish between static and dynamic forecasting. A static forecast uses the actual value of the regressor while a dynamic forecast uses the forecast value of the lagged dependent variable. For example, let's say there are 10 time periods and we have the data for the first 6 time periods and the model is AR(1). The static and dynamic forecast will be same for period 7, however, for period 8, the dynamic forecast will consider the forecasted value of period 7 while a static forecast cannot be computed as the actual value of period 7 is unknown. We determine the optimal method by training and testing the model on a specific time period. We train the model using the time period January, 1990 to November 2021 and we test it on the time period December 2021 to November 2022. The actual and forecasted value for the testing period are presented in Figure 8. With a Mean absolute percentage error[3] of 3.59%, it is established that AR(13) is confirmed as the optimal model and will be used for forecasting.

Figure 8 **Actual vs Forecast Value Using AR(13)**

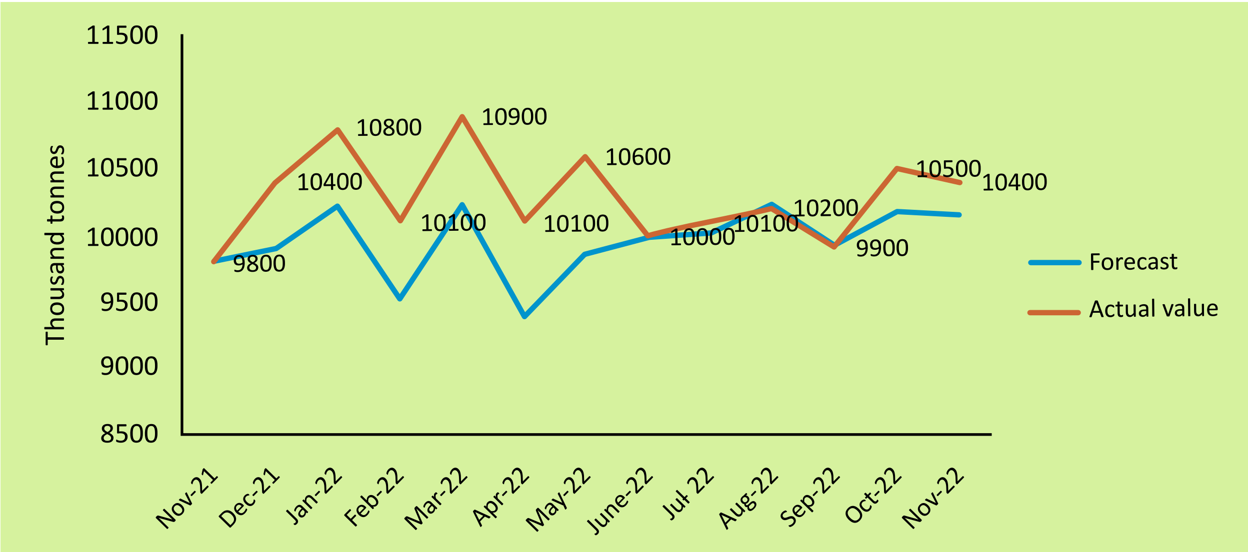
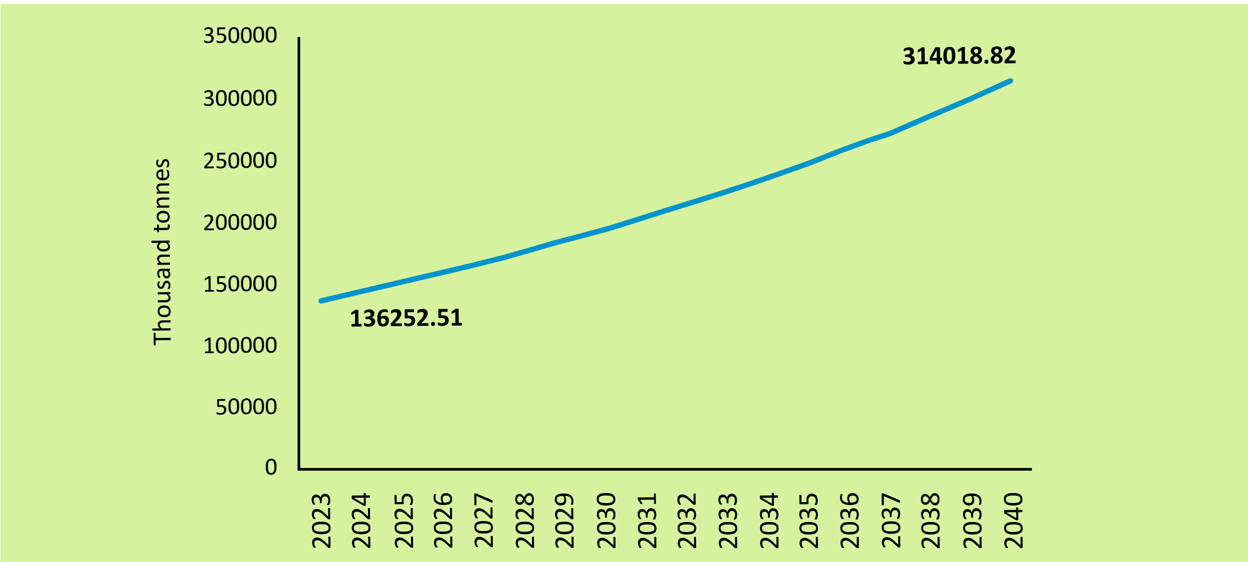


Figure 9 **Steel Production Forecast**



[3] Among the forecasting techniques, MAPE comparison is conducted to finalize a model. If the value of MAPE is less than 10%, the model is considered highly accurate
(Lewis, 1982)

5

Implications of Expanding Steel Production:

Effects on Industry, Economy and Import Dynamics

Although India has one of the world's largest coal reserves, it faces a domestic coal production shortfall that has significant implications for the steel industry. This has led to a notable increase in coal imports, primarily to meet the steel sector's demand for coking coal, which is in short supply as compared to thermal coal used in power plants. It imports nearly 80% of its coking coal requirements due to a lack of cost effective and high quality domestic coal. Furthermore, the production of sponge iron utilizes about 46 Mtce (Million tonnes of coal equivalent) of thermal coal, of which 85% is sourced from South Africa (International Energy Agency, 2021). This means, that as steel production increases, so will the demand for imported coking coal. In the previous section, we forecasted the steel production in India over almost the next two decades. In this section, we discuss the implications of expanding the production of steel as forecasted, on the steel and coal import dynamics of the economy. The implications on the steel sector are as follows:

Reduced dependence on steel imports: If India successfully increases its domestic steel production; there would be a reduced need for importing steel from other countries. This will have positive implication on the economy's balance of payments and increased savings in foreign exchange.

Increased demand for raw materials: To achieve a multi-fold increase in steel production, there would be a substantial surge in demand for raw materials such as iron ore, coal, etc. This could impact global commodity markets, potentially leading to increased competition for these resources.

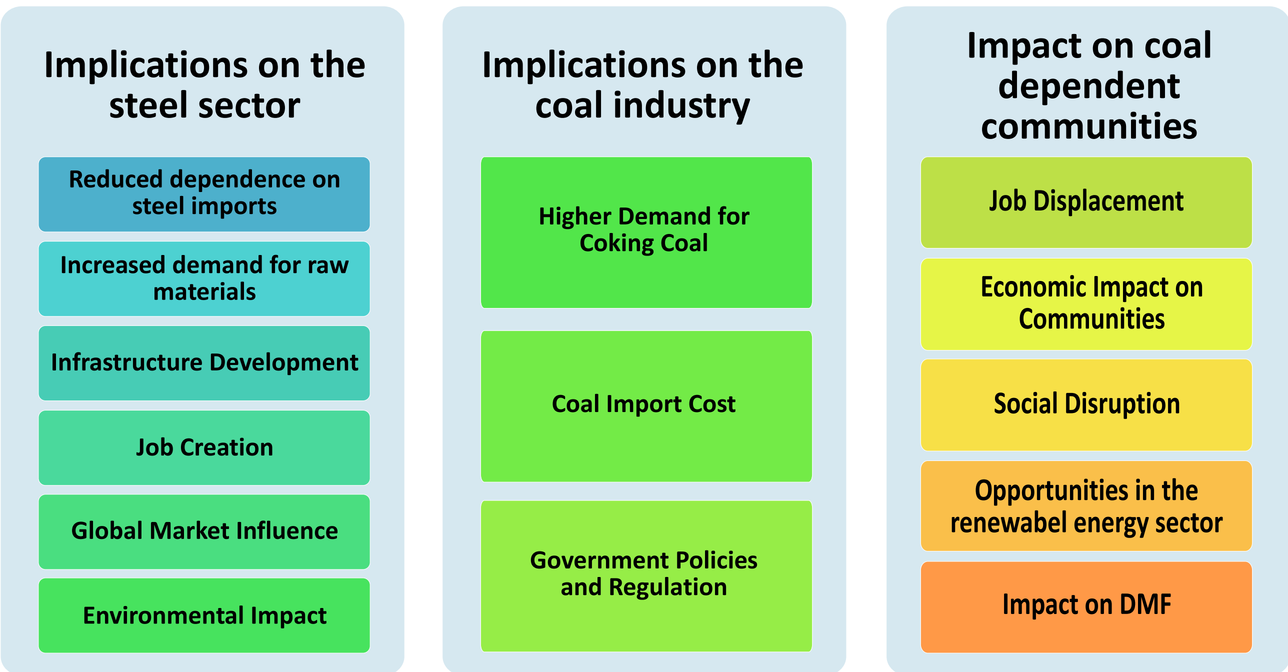
Infrastructure Development: Expanding steel production would require significant investments in infrastructure such as in transportation and energy sector leading to improved economic growth in regions associated with these sectors.

Job Creation: A major expansion in steel production will create jobs not only in the steel industry but also the connected sectors such as manufacturing, through its forward and backward linkages with several sectors of the economy.

Environmental Impact: A higher steel production is clearly associated with higher emissions, if green steel production mechanisms are not put in place.

Global Market Influence: A significant increase in India's steel production could lead to changes in global pricing and trade dynamics, making India an influential player in the steel sector.

Figure 10 **Implications of Expanding Steel Production**



Source: Collated by Author

Although an increase in steel production in India clearly correlates with an increased economic growth, however, its impact on the coal industry as well as on CO2 emissions contradict with the economy's goal of net-zero by 2070. Some of the implications on the coal industry are as follows:

Higher Demand for Coking Coal: Coking coal is one of the major raw materials used in production of steel. As a majority of coking coal is imported in India, an increase in steel production of over twice the current amount, will proportionately affect the amount of imported coking coal contributing negatively to India's Balance of Payments.

Coal Import Cost: The cost of importing coking coal for steel production will become a significant portion of the overall production costs, thus negatively affecting its cost-competitiveness in the global market. The price of coking coal will increase as the demand increases, further increasing the cost of production.

Government Policies and Regulations: Government policies and regulations will play a crucial role in shaping the coal import scenario. The Government may have to put stringent regulations in place, promoting the use of domestic coal, as well as pushing for a cleaner steel production mechanism as it could decrease coking coal imports.

Although steel industry primarily requires coking coal in its production process, thermal coal is also utilized for certain processes such as for power generation within the steel manufacturing plant and for other auxiliary processes that require heat and energy. Therefore, as steel transitions to cleaner production techniques, the demand for domestically produced thermal coal will decrease. This decrease can have significant impact on those dependent on the coal industry. Some of the impacts are discussed as follows:

Job Displacement: A reduction in coal consumption in steel sector may lead to job displacement for workers in the coal industry. This can have an effect on not just the coal producers but also those involved in coal transportation, processing and other related activities.

Economic Impact on Communities: Many communities in the coal rich regions of India have been dependent on coal for several generations. A decline in coal production will uproot such communities and cause economic hardships.

Social Disruption: Communities that rely on coal often have a strong social fabric tied to their economic activities. Reduction in coal production can lead to social disruption, as families face uncertainty due to potential migration of family members as they seek new job opportunities elsewhere.

Opportunities in the renewable energy sector: As coal consumption decreases, there may be opportunities for workers to transition to jobs in the renewable energy sector. However, for this purpose the government needs to intervene and create renewable energy training programmes to equip people with the skills required in the renewable energy industry.

Impact on DMF: The District Mineral Fund (DMF) is funded through contributions from mining companies operating in a particular district for the welfare of the communities affected by mining activities. With the decline in coal production, the DMF fund will also diminish, potentially leading to adverse consequences for communities relying on coal.

The expansion of steel production in India holds significant implications for the nation's economy, industry, and import dynamics. This growth presents both opportunities and challenges, impacting various stakeholders. Striking a balance between economic expansion and environmental sustainability is a major concern. The outcome will be significantly shaped by government policies, investments in clean technologies and sustainable infrastructure development. This transition offers an opportunity to promote economic growth, reduce emissions, and develop a more diverse and sustainable economy.

6 Conclusion and Recommendation

Production and consumption of steel comes with certain challenges. Hence, efforts are being made by the Indian government, industry stakeholders, and civil society organizations to address the environmental concerns associated with the steel industry in India. Balancing economic growth with sustainable development remains a key challenge, requiring a combination of effective regulations, technological advancements, and the adoption of cleaner and more efficient production practices to minimize the industry's environmental impact. Creating a green steel from brown steel has emerged as a novel approach to drive towards a clean transition in the steel production process. Though India has the capacity to transition to a green steel sector, strong policies relating to technological improvement (electrolysis technologies), and deployment of green steel projects are necessary to effectively bring about a major change that the decarbonization of steel demand for. For this, India should focus on both the demand and supply side decarbonization by playing a significant part in iron ore refinement and steel manufacture. Additionally, the production of steel should be taken care of by utilizing hydrogen as well as nitrogen in the steel sector. This approach will reduce the demand for coking coal in the steel making process and balance the emission levelin the near future and a world that leads green steel may be predicted. Some recommendations for a sustainable and equitable steel expansion are as follows:

Research and Development: Innovative measures may be adopted for the promotion and support of the deployment of decarbonized steel such as new production techniques, low-carbon technology options, etc. The techniques of Material efficiency involve enhancing steel production, light weighting vehicles, increasing lifetimes of building, as well as recycling steel, and Bio Energy with Carbon capture and Storage (BECCS) can be used as an instrument in the steel industry to curb the effect of carbon emissions. Collaboration with research-oriented laboratories to expand the research horizon as well as creating a collaborative environment with the developed countries for the industry transition is required.

Identification of Barriers: The major barriers to steel decarbonization may be identified and given importance, utilizing the measures of material efficiency to decrease wastage and optimal use might help in restricting growth in demand and consequently curb the effect of carbon emissions from steel production.

Figure 11 **Recommendations for Sustainable and Equitable Steel Expansion**

- Research and Development
- Transition Assistance
- Renewable Energy
- Identification of Barriers
- Financial Mechanisms
- Economic Diversification and Infrastructure Development
- Public Awareness and Stakeholders Collaboration
- Research and Monitoring
- Community Consultation to Develop Social Safety Nets

Renewable Energy: Raising the low-carbon steel (green steel) in the country is possible through the usage of renewable energies as well as increasing awareness regarding the green steel market. As an emerging economy, the green steel path can be achieved by following the approaches of the other major emerging economies like China, Brazil, and Russia as they have already taken initiatives and made investments for the deployment of green steel in their countries. Incentives may be provided to steel companies to adopt cleaner and more sustainable technologies, such as electric-arc furnaces and hydrogen based production methods.

Financial Mechanisms: Countries should fully support the financial mechanisms by implementing policies that cover a portion of the costs associated with decarbonization. International financial institutions can play a greater role to provide support in creating a decarbonizing industry.

Transition Assistance: Develop programmes and initiatives to support coal-dependent communities in transitioning to new job opportunities. This can be in the form of capacity building programmes. An important thing here is to make sure that such programmes are accessible and are tailored to the needs of those affected by this transition.

Economic Diversification and Infrastructure Development: Invest in diversifying the local and regional economies of coal dependent areas. Attract and support industries that can provide alternative employment opportunities, such as, renewable energy, manufacturing, and technology. Improvement of infrastructure such availability of roads and access to electricity will attract new industries and businesses that may help diversify the sources of income for the coal dependent communities.

Community Consultation to Develop Social Safety Nets: Engagement with local communities to understand their needs and concerns is a vital part of a fair energy transition. It is important to coordinate with them to design and implement policies that support their welfare during the transition. Other social safety nets such as education, healthcare, and financial assistance programmes may be developed for the most vulnerable communities.

Research and Monitoring: Continuously monitor the impact of the transition on coal-dependent communities and the progress of the steel industry's shift to cleaner mechanisms. Use the data to refine and adopt policies as necessary.

Public Awareness and Stakeholder Collaboration: Promote public awareness about the transition, its goals and its benefits. Inform people about the value of using cleaner production techniques and how they can help create a future that is more sustainable. In order to forge a consensus and guarantee a coordinated approach, it is also critical to collaborate with stakeholders, such as labour unions, environmental organisations, and local government agencies.

Balancing the need for a cleaner steel production with the welfare of coal dependent communities is a complex challenge, but with careful planning, sustained effort, and collaboration, it is possible to achieve a more sustainable and equitable future for all.

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