Rethinking the drivers of energy intensity in India's Iron and Steel firms: The role of imported intermediates

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Institute for Studies in Industrial Development

2024

Rethinking the drivers of energy intensity in India's Iron and Steel firms: The role of imported intermediates [1]

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Abstract

The improvements in energy intensity of India's iron and steel industry despite the limited R and D expenditure, high cost of adapting technologies/fuel, and heavy dependence on coal-based process is intriguing. In attempting to understand the underlying drivers, this paper uses firm-level panel data to show that firms have improved their energy intensity through retrofitting of the existing production utilities and 'brownfield' installations in the form of technology extensions. The improvements are essentially on account of the use of imported capital goods/equipment rather than core R and D. For policy, this highlights critical dependence on imports of green goods in meeting the net-zero targets. The finding is used to call for technology transfers as part of brownfield installations, and policy interventions to support the domestic capital goods industry to reduce the dependency on imports. On the sidelines, the results also show that trade has a positive externality through supporting the environment.

1. Importance of improvements in energy intensity of industry

The industrial activity accounts for a quarter of total greenhouse gases (GHGs) and one-third of the energy use, thereby highlighting the substantial contribution to global emissions (World Resources Institute, 2020). The emission share of industry is higher than any other activity. Within

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[1] Another version of the paper is published as Tandon, Anjali, 2024. "Rethinking the Drivers of Energy Intensity in India's Iron and Steel Firms: The Role of Imported Intermediates", Millennial Asia, 1–22. DOI: 10.1177/09763996241282355.

the broader industry, the iron and steel industry is distinct with a predominant share of 7.2% in the overall GHG emissions, thus emphasising the need to reduce energy intensity in the industry for a sustained rate of growth. The benefits of lower energy intensity are additionally through realizing enhanced energy security; lower costs and improved competitiveness; reduced public expenditure on fuel subsidies; and additional jobs in energy measurement and monitoring.

India is considered as a potential candidate for emission reductions due to its third largest CO_2 emissions with heavy dependence on fossil fuels which account for nearly 80% of the energy demand in the country. The fossil-fuel mix is dominated by coal which is also the primary source for thermal power. The industry remains the biggest consumer of coal and electricity with more than half of the final energy consumed (Ministry of Statistics and Programme Implementation (MOSPI), 2023). Within the broader industry, the share iron and steel industry accounts for as much as 15.4% of the total industrial consumption and 8% of the aggregate energy consumption.

To address the issues of climate change, the Indian government has committed to reduce the emission intensity of the GDP and to become carbon-neutral by the year 2070. Simultaneously, the development goals require increased access to infrastructure and utilities (power) among other requirements suggesting faster industrial growth. Studies identify accelerated industrialization as among the important contributors of growth in the demand for energy sources (Zhang, et, al, 2014), thereby raising environmental concerns from the expansion of industries, particularly those which are energy-intensive in nature. Indeed, the energy intensity of India's industrial GDP is high when compared to agriculture and services, thus necessitating the focus on significant and emitting industries such as the iron and steel. In particular, the emission concerns of the India's iron and steel industry are also significant given the forthcoming Carbon Border Adjustment Mechanism (CBAM) of the EU, as India exports about 10% of its steel production, of which more than 20%

is oriented to the three EU member countries, namely Italy, Belgium and Spain, among others (International Trade Administration, 2019).

In the backdrop of the broader issue around industrial decarbonization and the concerns to reduce energy intensity of India's iron and steel industry, the transition to low/zero-carbon technologies attains priority. Although green technologies such as the hydrogen injection, solid biomass substitution, low-carbon electricity, and carbon storage and sequestration (CCS) have been developed in more recent years, these are in early stages and will take few years before they are adopted on a commercial scale. Even then, the cost of adapting the clean technologies/fuel remains a deterrent for firms. Another constraint is the low R and D expenditure (in absolute and proportionate terms) of the Indian iron and steel industry (Ministry of Steel, 2023). Yet another limiting attribute in the Indian context is the continued heavy dependence on the coal-based process technology in the industry with low feasibility of fuel-switch given the preferences of the steel producing firms. Further, given the high capital investment cycles of about 25 years, the shift in process technologies is unlikely to happen in the medium-term.

Notwithstanding, energy intensity of India's iron and steel industry is observed to have declined over time, yet high than the Intended Nationally Determined Contributions for reducing GHG emissions. As a global leader in production of crude steel where India ranks second, the decarbonization challenge is pressing. Moreover, steel constitutes an input to overall manufacturing and other sectors of the economy. Therefore, improvements (reductions) in energy intensity of steel will contribute to similar improvements of the broader manufacturing and the overall economy. Hence, it will be useful to identify the factors driving energy improvements. Accordingly, future policy can be designed to support and accelerate the low-energy transition, while also lowering the external dependence for the feedstock and for technology and equipment.

In this light, we examine the firm-specific characteristics influencing energy intensity. In the paper we branch out from the existing literature by focusing on an alternate channel which is observed to be operative in the form of technology extensions/retrofitting of the existing plant and equipment. The empirical analysis shows that improvements in energy intensity are essentially on account of the use of imported capital goods/ equipment rather than due to core indigenous R and D activity. For policy, this highlights critical dependence on imports of green goods to meet net-zero targets and for energy competitiveness of the domestic manufacturing in the international markets.

2. Global iron and steel industry and emission concerns

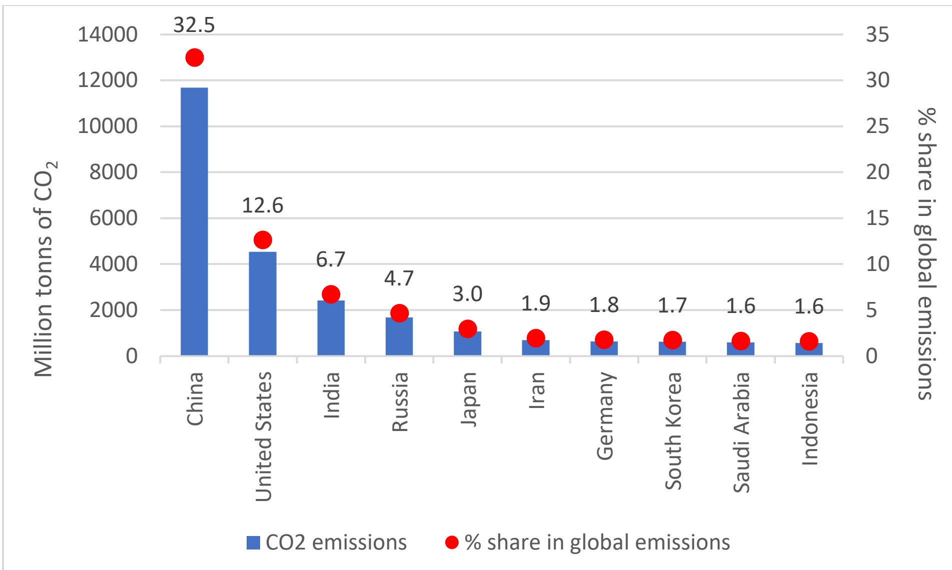
It is particularly alarming, that without interventions, the cumulative emissions form the global iron and steel assets are estimated to reach 60Gt CO_2 by 2060, accounting for an even higher share of 12.9% in the carbon budget (Swalec, 2021). The country-level and firm-level pledges of the steel making companies to turn carbon-neutral, collectively cover more than 75% of the operating steel capacity for decarbonization initiatives. Of the two main methods of steel production, namely the blast furnace-basic oxygen furnace (BF-BOF) route and the electric arc furnace (EAF) route, the former is more carbon emitting/ intensive. Notwithstanding the high-carbon emissions, preference for the BOF production is noted from its 60% share in steel making. Moreover, most of the planned steel capacities are of the BF-EOF type. This emphasizes the need to 'outfit' the existing BF-EOF capacities with the best available technology (BAT). The BAT refers to the technologies and processes which are available at a commercially feasible scale to transform the waste heat to useful energy, thereby reducing the energy intensity. Retrofitting the existing BF-EOF plants with BAT results in a lower carbon footprint. For instance, waste recovery mechanisms collect excess heat for further use, or send it to an external agency; coke dry quenching systems recover heat form coke ovens to generate electricity and /or lower the fuel consumption in coke oven; and top-pressure recovery turbines (TRTs) generate electricity form the BF gas heat.

According to the IEA (2020), as much as 85% of the cumulative emissions from the iron and steel industry can be reduced through improvements in material efficiency (including process efficiency) (40%), CCUS (24%), and technology performance improvements (21%) including the adoption of BAT. This ascertains that the role of continued technological performance improvements cannot be underplayed on the path to decarbonization. This further opens-up the discussion on the two alternate channels where the energy-related improvements are achieved through indigenous sources or by utilizing on the importations of the equipment. While there exist arguments in the favour of import utilization of the energy-saving equipment (Martin, 2011), there also exist counter arguments on employment leakages from the domestic economy due to the utilization of imported machinery and equipment (Tandon, 2024). Also, the import dependence on capital goods can result in further widening of the gap between India's indigenous technology and the domestic R and D vis-a-vis the developed country partners. Furthermore, import utilization is also a potential threat to local innovation, particularly during the present times when global trade is increasingly characterized by protectionist measures. The import dependence on capital goods during the period(s) of geopolitical uncertainty can have limiting effects on the development objectives. The long-term and continuous nature of the decarbonization agenda, in general and specifically for the iron and steel industry mandates that capacity and sources for technology performance improvements be indeed developed domestically, or else India's bargaining power in the climate agreements is likely to be diluted due to external dependence for meeting the goals.

3. India's iron and steel industry

At the aggregate-level of country-level activity, India is the third largest emitter of CO_2 emissions with a 6.7% share (Figure 1). Within the Indian economy, industry sector is the largest user of energy accounting for 36% of total final consumption of energy and a proportionately smaller share of GDP at 30% (IEA, 2021a). Therefore, the energy intensity of industrial GDP is 1.2, higher than that of services at 1.09 which account for 59% of the energy consumed and 54% of GDP.

Figure 1: Country-wise CO_2 emissions, 2020



Source: Emissions Database for Global Atmospheric Research (EDGAR) of the EU[2]

Economic profile of iron and steel industry

The iron and steel industry has a direct GDP contribution of 2%[3] to the Indian economy, with an output multiplier effect of 1.4 times and employment multiplier effect of 6.8 times (Ministry of Steel, 2017). India is the second most significant producer of crude steel with a volume of 118.1 million tonne (MT), distantly following China with 1032.8 MT.[4] About 10% of production is exported, with the exception of a higher share of 15.7% exports during the year 2017. Although

[2] https://worldpopulationreview.com/country-rankings/co2-emissions-by-country
[3] GDP contribution refers to the year 2016.
[4] Production volume refers to the year 2021.

India exports steel to 170 countries, the concentration is high with 63% exports destined to top 10 partners.[5] Further, three of the 27 EU member nations account for 20% share of India's total steel exports, which come under the purview of EU's forthcoming CBAM.

Energy profile of iron and steel industry

Within the board industry, iron and steel is most energy intensive industry accounting for 15.3% of total final energy consumption. Steel is the second largest consumer of coal after electricity (MOSPI, 2023). Coal provides for 85% of energy in the iron and steel industry (IEA, 2021a) contributing to 6.4% of total coal consumption. During the period from 2012-13 to 2021-22, energy consumption in the iron and steel industry increased at a compound annual rate of growth (CARG) of 2.64%. By comparison, the CARG has been negative for all other using industries such as cement, paper, textiles, fertilizers, with electricity as the only noted exception. In terms of emissions, iron and steel accounts for 30% of emissions of the industrial sector, and 4.8% of total GHGs without land use, land-use change and forestry (Kumar, 2022). The emission intensity of the Indian iron and steel industry has been high compared to global emission intensity (1.89 tonne CO_2 emissions per million tonne of steel in the year 2020) and also that of some other countries (Global Efficiency Intelligence). Canada and Spain have the lowest emission intensity of steel production.

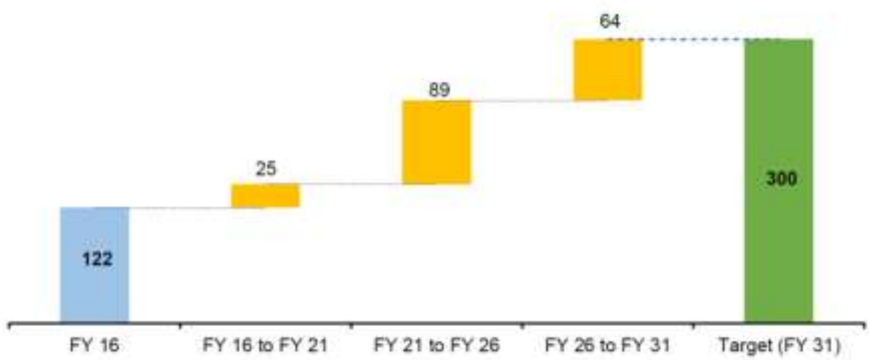
Steel demand and targets

Owing to its input for developmental activities, steel demand and consequently the production is expected to increase in future. According to the National Steel Policy (NSP) of 2017, the demand for steel is expected to grow three-fold to 212 - 247 MT by 2030-31, requiring an estimated crude steel capacity of 300 MT (Figure 2) due to the infrastructure push (housing, railways, ship building,

[5] Figures refer to the year 2018.

opening of defence sector for private sector, engineering & fabrication, automobiles, energy). The NSP envisages per capita steel consumption at 160 kg by 2030-31, more than double in less than a decade; yet lower than the present global per capita consumption. Presently, India has low steel consumption per capita consumption of 77.2Kg compared to 233Kg per capita consumption at the world level.[6]

Figure 2: Capacity addition in India's steel industry



Source: JPC (for present), MECON (for projection), Ministry of Steel (2017)
Note: Capacity additions are considered based on the announcement made by steel manufacturers.

The government envisages reaching global efficiency benchmarks for steel production and to become a world leader in steel production (Ministry of Steel, 2017).[7] The NSP policy emphasizes on technology improvements as one of its objectives to be supported by facilitating modernization, and through raising the level of R and D and developing manufacturing capacities for the technology and critical requirement for the steel making plants.

Process technologies and emission factors

The three main process technologies for producing steel include the BOF (45%), DRI (28%), induction furnace (IF) with production shares of 45%, 28%, and 27%, respectively (Table 1, Figure

[6] Refers to financial year 2022.
[7] Improvements in energy efficiency result in lower energy intensity and vice versa. Conventionally, the reciprocal of energy efficiency is referred to as energy intensity.

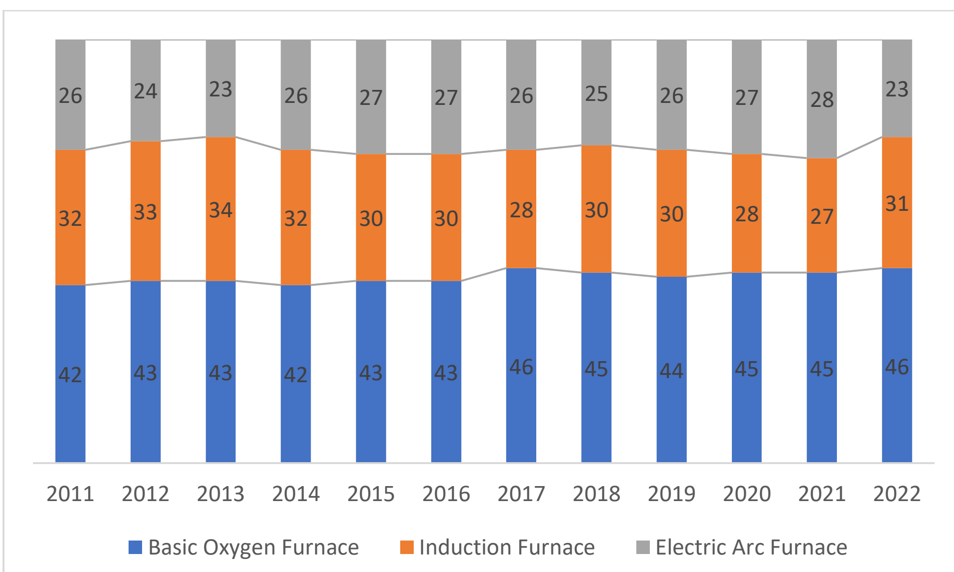
3). Owing to the lower costs of coal than electricity in India, producers prefer the use of BOF-based steel production. Even more important is to note that within the DRI, the fuel is predominately coal-based like in other countries where the process makes use of natural gas. Further the material requirement which is predominantly (82%) sourced from small coal-based units in mineral rich areas. Natural gas hasn't picked up due its higher prices than coal and non-availability.

Table 1: Distribution of steel production by process, India

Year	2016	2017	2018	2019	2020	2021	2022*
Coal-based	22.62	23.28	27.16	30.12	27.05	30.64	33.88
Gas-based	4.36	6.22	7.05	6.7	6.07	8.40	8.12
Total	26.98	29.51	34.21	36.82	33.13	39.04	42.00

Note: Figures for 2022 are provisional.
Source: Annual reports, Ministry of Steel, Government of India (various years).

Figure 3: Steel making process in India (% distribution)



Note: Figures for 2021 and 2022 are provisional.
Source: Annual reports, Ministry of Steel, Government of India (various years)

The Ministry of Steel has already submitted the INDC for reducing GHG emissions in iron and steel industry which *inter-alia* projects CO_2 emissions by 2030 at 2.2 – 2.4 tonne per tonne of crude steel in the BF-BOF route. This is lower when compared with the estimated emission factor of 2.5 in 2020-21 (Kumar, 2022). Similarly, the CO_2 emissions for the DRI-EAF route have been projected at 2.6 – 2.7 tonne per tonne of crude steel, in comparison to the estimated emission factor of 3 for the coal-based DRI/ IF and the estimated emission factor of 1.6 for gas-based DRI/ IF.

The projected emission intensities are higher than the global norms. For instance, emission intensity of even the coal-based DRI-EAF is at 1.9, much below the target 2030 under the NSP, 2017. Also, emission intensity of 1.5 as achieved in Canada and Spain is particularly impressive for the BF-BOF route. Since switching technology/fuel is difficult due to techno-economic constraints, continuous improvements in intensity become ever more important for net-zero emission goals.

Technology implementation despite low domestic technology development

The government has undertaken several domestic initiatives for decarbonization of the industry. Prominent among these is the Preform, Achieve and Trade (PAT) scheme which is an energy efficiency promoting mechanism and issues the energy-saving certificates, which can be traded, paving the way for further transition to carbon markets (under progress). Other initiatives include increasing the uptake of scrap. This, however, has limited impact due to availability constraints for steel scrap. The government has also encouraged the development and use of renewable energy, and is also promoting green-hydrogen. In addition, the Steel Research & Technology Mission of India (SRTMI) has been setup to encourage domestic R and D in the industry.

The emission intensity of the iron and steel industry is observed to have declined by 16% between 2005 and 2020 (Rocky Mountain Institute, 2023). Policies mandating energy improvements such as the PAT have contributed to the improvements. Since its inception in 2011, 163 iron and steel units have participated in the PAT scheme, suggesting widespread technology implementation.

Key measures adopted by firms include installation of top recovery turbines, and adoption of coke dry-quenching process, sinter plant heat recovery, pulverized coal injection system in BF, LD gas recovery plant in steel melting shop, direct rolling in mini steel plants, hot charging of DRI in EAF, and the use of measuring and monitoring equipment as required to meet the specific energy consumption (SEC) requirements under the PAT scheme.

At the same time, an insignificant indigenous technology development is also acknowledged by the Ministry of Steel (2020). The industry is importing technology and critical equipment, and system for steel plants as acknowledged in the NSP and also noted from the Annual Report of the firms. Available statistics confirm that India's R and D, both absolute as well as in percentage, has been low at 0.05 – 0.5% as against 1% in leading steel companies abroad in China, Japan, South Korea. Most of the high-end research is undertaken by leading companies such as SAIL, Tata steel and JSW, but disruptive innovation is lacking (Table 2). This encourages use of imported technological inputs (capital goods)/retrofitting of plants. Average lifecycle of a plant is around 40 years but rounds of refurbishment over several decades thereafter are also noted (IEA, 2020).

Table 2: R and D in select domestic iron and steel firms in India

Firm name	R & D (% of turnover)
SAIL	0.58
RINL	0.12
Tata Steel	0.30
JSW (Vijaynagar Works)	0.07

Source: Ministry of Steel (2020)

In a nutshell, while India is likely to indigenously meet the projected demand for steel, the capping of BOF at 65% seems challenging for India, as majority of expansion is through the BF-BOF route. The BF being more carbon-intensive, and difficult to decarbonize as coal is the reducing agent for ore to metal and difficult to substitute. Also the use of scrap as raw material remains low. Regarding the DRI process, most of the small manufactures produce between 37-77 million tonnes of crude steel during 20-21, contributing 41-51% of emissions, depend on coal-based DRI-EAF/IF, which is contrary to global experience on technology where this technology fairs better. The DRI produces more than half of the emissions from the steel sector.

The decarbonization options are through using clean(er) fuel (e.g., H_2), and/or through improvements in efficiency, which refers to the changes in methods. However, techno-economic viability of newer fuel may take time before it is commercially available on a large scale. Cost differences between setting up a low-carbon steel plant of 1MT annual capacity is estimated between $600-800 million (Energy Transition Commission, 2021). By contrast, retrofitting of a conventional plant can be achieved at one-third of the cost by technology implementation, not necessarily technology development). The latter is preferred in a highly competitive international market, with low margins. Longer investment cycles of 25 years, lifecycle of 40 years and lead time of more than 5 years for commercial-scale production from breakthrough technologies is another constraint. Therefore, technology performance improvements are of utmost importance to reduce the missions from the industry which are estimated to grow by 2.5 times between the period from 2020 to 2030 (Kumar, 2022).

4. Evidence on emission improvements and the import of energy-saving equipment

The IEA defines technology performance improvements to include the strategies and technologies which contribute to reductions in energy intensity of steel making process. These include the upgrades through the adoption of best available technologies (BAT), and process optimization strategies such as the best operational practices (BOP). The importance of technology performance improvements is reflected in their estimated 21% contribution to emissions reduction by 2050 (Swalec and Shearer, 2021). For instance, retrofitting the BF-EOF steel plants with BAT (discussed earlier in Section 2) and the BOP such as digitalization for optimization of the process gases, contribute through lower energy intensity. The added advantage is the relatively low levels of investment required.

Globally, the energy intensity of steel making has improved by 0.78% annually during the period 2000-2018 (Ministry of Power, 2021). The lower energy intensity of the iron and steel industry despite insignificant indigenous R and D without substantial change in the feedstock and production methods, hints on an alternate channel into effect. Therefore, it will be helpful to study the specific channel through which firms attempt to improve (i.e. reduce) energy intensity. This will be useful to guide future policy in terms of designing policy, e.g., state role and incentives, to maximize gains for the domestic industry and the overall economy while lowering external dependence for technology and equipment. Existing evidence on India confirms that acquisition of imported technology helps through lower intensity of energy as studied for an earlier period and for the aggregate manufacturing (Goldar, 2011). Import trade enhances the technology level directly and indirectly, and through spillovers. More importantly in the context of efficiency improvements, the imported goods are not only production technologies, but also energy saving technologies, and the ones which improve the utilization of energy in the process (Hao et al., 2022). Martin (2011) argues that imports of environmentally-friendly technologies as in capital goods can reduce pollution through lower energy intensity. Even if imported under second-hand conditions, these goods displace vintage machinery and less-efficient alternatives, leading to improvements in energy use. Another study relates the intensity of technology imports, including imports of capital goods, raw materials and royalty payments, to lower in energy intensity (Sahu and Narayanan, 2011). In a more recent work Sahu et al. (2021) highlight the need to replace old capital with new capital and better technology.

Also, the effect of R and D is not consistent across the full sample and sub-sample of manufacturing, suggesting to investigate on a narrow range of firms or industry rather than all manufacturing firms. In another study, the contribution of a channel other than R and D is emphasized in noting that even with a nearly entire proportion of energy inefficiency due to technical inefficiency, the problem can be addressed through imports of energy-saving products (Hao et al, 2022). Although there exists earlier research, there are some points that need to be perfected particularly in the context of R and D. While most researchers highlight the role of R and D for improvement in intensity, it has also been acknowledged that despite its contribution to technological change, energy R and D *per se* does not necessary lead to lower energy intensity (Sagar and Zwaan, 2006). It is also argued that the low scale of R and D by itself has a low/ insignificant impact on energy efficiency (Haider, 2021). Further contentions state that R and D expenditure may not necessary to improve energy efficiency; as it could instead be towards business process development, market expansion, new product development (Singh, 2022).

Thus, there remains the need to validate if the improvements have been achieved through spending on core R and D. Extending the line of thought, the present paper argues that Indian iron and steel firms tend to replenish profit for the import of capital goods to retrofit the existing plant set-up, thereby leading to lower energy intensity. By doing so, we are able to highlight at least two key facts: (1) the lack of core indigenous R and D being circumvented through imports of capital goods, and (2) the dependency on imports of green goods for achieving energy intensity improvements.

The choice of iron and steel industry specifically for analysis is motivated due to three reasons. First, iron and steel is the most energy-intensive manufacturing activity. Second, the improvements in energy intensity despite low indigenous R and D in an increasingly emission regulated scenarios strongly support the intuition on increasing import dependence for energy-saving equipment. And third, the available time gap before meeting the emission commitments and the introduction of CBAM needs to be used to advance domestic action to further improve intensity of the industry through focused initiatives for attaining *self-reliance* in machinery and equipment. [8]

Based on the available literature the paper proposes to test the following hypothesis. (1) Firms in the iron and steel industry improve their energy intensity through retrofits that are available in the form of imported equipment facilitating adoption of the BAT. (2) The R and D expenditure of the iron and steel firms does not necessarily contribute to intensity improvements.

5. Data, variables and model

The scope of analysis covers the firms as available in the Prowess database of the CMIE. Firms involved in producing in the basic iron and steel in primary form essentially operate in the National Industrial Classification (NIC) (2008) codes from 24101-24103. However, prominent players such as Tata Steel, which are also the leaders in technology and transition, are present in the downstream (forward) industries covering NIC 24104-24109. The overall sample is further expanded to include firms involved in casting activities NIC 24311-24319. Annualized data is used. The reference period covers the 13 years from 2010 to 2022 to align with the introduction of many key initiatives undertaken by the government such as the PAT scheme that became effective from April 2012.[9].

Variables and model

A study of the drivers of decarbonization requires explicit data on emissions, which is seldom available at the firm-level. However, energy consumed is a reasonable proxy due to its underlying use causing the emissions. Therefore, the we base the analysis on the energy intensity of firm.

[8] The CBAM is introduced in a phase manner by the EU. The initial transitional period from 1 October 2023 to 31 December 2025, is the monitoring period where emission data is being collected to give a firm shape to the CBAM for its definitive phase which comes into effect from 1 January 2026.

[9] The PAT scheme was introduced as a flagship scheme me under the National Mission for Enhanced Energy Efficiency (NMEEE), one of the eight missions outlined by National Action Plan for Climate Change (NAPCC) to address the climate change challenge.

Accordingly, the dependent variable, i.e. energy intensity, is defined expenditure on energy in the form of power and fuel per unit output. This approach is similar to the strategy chosen by Eskeland and Harrison (2003) and Cole et al. (2008). The value of sale is used as a proxy for output. Thus, energy intensity is the ratio of expenditure on power and fuel-to-total sales and is expressed in percentage form.

Key determinants of energy intensity include the scale of operations which is likely to reflect in the size of the firm. Among the various representation of the firm size are indicators such as assets, market value, number of employees, sales. In view of the use of sale value in the energy intensity, the firm size is represented by the gross fixed assets. The possibility of endogeneity is further eliminated by referring to firm-size based on the four quartiles. This has the added advantage of studying the differential influence on the energy intensity across different quartiles. The R and D indeed is a relevant variable. Also included in the list of explanatory variables is the global value chain (GVC) integration-level of the firms, due to its likely impact on business through the supply interactions with the upstream inputs and the demand relationships with the downstream users of the output. In fact, the steel industry has witnessed many companies investing in the downstream steel making facilities (e.g. rolling mills) and steel making capacities aboard (OECD, 2017). Given the significance of cross border trade of steel, firms tend to hedge against the market situations through deeper integration within the supply chain. Indeed, the steel industry has been characterized with increasing interconnectedness in the mode of production, where the intermediate goods are purchased from foreign economies for transformation locally into finished goods or another intermediate good for exports to other economies. The empirical investigation of relationship with regard to the GVC integration of the firms, is based on the argument that firms prefer integrated operations to take advantage from high value additions in the downstream products and uninterrupted supplies of the material inputs. Integration of the firms requires cost competitiveness of the operations, thereby prompting firms to achieve savings on cost through lower energy consumption. Also included in the analysis is the age of the firm to account for the vintage effect and the modernization efforts of the firms. A squared term is included to check for its non-linear effect on the dependent variable. Under the conditions of inadequate level of R and D in general as well as the risks associated with the long-term investments needed for in-house R and D, the firm tends to address the intensity challenges by sourcing modern technology and the adopting BAT through importations of capital goods such as the machinery and equipment, and monitoring equipment. Profit making firms are more likely to spend on purchase of equipment. Therefore, profit after tax of the firm is also included as a variable along with the expenditure on imports of capital goods. The definitions of variables are tabulated in the Table 3.

We use the fixed effect model for panel data analysis. This paper adopts the fixed effect of the firm to control for the firm-specific characteristics with a robust option, and also fix the time effect.

Table 3: Definition of independent variables used in the analysis

Variable	Form	Intuition	Expected relation
Firms size	Real value of gross fixed assets, and quartiles based on real value of gross fixed assets (Q2,Q3,Q4 compared with Q1), to differentiate among firms of different size-club[10]	Larger firms engage stronger in intensity efforts and more effectively lower the specific energy consumption[11]	negative
Profit after tax,	Real value in Rs. Million, logged form	Higher the firm-level profits, greater is the invest in achieving lower SEC	negative
Age (in years): linear, quadratic	Liner and quadratic form, measured from the year of incorporation for the	Older firms are more likely to engage in efforts to lower energy intensity, however, the behavior may trigger after a certain period, as	negative

[10] Since price deflators specific to assets of the industry are not available, the deflators for manufactured products

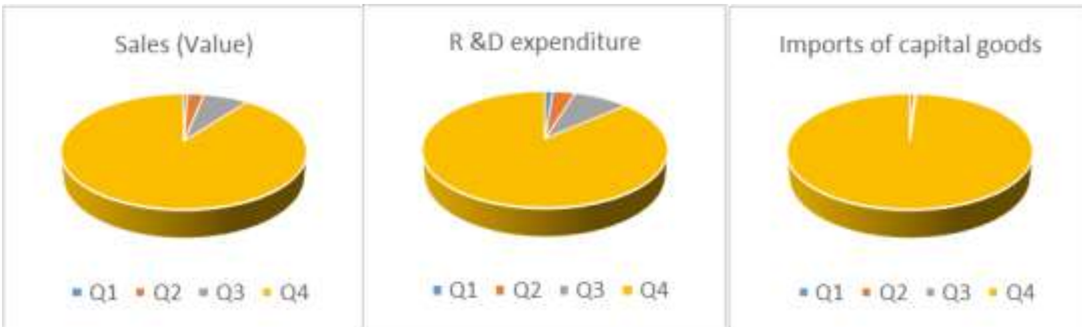
[11] The institution is also supported by design of PAT scheme which selects participants, i.e. designated consumers, based on their higher volume of energy consumption.

	given year in the panel	firms may not be concerned for energy intensity in initial years. Vintage effect	
GVC integration: Backward and forward linkages	(Export earnings + material imports)/Sales*100, using real values	Firms that are more integrated are likely to be cost competitive through better resource usage and hence have a lower intensity of energy	negative
R and D intensity	Expenditure on R and D expenditure as % of, using real values	Even though entire R and D expenditure may not be directly related to energy savings, it could be more in product innovations	-/+
Imports of capital goods	Imports of capital goods as % of sales, using real values	Capital goods can be representative of technology upgradation to meet higher performance and environmental standards among other improvements, thus contributing to lower energy intensity	Negative, will probably suggest the lack of domestic R and D for energy intensity

6. Distribution pattern of firms and trends in iron and steel industry

The distribution pattern shows that firms with large assets, as in the fourth size quartile, contribute significantly to the annual turnover, as also understandable (Figure 4). Also, the largest firms account for a substantial proportion of the expenditure on R and D and also have high imports of capital goods. The observations suggest that larger firms spend more on R and D, however do not necessarily confirm if the same is effectively supporting in terms of achieving lower energy intensity of the firm. It has been often argued that expenditure of R and D is inclusive of multiple activities, often less relevant for core innovation. Therefore, putting this for validation through empirical analysis will be ratifying. The high proportionate use of imported capital and equipment in the top quartile firms is suggestive of their dependency on imported equipment to improve (lower) energy consumption as mandated under specific energy conservation and efficiency improvement programmes of the government.

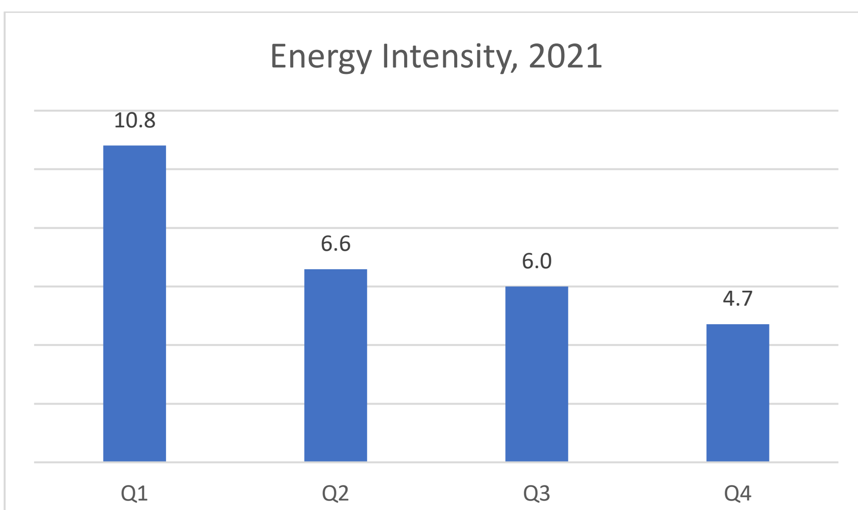
Figure 4: Distribution pattern of firm-quartiles



Note: The legend refers to four quartiles of firm-size in the increasing order of their size. Firms in Q1 are the smallest, while those in Q4 are largest in size.

Indeed, the intensity levels of firms in the top quartile with high values of gross fixed assets are the lowest when compared with other quartiles (Figure 5). This is suggestive that targeting for mandatory intensity improvements has been an effective policy instrument. Also, the relatively high-level of energy intensity for the firms in the remaining quartiles shows that there remains a scope for bringing the smaller firms under the ambit of regulation, despite their relatively small contribution to turnover.

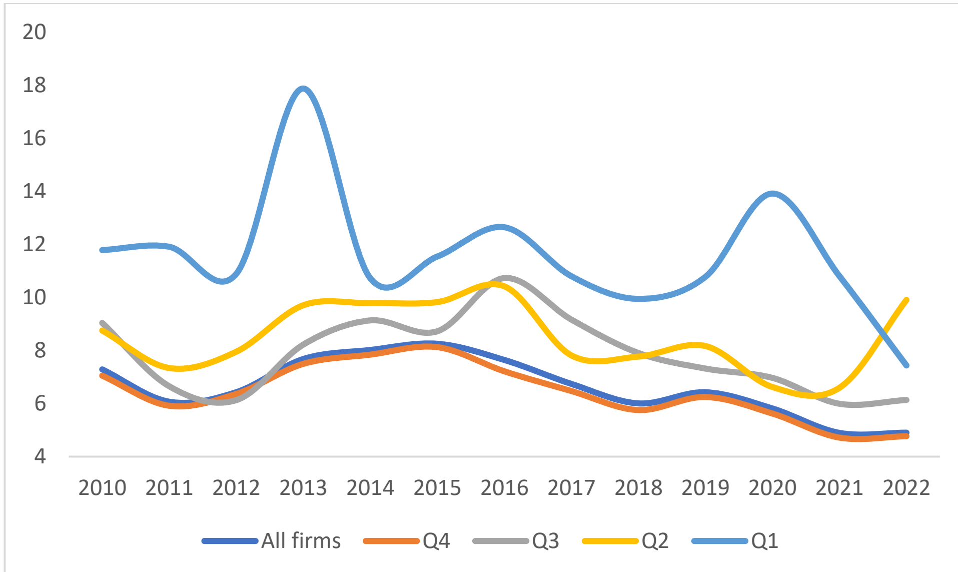
Figure 5: Energy intensity of the firm-quartiles, 2021



Note: The legend refers to four quartiles of firm-size in the increasing order of their size. Firms in Q1 are the smallest, while those in Q4 are largest in size.

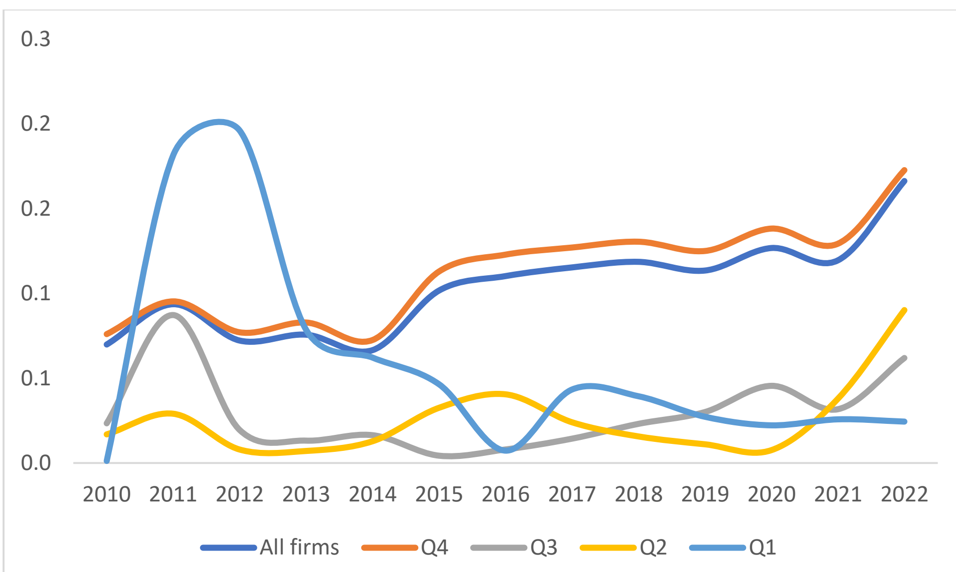
The time-trends in energy intensity of the firms in each of the four size quartiles exhibit a generally lower energy intensity over the reference period, with the exception of the increase observed for the second quartile in the most recent year (Figure 6). The overlapping movement of energy intensity of the fourth quartile and the overall industry reflects upon the significant contribution of the former in lowering energy intensity of the overall industry. Likewise, is the case with regard to R and D expenditure which is mostly in the firms belonging to the fourth quartile and has also increased over time (Figure 7). Similarly, in the early years of the reference period, imports of capital goods are observed mostly in the firms belonging to the fourth quartile (Figure 8). However, over the years even the large-sized firms have reduced their imports of capital goods as observed from the narrowing of the gap among the lines. Observed in combination with the downward movement of the energy intensity (in Figure 6), suggesting that aggressive imports of capital goods have been behind the lower energy intensity. We put this observation to further empirical scrutiny in the analysis by studying the effect of utilization of importations of capital goods such as equipment through a lower energy intensity at the firm-level. Also, flattening of the import curve in the more recent years shows that most energy-related measures have been implemented in the past years to meet the required energy/emission norms.

Figure 6: Trends in energy intensity



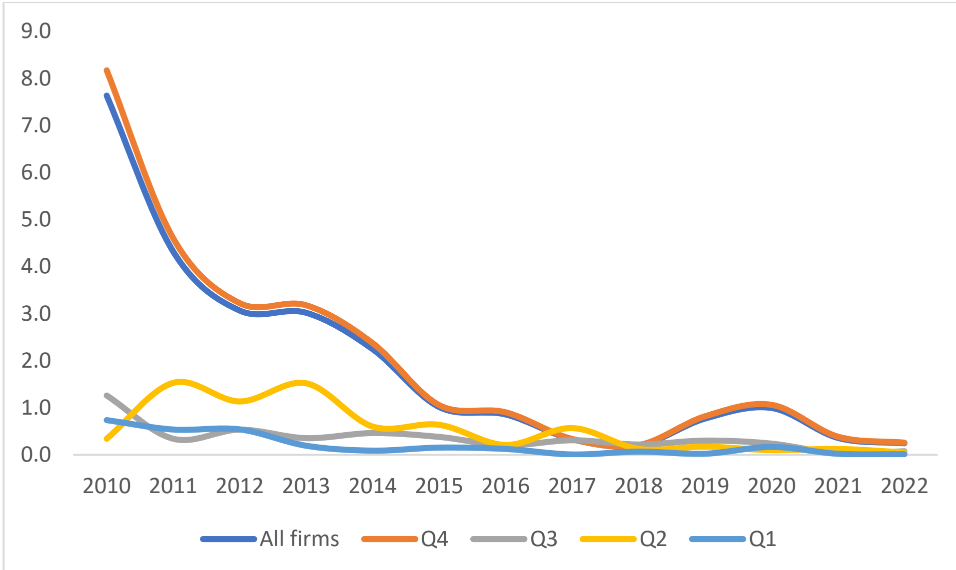
Note: The legend refers to four quartiles of firm-size in the increasing order of their size. Firms in Q1 are the smallest, while those in Q4 are largest in size.

Figure 7: Trends in R and D intensity



Note: The legend refers to four quartiles of firm-size in the increasing order of their size. Firms in Q1 are the smallest, while those in Q4 are largest in size.

Figure 8: Trends in intensity of capital goods imports



Note: The legend refers to four quartiles of firm-size in the increasing order of their size. Firms in Q1 are the smallest, while those in Q4 are largest in size.

7. Empirical results and discussion

As reported in the columns (1) to (5) of the Table 4, the effect of specific variables such as the size and R and D are found significant. Literature suggests that firms investing in increasing their internal knowledge base such through in-house R and D, improve their ability to absorb new technologies (Griffith et al, 2004), ultimately supporting their GVC upgradation (Criscuolo et al., 2015). However, the insignificant sign on the GVC variable in specification (6) suggests that R and D is not necessarily oriented for core activities such as technology related innovation for improving energy intensity. This is validated in the specification (7) by introducing the variables on profit of the firms and their import of capital goods. The underlying thought is to validate that higher profits of the firms support improvements in energy intensity. Firms adopt the BAT through retrofits acquired through imports of capital equipment. The effects of specific explanatory variables are discussed in the following.

Firm size is found to have a significant on energy intensity. The negative sign of the coefficient suggests that larger firms have lower intensity of energy use. Further, comparison within the broader group of firms belonging to the second, third and top quartiles, shows that largest firms have lowest intensity. This is a validation of the Perform, Achieve and Trade programme of the BEE, that is designed to identify the top most firms in the industry for achieving the targets to lower their respective SEC. The effect reduces progressively as the size of the firm increases suggesting the need to target the conservation measures at the bottom.

The age of a firm does not seem to have a significant influence on energy intensity. However, the significant and negative coefficient that appears of the square of age suggests that firms do not indulge in energy intensity activities in an explicit manner during their early years. Nevertheless, as they age beyond a threshold period, they actively attempt to reduce energy intensity in an attempt to catch up on the losses as the machines get older with time. Thus, non-compliance of small-sized firms with the norms can result in disproportionately high emissions per unit produced. Alternatively, this confirms that newer firms that have a smaller age are being setup with relatively better technology.

Firms which are relatively more integrated into the supply chains tend to be competitive through savings on their energy costs, as reflected from the negative and significant sign of the value chain participation indicator. Upstream integration of steelmaking firms is driven by the secure supplies of iron ore and coking coal, to make better margins (McKinsey & Company, 2014). Steel making firms tend to invest in downstream activities (e.g., steel rolling facilities) and steel-making capacity in foreign locations with insufficient domestic capacity (OECD, 2017). Downstream integration is also motivated by the higher value in downstream products which include hot-rolled products, coated steel, and steel forgings where value addition is 19%, 22%, and 23% respectively – much higher than the upstream products such as pig iron and ferro alloys where value added is 12% and 6% only.[12]

Since the expenditure on R and D is not explicitly noted towards developing technology and equipment, it is difficult to attribute the expenditure necessarily towards technological development to lower the energy intensity. This indeed, is found true, as the effect of R and D intensity becomes insignificant in presence of the profit variable.

As a follow up, we introduce the import of capital goods as a variable in the equation to be causing improvements in energy intensity and indeed find it significant and negative on sign. This confirms that R and D expenditure is not necessarily on energy-related improvements but could be rather on activities such as business process development, new product development, or simply the gross value of R and D equipment (Gajdzik and Wolniak, 2022), and that firm expends profit earnings to lower the energy intensity by using imported capital goods which help the manufacturing process adhere to the emission norms. These findings are in line with those of the Sahu et al (2021). We conclude that firms use their profits to import energy-related equipment to economize on the energy use through reduction in energy intensity, and that the R and D expenditure is not necessarily towards lowering the firm's energy intensity in the iron and steel industry. Thus, older equipment is being retrofitted with imported equipment.

Table 4: Determinants of energy intensity in iron and steel firms

	Dependent variable: Energy intensity						
	(1)	(2)	(3)	(4)	(6)	(5)	(7)
Size	-0.486*						
	(0.051)						
Quartile 2		-3.536***		-3.536***	-3.536***		-2.823***
		(0.000)		(0.000)	(0.000)		(0.000)
Quartile 3		-5.785***		-5.783***	-5.783***		-4.745***
		(0.000)		(0.000)	(0.000)		(0.000)
Quartile 4 (top)		-8.493***		-8.491***	-8.491***		-6.468***
		(0.000)		(0.000)	(0.000)		(0.000)

[12] Figures are in reference to South Korea.

R and D intensity			-0.867***	-0.810***	-0.810***	-0.866***	-0.484
			(0.000)	(0.000)	(0.000)	(0.000)	(0.151)
GVC intensity						-0.00616	-0.00991*
						(0.477)	(0.086)
Age					-0.0925**		0.0356
					(0.047)		(0.566)
Age square							-0.00307***
							(0.004)
Profit							-0.211**
							(0.014)
Import of capital goods (intensity)							-0.00965**
							(0.019)
Constant	11.70***	12.91***	8.545***	12.92***	14.60***	8.595***	13.28***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R-square	0.002195	0.097426	0.0040	0.100942	0.100942	0.004227	0.093282

8. Conclusion and policy suggestions

Improvements in energy intensity, particularly in the industrial sector, have a significant role on the pathway to sustainable development. In view of highest share of the iron and steel industry to industrial emissions, continuous improvement in the energy intensity is inescapable. Indeed, improvements in energy intensity have been registered in India's iron and steel industry, as also shown in the paper. For future improvements, it becomes pertinent to understand the factors driving the developments and to know if the improvements have been on the strength of indigenous factors or are have been driven external inputs which is then likely to wither the economy's *Atmanirbharta* in meeting the set targets for a low-carbon industry and overall economy.

Extending the existing literature, this paper branches out by drawing the attention to the firm's approach towards retrofits as the underlying mechanism. Results of the empirical excise show a significant effect of the firm-size implying that larger firms have lower energy intensity. While new firms do not explicitly engage in energy-related improvements immediately, firms beyond a threshold indeed show a concern for improvements. The increased GVC integration of the firm supports energy-related improvements, as the firms tend to be cost competitive through savings from reductions in per unit energy costs. We note that R and D activity does not necessarily contribute to lower energy intensity, suggesting that the expenditure is not in the core area for energy-related improvements. Instead, the firms improve sustainability of the production and maintain an edge in business through installation of the equipment. However, with a constrained domestic manufacturing of the equipment, as also acknowledged in the National Steel Plan, imports of capital goods are being used. Thus, the firms achieve improvements in energy intensity through technological upgradations with brownfield installations and retrofitting. The findings on retrofitting as a strategy to use the existing assets on a sustainable emissions pathway are also acknowledged in the technology roadmap (IEA, 2021b). The retrofits also permit some degree of fuel switching in using low-carbon intensive or reordered fuels. For this reason, in future there is going to be greater emphasis on retrofits even for the new and younger steel making assets. In the absence of a domestic availability of equipment which also requires long-term indigenous R and D, the sustainability goals are being achieved through utilization of imported machinery and equipment.

For policy, this highlights critical dependence on imports of green goods is to meet net-zero targets. The finding is used to call for technology transfers as part of brownfield installations, and policy interventions to support the domestic capital goods industry to reduce the dependency on imports. On the sidelines, the results also show that imports of equipment supports through lowering the intensity of energy use, thereby exhibiting a positive externality of trade in supporting the environment. Therefore, there could be a trade off in the short-run improvements through expediting the transition to cleaner fuels.

However, this does not undervalue the need for a domestic R and D eco system in the long-run. Indigenous R and D needs to be encouraged. Considering the forthcoming CBAM makes it urgent to attend to the energy intensity improvements for Indian steel firms to export to the EU without incurring the additional costs in the form of a carbon tax if found with higher intensity of energy than in the EU. Therefore, the government should also increase its activity towards preparing good policies to increase the innovativeness. The good policy of research and development spending to boost innovativeness is important because of a time lag which is observed between the growth dynamics of research and development expenditures and the growth dynamic of the industry. Although, the results in this paper are with reference to India's iron and steel industry, they also have value from a broader economy and government policy formulating point of view for other emission-intensive industries.

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