Trade and Economic Impacts of the EU's Carbon Border Adjustment Mechanism on India's MSME Sector

CRIT/CWS Working Paper Series No 83[1]

April 2025

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The paper analyses how firm level factors influence carbon emission intensity in India's Iron, Steel and Aluminium sectors in the context of the EU's Carbon Border Adjustment Mechanism (CBAM). Using CMIE Prowess data, it finds that greater investment in plant and machinery is linked to reduced emissions, although sectoral variations remain. The paper finds that MSMEs tend to have lower emission intensity than larger firms, while export orientation shows no clear advantage in carbon efficiency. Through these findings the paper attempts to highlight the differentiated impact of CBAM on firms of varying size. The study underscores the importance of sector-specific decarbonisation strategies, technology-led interventions, financial incentives, and regulatory reforms to align industrial growth with India's climate commitments.

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[1] This study builds upon and extends the analysis presented in *Working Paper No. 76* published by the Centre for WTO Studies, which examined the sectoral implications of the EU's Carbon Border Adjustment Mechanism (CBAM). An earlier version was presented at the first Global Business Research Conference organised by Indian Institute of Foreign Trade (26th to 28th March 2025) at New Delhi. The authors express their gratitude to the discussant, chair and co-chair for their valuable suggestions, which have been duly incorporated in the revised paper.

New Delhi – 100014

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1. Introduction

The debates on climate change are perceived as one of the most serious policy issues in the twenty-first century. Collaborative efforts are being directed toward addressing the urgent global challenges of climate change, carbon dioxide removal, and the widespread uptake of renewable energy sources. Therefore, the imperative to reduce carbon emissions has become increasingly recognised as a pivotal element in the pursuit of environmental sustainability on a global scale.

The industrial and energy sector is one of the most significant contributors to the increase in emissions. Globally, nations are progressively acting to reduce emissions from manufacturing goods, either individually or in concert. By formally informing the World Trade Organisation (WTO) of its plan to create a "Carbon Adjustment Mechanism," the European Union (EU) recently took a big step. A carbon tax on greenhouse gas emissions (GHGs) included in imports is the suggested method to stop such leakage. Iron and steel, aluminium, cement, fertiliser, electricity, and hydrogen are the six energy-intensive industries that are the primary focus of the EU's plan. This proposed carbon price is predicted to hurt exports from developing nations to the EU.

The most effective policies for reducing GHG emissions have not yet been established; hence, it is important to understand firms' behaviour in reducing GHG emissions to make these environmental policies effective. To mitigate climate change, the amount of GHGs emitted by firms has to be reduced. Hence, firm-specific factors need to be studied and analysed. In order to reduce a company's carbon footprint, researchers have discovered that elements including sales, corporate social responsibility (CSR) plans, and green innovation are essential (Hatakeda et al., 2012).

A significant region in the global economy, the Indian market is becoming increasingly well-known. Indian businesses, like those in other nations, deal with environmental obstacles. Due to substantial industrialisation growth in this region, our study focuses on Indian firms since they are crucial for studying factors affecting the effectiveness of carbon emission reduction performance. We can create a more efficient strategy to address environmental sustainability from both a firm and a national perspective, suited to the particular requirements of the Indian setting, by comprehending the role of these aspects.

MSME's are critical to India's ongoing energy transition efforts since they contribute to about 30% of India's GDP, employ an estimated 15.50 crore individuals and contribute to roughly 45% of India's total exports (Gowthami & Shah, 2024). It has been noted that India's MSME's face several challenges, including substantial energy consumption, which is responsible for about 110 million tonnes of carbon dioxide (CO_2) emissions annually and is projected to increase by 50% by 2030 (Gowthami & Shah, 2024). Hence, measures like the EU's CBAM proposal can cause added challenges to Indian MSME's due to rising costs, highlighting the need for urgent intervention.

Therefore, this research endeavour is centred upon the computation of carbon emission intensity within the iron & steel, and aluminium industries at the firm level, thereby delineating the influence of their energy sources. Moreover, to understand the relationship between investment in plant and machinery and carbon emission intensity in these sectors. This study is an extension of a previous study. In this study, we focus on only firms with available emissions data for all years. Moreover, we focus on how firm-specific factors differ across MSMEs and large firms, which is another new area of focus of this paper.

Our study proceeds as follows: Section 2 includes a survey of the literature. Section 3 then goes into further detail about the approach used. Sections 5 and 6 present the empirical results of the trends and patterns in carbon emission intensity that have been observed. Section 7 summarises the essential findings and outcomes, offers insights into the implications for Indian policymakers, and provides a basis for future avenues for further research in the area.

2. Literature Review

The environmental performance of businesses and their interaction with trade competitiveness and industrial sustainability have received increasing attention recently. Understanding the elements at the business level that affect carbon emission intensity is crucial in the Indian context, where fast industrial development and hopes for international commerce intersect with growing ecological issues.

One basic starting point in this field is the Porter Hypothesis. It argues that rather than stifling competitiveness, reasonable environmental limits can inspire efficiency and creativity (Porter & van der Linde, 1995). Strong support for this theory comes from further empirical studies, such as Lanoie et al. (2008) and Rubashkina et al. (2015), which imply that environmental policies might cause firm-level productivity-enhancing reforms, especially in the industrial sectors.

Moreover, this logic is reflected by empirical observations from Indian manufacturing. Goldar's (2012) assertion of a notable 60% drop in energy intensity across Indian companies between 1992 and 2009 points to a consistent but significant shift toward more energy-efficient production. Furthermore, Sahu et al. (2011) found that the average carbon emission intensity declined by 25% between 2000 and 2008, suggesting Indian companies have split development from emissions. While stressing the impact of structural and firm-specific elements, Sahu, Narayanan, and Banerjee (2013) also conducted a study focusing on inter-firm variance in emissions.

More recently, studies have emphasised how commerce and technology affect carbon results. For instance, Bagchi et al. (2022) examined the trade-offs between emissions and corporate output. They found that emission reductions can be achieved without jeopardising growth, especially when businesses implement clean technology and process changes. Reflecting similar results, Goldar et al. (2023) examined plant-level data between 2008 and 2015 to indicate that export-oriented companies, especially those in high energy-consuming sectors, often exhibit better energy efficiency. This tendency echoes earlier European results by Costantini et al. (2012), who noted that environmental levies and regulatory pressure can stimulate innovation and trade competitiveness in high- and medium-tech sectors.

Macro-level structural factors influence emissions paths, including urbanisation, energy consumption, and trade openness. A new analysis by Dasgupta, Mukherjee, and Roy (2023) shows that trade and urbanisation keep pushing carbon intensity upward, while economic growth can finally result in lower emissions. Sahu et al. (2013) show the need for industry-specific policy solutions and investigate how sectoral variances worsen the problem.

Recent data point to financial and strategic advantages for setting official carbon reduction goals. Sharma and Patel examined Indian companies that engaged in the Science-Based Targets initiative (SBTi) in their 2023 study and concluded that these companies not only improved the environment but also generated greater income. This points to a developing congruence between environmental responsibility and shareholder value—a hopeful indicator for sector players and legislators. Government action also promotes this change: the $1.74 billion plan of the Indian Ministry of Steel to decarbonise the steel sector shows a concrete step in helping industrial transformations (Government of India, 2024).

Industry-level studies can help to highlight the varied possibilities and difficulties in different sectors. For instance, the dynamics of world trade affect the steel sector. According to Gupta (2024), U.S. tariffs could aggravate dumping into the Indian market and hinder initiatives by home businesses to make investments in green technologies. Still, the fashion and textile sectors have seen notable developments in a sector long thought to be high-polluting. According to Kumar and Rathi (2023), companies depend more on renewable energy sources, including solar and biomass, to meet worldwide sustainability criteria and reduce their carbon footprint.

There are still many gaps, even if the literature presents perceptive knowledge on the factors influencing carbon emissions at the corporate level. For instance, especially in heavy industries, the exact effect that technological developments and machinery purchases have in reducing emissions intensity has not gotten much attention. Furthermore, even if firm-level data quality has increased dramatically, more exact policy targeting could be made possible by an additional breakdown, such as plant-level energy source patterns. Though uneven, India's path toward environmentally conscious industrialisation is in progress. A complex interaction of trade direction, technology choices, sectoral features, and policy frameworks shapes firm-level emissions intensity.

3. Data Sources and Methodology

This paper uses the following methodology to estimate the level of CO_2 emissions and CO_2 emissions intensity (ratio of aggregate carbon emissions to volume) at the firm level of particular industries.

3.1 Identification of Firms

Firstly, using CMIE Prowess IQ, we have extracted a list of all firms in the Metal and Metal Products Category, which includes ferrous metals such as iron and non-ferrous metals such as aluminium. At the preliminary level, 2,298 companies fall in this category. We have extracted energy consumption data for 2000-2022 for each of these companies.

Further, each firm in the listed dataset has been mapped to the national industrial classification (NIC) code. The NIC code is an essential statistical standard for developing and maintaining a comparable database according to economic activities, updated by the Central Statistical Organisation (CSO). The NIC codes were assigned to all the firms in our dataset, and NIC primarily falls into the divisions: Manufacture of essential metals; Manufacture of fabricated metal products, except machinery and equipment; Manufacture of machinery and equipment not elsewhere classified (n.e.c.,); Other manufacturing; and Repair and installation of machinery and equipment were of primary interest. The four-digit NIC interest codes were 2410, 2431, 2420, 3311, 2511, 2512, 2599, 2817, and 3290. The firms with NIC codes other than those mentioned above were omitted from the analysis, bringing down the number of firms to 960. Additionally, we further marked each firm's sector code against NIC codes.

3.2 The Calculation of CO_2 Emission Intensity

Estimating the intensity of CO_2 emissions at the firm level involves five steps. Firstly, a company's greenhouse gas emissions (carbon dioxide) are distributed across various energy source categories a firm utilises; hence, the first task was to harmonise the different energy sources into specific standard energy sources across all firms. Post bringing homogeneity to the energy sources, the primary energy sources part of the analysis is - Electricity, Diesel, Furnace oil, Coal, LPG, Wind Mills, Wood, Water, Solar energy, and Others. Each firm reported data on the quantity consumed in various units in each energy source. Hence, for comparison, the units were standardised. Additionally, based on our understanding of the other energy source, we have further divided the energy source based on units reported in nine of the above categories. However, we have dropped specific observations such as those with units- Cylinders, Numbers, Terms, and the TBTU[2]. In total, 40 such observations were dropped, out of which 9 were TBTU observations.

The second step in the analysis was to identify the accurate Net Calorific Value (NCV)[3] and Emission Factors (EF).[4] For each energy source the firm uses, the firm calculates the carbon emissions at the firm level. In this paper, the NCVs and EFs prepared by the Indian Network for Climate Change Assessment (INCCA) have been utilised. Further, the estimates were made using revised IPCC 1996 guidelines (1997), IPCC Good Practice Guidance (2000), and the LULUCF Good Practice Guidance (2003). The EFs were also a mix of default present in IPCC publications (1997, 2000, 2003, and 2006) and Country Specific (CS), but were of improved accuracy as a more significant number of CSs have been used in this assessment (35% of the source categories used CS factors). A simple representation of the methodology used in this paper for estimating carbon emissions from each energy source category is shown in the following formula:

$$CO_2 = QV * EF * NCV$$

where QV is the quantity consumed by each energy source.

Table 1: Choice of NCV and CO_2 EFs of different types of fuel used for estimation

Energy Source	NCV (Tj/kt)	Emission Factor (t/Tj)
Coal	23.66	25.55
Diesel	43.00	74.10
Oil	40.00	77.00
LPG	47.30	63.10
Wood	47.30	63.10

Source: "India: Greenhouse Gas Emissions 2007", Indian Network for Climate Change Assessment, Ministry of Environment and Forests, GoI 2007; Tj – Terajoule; kt- Kiloton; t- Tonne

Table 1 above accentuates the NCVs and EFs used in the analysis. Carbon emissions were assumed to be zero for renewable energy sources such as solar, wind, and water. The emission factors of fossil fuels such as coal, oil, and natural gas are the most critical considerations when estimating the GHG emissions from the combustion of these fuels. In India, coal as a fuel constitutes more than 50% of the total fossil fuel mix of the country, used for energy-related activities. We have taken a few more steps before the final

2 TBTU means trillion BTU (British thermal unit) a unit of measurement for energy.

3 Net Calorific Value (Net CV) is the practical amount of energy which may be realised at atmospheric (constant) pressure. This is the most practically meaningful value that is expressed on an 'as received basis' (i.e. including the moisture content), since that is typically how the fuel will be burned.

4 Definition. An emission factor is a coefficient which allows to convert activity data into GHG emissions. It is the average emission rate of a given source, relative to units of activity or process/processes. For example: the natural gas emits 0.244 kg CO2eq / kWh ICV (European mean) with 5% uncertainty.

assessment to obtain CO_2 emissions intensity (ratio of aggregate carbon emissions to volume) at the firm level.

The third step entailed extracting consolidated and standalone sales for each firm each year from the CMIE ProwessIQ database. Wherever consolidated sales were null, they were replaced by standalone sales, and in other cases where consolidated sales were present, that value was taken. This method prevents any bias and error due to double counting.

The fourth step was to extract prices NIC code-wise from the Annual Survey of Industries (ASI) from 2000 to 2022. Part 1 of the Annual Survey of Industries (ASI) schedule was structured in 14 blocks. It is the central part of the schedule and is meant to collect economic and related categorical data for the selected unit. In the ASI, block 1, Block A, had unique identification codes. The desired economic variables (sales and quantity) existed in block J. Hence, the five-digit NIC code in Block A was mapped in Block J, which had the desired variables to calculate the prices. Using the Despatch Serial Number (DSL) number, which is unique across the country for a particular year of survey, the NIC code was mapped from Block A to Block J. Next, in Block J, only those units which were in 'tonne' were kept part of the analysis and other units were dropped. After which, we kept only those values of quantity sold that were not zero. Finally, gross sales value was divided by the amount sold to obtain prices at the industry level. Lastly, average prices NIC-wise and year-wise were found.

Since the ASI has not been released for the years 2021 and 2022, for calculating the average price of 2021 and 2022, we have utilised the Annual Average of Monthly Index (Financial Year 2012-13 Onwards), which has 2011-12 =100 as the base. We multiplied 2011-12 prices by the index value of 2020-2021 & 2021-2022 to get the average prices for the recent years.

We would also like to point out that during the period taken for the analysis, 2000-2022, the NIC codes were revised thrice (NIC-1998, NIC-2004, and NIC-2008). We have considered these and mapped NIC-1998 and NIC-2004 to NIC-2008 using concordance tables to obtain accurate average price data.

The fifth step entailed using the average price data at the industry and firm levels. In this step, for each firm falling in an industry (identified by NIC code), we get the volume of firms by dividing the sales by the average price, which was in (Rs/Tonnes) as identified in the fourth step. Finally, we aggregated each firm's emissions from all energy sources to obtain the average emission intensity. In other words, emission intensity is defined as aggregated emissions divided by volume.

After obtaining the emission data, we observed that emissions were missing for several firms due to a lack of either aggregated emissions or volume data. Hence, including these would skew our results. Hence, we have shortlisted 275 firms across both sectors for which emission data existed from 2000 to 2022. Thus, a standardised data set for applying econometric exercises was created to analyse energy-intensive sectors like Iron, steel, and aluminum.

4. Econometric model

In this study, we employ a model inspired by the work of Sahu and Narayan (2014), who examined the carbon emission intensity of firms with regard to various firm-level characteristics. Our adaptation of their model focuses on elucidating the intricate relationship between a firm's investment in plant and machinery and its carbon emission intensity while controlling for factors such as size, experience, and capital intensity.

Carbon emission intensity, indicated in Equation 1, is the dependent variable in our study. It is calculated by dividing a company's total emissions by its output volume. A log-log model is used to reduce skewness and improve coefficient interpretation

$$
\begin{aligned}
Log(Carbon\ emission\ intensity)_{i,t} = \\
& \propto + \beta_1 Log(Investment\ in\ Plant\ and\ Machinery)_{i,t} \\
& + \beta_2 log(Capital\ intensity)_{i,t} + \beta_3 log(Sales)_{i,t} + \beta_4 log(Age)_{i,t} \\
& + \beta_5 Log(Investment\ in\ Plant\ and\ Machinery)_{i,t} * Sector\ dummy \\
& + \beta_6 Log(Investment\ in\ Plant\ and\ Machinery)_{i,t} * Exporter\ dummy \\
& + \beta_7 Log(Investment\ in\ Plant\ and\ Machinery)_{i,t} * MSME\ dummy \\
& + \mu_i + \delta_t + \varepsilon_{i,s,t} ----------------- (1)
\end{aligned}
$$

We have considered the gross plant and machinery value in a given year to indicate a firm's investment in plant and machinery. This variable captures the financial worth of a company's plant and machinery at its acquisition price. Theory suggests that companies investing more capital in plant and machinery tend to show lower carbon emission intensity.

Using the ratio of gross fixed assets to sales, we have added capital intensity as a further indication. Higher capital intensity companies are predicted to have lower carbon emission intensity, so fitting the idea that more capital investments could lead to using more sustainable and cleaner technology.

Furthermore, we integrate the logarithm of total sales as an indicator of firm size. Given the scale of their operations, larger firms are anticipated to have higher carbon emission intensity. At the same time, we measure a company's experience using its age since its founding. The fundamental idea is that older businesses could be more carbon-emitting, due to their past behaviours and technology obsolescence.

Equation 1 adds three dummy variables- the exporter, sector, and MSME dummy to investigate differences in the link between carbon emission intensity and investment in plant and machinery. The exporter dummy assumes a value of 1 if a firm's exports are more than 0 in a given year. Our hypothesis posits that firms engaged in exporting may exhibit a more pronounced correlation between investment and emission intensity. On the other hand, the sector dummy takes on a value of 1 for firms operating in the iron and steel sector and 0 for those in the aluminium industry. This difference lets us investigate whether different industries have different relationships between investment and emission intensity. Finally, for the MSME dummy, there were multiple instances where a company's yearly sales data was missing for specific years. Hence, we computed the average sales from 2000 to 2022. If the firm's average sales over this period were less than Rs 50 million, it was classified as an MSME in all years, and it takes on a value of 1 and 0 otherwise.

In our analysis, we conducted seven regression models. In the first regression, we regressed the log of investment in plant and machinery solely on carbon emission intensity. The second regression introduced an additional independent variable, the log of capital intensity. For the third regression, we added a third independent variable, the log of sales. The fourth regression incorporated all the previous independent variables and included the firm's age as an additional independent variable. The fifth regression model included an interaction term between the log of investment in plant and machinery and the sector dummy variable. The sixth regression model added an interaction term between the log of investment in plant and machinery and the exporter dummy variable. Lastly, the seventh regression model added an interaction term between the log of investment in plant and machinery and the MSME dummy variable.

We introduce firm and time-fixed effects into our model to account for unobserved heterogeneity. Given these elements, our research seeks to understand the intricate interaction between firm carbon emission intensity and investment in plant and machinery.

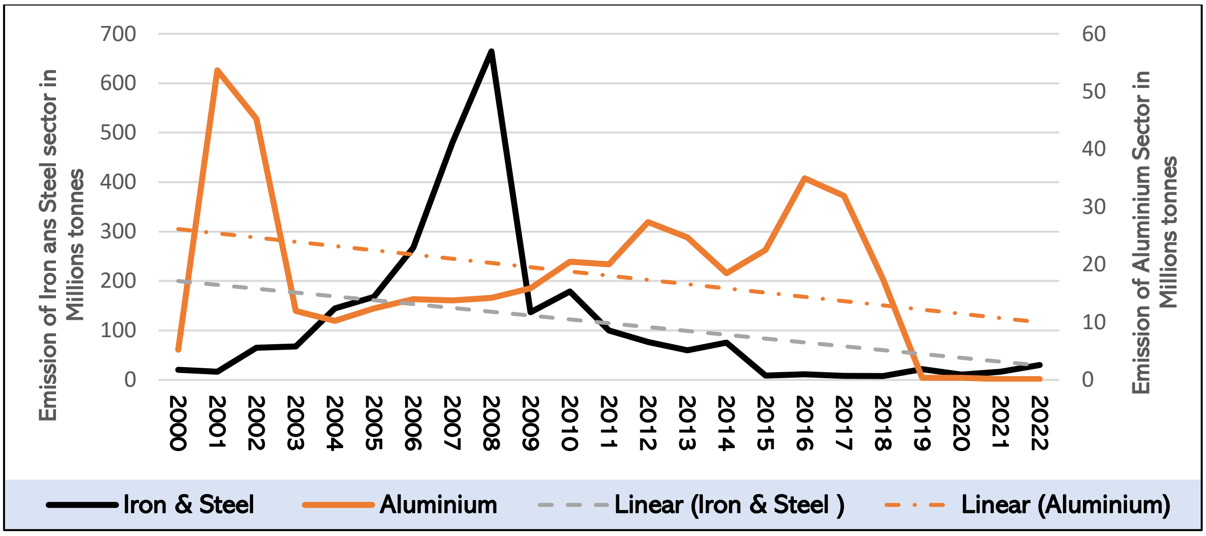
5. Descriptive Analysis

Analysis of carbon emissions from India's Iron and steel and Aluminium industries reveals clear and notable patterns. Analysing data from all the energy sources, including electricity, helps to show a company's carbon emissions fairly. Figure 1 presents a startling comparison of carbon emission patterns in India's iron and steel and aluminium sectors between 2000 and 2022. Not only does the emission level differ, but also the course each industry has pursued.

One especially notable sector for sheer volume and unpredictability is iron and steel. In the first decade, emissions varied greatly, with separate peaks in 2002, 2006, and 2009 each reaching the 600 million tons threshold. These highs most certainly line up with times of higher production. However, starting in 2010, there has been a clear decreasing trend as emissions taper slowly. Though not constantly or consistently across the period, the diminishing linear trend indicates that structural changes, whether via fuel substitution or energy efficiency gains, are starting to have an effect.

By contrast, the aluminium industry shows a significantly more muted and consistent emission profile. Emission levels have stayed low overall, never exceeded 35 million tonnes, and exhibit only slight swings. Pie chart studies below show that this relative stability could suggest smaller-scale operations, more regular manufacturing processes, or higher responsiveness to cleaner energy sources. The little drop in the trend line supports the perspective that, although on a smaller scale, the aluminium industry is gradually moving towards decarbonisation, albeit more silently.

Figure 1: Carbon Emissions in the Aluminium, Iron, and Steel Sector



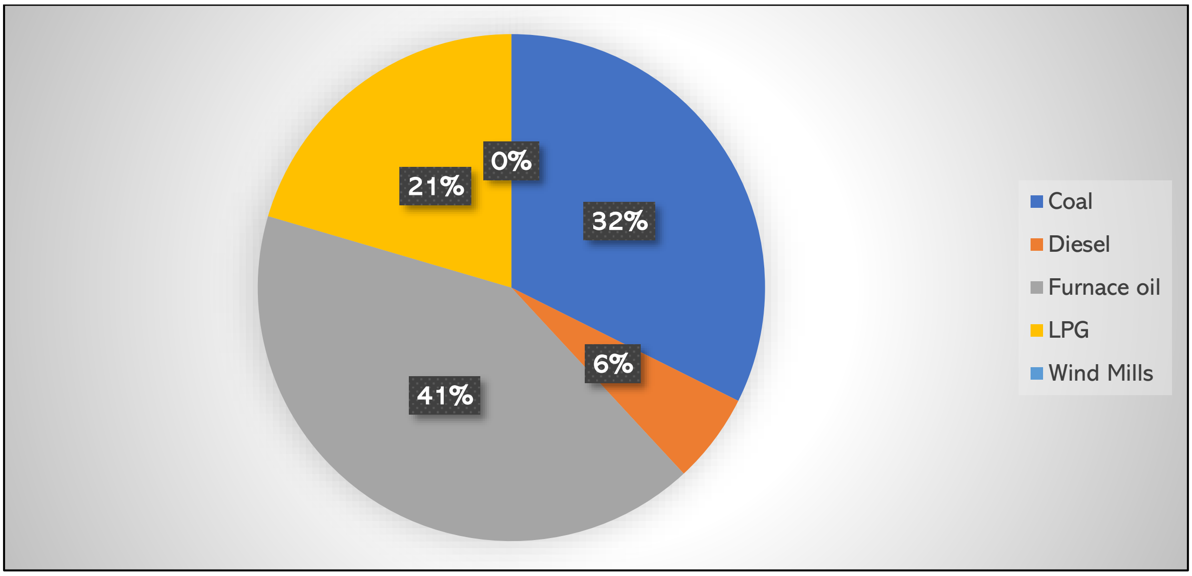
Source: Based on CMIE Prowess Database

The absolute emissions difference between the two industries stands out. Reflecting its energy-intensive character and greater industrial footprint, the iron and steel business emits significantly more carbon even at its lowest points than the aluminium sector. Simultaneous sharp changes in the iron and steel sectors indicate a more dynamic and maybe sensitive interaction between policy, production cycles, and emission results.

These opposing trends, taken together, suggest sector-specific routes of emission reduction. Although the aluminium industry seems to be on a slow and consistent road, the iron and steel sectors have more difficult management of both scale and variability in their emissions. These findings highlight the need for customised policy interventions that consider every industry's particular operational and structural aspects.

Additional understanding comes from a sectoral analysis of energy source contributions. Figure 2 shows that, within the Aluminium industry, furnace oil is the primary source, responsible for 41% of emissions; coal (32%), LPG (21%), and diesel (6%) follow. Wind and solar energy barely matter, emphasising how few renewable sources are used in this field. The sector's high emissions can be explained by its reliance on coal and furnace oil. Conversely, the minor percentage of LPG reveals some fuel diversification, but it is not clear enough to significantly lower total emissions.

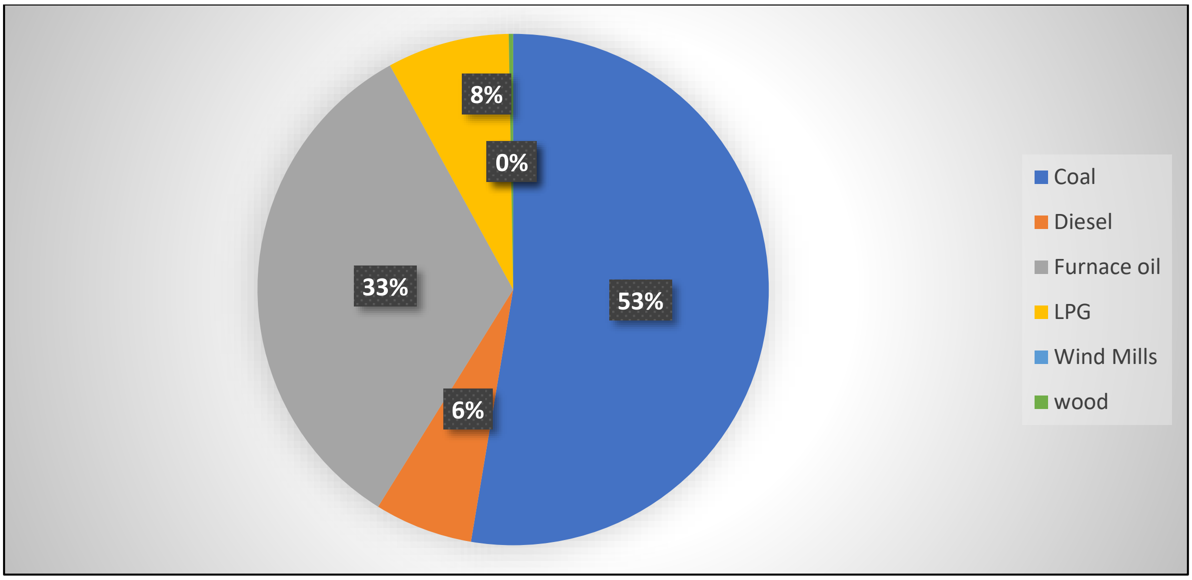
Figure 2: Sources of Carbon Emissions in the Aluminium Sector



Source: CMIE Prowess Database

Conversely, the iron and steel industry illustrated in Figure 3 exhibits a greater reliance on coal, accounting for 53% of total emissions, while furnace oil contributes 33%, LPG 8%, and diesel 6% of the remaining. The contribution of wind energy, similar to that of aluminium, is statistically negligible. The wood is also a marginal energy source. However, its effect on emissions is negligible. The persistent dependence on fossil fuels, especially coal and furnace oil, maintains elevated emissions, despite a gradual reduction over time.

Figure 3: Sources of Carbon Emission in Iron and Steel Sector

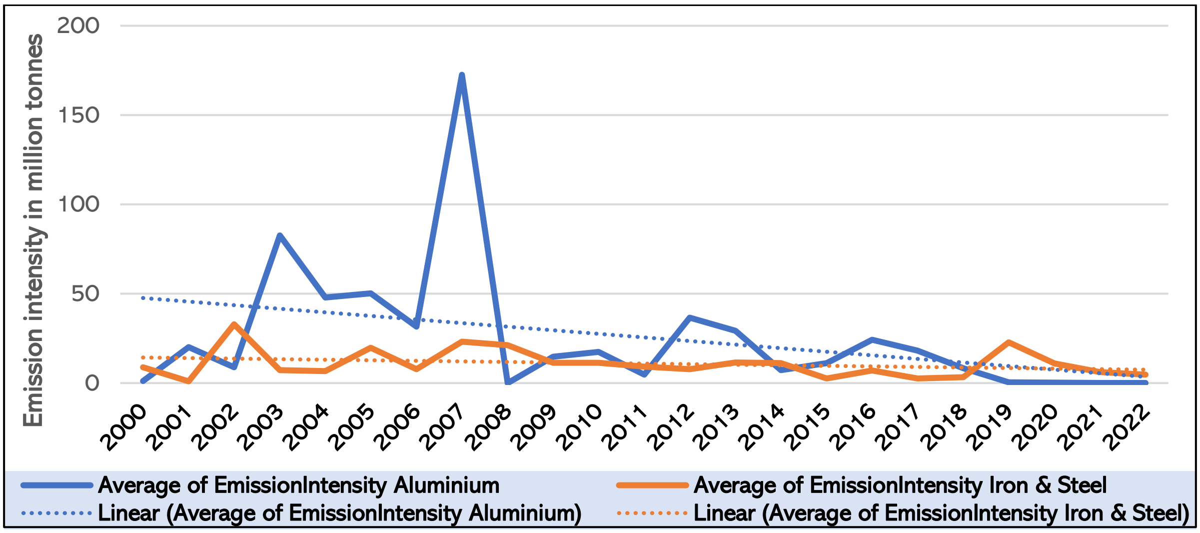


Source: Based on CMIE Prowess Database.

Although there are positive trends in emissions reduction, the persistent reliance on coal and furnace oil indicates that achieving deeper decarbonisation will require a more comprehensive adoption of clean energy technologies, specific policy incentives, and continuous improvements in production efficiency. The International Energy Agency (IEA) reports that energy-intensive industries account for nearly 80% of global industrial CO_2 emissions, with the Iron and steel sector contributing approximately 7% of global anthropogenic CO_2 emissions (IEA, 2023). India's experience is consistent with global observations. India, a prominent producer of steel and aluminium, has pledged to decrease the emissions intensity of its GDP by 45% by 2030 compared to 2005 levels, as outlined in its updated Nationally Determined Contributions (MoEFCC, 2022). Thus, the decarbonisation of these sectors is essential for meeting national climate objectives.

Analysis of emission intensity (emissions per unit of output) presented in Figure 4 indicates significant divergence between the two sectors. The aluminium sector demonstrates considerable volatility, reaching a peak of over 180 units in 2007 before stabilising post-2010. In contrast, the Iron and steel sector has exhibited consistently low emission intensity over the period, indicating more effective process management.

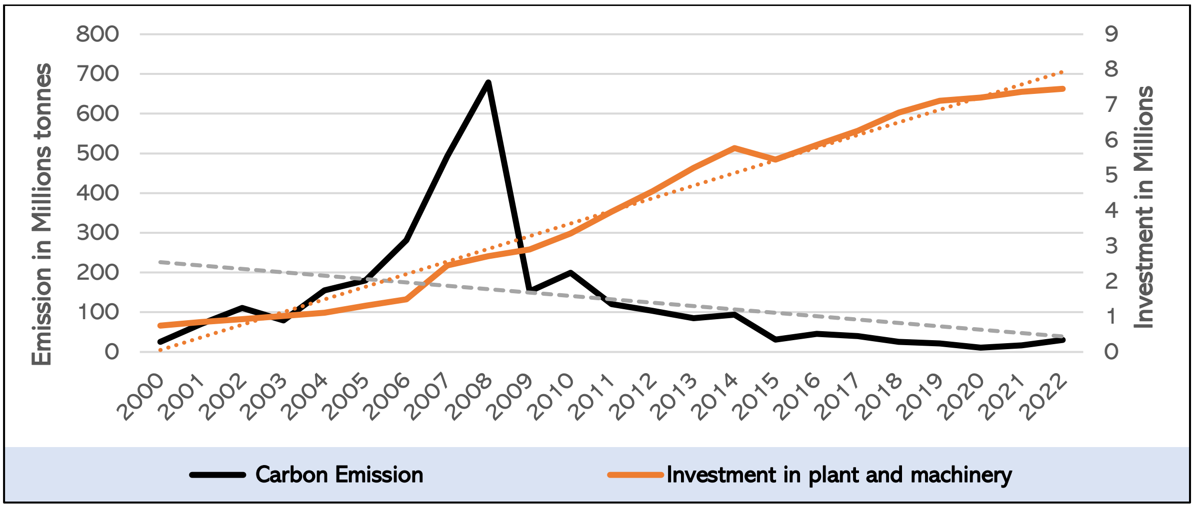
Figure 4: Emission Intensity in Aluminium, Iron, and Steel Sector



Source: Based on CMIE Prowess Database.

Figure 5 illustrates the reinforcement of the relationship between technological modernisation and emission reduction through capital investment trends. With the steady increase in investment in plant and machinery, culminating in nearly 8 million units, overall emissions exhibited a downward trend. Despite a surge in emissions around 2008, later increases in capital expenditure likely enabled the implementation of more energy-efficient and environmentally sustainable practices. The Iron & Steel sector exemplifies this dynamic, with innovations including carbon capture technologies, enhanced furnace designs, and alternative energy sources leading to reduced emission outputs.

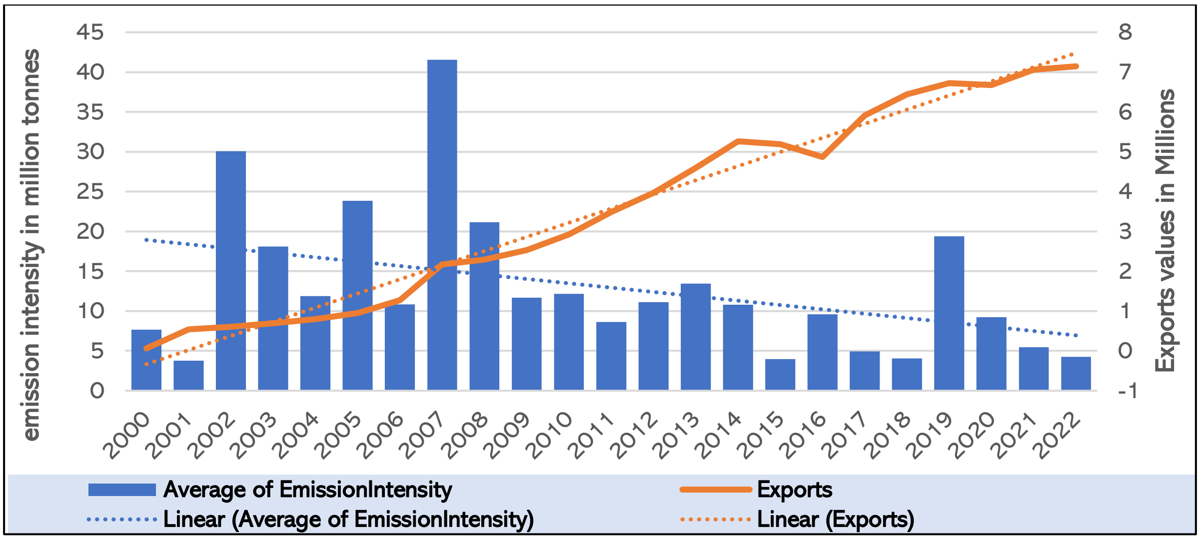
Figure 5: Carbon Emissions vs Investment in Plant Machinery



Source: Based on CMIE Prowess Database.

Trade performance contributes an additional dimension to this relationship. Figure 6 illustrates pronounced spikes in emission intensity, notably during the periods of 2005-2007 and 2020, signifying intervals of increased carbon-intensive production. This may be due to a greater dependence on high-emission energy sources or phases of elevated production activity lacking associated efficiency enhancements. From 2010 to 2015, it demonstrates a comparatively lower emission intensity, likely indicating efficiency-driven interventions or structural changes in production.

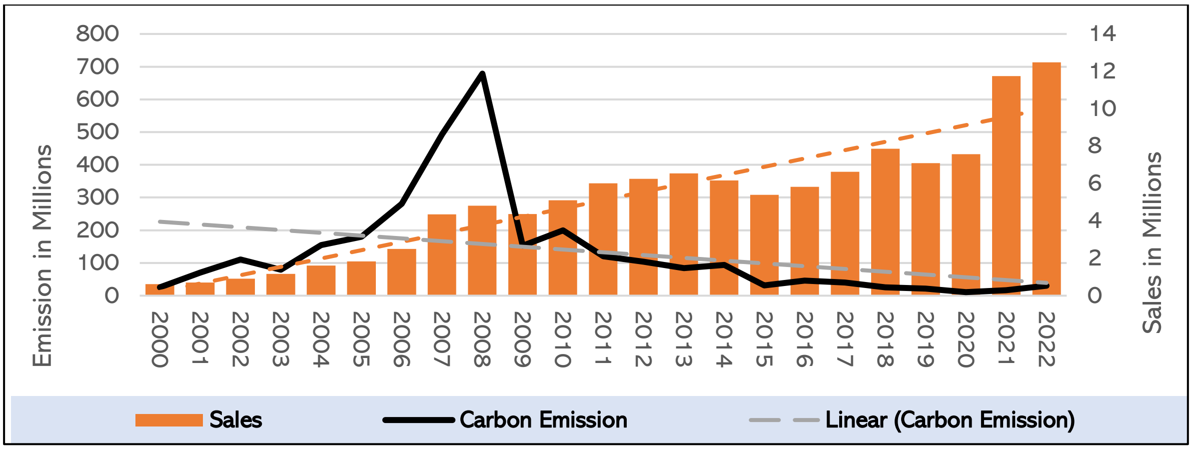
Figure 6: Emission Intensity vs Exports.



Source: Based on CMIE Prowess Database.

Exports exhibit a consistent upward trend, indicating ongoing growth in exports despite fluctuations in emission intensity. This trend indicates that although the industry has broadened its trade footprint over time, advancements in carbon efficiency have been variable. The disparity between export growth and variable emission intensity highlights a significant challenge in achieving increased industrial output and trade competitiveness without corresponding rises in emissions. The trend of rising exports indicates that trade growth has not consistently resulted in ongoing improvements in carbon efficiency, highlighting the necessity for enduring policy measures that incorporate both environmental and trade competitiveness factors.

Figure 7: Carbon Emissions vs Sales Revenue

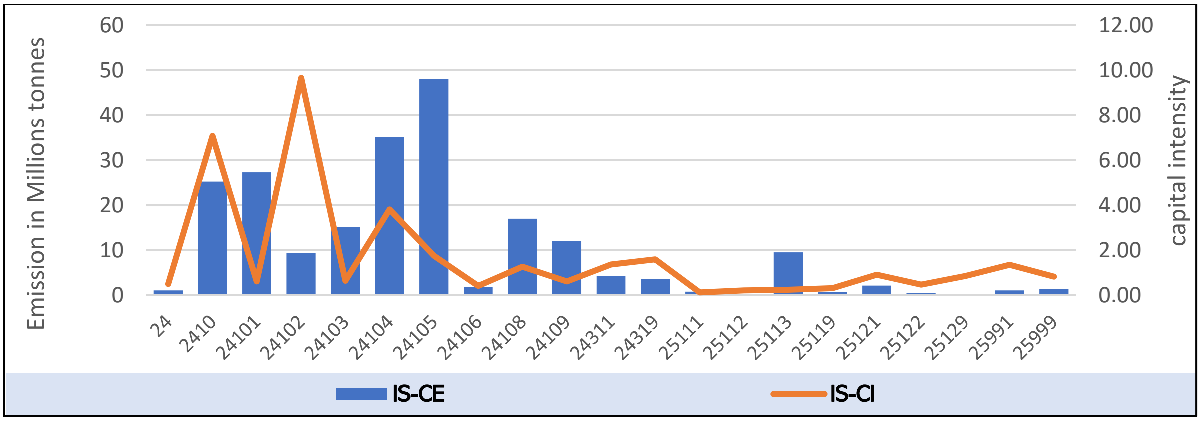


Source: CMIE Prowess Database

The inverse relationship between emissions and sales revenue, as illustrated in Figure 7, reveals another significant finding. Emissions peaked early and subsequently decreased, whereas sales revenue exhibited a consistent upward trajectory. This observation contests the assumed trade-off between environmental responsibility and economic performance. Companies that adopt low-carbon strategies frequently experience cost reductions, regulatory advantages, and improved market competitiveness (UNIDO, 2022).

An analysis of the Iron and Steel industry in Figure 8, categorised by specific NIC codes, uncovers unexpected patterns in the relationship between carbon emissions and capital intensity. It is a common assumption that increased investment in machinery and equipment correlates with reduced emissions; however, the data presents a more complex narrative.

Figure 8: Capital Intensity vs Emissions in the Iron and Steel Sector



Source: CMIE Prowess Database

Major emitters within the sector, specifically those classified under NIC code 24105, contribute more than 45 million tonnes of carbon emissions annually. However, these segments do not exhibit significant capital intensity. Conversely, segments such as 24101 are notable for their significant capital intensity, reflecting substantial investment in fixed assets, yet they generate considerably lower emissions in comparison. This indicates that companies may be employing more efficient or cleaner technologies in specific sectors of the industry, despite operating on a smaller scale. Codes 25122, 25991, and 25999 are located further down the value chain, characterised by low emissions and low capital intensity. These likely denote smaller, downstream activities, such as fabrication or finishing operations, which are characterised by lower energy intensity and, as a result, reduced pollution levels. There exists a distinct disparity between emission volumes and capital investment levels. The sectors with the highest emissions do not necessarily correspond to those investing the most in technology. This raises significant questions regarding the nature of the capital being utilised, specifically whether it is intended for scaling production or authentic modernisation to enhance efficiency. This diversity within the sector highlights the necessity for targeted interventions by policymakers. Segments characterised by elevated emissions and moderate capital intensity, such as 24104 and 24105, could gain from focused assistance to enhance their technology. Simultaneously, capital-intensive yet lower-emission units may lead to testing advanced, cleaner processes. This analysis underscores that a universal approach is ineffective. The approach to decarbonizing the iron and steel industry must consider the diverse conditions present in its various sub-sectors.

6. Results

The log-log nature of our dependent and independent variables necessitates the interpretation of percentages. Specifically, a percentage increase in investment in plant and machinery is associated with a reduction in carbon emission intensity, but the effect varies across specifications. A statistically significant decrease in carbon emission intensity of 0.054% from a 1% increase in plant and machinery investment was found. Investments in equipment could enable companies to lower carbon emissions, given changes in manufacturing processes or technological advancements. From the policy-making perspective, the stated coefficient, however small, is important for grasping the financial consequences of meeting worldwide criteria for carbon emission intensity. Statistically, higher capital intensity correlates with higher carbon emission intensity. Specifically, Regression (2) predicts that a 1% rise in capital intensity causes a 0.214% rise in carbon emission intensity. Capital-intensive firms, especially in the steel industry, emit more carbon due to reliance on the Blast Furnace method rather than the Electric Arc Furnace (EAF) method.

Moreover, our study sheds light on firm size, measured by total sales, as a factor in carbon emissions. The coefficient on sales is negative but statistically insignificant in all specifications, suggesting that firm size alone does not determine carbon intensity. In Regression (4), age is a significant factor as older companies show less carbon emission intensity. This implies that older companies might have adjusted to more sustainable manufacturing practices. Firm age, however, shows a positive and significant impact in Regression (7), suggesting possible variation in how older companies affect carbon emissions.

Table 2: Results of the Regression Models

Variables	1	2	3	4	5	6	7
log (Investment in Plant and Machinery)	0.004	-0.054*	-0.038	-0.038	-0.054	-0.056	-0.038
	(0.029)	(0.031)	(0.039)	(0.039)	(0.052)	(0.042)	(0.039)
log (Capital Intensity)		0.214***	0.179***	0.179***	0.171**	0.179**	0.179**
		(0.044)	(0.067)	(0.067)	(0.069)	(0.067)	(0.067)
log (Sales)			-0.045	-0.045	-0.051	-0.047	-0.045
			(0.065)	(0.065)	(0.066)	(0.065)	(0.065)
Age				-0.034***	-0.034***	-0.034***	0.237***
				(0.011)	(0.011)	(0.011)	(0.089)
log (Investment in Plant and Machinery) * Sector Dummy					0.026		
					(0.057)		
log (Investment in Plant and Machinery) * Exporter Dummy						0.031	
						(0.29)	
log (Investment in Plant and Machinery) * MSME Dummy							0.017
							(1.405)
Constant	1.315***	0.906***	1.288**	1.597**	0.509	1.701**	-0.843
	(0.278)	*(0.289)*	*(0.625)*	*(0.689)*	*(0.651)*	*(0.697)*	*(1.069)*
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations (n)	2,351	2,351	2,351	2,350	2,350	2,350	2,350
R^2	0.46	0.47	0.47	0.47	0.47	0.47	0.47
Adjusted R^2	**0.41**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**

Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Regression (5) allows us to separate the effects of sectoral investment in plant and machinery. The sectoral interaction term is positive but statistically insignificant, suggesting that the link between investment and emission intensity does not differ much between the aluminium and iron and steel sectors. In Regression (6), we investigate how exporting companies shape this relationship and find that the interaction between investment and export status is positive but statistically insignificant. This suggests that exporting companies do not show a different emission intensity. This may be due to the historical absence of carbon efficiency requirements for exporting firms. However, changing international trade regulations, such as the EU's Carbon Border Adjustment Mechanism (CBAM), may incentivise cleaner investments.

Regression (7) also includes an interaction term about MSME, and the coefficient is positive but statistically insignificant, suggesting that small enterprises do not show a clear pattern in the correlation between investment and carbon emission intensity relative to larger companies.

Beyond interaction terms, the Sector Dummy variable is positive and statistically significant, suggesting that companies in the iron and steel industry usually have more carbon emission intensity than companies in the aluminium industry. This emphasises the significance of sector-specific measures to tackle carbon emissions.

The Export Dummy variable, however, is negative but statistically insignificant, suggesting that exporting firms do not exhibit systematically lower carbon emission intensity compared to non-exporting firms. Though future rules like the CBAM might change this dynamic, exporters have no rigorous historical carbon efficiency criteria, which may explain this..

Finally, the MSME Dummy variable is negative and highly significant, suggesting that small firms produce far less carbon emission intensity than bigger companies. This could be due to MSMES using fewer energy-intensive processes, or it could also indicate the technological constraints limiting their total manufacturing capacity.

Our findings highlight the intricate interplay between carbon emission intensity and company traits. Although investment in equipment and machinery seems to impact lowering emissions, the impact is not always statistically significant. Higher emissions are also related to capital intensity, stressing the need for technological decisions to determine environmental results. Future studies should investigate these dynamics, especially regarding changing industry-specific variations and regulatory systems. Lastly, so far, electricity as an energy source has been omitted from our analysis, for results after inclusion of electricity refer to Table 3 in the annexure.

7. Conclusion

This paper contributes to the empirical understanding of carbon emission intensity at the firm level by analysing two of India's most energy-intensive industrial sectors, iron and steel and aluminium, using a panel of 275 firms over the period 2000–2022. Employing a log-log fixed effects regression framework, we examine the role of firm-specific factors, including investment in plant and machinery, capital intensity, firm size, age, and trade orientation, while controlling for time and firm heterogeneity.

Our findings provide interesting results. Though this relation's size and statistical significance may differ among specifications, we find that greater investment in plant and machinery is linked with decreased carbon emission intensity. On the other hand, capital intensity is positively correlated with emission intensity, especially in the iron and steel industry, where carbon-intensive technologies like the blast furnace route continue to dominate production processes. Firm age and MSME status also emerge as significant predictors, with older firms and micro, small and medium enterprises (MSMEs) tending to emit less per unit of output. However, export orientation, a commonly assumed driver of environmental upgrading, does not exhibit a significant effect, suggesting that carbon efficiency has yet to become a binding constraint for export performance in India.

These results underline the sector-dependent character of company-level environmental performance. The noted diversity supports that environmental regulatory measures could be sub-optimal in heterogeneous industries. Our findings show that raising capital outlays is inadequate without corresponding changes in technology adoption and energy mix. The iron and steel industry stays tied to coal and furnace oil, restricting the potential for decarbonisation of capital investments, even while the aluminium industry exhibits slow change toward cleaner fuels like LPG.

From the policy standpoint, these findings point to the requirement of focused sector-specific abatement plans that integrate both the cost heterogeneity and technical rigidities in these sectors. A differentiated carbon pricing system could include interventions like carbon audit obligations, performance-linked incentives for energy efficiency, and preferential finance for EAF-based steelmaking. Though they emit less intensity, MSMEs need organised assistance to overcome size-related obstacles to adopting clean technologies. Furthermore, with the growing popularity of global climate-linked trade tools like the EU's Carbon Border Adjustment Mechanism (CBAM), matching trade competitiveness with emissions performance will turn from a choice to a need.

Limitations and Future Directions

Although this paper uses a strong econometric identification technique and a large firm-level dataset, some drawbacks remain. First, the study is limited by the availability and dependability of emissions data, which limits our sample to companies with consistent reporting over two decades. Second, estimated output volumes and sector-average price deflators cause measurement errors that could weaken coefficient estimations. Third, unobserved technological or regulatory shocks, such as changes in energy policy and global fuel prices, are not explicitly modelled, though fixed effects may partially absorb these effects.

Future research could benefit from disaggregated plant-level or facility-level emissions data, allowing for more precise identification of energy efficiency interventions. Including dynamic panel models or instrumental variable techniques would also help to solve possible endogeneity between investment and emission results. Including Scope 2 and Scope 3 emissions in the study, especially for exporting companies, could be another area for future research. At last, measuring the cost-effectiveness of low-carbon technology uptake across company sizes and industries would provide helpful information for creating focused financial and regulatory actions.

Ultimately, India's industrial decarbonisation route is not linear or consistent. It depends on a company's technological foundation, sectoral features, and policy environment. Studies like this one are essential for closing the gap between top-down emission goals and the micro-level reality of companies, hence guiding more reasonable, fair, and efficient climate policy creation.

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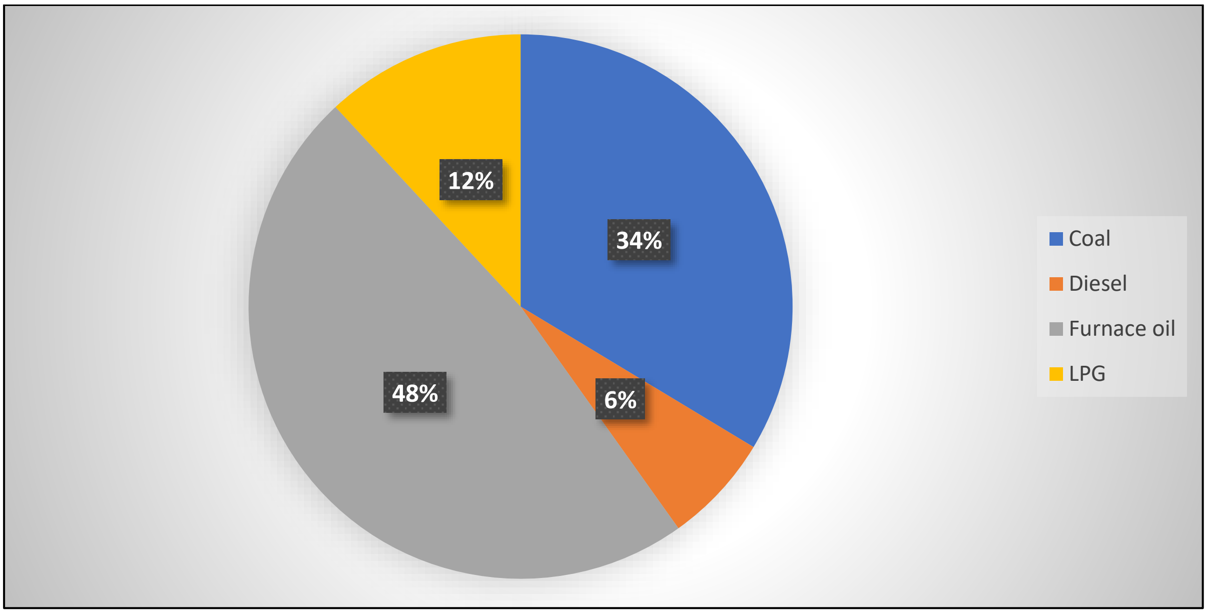
9. Annexure

A comparative review of carbon emission sources, as in Figure 8, within the aluminium sector shows considerable transformation over the two decades. During 2000–2010, furnace oil emerged as the dominant emission source, constituting 48% of total emissions, followed by coal at 34%. LPG and diesel contributed 12% and 6%, respectively, forming a relatively minor share of the overall emission profile.

Annex Figure 1: Sources of Carbon Emission in Aluminium Sector (2000-2010)



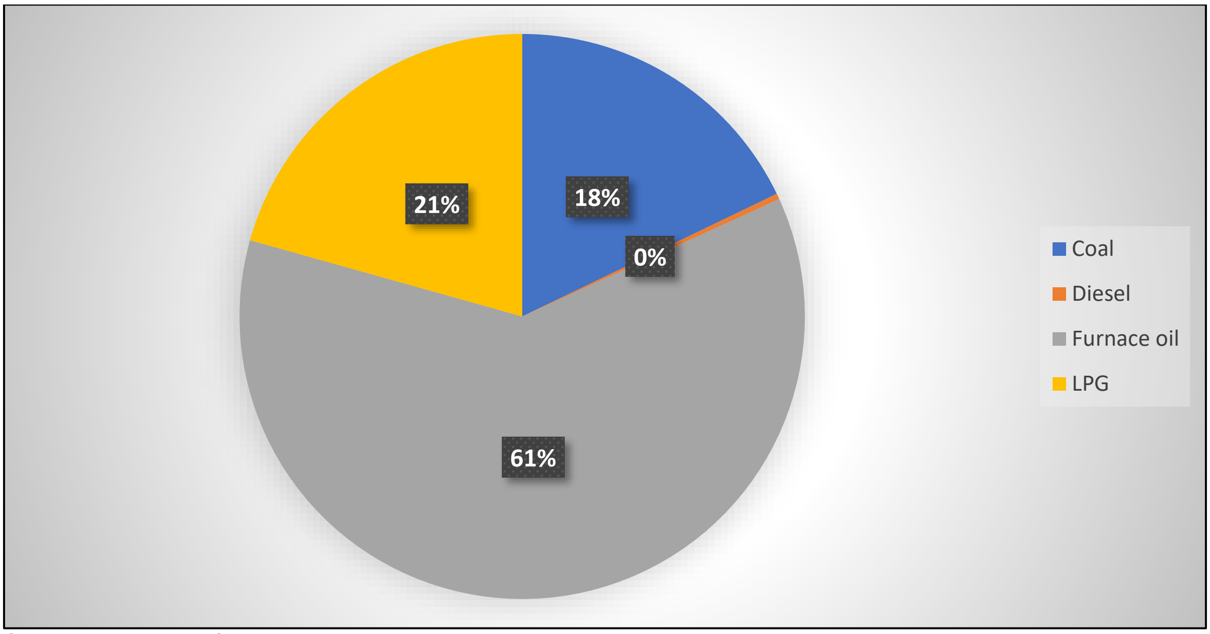
Source: Based on CMIE Prowess Database

The second period (2011–2022) marks a substantial shift in the energy mix as seen in Figure 9. Furnace oil increased its share to 61%, reinforcing its status as the principal source of carbon emissions in the aluminium industry. Conversely, coal usage declined sharply to 18%, a reduction of 16 percentage points from the earlier period. Notably, diesel witnessed a complete phase-out, registering 0% share, while LPG increased its contribution to 21%, nearly doubling its earlier share. This surge in LPG use indicates a broader industry trend toward more adaptable and cleaner fuel alternatives, possibly driven by regulatory pressures and cost competitiveness.

These significant changes reveal a realignment in the aluminium sector's emission sources, characterised by increased dependence on furnace oil, a gradual decline in coal reliance, and an evident rise in LPG. Such shifts underscore a strategic adaptation in energy sourcing patterns, albeit within a fossil fuel-dominated framework.

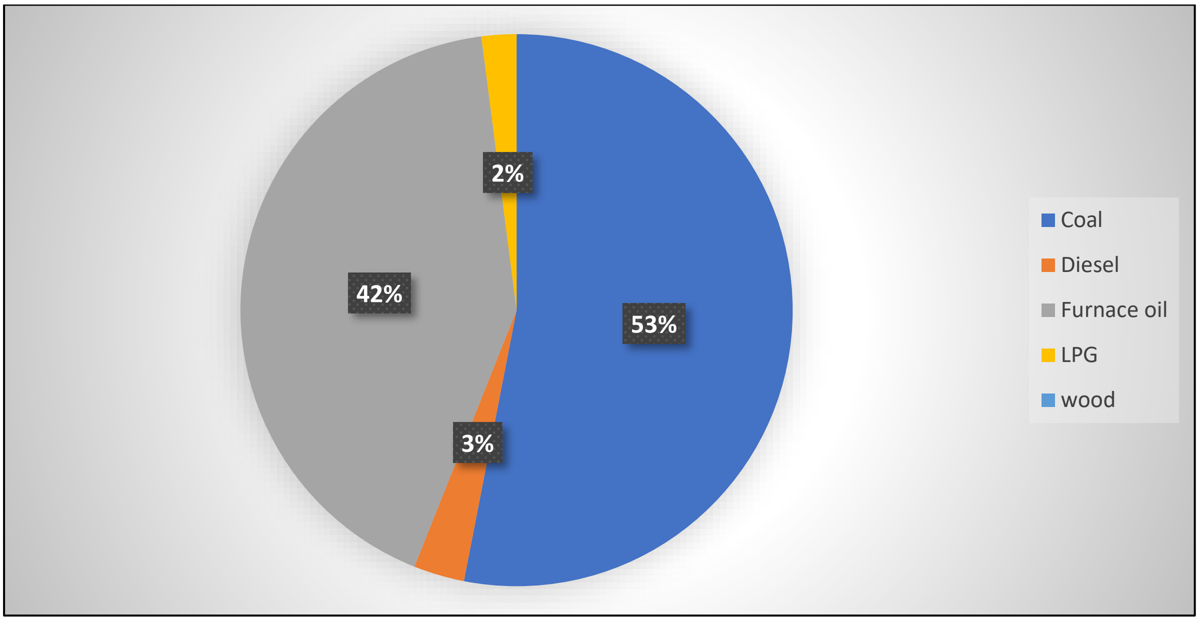
An analysis of average carbon emissions in the iron and steel industry during the decade 2000–2010 highlights the dominance of coal, which contributed 53% of total emissions, affirming its long-standing role as the sector's principal energy source. Furnace oil followed closely, accounting for 42%, while diesel and LPG played relatively marginal roles, contributing 3% and 2%, respectively. This configuration reflects a traditional energy mix that heavily depends on coal and furnace oil.

Annex Figure 2: Sources of Carbon Emission in Aluminium Sector (2011-2022)



Source: Based on CMIE Prowess Database

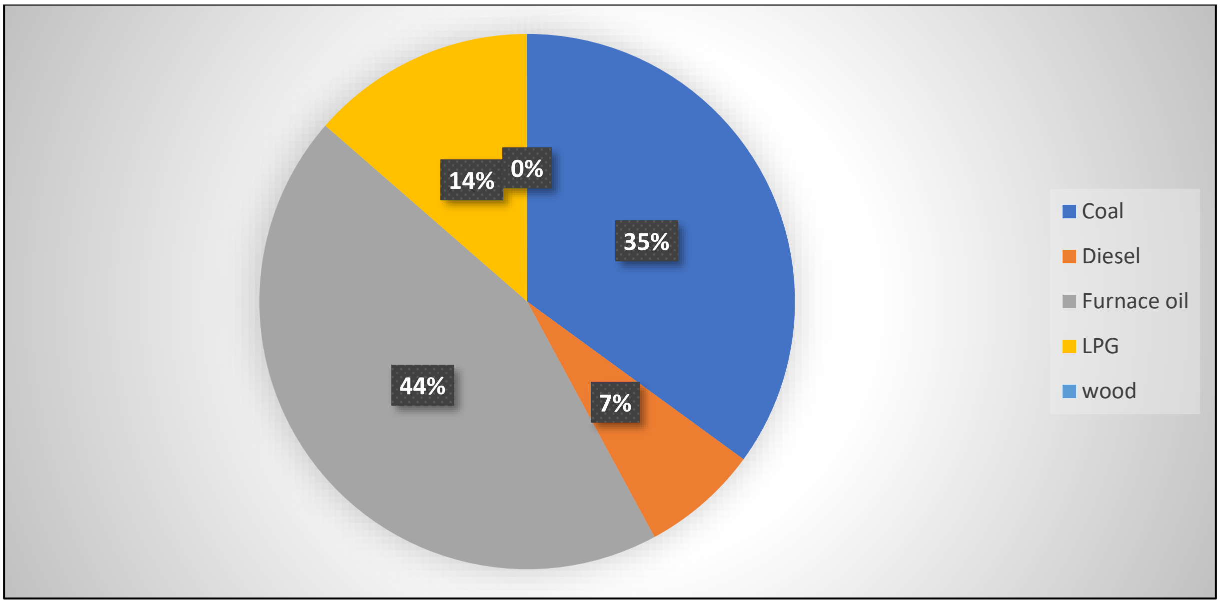
Annex Figure 3: Sources of Carbon Emission in Iron & Steel Sector (2000-2010)



Source: Based on CMIE Prowess Database

However, a structural shift becomes evident when examining the subsequent decade (2011–2022). The contribution of coal declined significantly to 35%, marking an 18-percentage-point drop. Interestingly, furnace oil sustained its central role, maintaining a 44% share, only marginally higher than the previous period. Diesel slightly increased to 7%, while LPG experienced a notable rise from 2% to 14%, indicating a strategic transition towards cleaner fuel options. The growing share of LPG suggests a gradual adoption of alternative fuels, possibly to address emission concerns and fuel cost fluctuations. Notably, wood and other biofuels remained negligible or absent, reinforcing the fossil fuel-centric nature of the sector. These evolving trends signal a moderate shift in the emission profile, with incremental diversification but continued heavy reliance on high-emission energy sources.

Annex Figure 4: Sources of Carbon Emission in Iron & Steel Sector (2011-2022)



Source: Based on CMIE Prowess Database.

Annex Table 1: Results from Regression after including Electricity as a source of energy

Variables	1	2	3	4	5	6	7
log (Investment in Plant and Machinery)	0.076***	-0.048**	0.026	0.025	0.010	0.009	0.008
	(0.024)	*(0.024)*	*(0.033)*	*(0.033)*	*(0.049)*	*(0.051)*	*(0.051)*
log (Capital Intensity)		0.447***	0.310***	0.310***	0.307***	0.305***	0.302***
		(0.032)	*(0.052)*	*(0.052)*	*(0.053)*	*(0.053)*	*(0.053)*
log (Sales)			-0.167***	-0.167***	-0.170***	-0.176***	-0.179***
			(0.051)	*(0.051)*	*(0.051)*	*(0.052)*	*(0.052)*
Age				-0.060***	-0.060***	-0.060***	0.515***
				(0.009)	*(0.009)*	*(0.009)*	*(0.077)*
log (Investment in Plant and Machinery) * Sector Dummy					0.021	0.02	0.02
					(0.049)	(0.05)	(0.05)
log (Investment in Plant and Machinery) * Exporter Dummy						0.002	0.004
						(0.025)	*(0.025)*

log (Investment in Plant and Machinery) * MSME Dummy							0.983
							(0.663)
Constant	5.886***	5.083***	6.431***	6.972***	5.403***	5.429***	-4.904***
	(0.254)	*(0.253)*	*(0.480)*	*(0.534)*	*(0.521)*	*(0.533)*	*(1.492)*
Firm fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations (n)	3,454	3,454	3,454	3,453	3,453	3,453	3,453
R^2	0.663	0.683	0.684	0.684	0.684	0.684	0.684
Adjusted R^2	0.634	0.656	0.657	0.657	0.657	0.657	0.657
Note:	*p<0.1; **p<0.05; ***p<0.01						

Table 3 highlights the regression results after including electricity as an energy source. In Model 2, we find a significant negative relationship between investments in machinery and emission intensity.

We always find a positive and highly significant relation between capital and carbon emission intensity. Regarding sales, larger firms tend to have lower carbon emission intensity. The coefficient is negative and significant throughout. As in the above cases, the iron and steel sector has a higher emission intensity, and MSME firms have a lower emission intensity vis-à-vis large firms.

We also find a negative and significant relationship between a firm's age and carbon emission intensity. Lastly, being in a particular sector, exporting, or having MSME status, does not significantly impact the relationship between investment in plant and machinery and carbon emission intensity.

*****

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India's Foreign Trade Policy (FTP) Statement 2015-20 suggested a need to create an institution at the global level that can provide a counter-narrative on key trade and investment issues from the perspective of developing countries like India. To fill this vacuum, a new institute, namely the Centre for Research on International Trade (CRIT), was set up in 2016. The CRIT's vision and objective were to significantly deepen existing research capabilities and widen them to encompass new and specialised areas amidst the growing complexity of globalisation and its spill-over effects in domestic policymaking. Secondly, enhancing the capacity of government officers and other stakeholders in India and other developing countries to deepen their understanding of trade and investment agreements

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