Ecologically Unequal Exchange in India-EU Trade: Structural Path Analysis of Embodied Carbon

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Abstract

Reducing the environmental impacts of economic activities is no longer a policy choice but a prerequisite for international market access. Production structures in developing countries like India, remain more emission-intensive than those of their developed counterparts. As per Ecologically Unequal Exchange (EUE), international trade often leads to a net flow of energy and materials from the Global South to the Global North, allowing high-income regions more value per unit of environmental burden. Production and consumption-based carbon accounting approaches estimate net emission displacement, but they do not identify the specific supply-chain paths and tiers through which carbon and value are exchanged. Using ADB's environmentally extended Multi-Region Input-Output (EE-MRIO) tables for 2017 and 2023, and Structural Path Analysis, this study examines, (i) how export-driven embodied carbon intensity (emissions embodied in exports per unit of embodied value added) differs for Indian versus EU exports and how the gap changed, (ii) which tiers and sectors drive these emissions, and, (c) whether metals' emissions are exported indirectly through downstream goods, exposing India to the potential CBAM expansion.

Results show that export-driven embodied carbon intensity gap narrowed from 2017 to 2023, but the gap remains persistent and severe, consistent with EUE. India's carbon emissions are largely embedded upstream: Tier 1 emissions (30.5%) exceed direct Tier 0 emissions (27.3%), driven mainly by domestic electricity grids supplying power to the manufacturing sectors, particularly metals. By contrast, 44.5% of the EU's exported footprint occurs directly at Tier 0, largely driven by international maritime transport services. Also, a significant volume of Scope 1 emissions generated by India's metals sector crosses the EU border indirectly, embedded in downstream manufactured goods such as electrical and transport equipment. A downstream expansion of CBAM may expose India's manufacturing sectors to border carbon adjustment. It suggests that the core challenge is not only to curb the aggregate emissions but to transform the production paths through which emissions are most embodied in trade.

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1. Introduction

The global shift towards a low-carbon economy has reached a stage where reducing the environmental impacts of economic activities is no longer a policy choice but a prerequisite for access to international markets. Historically, developing countries used to leverage lower factor costs to have production-led comparative advantage, but in present times, carbon efficiency is also emerging as another major determinant of carbon access. This is because, certain unilateral climate-trade measures like the European Union's Carbon Border Adjustment Mechanism (CBAM) are now reshaping the conditions of competitiveness and market access by internalising the carbon costs at the border.

India is pursuing manufacturing-led industrial growth under initiatives like Make in India and aiming at deeper participation in global value chains (GVCs). However, production activities within developing nations like India are relatively more emission intensive than those in their developed counterparts (Jorgenson, 2012; El Tinay, 2024). Moran et al. (2013) and Hickel et al. (2022) found that global trade often facilitates a net flow of energy and resources from global south to global north, which enabled high-income countries to capture significant monetary surpluses per unit of environmental burden while shifting the burden of ecological degradation to their trading partners. This asymmetric carbon-value relationship is also known as ecologically unequal exchange (EUE) theory, which states that international trade leads to asymmetric flow of natural resources from poor to rich countries (Dorninger et al., 2021). There is concern that developing nations like India remains locked into relatively high-emission stages of GVCs, while advanced trading partners like EU increasingly specialise in high-value and relatively less-emission intensive sectors (Althouse et al., 2023). It is important to examine if there exists this asymmetry and if it does, what are the major driving trading paths.

While standard production and consumption-based emission accounting approaches help us track who produces and who ultimately consumes emissions, it does not map the specific industrial paths through which emissions are traded through supply chains (Peters & Hertwich, 2009; R. Xie et al., 2020). Structural Path Analysis may be used for examining these pathways, as it decomposes the Leontief inverse matrix into numerous supply-chain pathways, helping us to identify the hidden upstream drivers of embodied emissions (Peters & Hertwich, 2006; Wood, 2008; Owen et al., 2016).

The primary objective of this study is to move beyond aggregate embodied-emission accounting and map the specific pathways contributing to these embodied emissions and examine if carbon-value asymmetries exist in the India-EU trade relationship[1]. With this objective, the study is trying to address three interrelated questions. First, if the export-driven embodied carbon intensity (defined as emissions embodied in exports per unit of value added retained from those exports) differ between Indian exports to the EU and EU exports to India, and if this gap has changed between 2017 and 2023. Second, what are the specific underlying

[1] The focus of this study is on India-EU trade relationship because EU has already implemented its CBAM which targets imports of certain emission-intensive imports, and for India, EU is the largest export destination. For the EU too, India is amongst its top 10 trading partners.

tiers and paths driving these trade embodied emissions for both India and the EU. Third, to what extent are emissions from India's metal sector are indirectly exported to the EU through downstream goods, and if this pattern exposes Indian manufacturing sectors to the potential expansion of CBAM's scope. To examine these research questions, the study uses the environmentally extended multi-regional input-output (EE-MRIO) framework. The Structural Path Analysis (SPA) is also used to trace the specific tiers and paths contributing to emissions embodied in India-EU trade.

The rest of the paper is structured as follows. Section 2 reviews the existing literature related to ecologically unequal exchange and MRIO-based structural path analysis. Section 3 details the data and methodological framework used in this study to address the research questions. Section 4 presents and discusses the findings of the study, followed by conclusions and policy discussions in Section 5.

2. Literature Review

2.1 Ecologically Unequal Exchange

Ecologically Unequal Exchange (EUE) provides the central theoretical framework for understanding why economic gains and environmental burdens of global trade are distributed asymmetrically. Early studies find that the vertical flow of exports from lower to higher income nations tends to suppress domestic consumption and development possibilities in the exporting nation while enabling capital accumulation in the core (Jorgenson, 2006, 2012; Rice, 2007). Many studies later using the environmentally extended multi-regional input-output models have found the existence of EUE. Moran et al. (2013), Dorninger & Hornborg (2015) and Dorninger et al. (2021) found that high-income regions capture massive monetary surpluses per unit of environmental burden, externalising their local environmental degradation to trading partners.

Recent contributions have extended the framework and linked EUE to GVCs. Althouse et al. (2023) found that when upstream segments of the supply chain remain energy and material intensive, industrial upgradation in semi-peripheral economies often intensifies their ecological burdens instead of relieving it. El Tinay (2024) argued that semi-periphery economies may simultaneously absorb resources from their low-income suppliers and supplies carbon-intensive intermediates and manufactures to high-income economies. The monetary valuation of trade further obscures these imbalances, as high-income importers pay relatively low prices for carbon-intensive imports, whereas exporting nations bears the environmental and health costs (Ricci, 2023). Hickel et al. (2022) estimated that between 1990 and 2015, the cumulative drain from the Global South associated with this unequal exchange reached as high as USD 242 trillion. These findings motivate the present focus on export-driven embodied carbon intensity measured per unit of value added rather than per unit of gross output or export value, an indicator that tries to capture the emission-value asymmetry associated with EUE.

2.2 Accounting Emissions Embodied in International Trade and Structural Path Analysis

Two approaches have been widely used in the literature for estimating emissions- production-based accounting (PBA) and consumption-based accounting (CBA). Since PBA accounts for emissions generated within the domestic territory of an economy, CBA instead accounts emissions associated with consumption, irrespective of location they were generated. Peters and Hertwich (2006, 2009) find that production-based approach systematically understates the emissions attributable to final consumption in high-income countries. Multi-regional input-output (MRIO) frameworks allow distinguishing the domestic and foreign components of supply chains, and have thus became the standard for quantifying emissions embodied in trade (Wiedmann et al., 2007; Peters et al. 2011, Franzen & Mader, 2018). While PBA and CBA help examine the emissions generated, consumed and displaced by the economies, they remain silent on tracing the industrial pathways through which carbon is embodied and transferred. Structural Path Analysis (SPA) overcomes this limitation as it identifies different tiers and paths in the supply-chain through which inter-sectoral and inter-regional trade of emissions and value take place (Peters & Hertwich, 2006; Wood, 2008; R. Xie et al., 2020).

Using SPA, many studies have mapped critical carbon transmission paths. A significant body of literature finds that electricity generation (especially coal-fired), basic metals smelting and pressing, non-metallic minerals and chemicals as the dominant upstream sectors often propagate significant indirect emissions into downstream manufacturing, construction and exports (B. Zhang et al., 2017, 2020; J. Chen et al., 2025; J. Hong et al., 2016; J. Peng et al., 2018; L. Wen & Y. Zhang, 2020; L. Yang et al., 2020; Q. Li et al., 2021; H. Zhang & C. Zhang, 2025). Cross-country comparisons find differences in path structures between the United States and China, or between China and the EU, emphasizing the role of development stage and energy mix (D. Xu et al., 2022; Y. Lai & Y. Song, 2024; Y. Zhang et al., 2023). While the SPA has been used widely for economies like China, India specific studies remain limited. Using input-output, social accounting matrix, and the emissions-embodied in bilateral-trade (EEBT) frameworks, Li et al. (2018) and Dwivedi & Soni (2022) found the key role of electricity and metal sector in India's domestics and exported emissions.

2.3 Identification of Research Gaps

The reviewed literature establishes a strong methodological foundation in MRIO and SPA for estimating the trade-embodied emissions and tracing the specific paths, and also a theoretical rationale in EUE for examining the emission-value asymmetries. However, several gaps remain. First, there are limited SPA based analysis for India, and as per author's understanding detailed SPA studies focusing on India-EU trade are particularly scarce. Second, temporal comparisons using consistent MRIO tables for latest years, especially for India are limited. Third, the usage of SPA for integrating upstream path identification with downstream policy exposure has not been undertaken for Indian manufacturing sectors. This is particularly important because, to date, the EU CBAM is the most ambitious attempt to address carbon leakage through border carbon adjustment. While currently it targets limited sectors, current policy discussions signal potential expansion to additional downstream activities, which may have serious implications for the downstream sectors.

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The present study tries to address these gaps by focusing on (a) measurement and comparison of export-driven carbon intensity per unit value added for both India and the EU, (b) full SPA analysis of major upstream drivers of emissions embodied in India-EU trade, (c) examining how CBAM's scope expansion may expose Indian manufacturing.

3. Methodology

3.1 Data Sources

This study uses the Asian Development Bank (ADB) Environmentally-extended multi-regional input-output (EE-MRIO) tables for the years 2017 and 2023[2]. The ADB MRIO tables used in this study are valued in 2010 constant-prices. It covers 35 sectors based on the International Standard Industrial Classification (ISIC) and 5-final demand categories across 63 economies, including a rest-of-the-world region. The corresponding environmentally extended satellite accounts for carbon dioxide (CO_2) emissions for years 2017 and 2023 are also sourced from ADB. Direct emission intensities are calculated as sector- and country-specific CO_2 emissions per unit of gross output.

3.2 Environmentally Extended Multi-Regional Input-Output Framework

Traditionally environmentally extended input-output (EEIO) models have been used for analysing emissions embodied in trade. These models generally follow one of two approaches, 1) MRIO with final demand, and 2) Emissions Embodied in Bilateral Trade (EEBT). While first approach, i.e., MRIO with final demand allows estimation of emissions using the global Leontief inverse, it is often applied to final demand exports. This approach captures the multi-country transactions, but does not include emissions embodied in intermediate goods exports, as the same is captured in the global Leontief inverse matrix. This approach may thus understate the full carbon content of bilateral trade. Second approach, i.e., EEBT generally relies on a local Leontief inverse rather than global Leontief inverse. While it can incorporate intermediate exports, it may fail to fully capture global value chain feedback loops and inter-country production interdependencies.

3.3 Ecologically Unequal Exchange

Following the Ecologically Unequal Exchange (EUE) framework, structural asymmetry is measured by comparing the embodied carbon intensity of value-added (ECI), which here is defined as the ratio of total embodied emissions driven by exports to the value added driven by those same exports.

$$ECI_{rs} = \frac{E_{rs}}{V_{rs}} \quad (1)$$

where E_{rs} denotes total CO_2 emissions embodied in exports from region r to region s, and V_{rs} denotes the value added retained in region r from the corresponding exports.

[2] The ADB EE-MRIO tables are available for year 2017-2023. While the ADB MRIO is available for more years, environmental accounts are not published for those years.

Based on the conventional consumption-based accounting with final demand, and global Leontief inverse matrix, total emissions and value-added embodied in exports of region r to s may be estimated as:

$$E_{rs} = f\,(I - A)^{-1} Y^{rs} \quad (2)$$

$$V_{rs} = v\,(I - A)^{-1} Y^{rs} \quad (3)$$

Where, f is the emission intensity, v is value-added per unit of output, $(I - A)^{-1}$ is the global Leontief inverse, and Y^{rs} is the final demand of goods and services in country s produced by country r (final exports of r to s).

3.4 Modified Leontief Inverse and Structural Path Analysis

One of the key research objectives of this study is to estimate the emissions embodied in both final and intermediate exports. Since global Leontief inverse matrix already captures all the intermediate trade happening across all the regions, using the standard global Leontief inverse matrix with the gross export vector leads to double-counting of intermediate goods.

To address the same, this study adopts the modified Leontief inverse approach introduced by Nagashima (2025). In this approach, specific bilateral intermediate trade blocks from the exporting region (r) to the destination region (s) are set to zero before the Leontief inverse matrix is calculated. Emissions embodied in the gross exports of region r to region s are then estimated as:

$$E_{rs} = f\,(I - A_{rt})^{-1} EX^{rs} \quad (4)$$

Where, t is defined as any country but not country s, and EX^{rs} is the gross export vector from r to s, which includes both intermediate and final exports. This modified approach ensures that all inter-country transactions are retained within the global Leontief inverse matrix, except for intermediate exports from r to s, which are instead included directly in the gross exports vector.

While the above equation (4) quantifies the total carbon emissions embodied in exports of region r to region s, it does not reveal the specific supply-chain pathways responsible. Structural Path Analysis (SPA) is therefore applied to the emission flows generated by the modified Leontief framework. It allows us to trace emissions from India's exports to the EU and vice versa across distinct tiers to reveal the major pathways driving emissions embodied in their respective exports. SPA relies on the power series (Taylor expansion) of the Leontief inverse matrix:

$$(I - A_{rt})^{-1} = I + A_{rt} + {A_{rt}}^2 + {A_{rt}}^3 + {A_{rt}}^4 + \ldots\ldots \quad (5)$$

By pre-multiplying it with emission intensity (f) and post-multiplying with gross exports, emissions across different tiers may be estimated as:

Tier 0: $f.I.EX^{rs}$ (Emissions generated directly by the exporting sector itself)

Tier 1: $f.A_{rt}.EX^{rs}$ (Emissions from the immediate suppliers to the exporter)

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Tier 2: $f.{A_{rt}}^2.EX^{rs}$ (Emissions from the suppliers of the suppliers), and so.

While there can be infinite number of tiers and paths, a threshold is applied, which estimates all those critical paths where estimated embodied emissions are greater than 0.1 kt. Since this study focuses on examining and comparing the different tiers and paths driving emissions embodied in India's exports to the EU and vice-versa, same framework is applied to both the Indian export vector to the EU and the EU export vector to India.

The third objective of this study is to examine the potential exposure to an expansion of the EU Carbon Border Adjustment Mechanism (CBAM) to downstream sectors. Based on SPA framework, this study also isolates those structural paths which originate in India's basic metals and fabricated metal sector (c12) and subsequently feed into downstream manufacturing sectors whose output is then exported to the EU. This identifies the Scope 1 emissions generated by Indian metals (c12) that cross the border indirectly via exports of downstream manufacturing sectors. These estimations are also done for the same two years, i.e., 2017 and 2023 with the same sectoral and regional classifications, ensuring that observed changes can reflect dynamic changes.

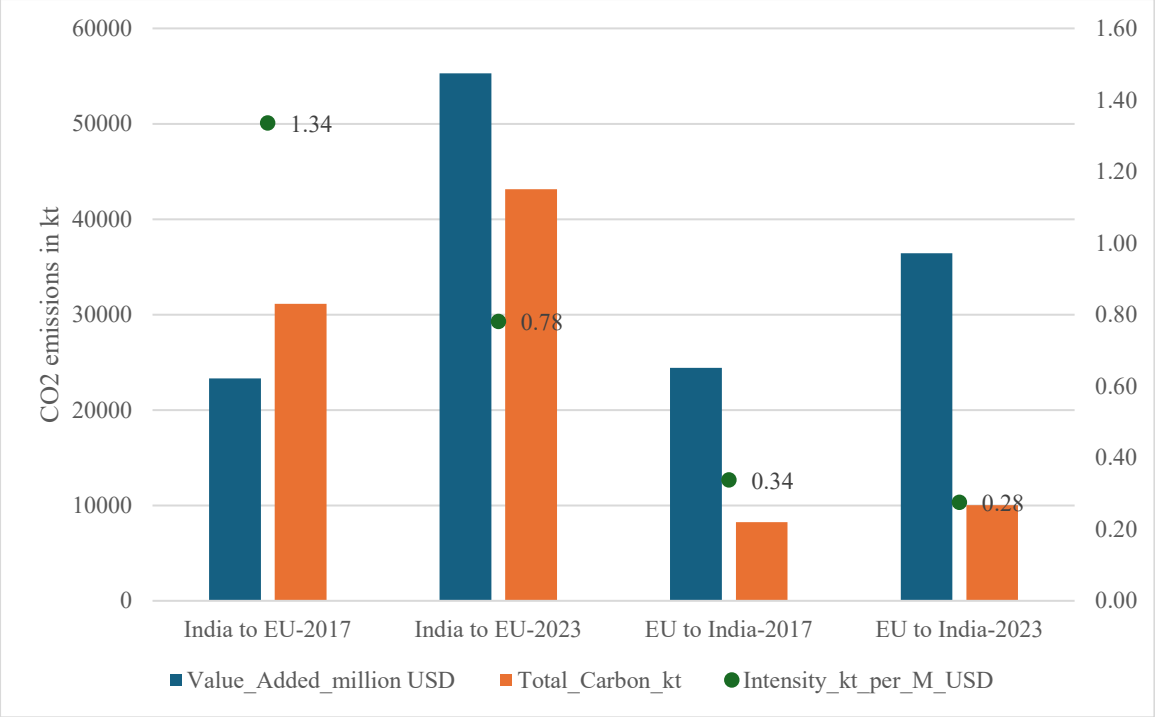
4. Results and Discussion

4.1 Ecologically Unequal Exchange and persistence of carbon-value asymmetry

The estimated emissions and value embodied in India-EU trade as per equations (2) and (3) provide strong evidence of an asymmetric carbon-value relationship. The results show that while the emissions embodied in India's exports to the EU have increased from 2017 to 2023, the value added embodied in those exports ad retained in India increased much more than emissions, which resulted in a declining export-driven embodied carbon intensity for India. Similarly for EU, the export-driven embodied carbon intensity declined as the increase in value added outpaced the increase in emissions embodied in its exports to India. Although, both India and the EU exhibited a decline in this intensity between 2017 and 2023, the bilateral gap remains significant. In 2017, India emitted 3.95 times more carbon than the EU to achieve the same dollar value of added value. By 2023, it declined to 2.84 times, indicating significant improvement in India's export-related emission efficiency. However, the existence of almost threefold gap suggests that the structural imbalance embedded in bilateral trade still exists.

Figure 1: Export-Driven Embodied Carbon Intensity in India-EU Trade, 2017 and 2023

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Source: Author's construction

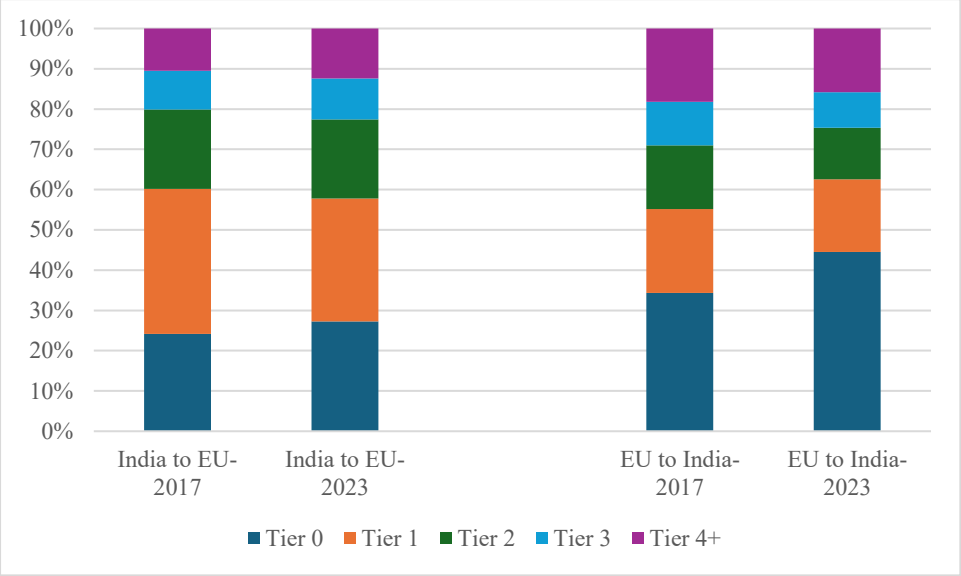
This result suggests that the trade that appears mutually beneficial in value terms may still involve an unequal distribution of environmental burdens. In the context of EUE, India continues to apply large quantity of carbon per unit of value added it retained from its exports to the EU, whereas the EU retained significantly higher value added with a lower carbon burden. This asymmetry reflects deeper differences in production structure across the two nations, and the tier-wise and path-wise SPA may better highlight these structural differences.

4.2 Tier-wise distribution of embodied emissions

The tier-wise decomposition of embodied emissions estimated using the modified Leontief inverse approach reveals a clear distinction in embodied emissions pattern of the two countries. Figure 2 shows that also, export-related emissions are not concentrated only in the final exporting sector, but a substantial share of emissions is originated from the upstream supply-chain tiers. For India, Tier 0 emissions in 2023 accounted for 27.3% of total emissions embodied in its exports to the EU, while Tier 1 emissions accounted for 30.5%, exceeding the direct contribution of exporting sectors themselves. Similar has been the case for 2017, when direct emissions (Tier 0) accounted for a quarter of EU bound total embodied emissions. This result suggests that India's export footprint is highly supply-chain embedded, with immediate suppliers to export sectors generating a larger share of embodied emissions than the final exporting sectors. These findings suggest that India's export footprint is highly supply chain embedded, as suppliers to export sectors generate a large share of embodied emissions than the final exporting sectors. This can have important implications for carbon accounting and policy design. If indirect emissions also get incorporated into carbon border measures, the exposure of Indian exporters could extend well beyond the sectors that are currently understood as directly emission-intensive.

For the EU, while the share of indirect emissions is higher than the direct emissions, the pattern is different from India. The share of direct emission (at Tier 0) is significantly higher in the EU and also increased from around 34% to 45% from 2017 to 2023. It suggests that EU's emissions bound to India are more immediately attributable to the exporting sector itself, and relatively lesser dependent on multi-tier supply chain than those of India. This difference between the two countries is analytically important because it suggests that export decarbonisation in India can't be achieved just by sector-specific interventions, but it requires broader decarbonisation of various upstream sectors. The next sub-section will thus look into the major paths that contribute most to these embodied emissions.

Figure 2: Tier-wise Distribution of Emissions Embodied in India-EU Exports, 2017 and 2023



Source: Author's computations

4.3 Structural Path Analysis - Major paths driving emissions embodied in India-EU trade

Using the SPA framework as discussed in equation (5), emissions embodied in India-EU trade has been isolated into numerous paths across different tiers. In order to make it computationally viable, only those paths have been isolated, which contributes to at least 0.1 kt of embodied emissions. This threshold successfully captured 6339 distinct paths (representing 76% of the total embodied emissions) for India to the EU trade, and 5512 distinct paths (representing 62% of total embodied emissions), for the EU to India trade. Of these thousands of paths, the Tables 1 to 4 below shows the top 10 paths which drove the emissions embodied in India-EU trade the most during the studied years.

4.3.1 India's exports to the EU

The SPA results for India shows that for India's exports to the EU, some of the heavy manufacturing sectors like metals, power, chemicals, textiles, etc. as the major pathways through which embodied emissions are generated. These top structural paths show persistence and change between 2017 and 2023. The largest direct pathway in both the years

has been IND_Metals to EU_Demand. Additionally, emissions along this path have increased from 1,978 kt in 2017 to 3,487 kt in 2023, making metals the largest contributor to India's export-related embodied emissions to the EU. This massive increase over the years suggests that India's exports to the EU increasingly include emission-intensive basic and fabricated metals, which also includes CBAM targeted sectors like aluminium, and iron and steel. Additionally, direct emissions from manufacturing, n.e.c. (c16), fossil fuels (which includes coke, refined petroleum, and nuclear fuel, i.e., c8), other non-metallic minerals (c11), chemicals (c9), etc. also remain significant, which indicates that India's export basket has a strong dependence on carbon-intensive industrial sectors.

One concerning result related to the power sector's role in India's emissions. In 2017, many of these Tier 1 paths involved power sector (c17) supplying embodied emissions to many downstream sectors including chemicals, textiles, fossil fuels, etc. By 2023, IND_Power to IND_Metals to EU_Demand emerges as the third largest pathway, contributing 1,332 kt CO_2. These results imply that emission intensity of electricity is not just a domestic production matter, as it directly leads to have an impact on the indirect emissions content of India's exports to the EU. While the CBAM in its present form covers limited sectors and also does not target all the indirect emissions, however, future extensions in its scope may have serious implications for India's exports.

Table 1: Top 10 paths contributing most to embodied emissions in India's exports to the EU in 2017

India to EU	2017	
Tier	Path	CO2 (kt)
Tier 0	IND_Metals -> EU_Demand	1978
Tier 1	IND_Mining -> IND_Fossil -> EU_Demand	1739
Tier 0	IND_Fossil -> EU_Demand	1666
Tier 1	IND_Power -> IND_Chemicals -> EU_Demand	1343
Tier 1	IND_Power -> IND_Textile -> EU_Demand	1325
Tier 0	IND_Chemicals -> EU_Demand	1144
Tier 1	IND_Power -> IND_M&Eq Rent & Others -> EU_Demand	1009
Tier 0	IND_Manuf nec -> EU_Demand	911
Tier 0	IND_Other minerals -> EU_Demand	868
Tier 1	IND_Power -> IND_Fossil -> EU_Demand	689

Source: Author's computations

Table 2. Top 10 paths contributing most to embodied emissions in India's exports to the EU in 2023

India to EU	2023	
Tier	Path	CO2 (kt)
Tier 0	IND_Metals -> EU_Demand	3487
Tier 0	IND_Manuf nec -> EU_Demand	1768
Tier 1	IND_Power -> IND_Metals -> EU_Demand	1332
Tier 0	IND_Fossil -> EU_Demand	1229
Tier 0	IND_Other minerals -> EU_Demand	1186
Tier 1	IND_Mining -> IND_Fossil -> EU_Demand	1063
Tier 0	IND_Chemicals -> EU_Demand	1059
Tier 0	IND_Retail & Repair -> EU_Demand	1042
Tier 1	IND_Power -> IND_Air Trans -> EU_Demand	921
Tier 1	IND_Power -> IND_Textile -> EU_Demand	849

Source: Author's computations

4.3.2 EU's exports to India

The SPA results for the EU's exports to India show some different supply chain footprint. Unlike India, the EU's all 10 largest embodied-emission paths are concentrated at Tier 0, indicating that a lot of its emissions associated with exports to India are generated directly by exporting sector itself. Tables 3 and 4 show that, both in 2017 and 2023, most important pathway is GRC_Water Trans to India_Demand, emissions of which increased from 2,092 to 2,842 kt CO_2. Other significant paths also include transport pathways from France, Italy, Belgium and Sweden. These findings indicate that emissions embodied in the EU's exports to India are largely direct and associated with logistics, especially, maritime logistics. On the other hand, for India, a large part of export related emissions is generated from manufacturing sectors like metals, power, fossil fuels, chemicals, textiles, etc.

This logistics emissions dominance in this case also has an important emission accounting implication. As per UNFCCC reporting guidelines emissions from international bunkers are generally reported as memo items and are not included in national greenhouse gas emission inventories. It implies that even though maritime transport dominates EU's export related emission pathways, a large part of EU's emissions associated with its exports to India may be institutionally excluded from its national emissions. It highlights a serious limitation of the existing emission reporting guidelines, because while value added associated with these trade flows accrue to the exporting nations' accounts, emissions associated with international bunkers and aviation gets accounted as memo item.

Table 3: Top 10 paths contributing most to embodied emissions in the EU's exports to India in 2017

EU to India	2017	
Tier	Path	CO2 (kt)
Tier 0	GRC_Water Trans -> India_Demand	2092
Tier 0	FRA_Water Trans -> India_Demand	324
Tier 0	BEL_Fossil -> India_Demand	297
Tier 0	BEL_Chemicals -> India_Demand	272
Tier 0	FRA_Air Trans -> India_Demand	264
Tier 0	BEL_Metals -> India_Demand	111
Tier 0	BEL_Other minerals -> India_Demand	103
Tier 0	SWE_Water Trans -> India_Demand	74
Tier 0	FRA_Metals -> India_Demand	73
Tier 0	ITA_Chemicals -> India_Demand	72

Source: Author's computations

Table 4: Top 10 paths contributing most to embodied emissions in the EU's exports to India in 2023

EU to India	2023	
Tier	Path	CO2 (kt)
Tier 0	GRC_Water Trans -> India_Demand	2842
Tier 0	FRA_Water Trans -> India_Demand	500
Tier 0	POL_Fossil -> India_Demand	209
Tier 0	FRA_Air Trans -> India_Demand	205
Tier 0	FRA_Wholesale Tr -> India_Demand	178
Tier 0	ITA_Water Trans -> India_Demand	151
Tier 0	BEL_Water Trans -> India_Demand	110
Tier 0	FRA_Chemicals -> India_Demand	95
Tier 0	SWE_Water Trans -> India_Demand	93
Tier 0	POL_Other minerals -> India_Demand	91

Source: Author's computations

4.4 Downstream Exposure to potential CBAM Scope Extension

The EU-CBAM currently covers a limited number of sectors, but there are deliberations to extend its scope further to downstream steel and aluminium products. SPA also allows tracing of Scope 1 emissions generated in India's metals sector (c12) that are indirectly embodied in downstream exports to the EU. The results in Table 5 show that emissions of India's metal sector are increasingly embedded in downstream manufacturing pathways, including the transport and electrical equipment (c15 and c14, resp.), and metals sectors (c12) itself.

While many of these sectors are not yet covered under CBAM, but given the ongoing discussions regarding extension in scope of EU-CBAM, some of these sectors may face future exposure. In such a scenario, compliance costs burden may also get shifted to a number of India's manufacturing sectors which use metals as inputs.

Table 5. Key Pathways of India's Metal-Sector Emissions Embodied in Downstream Exports to the EU

Tier	Path	CO2 (kt) 2017	CO2 (kt) 2023
Tier 1	IND_Metals -> IND_Metals -> EU_Demand	246	809
Tier 1	IND_Metals -> IND_Trans eqp -> EU_Demand	186	332
Tier 1	IND_Metals -> IND_Elec eqp -> EU_Demand	127	207
Tier 2	IND_Metals -> IND_Metals -> IND_Metals -> EU_Demand	31	188
Tier 1	IND_Metals -> IND_Mach nec -> EU_Demand	184	153
Tier 1	IND_Metals -> IND_Manuf nec -> EU_Demand	27	91
Tier 2	IND_Metals -> IND_Metals -> IND_Trans eqp -> EU_Demand	23	77
Tier 2	IND_Metals -> IND_Cons -> IND_M&Eq Rent & Others -> EU_Demand	2	71
Tier 2	IND_Metals -> IND_Trans eqp -> IND_Trans eqp -> EU_Demand	26	50
Tier 2	IND_Metals -> IND_Metals -> IND_Elec eqp -> EU_Demand	16	48
Tier 1	IND_Metals -> IND_Chemicals -> EU_Demand	9	39
Tier 2	IND_Metals -> IND_Metals -> IND_Mach nec -> EU_Demand	23	36

Source: Author's computations

5. Conclusion

Using an environmentally-extended multi-regional input-output framework along with Structural Path Analysis (SPA), this study examined the carbon emissions and value added

embodied in India-EU trade. It moves beyond aggregate embodied emission accounting and traces specific tiers and paths through which emissions in India-EU bilateral trade are transmitted.

The results confirm the persistence of a massive gap in export-driven embodied emission intensity of the two nations. While the export-driven embodied carbon intensity gap narrowed from 3.96 times in 2017 to 2.84 times in 2023, the asymmetry remains severe. The bilateral relationship continues to function as an ecologically unequal exchange, wherein India continues to bear a disproportionate carbon burden per unit of value added generated through exports. Further, the SPA results explain why this asymmetry persists. India's export-related emissions are largely embedded in upstream supply chains, with Tier 1 emissions (30.5 per cent) contributing a larger share of emissions than the direct Tier 0 emissions (27.3 per cent). This was majorly driven by upstream suppliers like domestic electricity grids, fossil fuels, metals, chemicals, etc., supplying intermediates to the manufacturing sectors, particularly basic metals. The EU's emissions to India were however dominated by direct Tier 0 pathways, especially water and air transport services. These findings highlight that India's carbon exposure is largely an upstream industrial problem, whereas the EU's exported emissions are comparatively direct and service oriented. Further examination of exposure of downstream sectors to a potential expansion of the EU CBAM indicates that emissions originating in India's basic and fabricated metals sector are increased embedded in many downstream manufacturing exports, including transport equipment, electrical equipment, machinery, and metals sectors too. These results suggest that industrial upgrading and moving up the value chain may not necessarily reduce carbon exposure if upstream inputs remain carbon-intensive.

These findings have some important implications. First, India's decarbonisation is more challenging than the EU, as it is not confined to direct exporting sectors, but is closely linked to decarbonisation of entire supply chain, especially of upstream electricity, metals, fuels and chemical sectors. Second, if scope of CBAM gets expanded to include certain downstream products of metal sector, Indian exporters with complex upstream dependencies on these sectors may face significant exposure. Thus, the core challenge before Indian industry is not only to reduce aggregate emissions, but to transform certain production paths, through which emissions are embodied in trade the most.

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