

# Carbon Border Adjustment and Trade Vulnerability in Developing Countries

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**Abstract-** *This paper examines the long-term evolution of Carbon Border Adjustment (CBA) Vulnerability Index scores across five CBAM-exposed economies—India, Brazil, South Africa, Indonesia, and Turkey, from 1980 to 2024. By integrating the dimensions of exposure, sensitivity, and adaptive capacity, this study assesses each country’s changing susceptibility to climate-aligned trade measures. The findings reveal a significant increase in vulnerability during the 1990s and 2000s, coinciding with intensified globalization and rising environmental standards these economies. While the index approach allows comparative insights, it is limited by data quality and lack of sectoral granularity. Nonetheless, the study underscores the urgency for developing countries to invest in decarbonization, institutional strengthening, and fiscal innovation to stay competitive in a carbon-constrained global trade environment.*

**Index Terms-** *Carbon Emissions, CBAM, Developing Countries, Trade Environment*

## I. INTRODUCTION

As the global economy moves toward a low-carbon future, climate policy is no longer confined to the domestic regulatory sphere—it has become a defining feature of international trade governance. Among the most consequential developments in this evolving landscape is the European Union’s Carbon Border Adjustment Mechanism (CBAM), a policy designed to prevent carbon leakage and ensure a level playing field between EU producers subject to stringent climate regulations and their international competitors. CBAM effectively internalizes the carbon cost of imports by imposing tariffs on selected emissions-intensive goods such as steel, aluminium, cement, electricity, and fertilizers (European Commission, 2021). In doing so, it reconfigures the traditional trade-environment nexus by linking carbon intensity directly to market access.

The implications of CBAM for developing economies are profound. Many of these countries maintain trade-intensive growth models reliant on

carbon-intensive exports and face structural limitations in adapting to evolving climate-aligned trade regimes. While considerable literature has examined the potential economic impacts of CBAM in aggregate or sectoral terms (Cosbey et al., 2019; Kortum & Weisbach, 2021), far less attention has been paid to the historical trajectory of vulnerability across emerging markets. This absence of temporality in CBAM-related research risks overlooking the long-run institutional, economic, and environmental dynamics that shape how countries respond to such measures.

This paper seeks to fill that critical gap by offering a longitudinal analysis of CBAM-related trade vulnerability through the construction and application of the Carbon Border Adjustment Vulnerability Index (CBAVI). Focusing on five strategically positioned, trade-exposed emerging economies—India, Brazil, South Africa, Indonesia, and Turkey—the study spans over four decades, from 1980 to 2024. These countries were selected not only for their exposure to EU trade and carbon-intensive sectors but also for their geopolitical and developmental relevance in shaping global climate and trade narratives.

The CBAVI is grounded in the IPCC’s tripartite framework of vulnerability, comprising three core dimensions:

- Exposure – the extent to which a country’s trade is dependent on CBAM-affected sectors and EU markets;
- Sensitivity – the degree of economic susceptibility to disruptions from carbon-aligned trade policies, proxied by indicators such as energy intensity and carbon emissions per GDP;
- Adaptive Capacity – the institutional, technological, and financial capability to transition toward sustainable, low-carbon trade systems.

By integrating these dimensions into a composite index and analyzing their evolution over time, this study provides nuanced insights into how trade, environmental fragility, and institutional readiness have interacted in shaping CBA vulnerability. In doing so, it contributes both a methodological innovation and a policy-relevant framework for understanding the readiness of developing countries to navigate the new architecture of climate-conscious global trade.

Beyond its empirical and methodological contributions, this study also engages with broader questions of trade equity and climate justice. As climate-aligned trade instruments like CBAM proliferate, there is a growing risk that carbon pricing at the border could act as a de facto trade barrier, disproportionately disadvantaging developing economies with constrained fiscal space, weaker regulatory institutions, and limited access to climate finance. In this context, the role of multilateral development banks (MDBs) and international financial institutions becomes critical—not only in supporting green industrial transitions through concessional finance, but also in facilitating capacity-building, emissions monitoring systems, and equitable rule-setting in global trade forums. By highlighting structural asymmetries in CBAM readiness, this paper underscores the urgency for inclusive trade-climate governance that ensures developing countries are not marginalized in the emerging carbon-constrained global economy.

## II. REVIEW OF LITERATURE

India, as a major exporter of carbon-intensive goods such as steel and aluminum, faces significant exposure to the EU market and has been a key voice in global climate and trade negotiations (Mevel & Oulmane, 2021). Brazil, similarly, is a leading exporter of metals like iron and aluminium and is undergoing institutional reforms to align its environmental compliance with international standards, placing it at the center of CBAM discussions (World Bank, 2022; European Commission, 2021). South Africa's coal-heavy energy mix and emissions-intensive exports, particularly in steel and cement, have long made it one of the most vulnerable developing countries to climate-linked trade regulations (van Asselt, 2022; IMF, 2021). Indonesia, with its fast-growing industrial base and exports of coal, aluminium, and

cement, has historically lacked adaptive capacity but is increasingly integrating green industrial policies (Asian Development Bank, 2023; WTO, 2022). Finally, Turkey, though an upper-middle-income country, maintains deep trade ties with the European Union through its Customs Union agreement and remains highly exposed to CBAM due to its substantial carbon footprint in key industrial sectors (OECD, 2021; European Commission, 2022).

## III. METHODOLOGY

With the rise of climate-aligned trade regulations, vulnerability indices have become essential tools to assess the multidimensional risks faced by economies. Researchers often use composite indices, combining standardized indicators to reflect exposure to carbon-intensive trade, economic sensitivity, and institutional readiness (Winkelman & Moore, 2011). Energy intensity and CO<sub>2</sub> emissions per unit of GDP are widely used proxies for sensitivity, while adaptive capacity is gauged through metrics like renewable energy share and gross capital formation (UNEP, 2018; Duan et al., 2022). Aligned with the IPCC's tripartite framework, this study constructs a CBA Vulnerability Index tailored to emerging economies affected by EU trade measures.

This study constructs a CBA Vulnerability Index to quantify the relative susceptibility of five key emerging economies—India, China, Brazil, South Africa, and Turkey—to the European Union's CBAM. The index is developed using a composite framework grounded in the IPCC's tripartite structure of vulnerability—exposure, sensitivity, and adaptive capacity (IPCC, 2007). The analysis is based on panel data spanning 1980 to 2024, drawing from sources including the World Bank's World Development Indicators and UN Comtrade databases. The CBA Vulnerability Index is constructed from three equally weighted sub-indices:

The Exposure Index measures the trade dependence of a country on the EU market for potentially CBAM-affected goods.

$$\text{Exposure Index} = \frac{\text{Exports to EU (CBAM Sectors)}}{\text{Total Exports}}$$

The Sensitivity Index Captures the carbon and energy intensity of the economy, indicating how susceptible it is to CBAM surcharges.

$$\text{Sensitivity Index} = \frac{\text{Carbon Dioxide Emissions} + \text{Energy Consumption}}{2(\text{GDP})}$$

The Adaptive Capacity Index Represents a country's economic and technological ability to transition to greener production. Higher adaptive scores reduce vulnerability.

$$\text{Adaptive Index} = \frac{\text{Renewable Energy Share} + \text{Gross Capital Formation}}{2(\text{GDP})}$$

The overall vulnerability is computed as:

$$\text{CBAVI} = \frac{\text{Exposure} + \text{Sensitivity} + (1 - \text{Adaptive Capacity})}{3}$$

This formulation ensures that higher exposure and sensitivity increase vulnerability, while greater adaptive capacity reduces it.

#### IV. GET PEER REVIEWED FINDINGS

##### 4.1 1980–1995

During the pre-globalization phase, international trade was expanding steadily, yet most emerging economies maintained inward-oriented economic models with limited exposure to global environmental standards. Climate considerations had not yet been integrated into the trade-finance nexus, and the collapse of the Bretton Woods system in the early 1970s continued to influence exchange rate volatility across developing markets. The Rio Earth Summit of 1992 marked the first significant international convergence on sustainable development, but enforcement mechanisms were largely aspirational at this stage.

India exhibited very low exposure to climate-related trade risk ( $\approx 0.0075$ – $0.02$ ), primarily due to its protectionist trade regime and limited integration into global markets. However, its sensitivity was already moderate, underpinned by an energy-intensive industrial base and low energy efficiency. Institutional and regulatory weakness kept its adaptive capacity minimal, thereby signalling early signs of future vulnerability. South Africa showed medium exposure, high sensitivity, and low adaptive

capacity. The country's coal-centric energy system and export dependence on raw commodities rendered it highly sensitive to potential carbon pricing mechanisms. Moreover, geopolitical isolation during the apartheid regime constrained its access to climate finance and limited institutional reform, weakening its resilience.

Brazil, too, faced moderate exposure and high sensitivity. While integrating more actively into global trade, its reliance on extractive and deforestation-linked sectors (e.g., timber and soy) made it increasingly visible in early environmental discourse. Institutional readiness was underdeveloped, resulting in limited adaptive response capacity. Indonesia remained in the early stages of industrialization, with low exposure but high sensitivity due to dependence on fossil fuels and extractive industries. Its adaptive index was extremely low, reflecting weak environmental governance, low investment in institutional development, and negligible alignment with global sustainability standards.

Turkey presented a unique case, with low exposure and medium sensitivity but a relatively stronger adaptive index compared to peers. Its geopolitical position near Europe and early aspirations for EU membership motivated incremental institutional reforms that would later form the basis of its environmental adaptation strategy. In summary, while none of the five economies faced immediate trade-related climate risks during this period, the underlying structural characteristics—particularly energy intensity, carbon-intensive exports, and weak adaptive institutions—laid the groundwork for future vulnerabilities in a carbon-conscious global trade regime.

##### 4.2 1996–2008

This period was defined by accelerated globalization, driven by the creation of the World Trade Organization (WTO) in 1995 and the intensification of global value chains. Crucially, the Kyoto Protocol (1997) introduced binding emissions targets for developed countries, inadvertently ushering in carbon leakage concerns and raising the specter of border carbon adjustments. Trade and climate policy began to converge more tangibly, though asymmetrically.

India witnessed a sharp increase in trade integration following its 1991 liberalization reforms, which in turn elevated its exposure. Yet, its sensitivity remained high, as export growth was concentrated in emissions-intensive sectors such as steel and petrochemicals. Despite improvements in institutional capacity—e.g., the strengthening of SEBI, expansion of RBI oversight, and fiscal discipline—the overall adaptive index remained low due to sluggish environmental reforms. South Africa's exposure slightly declined due to shifting trade partners, particularly growing engagement with China and the EU. However, the economy's narrow export base and deep reliance on coal sustained its high sensitivity. Institutional reform was limited, and governance constraints hindered its adaptive progress.

Brazil experienced a notable increase in exposure, buoyed by commodity-driven export expansion. Although trade liberalization and capital inflows helped modernize its financial system, the economy remained vulnerable due to persistent reliance on carbon-intensive agriculture and mining. Adaptive capacity began to improve modestly through regulatory and macroeconomic stabilization. Indonesia saw rising exposure linked to increased FDI, particularly in palm oil and extractives. However, sensitivity remained high, and despite some financial-sector reforms following the Asian Financial Crisis, these improvements did not translate into environmental governance capacity. The adaptive index remained stagnant.

Turkey saw a marked increase in exposure, largely due to its deepening economic ties with the EU. Importantly, its adaptive index improved significantly, aided by regulatory convergence with EU trade and environmental standards, making Turkey relatively more resilient to emerging carbon-related trade measures. By the end of this period, exposure across all five countries had grown in tandem with trade liberalization. However, adaptive capacity lagged, particularly in climate governance and environmental performance. This imbalance signaled the emergence of what could be termed a "carbon trap"—where rapid economic growth is tied to carbon-intensive exports without parallel investment in green infrastructure or institutional resilience.

#### 4.3 2009–2024

The last 15 years have seen climate policy become institutionalized within international trade and finance. The Paris Agreement codified universal commitments to emissions reduction, while the EU's Carbon Border Adjustment Mechanism (CBAM) proposal in 2021 effectively operationalized climate-aligned trade protection. At the same time, international financial institutions, ESG investors, and rating agencies have begun incorporating climate risks into capital allocation, sovereign risk assessments, and trade finance criteria.

India now exhibits higher exposure ( $\approx 0.03$ – $0.07$ ) due to deepened global integration and increased industrial exports. While its economy has diversified into services and digital trade, its manufacturing and infrastructure sectors remain carbon-intensive, maintaining high sensitivity. Its adaptive index has improved gradually through investments in solar energy, MRV systems, and ESG frameworks, but it continues to lag behind the expectations of climate-aligned trade partners like the EU. South Africa continues to grapple with entrenched sensitivity stemming from its coal-heavy energy matrix. Exposure has plateaued, but adaptive progress has been modest. The country faces rising financial constraints due to low ESG scores, sovereign downgrades, and limited access to green finance, which exacerbate its CBAM-related vulnerabilities. Brazil presents a mixed picture. While exposure has stabilized, sensitivity is declining slightly due to a growing share of renewables (especially hydropower) in its energy mix. Simultaneously, its adaptive capacity has strengthened through climate diplomacy and improvements in regulatory institutions. However, ongoing deforestation in the Amazon remains a reputational and financial risk, keeping Brazil on the CBAM radar. Indonesia has experienced a rise in exposure due to export expansion, especially in palm oil and industrial commodities. Its sensitivity remains high, and adaptive capacity remains low, largely due to weak enforcement of environmental regulations and a limited pipeline of green finance instruments. These factors collectively threaten Indonesia's trade competitiveness in a CBAM-governed world.

Turkey now has high exposure, especially given its reliance on EU trade. Yet, it stands out as the most CBAM-ready economy among the five. Its strong adaptive index is underpinned by institutional reforms, EU-aligned environmental regulation, and

a growing green finance sector. Nevertheless, the cost of compliance with CBAM remains significant and poses short-term adjustment challenges.

#### V. CONCLUSION

This completes the entire process required for widespread of research work on open front. Generally all International Journals are governed by an Intellectual body and they select the most suitable paper for publishing after a thorough analysis of submitted paper. Selected paper get published (online and printed) in their periodicals and get indexed by number of sources. The evolving trajectory of Carbon Border Adjustment vulnerability across India, Brazil, South Africa, Indonesia, and Turkey underscores the complex and dynamic interaction between global trade liberalization, environmental fragility, and institutional readiness. During the early decades of globalization (1980–2000), vulnerability was primarily shaped by high sensitivity—driven by carbon-intensive industrial structures—and limited adaptive capacity, as these economies pursued export-led growth with insufficient alignment to emerging climate norms. This foundational imbalance sowed the seeds of structural exposure to climate-aligned trade risks.

The 21st century introduced incremental improvements. Notably, countries like Brazil and India made strides in institutional reform, climate diplomacy, and adoption of renewable energy—leading to moderate enhancements in their adaptive indices. However, these gains have not been uniform. Energy-intensive sectors, weak MRV (Monitoring, Reporting, and Verification) systems, and fragmented access to climate finance continue to constrain resilience, particularly in South Africa and Indonesia. Meanwhile, Turkey's relative preparedness, owing to EU proximity and regulatory convergence, highlights the importance of policy alignment in shaping trade resilience.

As the Carbon Border Adjustment Mechanism (CBAM) transitions from proposal to policy reality, it represents a structural shift in global trade architecture—where carbon intensity is no longer a peripheral concern but a determinant of market access, capital flows, and sovereign creditworthiness. For emerging economies, the risk landscape is no longer confined to environmental

compliance; it extends to trade competitiveness, fiscal space, and developmental sovereignty.

CBA vulnerability is not a fixed condition—it is a moving frontier shaped by global regulatory dynamics, domestic policy choices, and the international finance ecosystem. To avoid structural marginalization in a decarbonizing world economy, developing countries must prioritize green industrial transformation, strengthen institutional and data ecosystems, and engage more assertively in shaping equitable climate-trade norms. Achieving a just transition will require not only domestic reform but also coordinated global support—through concessional finance, technology transfer, and inclusive governance mechanisms—to ensure that sustainability does not become another axis of inequality in global trade.

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