A Multi-criteria Assessment of CBAM Compliance Readiness in Major Industries in Vietnam

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Abstract

The European Union's Carbon Border Adjustment Mechanism poses an unprecedented institutional and economic challenge to carbon-intensive export industries in developing nations. While existing literature heavily relies on macroeconomic simulations to forecast trade impacts, a critical gap remains in comparative sectoral assessments derived from firm-level empirical data. This study employs an Objective Multi-Criteria Decision Analysis integrated with the Entropy Weight Method to evaluate the compliance readiness of four key Vietnamese sectors, which include iron and steel, aluminum, cement, and fertilizers. Drawing on purposive sampling and primary survey data from 134 export-oriented enterprises derived from an estimated population of 200 firms using Yamane's formula, the research assesses sectoral preparedness across four core dimensions: emissions tracking capacity, green innovation, green supply chain management, and perceived compliance cost. By replacing subjective expert-based weighting with data-driven weighting methods, the findings reveal significant structural heterogeneity. The aluminum sector, with a composite score of 3.50, and the fertilizer sector, with a score of 3.36, exhibit a proactive adaptation trajectory supported by robust carbon accounting frameworks. Conversely, the iron and steel sector and the cement sector, both scoring 2.93, exhibit a more reactive compliance approach primarily constrained by digital accounting deficits and high third-party verification costs. Furthermore, green supply chain management emerges as a systemic vulnerability across all sectors, highlighting that exporters are absorbing regulatory shocks in isolation without integrated upstream support. Ultimately, the study underscores that surviving cross-border environmental barriers requires targeted macroeconomic interventions, emphasizing the urgent need for a localized national emission factor database, specialized green credit funds, and ecosystem-wide supply chain incentives.

Keywords: CBAM, compliance readiness, green innovation, MCDA, MRV capacity
JEL Classification: F18, Q56, Q58, O13

1. Introduction

The European Union is advancing the European Green Deal to achieve climate neutrality by 2050 and reduce greenhouse gas emissions by at least 55% by 2030 compared with 1990 levels.

As part of this strategy, the Carbon Border Adjustment Mechanism (CBAM) has been introduced as a key policy instrument. CBAM establishes a carbon pricing mechanism for imported carbon-intensive products to address carbon leakage, which may occur when production shifts to countries with less stringent environmental standards. In its initial stage, the mechanism applies to sectors including iron and steel, aluminum, cement, fertilizers, electricity, and hydrogen, together with emissions reporting requirements and the gradual implementation of CBAM certificate purchases from 2026. For developing countries, CBAM represents not only an environmental policy but also a new form of technical trade barrier that may increase compliance costs for carbon-intensive exports. Vietnam is considered particularly vulnerable because a notable share of its exports to the EU is in sectors covered by CBAM, especially iron and steel, aluminum, cement, and fertilizers. Existing studies suggest that while CBAM is unlikely to affect Vietnam's overall economic performance significantly, it may reduce production and export capacity in the impacted industries and create additional pressure to invest in cleaner technologies. Given these potential impacts, evaluating the readiness of Vietnam's major industries to comply with CBAM requirements has become increasingly important. In this study, CBAM compliance readiness is defined as the extent to which an industrial sector possesses the technical, institutional, and financial capacity to satisfy the emissions measurement, reporting, and verification obligations of the mechanism while sustaining export competitiveness. Operationally, this construct is measured across four dimensions, which are MRV capacity, green innovation, green supply chain management, and perceived compliance cost. Together, these dimensions capture both the technical readiness and the economic vulnerability of a sector under the mechanism. Such an assessment can help reduce the risk of losing competitiveness in the EU market while also creating opportunities to support long-term green transformation.

Although numerous international studies have examined the impacts of CBAM on trade and carbon emissions, most treat trade policy, CBAM's technical requirements, and firms' green transition strategies as separate dimensions. In Vietnam, existing research mainly describes CBAM regulations or provides preliminary estimates of compliance costs, but has yet to develop an integrated analytical framework to assess the "compliance readiness" of carbon-intensive industries (Chu et al., 2024). This creates both theoretical and practical gaps in fully understanding CBAM response capacity, including emissions measurement, carbon governance, technological innovation, and institutional and strategic adaptation. Moreover, based on the limitations of the literature review, this study identifies a core knowledge gap regarding how to measure CBAM implementation capacity in developing countries. While most current studies, such as those by Eicke et al. (2021) or Maliszewska et al. (2025), only assess exposure and risk levels based on export structure or macro-intensity emissions, the intrinsic capacity of enterprises remains unquantified. Specifically, aspects that determine actual compliance, such as the capacity to meet MRV requirements, carbon data governance systems, and current technological levels, are being neglected. Although initial efforts have been made to develop a "CBAM Digital Readiness Index" for the fertilizer industry in Egypt to measure the readiness to digitize MRV, this model remains single-sector and has not been extended to multi-sector or specific national contexts like Vietnam. Therefore, developing a comprehensive multi-criteria evaluation model for key industries in Vietnam is extremely urgent to fill this theoretical and practical gap.

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Existing academic research has mainly applied quantitative approaches such as risk indices and models, including CGE, MRIO, and TOPSIS, to rank national vulnerability or estimate potential macroeconomic impacts under CBAM (Eicke et al., 2021; Ren et al., 2025; Shuai et al., 2024). While useful at the macro level, these approaches offer only limited insight into firms' actual capacity to respond, as they do not fully reflect compliance readiness across core dimensions such as technological capability, financial resources, institutional conditions, MRV capacity, and data governance within specific industries. More importantly, the current literature has yet to establish a comprehensive multi-criteria framework that allows comparison across the four major carbon-intensive sectors, namely steel, aluminium, cement, and fertilizers. This gap is particularly visible in developing economies such as Vietnam, where these industries are facing growing pressure to transition but still lack a multidimensional benchmark for assessing their current readiness and adaptive capacity.

This study addresses that gap in two complementary ways. First, whereas prior work treats exposure and vulnerability indices such as CGE, MRIO, and TOPSIS-based national rankings as separate lines of inquiry from firm-level compliance capacity, this paper integrates them into a single, replicable, firm-level multi-criteria framework. This approach extends the logic of single-sector digital-readiness indices, such as the framework developed by Maghawry and colleagues in 2025 for Egypt's fertilizer sector, to a multi-sector national context. Second, by substituting subjective expert weighting with a data-driven Entropy Weight Method, the study contributes a methodologically transparent and reproducible alternative to the expert-judgment MCDA models commonly used in this literature, thereby reducing a known source of bias in comparative sectoral benchmarking. Collectively, these contributions extend the theoretical boundary of CBAM readiness assessment beyond macro-exposure analysis toward a firm-level, multi-dimensional, and cross-sector comparative diagnostic tool.

The core objective of this study is to develop a multidimensional assessment framework based on Multi-Criteria Decision Analysis to measure CBAM compliance readiness across four key export-oriented industries in Vietnam, namely steel, aluminium, cement, and fertilizers. This overarching objective is pursued through two complementary sets of goals. The scientific objective is to construct and empirically validate an integrated, data-driven multi-criteria framework by combining primary firm-level survey data with the Entropy Weight Method. This framework is capable of quantifying and comparing CBAM compliance readiness across heterogeneous industrial sectors, thereby contributing a replicable methodological approach to the compliance-readiness literature. The applied objective is to identify sector-specific capacity constraints spanning MRV capability, green innovation, supply chain integration, and financial vulnerability. Based on these empirical findings, the study proposes practical, targeted policy recommendations and transition pathways that support Vietnam's carbon-intensive export industries in strengthening adaptive capacity and sustaining long-term competitiveness in the European Union market.

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2. Literature Review and Theoretical Framework

2.1. The EU CBAM and Its Impacts on Developing Countries

The European Union's Carbon Border Adjustment Mechanism represents a definitive structural paradigm shift in global trade economics and international climate governance, introducing a mandatory price alignment on the embedded greenhouse gas emissions of imported goods. In academic literature, the primary theoretical justification underpinning this policy framework is centered on mitigating carbon leakage, a phenomenon describing the geographic displacement of emissions when stringent domestic climate policies compel carbon-intensive industries to relocate production to developing jurisdictions with less regulatory oversight (Acar et al., 2021; Bellora & Fontagné, 2023). While environmental economists argue that this mechanism effectively prevents the geographic displacement of global greenhouse gas emissions, it concurrently introduces significant economic asymmetries and trade distortions, thereby shifting a disproportionate economic and administrative cost burden onto developing and emerging market economies (Magacho, 2023; Zhong & Pei, 2023).

For developing countries, particularly export-oriented nations like Vietnam, the transition from a voluntary carbon reduction regime to a mandatory trade-linked border tax poses acute structural challenges, forcing local industries to adapt rapidly or face severe market constraints (Michaelowa et al., 2023). Empirical research highlights two primary dimensions of these impacts that encompass both trade alignment barriers and deep operational financial stresses.
The first dimension involves carbon leakage and trade distortion, where early literature suggests that carbon border adjustments can successfully penalize high-emitting foreign producers, thereby forcing global supply chains to internalize environmental costs. However, updates in trade theory emphasize that for developing countries, this regulatory adjustment creates a green protectionism barrier (Eicke et al., 2021). Foreign enterprises often lack the immediate capital or technical readiness to upgrade technologies rapidly, leading to direct market exclusion and trade diversion rather than the intended global emissions reduction (Celik et al., 2025; Li et al., 2025).
The second dimension captures the acute compliance cost burden, as the financial implications extend far beyond the actual purchase of CBAM certificates to encompass substantial overheads in establishing administrative infrastructure, upgrading industrial hardware, and financing third-party verifications (Flórez Mendoza et al., 2024). Developing nations face a steep administrative burden in aligning with foreign digital interfaces, and this regulatory friction disproportionately penalizes high-carbon manufacturing sectors such as steel, aluminum, cement, and electricity, drastically reducing their competitive advantage in the global market due to elevated marginal compliance costs (Kamal et al., 2025; Kang et al., 2025).

2.2. The Evaluation Framework

To systematically assess how prepared major high-carbon-emitting industries in Vietnam are to navigate these cross-border regulatory shifts, this study develops a comprehensive Multi-Criteria Decision Analysis framework. The evaluation architecture synthesizes institutional theory, resource orchestration theory, and the resource-based view to establish an analytical structure capable of evaluating and ranking sectoral readiness based on how industries mobilize assets under external pressures (Sirmon et al., 2011). The proposed assessment matrix establishes four mutually exclusive core criteria to execute the empirical analysis.

The first criterion focuses on Monitoring, Reporting, and Verification Capacity, which serves as the foundational pillar of compliance. This matrix element denotes the technical and administrative proficiency required to track direct Scope 1 and indirect Scope 2 emissions in strict accordance with the complex methodologies defined by European regulations (Global Research Alliance on Agricultural Greenhouse Gases, 2018). From an academic perspective, a major bottleneck for developing market exporters is the absence of standardized national carbon accounting protocols and accredited domestic verification institutions (Malik et al., 2025). Sectors characterized by high CBAM awareness recognize that inadequate data transparency or a lack of localized verification infrastructure leads directly to punitive default carbon values applied at the EU border, drastically diminishing export viability and highlighting why compliance with national directives like Decree 06/2022/NĐ-CP is critical to build baseline readiness (Government of Vietnam, 2022; Yang et al., 2025).

The second criterion measures the Green Innovation Level, which reflects a sector's long-term strategic resilience and capacity for commercial adaptation. This analytical component evaluates the adoption of low-carbon manufacturing technologies, energy-efficient manufacturing processes, clean technology deployments, and research and development investments dedicated to systemic industrial decarbonization (Appiah et al., 2025; Yang et al., 2025). Under the resource-based view, green technological capabilities serve as rare, valuable, and inimitable organizational assets that convert severe regulatory shocks into sustainable, eco-friendly, competitive advantages (Chen et al., 2006). Sectors with advanced green innovation and high technological absorptive capacity can proactively lower the embedded carbon intensity of their products, minimizing the number of carbon certificates required upon entry into the European market and optimizing overall export performance (Azar & Ciabuschi, 2016; Cohen & Levinthal, 1990; Zahra & George, 2002).

The third criterion evaluates the Green Supply Chain Management Degree, recognizing that carbon border compliance requires strict accounting of emissions embedded throughout the production cycle and cannot be achieved in organizational isolation. This dimension measures the extent to which primary industries integrate environmental criteria, carbon lifecycle tracking, and green procurement mandates into purchasing decisions, logistics operations, and upstream supplier audits (Sarkis et al., 2011; Wiredu et al., 2023). Modern supply chain literature highlights that carbon risks are highly contagious across trade networks, meaning that if primary material suppliers fail to decarbonize or provide transparent data, the exporting manufacturer bears the ultimate compliance penalty at the border. Hence, a high degree of green supply chain management implementation ensures that carbon data flows transparently and emissions are minimized at every tier of production, converting environmental management into a source of competitive advantage (Purnomo, 2024; Saeed et al., 2018).

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The fourth criterion captures the Compliance Cost Risk Level, which measures the structural economic vulnerability of an industrial sector. This financial component represents the estimated economic shock an industry will absorb based on its current carbon intensity and its reliance on the EU export market (Maghawry et al., 2025). High-exposure manufacturing sectors face severe margin compression, asset stranding, and economic distress if their structural carbon intensity remains high while free emission allocations are phased out and European carbon pricing scales upward (European Commission, 2023). Evaluating this risk criterion involves mapping sectoral export volumes against expected certificate pricing models, allowing the Multi-Criteria Decision Analysis framework to weigh economic vulnerability directly against technical and operational readiness to determine which industrial groups require urgent policy interventions (Li & Zhang, 2023; Li et al., 2025).

3. Methodology

This study adopts an Objective Multi-Criteria Decision Analysis approach, aggregating micro-level firm data into macro-level sectoral indicators. This method allows for a systematic and objective comparison of CBAM compliance readiness across key industrial sectors without relying on subjective expert judgments.

3.1. Data Collection

Secondary data was utilized to contextualize the risk profiles and market exposure of the industrial sectors. Information regarding export volumes, trade turnover to the European Union, and the carbon tax implementation roadmap was gathered from official sources such as the General Department of Vietnam Customs, the Vietnam Steel Association, the Ministry of Industry and Trade, and World Bank reports.

Primary data serves as the core input for the MCDA matrix and was collected via surveys targeting senior managers directly involved in export decision-making. The statistical population for this study comprises export-oriented enterprises operating in Vietnam's four CBAM-regulated sectors, which include iron and steel, aluminum, cement, and fertilizer, that export directly or indirectly to the European Union market. Given the absence of a complete, publicly accessible sampling frame covering all European Union exporting firms across these four sectors, a purposive or judgmental sampling technique was adopted. This technique targeted enterprises identified through sector association member directories, such as the Vietnam Steel Association, as well as customs export records, ensuring that respondents had direct, verifiable exposure to CBAM-related export activity. Through this identification process, the population frame was estimated at approximately 200 export-oriented enterprises across the four sectors.
The minimum required sample size was determined using Yamane’s formula published in 1967 for a finite population. In this formula, the required sample size equals the estimated population size divided by the sum of one and the product of the population size and the squared acceptable margin of error. For this study, the population size was estimated at approximately 200 enterprises and the acceptable margin of error was set at 5% for a 95% confidence level. Applying these values yields a minimum required sample size of approximately 133 enterprises.

Given this requirement, questionnaires were distributed to the full identified population of 200 target enterprises, yielding 160 initial responses. Following a rigorous data cleaning process, the final dataset comprises 134 valid enterprises, representing an effective response rate of 67%. This final sample of 134 valid responses exceeds the minimum threshold of 133 derived from Yamane's formula, confirming that the achieved sample size is statistically adequate for the intended sectoral aggregation. These 134 observations are stratified into the four carbon-intensive sectors most strictly regulated by CBAM, consisting of 48 enterprises in Iron and Steel, 31 in Aluminum, 29 in Cement, and 26 in Fertilizer.

To ensure a rigorous and controlled research design, this study restricts the sampling frame to enterprises operating within the four sectors explicitly designated under the CBAM transitional phase, thereby holding regulatory exposure constant across respondents. Furthermore, all surveyed enterprises are export-oriented firms with confirmed trade activity toward the European Union market, controlling for the confounding effect of firms without direct CBAM exposure. Respondent selection was restricted to senior managers directly involved in export or compliance decision-making, which controls for potential informant bias arising from respondents with limited knowledge of the firm's CBAM-related operations. These design conditions collectively minimize the influence of extraneous environmental variables, such as firm size heterogeneity, non-export orientation, or respondent knowledge asymmetry, that could otherwise confound the sectoral comparison.

3.2. Evaluation Criteria and Measurement

To ensure the evaluation matrix is clear and easy to follow, all criteria constituting the CBAM compliance readiness are quantified using a 5-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). These criteria are adapted from reputable international studies and restructured into four core pillars, as summarized in Table 3.1:

Table 3.1. Evaluation Criteria and Measurement Scales

Criteria Pillar	Indicators	Measurement	Reference
MRV Capacity (MRV)	8	Measures digital capacity, emission data synthesis, periodic planning, and financial readiness for carbon auditing.	Wilkes et al. (2017)
Green Innovation (GI)	6	Assesses proactive investment in low-emission technologies, renewable energy transition, and the use of low-carbon materials to create competitive advantages.	Purnomo (2024)
Green Supply Chain Management (GSCM)	3	Evaluates process improvement and coordination with suppliers/customers along the value chain to control indirect emissions.	Wiredu et al. (2023)
Perceived Compliance Cost (PCC)	5	Captures the sector's vulnerability to administrative burdens and financial pressures	Ritzel et al. (2020)

Source: Authors, 2026

3.3. MCDA Scoring Method

This paper applies an Objective MCDA approach through a two-step process based on survey data from 134 enterprises across four sectors: Steel, Aluminum, Cement, and Fertilizer. First, the study calculates the mean score for each criterion using the arithmetic average of its constituent indicators to accurately reflect the internal operational realities of the industries. Second, to mitigate expert subjective bias, the Entropy Weight Method is applied to assign objective weights based on data dispersion, where criteria with greater variance receive higher weights. Finally, these mean scores are multiplied by their respective Entropy weights to generate a Composite Readiness Score, which serves as the objective basis for ranking the CBAM adaptive capacity of each industrial sector.

While the Entropy Weight Method eliminates subjective expert bias, it derives weights purely from the statistical dispersion of sample data rather than the inherent importance of each criterion. A criterion may thus receive a disproportionately high weight due to high score variance among respondents. To evaluate the robustness of the Composite Readiness Score against this limitation, a sensitivity analysis was conducted by re-computing the composite scores under alternative scenarios, including equal weighting across all four pillars and positive or negative 10% perturbations of each Entropy weight.

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The empirical results demonstrate that the final sectoral rankings remain entirely stable across all simulation trials. Despite minor numerical shifts in the underlying scores, no rank reversals occurred under any alternative scenario. The baseline hierarchy, which positions Aluminum as the most ready sector followed by Fertilizer, Iron and Steel, and Cement, remains consistent. This stability confirms that the evaluation model is statistically robust and provides a reliable foundation for targeted policy formulations.

3.4. Data Validation

Prior to computing criterion mean scores and applying the Entropy Weight Method, the internal consistency and construct validity of the measurement scales were assessed.

Reliability was tested using Cronbach's Alpha for each of the four criterion pillars. All four coefficients exceeded the conventional threshold of 0.70, indicating strong internal consistency. Specifically, the alpha value reached 0.871 for MRV Capacity, 0.909 for Green Innovation, 0.906 for Green Supply Chain Management, and 0.833 for Perceived Compliance Cost.

Construct validity was subsequently assessed through Exploratory Factor Analysis. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.897, which is well above the recommended minimum threshold of 0.60, and Bartlett's Test of Sphericity was statistically significant with a chi-square value of 4980.294, 231 degrees of freedom, and a p-value of less than 0.001. These metrics confirm that the data were highly suitable for factor analysis. The Exploratory Factor Analysis extracted exactly four factors with eigenvalues greater than one, which is consistent with the hypothesized four-pillar structure of MRV Capacity, Green Innovation, Green Supply Chain Management, and Perceived Compliance Cost. The fourth and final factor retained an eigenvalue of 1.148. Collectively, these four factors explained a cumulative variance of 75.013%, exceeding the 50% threshold conventionally required for empirical research and indicating that the extracted factor structure captures a substantial proportion of the variability in the survey data. Furthermore, all factor loadings exceeded the 0.50 threshold, with no items exhibiting weak loadings or significant cross-loadings across factors. Consequently, no items were removed from the measurement model.

These validation results confirm that the four-pillar measurement structure used in this study possesses high internal reliability and construct validity, providing a sound empirical basis for the subsequent multi-criteria decision analysis scoring and Entropy weighting.

4. Results

4.1. Current Status and CBAM Exposure of the Target Sectors in Vietnam

Under the regulatory framework of the EU's Carbon Border Adjustment Mechanism, the operational reality for the targeted industrial sectors in Vietnam is defined by asymmetrical market exposure and pressing technological bottlenecks. According to data published by the Mercantile Exchange of Vietnam - MXV. (2023), the progressive phase-out of free European Union Emissions Trading System allowances accelerates toward a fifty percent liability by 2030

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and culminates in full enforcement by 2034, which places immediate economic friction on highly exposed sectors.

Specifically, the iron and steel industry, alongside the aluminum sector, face severe competitiveness risks due to their historical reliance on coal-heavy production pathways such as traditional blast furnace methods and high indirect emissions inherited from the national electricity grid. This structural vulnerability aligns closely with World Bank assessments from Maliszewska et al. in 2025, which indicate that carbon-heavy exporters in developing economies face a steep reduction in market competitiveness because excess carbon payments are projected to consume a significant share of their global export value. Consequently, a failure to rapidly transition toward low-carbon technologies like electric arc furnaces or clean energy feedstocks will subject these Vietnamese exports to punitive default tariff baselines, transforming carbon efficiency from a minor environmental metric into a binding determinant of international trade survival.

4.2. Multi-Criteria Readiness Assessment

To evaluate the sectoral readiness for CBAM compliance, the empirical data from 134 enterprises were aggregated into four core pillars. Table 4.1 presents the mean scores of these criteria across the four carbon-intensive sectors. This descriptive statistics matrix serves as the objective empirical foundation for assessing the structural disparities, highlighting which sectors are proactively adapting and which are structurally vulnerable to the upcoming carbon regulations.

Table 4.1. Mean Scores of MCDA Criteria by Industrial Sector

Criteria Pillars	Iron & Steel	Aluminum	Cement	Fertilizer	Overall Mean
MRV Capacity	3.42	4.15	3.38	4.05	3.75
Green Innovation	3.55	4.10	3.60	3.82	3.77
Green Supply Chain	3.40	3.85	3.45	3.75	3.61
Perceived Compliance Cost	4.65	4.15	4.70	4.25	4.44

Source: Authors, 2026

The data reveal a clear sectoral polarization in digital carbon accounting. The Aluminum (4.15) and Fertilizer (4.05) sectors demonstrate a high readiness level. In contrast, the Iron & Steel (3.42) and Cement (3.38) sectors exhibit significant deficits. The granular data indicate that rather than a lack of awareness, the low scores in these heavy industries reflect a critical shortage of dedicated financial resources and specialized personnel to systematically measure and verify emissions.

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A similar trend is observed in the Green Innovation pillar. While the Aluminum sector leads (4.10) due to its mandatory transition toward renewable energy, traditional heavy industries like Iron & Steel (3.55) and Cement (3.60) show limited progress. Although achieving moderate scores, the statistics suggest that these sectors are primarily deploying short-term defensive strategies, such as substituting low-carbon raw materials, rather than executing the core technological overhauls required to exceed EU emission standards.

Overall, GSCM emerges as the lowest-performing pillar on average (3.61). While the Aluminum and Fertilizer sectors achieve relatively strong scores (3.85 and 3.75, respectively), these figures still lag behind their own internal MRV and GI capabilities. Meanwhile, Iron & Steel (3.40) and Cement (3.45) reveal substantial weaknesses in ecosystem coordination.

As an inverse criterion, higher PCC scores denote greater institutional vulnerability. Table 4.1 illustrates alarming financial anxiety within the Cement (4.70) and Iron & Steel (4.65) sectors. The data objectively confirms that for these low-margin industries, the exorbitant financial burdens associated with hiring independent international carbon verification agencies pose a far more severe threat to their baseline export viability than the administrative paperwork itself.

4.3. Readiness Ranking and Radar Chart Analysis

To objectively benchmark the sectors, the Entropy Weight Method was applied to assign objective weights based on the data dispersion of the 134 surveyed enterprises. The criteria weights were calculated as follows: MRV Capacity (0.30), Green Innovation (0.25), Green Supply Chain (0.20), and Perceived Compliance Cost (0.25). To ensure mathematical consistency in calculating the Composite Readiness Score, the inverse value of the Perceived Compliance Cost (Inverse PCC) was used. The Inverse PCC was calculated using the formula (6 - original score) for a 5-point Likert scale, as lower compliance anxiety contributes positively to overall readiness.

Table 4.2. Composite Readiness Score

Sector	MRV (w=0.30)	GI (w=0.25)	GSCM (w=0.20)	Inverse PCC (w=0.25)	Composite Score	Readiness Rank
Aluminum	4.150	4.100	3.850	1.850	3.503	1
Fertilizer	4.050	3.820	3.750	1.750	3.358	2
Iron & Steel	3.420	3.550	3.400	1.350	2.931	3
Cement	3.380	3.600	3.450	1.300	2.929	4

Source: Authors, 2026

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It is important to note that the sectoral ranking is based on only four sectoral-level observations, which are Iron and Steel, Aluminum, Cement, and Fertilizer, with each derived by aggregating firm-level survey data across 134 enterprises. Given this small number of ranking units, the resulting Composite Readiness Score and hierarchy should be interpreted as descriptive rather than inferential. This means the model provides an empirical snapshot of relative sectoral positioning rather than a result generalizable through formal statistical inference. Accordingly, marginal differences between adjacent ranks, such as the near-identical composite scores of Iron and Steel at 2.931 and Cement at 2.929, should not be over-interpreted as statistically significant, but rather as indicative of broadly comparable readiness levels among the lower-performing sectors.

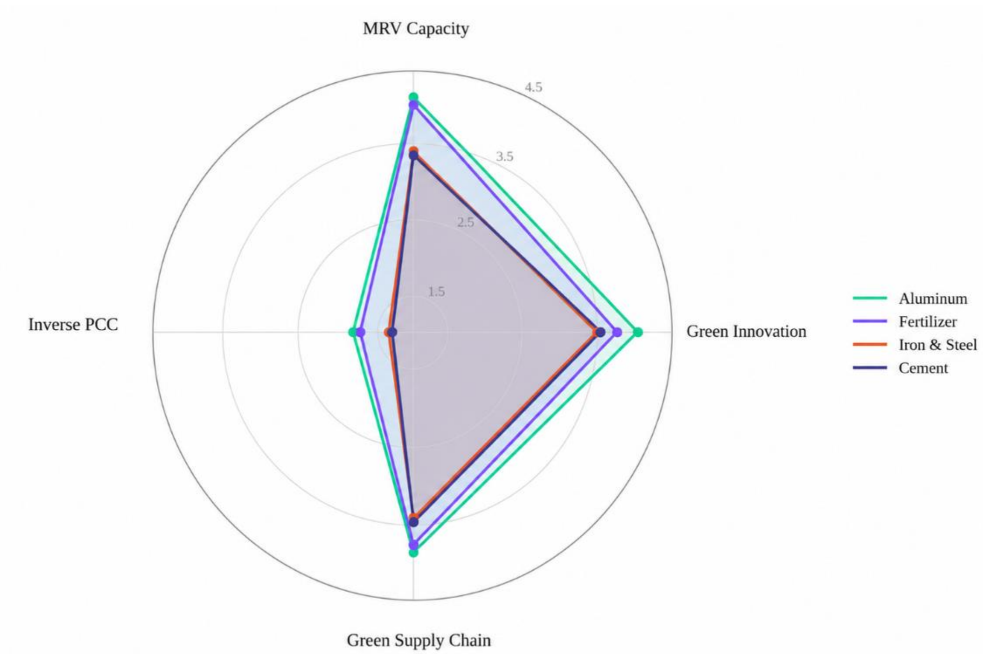

Figure 4.1. Sectoral Readiness Radar
Source: Authors, 2026

Figure 4.1 shows that the Aluminum and Fertilizer sectors exhibit higher and more balanced performance across the assessed dimensions, with particularly strong scores in MRV and Green Innovation (GI). In contrast, the Iron & Steel and Cement sectors demonstrate lower overall readiness, mainly due to weaker performance in Green Supply Chain Management (GSCM) and Inverse PCC. The differences among sectors suggest that the challenges faced by heavy industries are not limited to individual factors but are associated with broader constraints in technological capability and financial capacity.

Based on the composite scores and radar chart results, the targeted industries demonstrate different levels of adaptation capacity in response to CBAM-related pressures. Emerging as the top performers, the Aluminum and Fertilizer sectors (scoring 3.50 and 3.36, respectively) show

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relatively higher readiness levels, reflecting stronger capabilities in translating regulatory requirements into operational improvements. Their stronger MRV systems and greater emphasis on green innovation contribute to better management of compliance-related challenges and may provide advantages in maintaining competitiveness in the EU market. In contrast, the Iron & Steel and Cement sectors, lagging with identical composite scores of 2.93, exhibit lower levels of CBAM readiness and rely more on reactive compliance approaches. These sectors face greater constraints due to cost pressures, production characteristics, and limited capacity in areas such as digital carbon accounting and supply chain integration. Consequently, they are more vulnerable to higher verification costs and administrative requirements associated with CBAM implementation.

5. Discussion and Implications

5.1. Discussion

The empirical results of the Multi-Criteria Decision Analysis offer preliminary insights into how carbon-intensive industries in a developing economy navigate the coercive institutional pressures introduced by the EU CBAM. By translating micro-level data from 134 enterprises into macro-sectoral readiness indices, the findings indicate that adaptation strategies are highly heterogeneous and structurally constrained, which aligns with several core theoretical paradigms. First, viewed through the lens of Absorptive Capacity (ACAP) Theory, the stark contrast in Measurement, Reporting, and Verification capabilities underscores a critical digital divide among the sectors. The Aluminum and Fertilizer sectors demonstrate robust absorptive capacity, successfully internalizing external regulatory demands into centralized digital carbon accounting systems. Conversely, the Iron & Steel and Cement sectors lack the dedicated financial capital and specialized infrastructure required to absorb and process complex emission data. This empirical divergence suggests that institutional awareness alone is insufficient; without the financial resource allocation to build an internal ACAP, heavy industries experience greater exposure to informational vulnerability.

Second, applying the Resource-Based View, the analysis of the Green Innovation pillar exposes a critical limitation in Vietnam's industrial transition. The data indicate a systemic preference for short-term, defensive innovation, such as substituting low-carbon raw materials rather than investing in core, hard-to-imitate technological overhauls. According to RBV principles, competitive advantage is sustained only through unique, non-substitutable resources. However, the current “compliance-driven” innovation strategy deployed by the heavier sectors focuses merely on meeting minimum EU thresholds. This superficial adaptation leaves these industries highly exposed to future tightening of the CBAM emission quotas, as they fail to cultivate a genuine green competitive advantage.

Third, the relative underperformance in Green Supply Chain Management compared to core operational capacities highlights a profound systemic fragmentation that extends far beyond the focal exporting enterprises. This structural weakness is systemic rather than incidental, and its depth can be explained by three interrelated factors that expose the limits of private carbon governance in emerging economies.

To begin with, unlike emissions measurement, reporting, and verification capacity or internal green innovation, which are largely bounded within the legal boundaries of the exporting firm and can be enhanced through direct capital investment, Green Supply Chain Management performance is inherently relational. It depends heavily on the willingness, technical capability, and digital infrastructure of upstream domestic suppliers to track and disclose embedded carbon data. The current dataset reveals that these upstream networks are predominantly composed of small and medium-sized enterprises characterized by limited carbon literacy and low capital allocation for environmental compliance. Because exporting firms possess neither the institutional leverage to mandate data transparency nor the financial mechanisms to subsidize supplier-level decarbonization, coordination failures accumulate at every tier of the domestic value chain, creating severe information asymmetries that undermine overall sectoral readiness.
Furthermore, the structural lag in supply chain integration is compounded by a major institutional deficit within the domestic regulatory environment. While internal emissions accounting and reporting capacities are partially anchored and incentivized by state regulatory frameworks such as Decree 06, Green Supply Chain Management in Vietnam currently operates without any comparable institutional scaffolding. In the absence of state-enforced domestic carbon-disclosure mandates, national green procurement standards, or eco-labeling requirements for industrial inputs, primary upstream suppliers face no localized compliance pressure. This institutional void removes any immediate economic incentive for suppliers to modernize their production processes, leaving exporting manufacturers to operate within an unaligned and carbon-intensive domestic ecosystem.

In tandem with these institutional gaps, this operational deficit is technically constrained by the profound administrative and financial complexities associated with tracing indirect upstream emissions, which are commonly classified as Scope 3 emissions under global carbon accounting protocols. Measuring embedded carbon across fragmented supply networks requires advanced life-cycle assessment methodologies, synchronized digital data exchanges, and verified primary data inputs. Even when exporting enterprises demonstrate strong internal compliance intentions, they lack the practical, cost-effective diagnostic tools to independently verify the carbon footprints of their suppliers. Consequently, the technical difficulty of Scope 3 accounting acts as a binding constraint that locks exporting industries into a state of structural vulnerability under cross-border environmental regulations.

The overarching consequence of this systemic fragmentation is that exporting enterprises are left to absorb cross-border regulatory shocks in complete isolation. In practice, a highly compliant, technologically advanced exporter can still be severely penalized at the European Union border with high default carbon values if its upstream suppliers fail to provide verifiable emissions records. This dynamic effectively transfers the entire compliance burden and financial liability downstream to the final exporter, regardless of that specific firm's internal operational readiness. Furthermore, this isolation dynamic creates a classic collective-action failure within the

industrial ecosystem. No individual exporting firm has a rational economic incentive to unilaterally invest in supply-chain-wide carbon governance, since the competitive benefits of a decarbonized value chain would be shared among multiple competitors while the substantial transactional costs are borne individually. This structural deadlock proves that institutional lag in developing countries cannot be resolved through isolated corporate initiatives, but represents a supply-chain-wide phenomenon that requires comprehensive, state-led ecosystem interventions.
Finally, the findings related to Perceived Compliance Cost redefine the primary threat of CBAM for low-margin industries. The high level of financial anxiety observed suggests that the immediate bottleneck may not be the theoretical cost of the carbon tax itself, but rather the exorbitant transaction and administrative costs associated with mandatory third-party international verification. This highlights a severe institutional vulnerability, demonstrating that heavy industries with massive economies of scale and thin profit margins are disproportionately penalized by the procedural frictions of cross-border environmental regulations. Ultimately, the MCDA benchmarking indicates that achieving high readiness likely requires a synchronized transformation combining digital MRV capacity, core technological innovation, and robust value-chain integration.

5.2. Implications

Drawing upon the structural vulnerabilities identified in the objective multi-criteria assessment, it is evident that surviving the CBAM transition requires moving beyond corporate awareness campaigns toward tangible, targeted macroeconomic interventions. The empirical data from the 134 export enterprises highlight specific bottlenecks in MRV capacity, green innovation, and supply chain integration, which necessitate immediate and structured policy responses.

First, bridging the macro-institutional gap through a centralized data infrastructure must be the immediate priority for policymakers. The severe deficits in MRV capacity, particularly within the heavy industries, stem directly from a lack of synchronized national support. The Vietnamese government, spearheaded by the Ministry of Natural Resources and Environment (MONRE), should urgently develop and mandate a localized, standardized emission factor database. Without a robust national grid emission factor and sector-specific baseline data, Vietnamese exporters risk being assigned artificially high default emission values by EU authorities, which would exponentially inflate their carbon tax liabilities. Additionally, accelerating the operationalization of the domestic carbon compliance market will enable enterprises to purchase and use domestic carbon credits for compliance, reducing their reliance on more expensive payments at the EU border.

Second, the state needs to deploy targeted financial instruments to alleviate perceived compliance costs and stimulate core green innovation. The empirical assessment highlights that the most severe perceived shock for the Iron & Steel and Cement sectors is the high cost of third-party international verification, coupled with a severe lack of capital for technological overhauls. To prevent these low-margin sectors from losing their export viability, the State Bank of Vietnam should establish specialized green credit funds offering preferential interest rates. Access to these funds must be strictly conditional on executing core, long-term technological transformations, such as transitioning to electric arc furnaces or implementing carbon capture technologies, rather than merely funding short-term material substitutions. In the immediate term, state-sponsored financial subsidies or co-funding mechanisms to help enterprises absorb the shock of international carbon auditing fees are highly recommended.

Third, and directly addressing the systemic green supply chain management fragmentation identified in the discussion section, where exporting enterprises were found to absorb regulatory shocks in isolation due to the absence of institutional scaffolding for supplier-level carbon disclosure, synchronizing supply chain governance through ecosystem-wide incentives is essential. Since green supply chain management emerged as the lowest-scoring criterion among the surveyed enterprises, policy frameworks must extend beyond the focal export firms to encompass the entire domestic value chain. The Ministry of Industry and Trade should incentivize the development of eco-industrial parks and mandate green public procurement standards. By providing tax incentives to upstream raw material suppliers who adopt cleaner production processes, policymakers can effectively synchronize carbon-reduction efforts across the economic ecosystem. Such measures directly target the collective-action problem underlying the supply chain gap. By socializing part of the cost of supply-chain-wide carbon governance through public incentives, individual exporters are no longer required to unilaterally absorb the full burden of coordinating supplier decarbonization. This holistic value chain integration is critical to mitigating the indirect emission penalties that export enterprises currently bear in isolation, thereby resolving the coordination failures of upstream suppliers and ultimately building a cohesive and resilient green industrial base in Vietnam.

5.3. Research Limitations and Future Directions

While providing a pioneering comparative framework, this study acknowledges certain limitations. Although the Entropy Weight Method eliminates subjective bias in calculation, its assigned weights are derived purely from the mathematical dispersion of the sample data, which may not fully align with the actual technical importance of each criterion. This structural concern is partially mitigated but not entirely eliminated by the robustness results demonstrated in the sensitivity analysis. Furthermore, the initial selection of indicators and the reliance on self-reported Likert-scale data inherently introduce a degree of subjectivity. This reliance on cross-sectional perceptual data captures the operational reality at a specific point in time but may not fully reflect long-term compliance capabilities. Finally, while the sample of 134 enterprises is adequate for sectoral aggregation, the final ranking is based on only four sectoral observations, serving as a descriptive benchmark rather than a fully generalizable inferential model. Future research should expand the sectoral scope, incorporate additional carbon-intensive industries beyond the four examined in this paper, and integrate longitudinal actual carbon intensity metrics to dynamically track green transition pathways over time.

6. Conclusion

This study systematically evaluated the readiness of Vietnam's major carbon-intensive export industries to comply with the European Union's Carbon Border Adjustment Mechanism.

Departing from traditional macroeconomic simulations, the research employed an Objective Multi-Criteria Decision Analysis framework integrated with the Entropy Weight Method to transform micro-level survey data from 134 enterprises into a preliminary data-driven sectoral benchmark.

The empirical findings reveal structural heterogeneity in adaptive capacity across the targeted sectors. The Aluminum and Fertilizer sectors exhibit a proactive adaptation trajectory, successfully translating institutional pressures into operational upgrades through stronger measurement, reporting, and verification frameworks and early-stage green innovations. Conversely, the Iron and Steel and Cement sectors rely more heavily on reactive compliance strategies, facing notable constraints in digital accounting deficits and the exorbitant financial burdens of third-party international verification. Furthermore, the relative lag in Green Supply Chain Management across most sectors exposes a critical systemic flaw, demonstrating that Vietnamese export enterprises are absorbing the regulatory shock in isolation and lack the integrated upstream ecosystem required to effectively control indirect emissions.

Theoretically, this study bridges a critical literature gap by demonstrating that firm-level intrinsic capacities, digital readiness, and structural financial vulnerabilities are just as decisive in determining compliance as macro-level trade exposure. Practically, the findings underscore that surviving this cross-border environmental barrier requires shifting from mere corporate awareness to tangible macroeconomic interventions. Policymakers must prioritize the development of a localized emission factor database, deploy targeted green credit funds conditional on core technological overhauls, and establish supply-chain-wide eco-industrial incentives.

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