

The Operational Impacts of Carbon Border Adjustment Mechanism on Vietnamese Steel Export

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Abstract— The European Union officially introduced the Carbon Border Adjustment Mechanism (CBAM) on May 10, 2023, marking a pivotal development in global efforts to address carbon leakage and promote sustainable trade. Scheduled to take effect in 2026, the mechanism will apply carbon-based costs to imported goods, compelling exporting countries such as Vietnam to reduce emissions and adopt greener technologies to remain competitive. CBAM places considerable pressure on industries with high carbon intensity, particularly the steel sector. This study employs a quantitative approach using a partial equilibrium model to forecast export of Vietnam's steel industry through 2030 and 2035. The results indicate that while CBAM can accelerate the transition toward clean energy, in the meanwhile it may also lead to a sharp decline in steel exports to the EU. Consequently, the research proposes a set of technological innovations, policy adjustments, and long-term strategic measures to support the sustainable adaptation of Vietnam's steel industry under the evolving European carbon framework.

Keywords— CBAM, carbon pricing, steel exports, green transition, Vietnam, European union.

I. INTRODUCTION

In the contemporary global landscape, climate change and greenhouse gas emissions pose significant obstacles to global sustainable development, compelling nations to undertake a green transition to attain carbon neutrality by the mid-21st century. In this context, the European Union (EU) has initiated the Carbon Border Adjustment Mechanism (CBAM) - a mechanism established to avert "carbon leakage," maintain equitable competition, and advance global environmental norms [1], [2].

The steel industry is particularly impacted because to its significant emissions and its status as a crucial export commodity for numerous economies, including Vietnam [3], [4]. Steel exports to the EU represent a substantial share, and the implementation of CBAM presents Vietnam with both opportunities and challenges: the opportunity to advance technological innovation, transition to sustainable production methods, conserve energy, and mitigate greenhouse gas emissions; concurrently, it poses a significant challenge as businesses confront elevated clean technology investment costs and the potential for diminished profits or loss of market share due to carbon tax obligations.

CBAM represents not merely a challenge but also a significant impetus for Vietnam to enhance its domestic carbon market, broaden sustainable trade collaboration with the EU, and assert its proactive role in the transition to a global green economy. participant in the transition to a global

green economy, aiding in the creation of a sustainable and low-carbon future [5], [6].

The topic "The operational impacts of the EU's carbon border adjustment mechanism on Vietnamese steel export" was chosen to address the deficiency in academic research regarding CBAM in Vietnam. It aims to furnish scientific and practical insights to assist steel enterprises, industry associations, and governmental agencies in formulating effective adaptation strategies, preserving competitive advantages, and advancing sustainable development amid profound international economic integration.

The remainder of this paper is structured as follows: Section 2 provides a comprehensive review of the relevant theoretical foundation of CBAM and carbon pricing. Section 3 describes the research methodology, including the model, data sources, and analytical techniques. Section 4 reports the empirical results and key findings of the analysis. Section 5 proposes feasible policy recommendations to support Vietnam's steel industry in adapting to CBAM and advancing toward green and sustainable development.

II. CARBON BORDER ADJUSTMENT MECHANISM AND CARBON PRICING

- The Carbon Border Adjustment Mechanism (CBAM) is the EU's tool to put a fair price on carbon emitted during the production of carbon-intensive goods that are entering the EU, and to encourage cleaner industrial production in non-EU countries (Taxation and Customs Union) [7]. The CBAM operates through a system of purchasing and surrendering emission certificates corresponding to the quantity of greenhouse gases embedded in imported products. Importers subject to the CBAM are required to register with the competent authorities to obtain CBAM certificates, which are priced in alignment with the European Union Emissions Trading System (EU ETS). These certificates serve as a mechanism for importers to declare and offset the carbon emissions associated with their imported goods (Ministry of Industry and Trade of Vietnam) [8], [13].
- Carbon pricing is an instrument that captures the external costs of greenhouse gas (GHG) emissions - the costs of emissions that the public pays for, such as damage to crops, health care costs from heat waves and droughts, and loss of property from flooding and sea level rise - and ties them to their sources through a price, usually in the form of a price on the carbon dioxide (CO₂) emitted [9], [12].

Simplify, carbon pricing is a mechanism that requires companies to pay a certain amount in accordance with the amount of carbon they emit into the environment during their production and business operations. The government will not be required to employ coercive instruments; rather, it will establish a market mechanism for emission facilities to operate [10].

III. METHODOLOGY

The research employs a quantitative methodology to accurately assess the impact of CBAM on the Vietnamese steel industry. Insufficient research exists in the country about the relationship between CBAM, carbon pricing, and steel exports, accompanied by a lack of unambiguous quantitative analysis. A modeling method is required to establish more robust scientific evidence. The quantitative method can be employed to predict future outcomes, particularly for the pivotal years of 2030 and 2035. The research may statistically assess potential changes in Vietnam's steel export patterns influenced by CBAM and establish a basis for advocating adaptable technological and regulatory measures.

The partial equilibrium model is utilized to examine the steel market in Vietnam, distinguishing it from the general equilibrium model by concentrating just on the steel sector. This model includes various technologies, namely basic oxygen blast furnaces (BF-BOF) and electric arc furnaces (EAF), which demonstrate considerable differences in CO₂ emissions. Data regarding steel trade is initially sourced from the ITC Trade Map, an international trade database that provides statistics on steel production and imports by market.

IV. RESEARCH RESULTS

Vietnam is presently the biggest steel-producing nation in Southeast Asia and holds the 12th position [18], with an average output of around 27 million tons per year from 2019 to 2023 [19]. During this time, Vietnam's crude steel output saw an average growth rate above 10% per year, whilst worldwide steel production increased by around 3.6% per year, showing Vietnam's progressively significant role in the global steel sector.

Vietnam actively engages in the international trading of steel goods subject to CBAM. According to data from the Trade Map Database, in the period 2019-2023, Vietnam exported steel to 123 countries and imported it from 84 countries, with 79 of them being bilateral partners. In those five years, the total volume of steel exported amounted to around 8.6 million tons, with an average annual value of 7.6 billion USD. The European Union constitutes around 23% of the overall export value and is the market profoundly affected by the CBAM mechanism [15], [16], [17].

In terms of production technology, the Vietnamese steel industry is now primarily utilizing two primary production technologies. These technologies are the blast furnace-oxygen furnace (BF-BOF) and the electric arc furnace (EAF). The BF-BOF technology is a conventional approach that is primarily dependent on coal [20]. As a result, the emissions of greenhouse gases are higher than those produced by EAF

technology, which is a technique that employs electricity to heat raw materials. In the world, BF-BOF technology accounts for about 71.1% of steel production [21]. While in the EU, this percentage is around 55.2%, the remaining portion is produced by EAF [22] [11].

The effect estimates of CBAM and its combination with carbon pricing are obtained by contrasting the baseline (BAU) scenario, which does not involve any policy modifications, with the scenario that incorporates the policy. This study contends that the BAU scenario forecasts the Vietnamese steel industry, including the entire production technology sector, to grow at an average rate of 10% annually. This growth rate is consistent with data from the World Steel Association for 2019 to 2023. The average annual steel production in Vietnam from 2019 to 2023 is approximately 17.8 million tons. According to this assumption, business-as-usual (BAU) production by 2030 is expected to be approximately 51 million tons. This figure includes 46 million tons generated by Blast Furnace-Basic Oxygen Furnace (BF-BOF) technology and 5 million tons produced by Electric Arc Furnace (EAF). Business-as-usual output is anticipated to reach approximately 81.8 million tonnes by 2035. This figure includes 73.6 million tonnes from blast furnace-basic oxygen furnace and 8.2 million tonnes from electric arc furnace. The policy impact is evaluated by comparing the economic repercussions of the BAU scenario with those of the CBAM-plus scenario, as well as the plus scenario, which concurrently levies carbon domestically. Table's parameter table offers a thorough summary of the pertinent assumptions and hyperparameter ranges.

The table below provides a summary of the anticipated effects of the Carbon Border Adjustment Mechanism (CBAM) on the entire industry and each steel production technology (BF-BOF and EAF) at two distinct time points: 2030 and 2035. The government has established a goal to reverse the increasing trend of greenhouse gas emissions by 2035, which means that emissions must peak and then progressively decline to reach equilibrium by 2050. These are important steps in Vietnam's roadmap toward its goal of net-zero emissions by 2050. The findings indicate that the steel industry's production, exports, domestic consumption, imports, emissions, and financial obligations will be significantly affected by CBAM.

The BF-BOF technology is the most affected in terms of output, with an average decrease of 0.8 million tons in 2030 (1.8% compared to the BAU scenario, CI = [0.2%; 2.8%]) and 1.4 million tons in 2035 (1.9%, CI = [0.2%; 2.9%]). In contrast, the output of EAF decreased by a mere 0.2 million tons in 2030 (1.0%, CI = [0.1%; 1.8%]) and 0.1 million tons in 2035 (1.1%, CI = [0.1%; 1.9%]). In general, the industry's total production is expected to decrease by 0.9 million tons by 2030 (1.7%, CI = [0.2%; 2.7%]) and by 1.5 million tons by 2035 (1.8%, CI = [0.2%; 2.8%]).

In terms of exports, CBAM has a substantial impact on the EU, particularly for BF-BOF. The value of exports to this market is expected to decrease by nearly 87% by 2030 (approximately USD 1.6 billion) and by nearly 89% by 2035 (USD 2.7 billion). The impact also extends to EAF, which

experiences a 45.7% decrease in 2030 (USD 0.1 billion) and a 49.5% decrease in 2035 (USD 0.2 billion). Nevertheless, exports to non-EU markets exhibit a modest increase, with BF-BOF increasing by 2.6% (\$0.4 billion) in 2030 and 2.7% (\$0.7 billion) in 2035, and EAF increasing by 1.6% (\$0.1 billion) and 1.7% (\$0.1 billion) during the same period.

Nevertheless, this increase is insufficient to counteract the EU's decline, resulting in a 6.0% decrease in the total export value of the entire industry in 2030 (equivalent to 1.2 billion USD, CI = [4.0%; 7.2%]) and a 6.2% decrease in 2035 (2.1 billion USD, CI = [4.1%; 7.4%]).

TABLE 1: Effects of CBAM on Vietnam's steel export

	Unit	BF-BOF		EAF		Total	
		2030	2035	2030	2035	2030	2035
Production quantity	(%)	-1.8 [-2.8 : 0.2]	-1.9 [-2.9 : 0.2]	-1.1 [-1.8 : 0.1]	-1.1 [-1.9 : 0.1]	-1.7 [-2.7 : 0.2]	-1.8 [-2.8 : 0.2]
	million tonnes	-0.8 [-1.3 : 0.1]	-1.4 [-2.1 : 0.1]	-0.1 [-0.1 : 0.0]	-0.1 [-0.2 : 0.0]	-0.9 [-1.4 : 0.1]	-1.5 [-2.3 : 0.1]
Total export	(%)	-6.3 [-7.5 : -4.2]	-6.5 [-7.7 : -4.3]	-3.2 [-4.6 : -1.8]	-3.5 [-4.9 : -2.1]	-6.0 [-7.2 : -4.0]	-6.2 [-7.4 : -4.1]
	billion USD	-1.2 [-1.4 : -0.8]	-2.0 [-2.3 : -1.3]	-0.1 [-0.1 : 0.0]	-0.1 [-0.2 : -0.1]	-1.2 [-1.5 : -0.8]	-2.1 [-2.5 : -1.4]
Export to EU	(%)	-86.3 [-97.1 : -62.5]	-88.7 [-98.1 : -66.5]	-45.7 [-62.7 : -24.0]	-49.5 [-67.1 : -26.6]	-82.1 [-93.6 : -58.5]	-84.7 [-94.9 : -62.3]
	billion USD	-1.6 [-1.8 : -1.2]	-2.7 [-3.2 : -2.0]	-0.1 [-0.1 : 0.1]	-0.2 [-0.2 : 0.1]	-1.7 [-2.0 : -1.2]	-2.9 [-3.2 : -2.1]
Export to non-EU	(%)	2.6 [0.7 : 5.8]	2.7 [0.7 : 5.9]	1.6 [0.3 : 3.7]	1.7 [0.3 : 4.0]	2.5 [0.6 : 5.6]	2.6 [0.7 : 5.7]
	billion USD	0.4 [0.1 : 1.0]	0.7 [0.2 : 1.6]	0.1 [0.0 : 0.1]	0.1 [0.0 : 0.1]	0.5 [0.1 : 1.1]	0.8 [0.2 : 1.7]
Domestic consumption	(%)	1.9 [0.7 : 3.7]	2.0 [0.8 : 3.9]	0.8 [0.2 : 1.7]	1 [0.2 : 1.9]	1.8 [0.7 : 3.5]	1.9 [0.7 : 3.6]
	million tonnes	0.5 [0.2 : 0.9]	0.8 [0.3 : 1.5]	0.0 [0.0 : 0.0]	0.0 [0.0 : 0.1]	0.5 [0.2 : 1.0]	0.8 [0.3 : 1.6]
Import Value	(%)					-0.8 [-1.9 : 0.1]	-0.8 [-2.0 : 0.1]
	billion USD					-0.1 [-0.6 : 0.6]	0.0 [-0.6 : 0.6]
Emission Amount	(%)	-1.8 [-2.8 : -0.2]	-1.9 [-2.9 : -0.2]	-1.0 [-1.8 : -0.1]	-1.1 [-1.9 : -0.1]	-1.8 [-2.8 : -0.2]	-1.9 [-2.9 : -0.2]
	million tonnes	-1.9 [-3.0 : -0.2]	-3.2 [-5.0 : -0.3]	-0.1 [-0.1 : 0.0]	-0.1 [-0.1 : 0.0]	-2.0 [-3.1 : -0.2]	-3.3 [-5.1 : -0.3]
CBAM Payment	million USD	52 [11 : 142]	77 [13 : 229]	6 [4 : 9]	11 [7 : 15]	58 [15 : 150]	88 [20 : 245]

Note: Mean values are presented outside parentheses, while 95% confidence intervals are indicated within parentheses. At present, Vietnam does not categorize imported steel based on technology.

This decrease in exports concurrently resulted in a transition toward the domestic market. Domestic consumption of BF-BOF increased by USD 0.19 billion (1.9%) in 2030 and USD 0.2 billion (2.0%) in 2035, while EAF also increased by USD 0.08 billion (1.9%) and USD 0.1 billion (2.0%) during the same period. This will result in a 1.8% increase in total domestic consumption within the industry by 2030 and a 1.9% increase by 2035. In the interim, steel imports are expected to experience a modest decline as a result of competition from domestic goods. This decline is expected to be approximately 0.8% by 2030 and 0.6% by 2035 (USD 0.1 billion).

CBAM contributes to the reduction of greenhouse gases by reducing emissions. BF-BOF is expected to decrease by 1.8% (1.9 million tons) in 2030 and 1.9% (3.2 million tons) in 2035,

while EAF is expected to decrease by 1.0% (0.1 million tons) and 1.1% (0.1 million tons) at the two corresponding milestones. In general, it is anticipated that emissions in the total sector will decrease by 1.8% (2.0 million tons) by 2030 and 1.9% (3.3 million tons) by 2035. It is important to note that the emission reduction is marginally greater than the production decline as a result of the structural transition from high-emission to low-emission technologies.

Furthermore, the financial obligations of CBAM are a substantial burden, as Vietnamese steel companies are required to pay USD 52 million in 2030 and USD 77 million in 2035 for BF-BOF, whereas EAF only costs approximately USD 6 million and USD 11 million in the corresponding

years. We anticipate that the entire industry will distribute 58 million USD in 2030 and 88 million USD in 2035.

In conclusion, CBAM significantly impacts the steel industry in Vietnam, particularly in the area of BF-BOF technology. Production, exports, and costs have decreased as a result. Nevertheless, it also stimulates the transition to EAF technology and the domestic market, thereby promoting the objective of achieving net-zero emissions by 2050 and contributing to emissions reduction.

The findings of the simulation in Table indicate that the Vietnamese steel industry's production, trade, and emissions have experienced substantial fluctuations during the 2030-2035 period because of the concurrent implementation of a domestic carbon pricing mechanism and the EU CBAM. In 2030, the production output of BF-BOF technology increased slightly by 1.394% (95% CI = [1.320:1.467]), but it decreased to only 0.992% in 2035 (95% CI = [0.916:1.069]), which is equivalent to approximately 0.379-0.383 million tons of steel. The growth momentum of 9,168% in 2035 (95% CI = [9,088:9,248]) is maintained by EAF production, which increases by 1,117% in 2030 (95% CI = [1,040:1,193]). This demonstrates the advantages of electric arc furnace technology during periods of high carbon costs. Production is anticipated to increase by 0.91% in 2030 and 0.54% in 2035 for the complete industry, which corresponds to an increase of approximately 0.64 million tons of steel. Therefore, carbon pricing policies do not decrease the total output; rather, they promote a gradual transition from BF-BOF to EAF technology, which is in accordance with the long-term objective of reducing emissions.

The total export value of BF-BOF decreased by -0.979% in 2030 and -4.268% in 2035, while EAF experienced a smaller decrease (-0.222% and -2.891%) in terms of exports. The total export value of the entire industry decreased by -0.66% in 2030 and -30.89% in 2035, which is equivalent to a decrease of approximately 0.52-0.50 billion USD. This demonstrates that the efficacy of Vietnamese steel in the international market is diminished by the domestic carbon price. The direct impact of CBAM is evident in the significant decrease in exports to the EU, which was -348.7% in 2030 and -583.0% in 2035. This is due to the fact that products are subject to double carbon costs, both domestically and from the EU. Concurrently, exports to non-EU markets experienced a decrease, albeit less pronounced, with BF-BOF exports decreasing by -1.996% and -4.786%, and EAF exports decreasing by -0.017% and -2.237%. In 2030, the value of non-EU exports decreased by -10.31%, and in 2035, it decreased by -40.32%.

The increase in domestic steel prices and the resulting increase in production costs have a double impact on domestic consumption. Domestic consumption for BF-BOF decreases by -1.516% and -3.548% in 2030 and 2035, respectively, while EAF decreases by -0.973% and -0.982%. The total reduction for the entire industry was -10.32% in 2030 and -30.48% in 2035, which corresponds to a decrease of approximately 1-3.5 million tons in domestic steel consumption. In contrast, the demand for imports was marginally increased by the escalating costs of domestic

production, resulting in a slight increase in import values. The total import value increased by 40.23% in 2030 and 50.16% in 2035, resulting in a total of approximately 0.254 billion USD. The combined policy produces favorable outcomes with respect to emissions. BF-BOF reduces emissions by -1.357% in 2030 and -0.937% in 2035, while EAF experiences a modest increase as a result of scaling up. The total industry emissions decreased by -1.04% in 2030 and -0.51% in 2035, which is equivalent to -0.47 to -0.52 million tons of CO₂. This downward trend in emissions is evident, albeit modest.

When Vietnam implements domestic carbon pricing, the CBAM cost that is owed to the EU is nearly eliminated. Implementing domestic carbon pricing substantially reduces the burden of export costs. CBAM obligations for BF-BOF and EAF decrease by -99.62% in 2030 and -180.09% in 2035, and by -97.06% and -176.42%, respectively. In total, Vietnam will be required to pay an estimated -2.612 billion USD in 2030 and -3.880 billion USD in 2035, which represents a reduction of over 99% when contrasted with the single CBAM scenario. In contrast, the financial advantages generated by domestic carbon pricing mechanisms are substantial. The total domestic carbon revenue collected is expected to reach USD 1.162 billion in 2030 and USD 1.183 billion in 2035, thereby enabling Vietnam to retain revenue that would otherwise be transferred to the EU. High-emission BF-BOF facilities provide the majority of this funding, offering a chance to reinvest in green technology and boost competitiveness.

In conclusion, the combined impact of "CBAM and domestic carbon pricing" is analyzed and evaluated, and it is evident that there is a positive trend toward technological structural transformation, a minor reduction in emissions, and an increase in carbon revenue for the budget. Nevertheless, it also results in a substantial decrease in domestic consumption and exports. Vietnam must achieve a balance between emission reduction objectives and economic growth by reinvesting revenue from carbon pricing into low-emission technology transitions, supporting exporting businesses, and adjusting carbon pricing levels to align with the industry's capacity.

Vietnam's steel exports are undergoing a transformation, which suggests that the market is becoming more diverse and adaptable. Commodities primarily travel to the ASEAN region, which accounts for nearly 26% of total exports. The European Union (EU) is the second greatest market, representing approximately 23% of total exports. Nevertheless, it is challenging for steel shipments to the EU to adhere to environmental regulations. This data suggests that Vietnamese enterprises are becoming more inclined to transition across markets while simultaneously prioritizing ASEAN. Taiwan, India, and the United States have regulations that are less stringent than those of the European Union [14].

In countries such as Vietnam that export products to other nations, the CBAM strategy may not perform as anticipated in the medium term. CBAM is not promoting the advancement of new technologies; rather, it is redirecting trade flows. Companies strive to generate revenue in regions that are more easily accessible, including the United States, India, Taiwan,

and ASEAN. In the end, such actions could potentially delay the transition of Vietnam's steel industry to a more sustainable environment. It emphasizes the importance of low-carbon industrial finance and ecological credit systems in order to promote investment.

V. POLICY IMPLICATIONS

Based on these results, some feasible policy solutions are proposed:

For innovation in production technology:

Firstly, allocate resources towards advanced technologies and transition to electric arc furnaces (EAFs) to mitigate CO₂ emissions. Advocate for the adoption of renewable energy and automation to enhance efficiency, lower expenses, and bolster competitiveness. Secondly, progressively phase out coal and transition to clean, sustainable energy sources such as solar, wind, or hydropower. This technology mitigates CO₂ emissions, decreases CBAM expenses, and enhances the competitiveness of the Vietnamese steel sector in the global market.

For environment and carbon:

Firstly, technological and managerial strategies for enhancing energy efficiency must be aligned. Companies should invest in new technology, automation, renewable energy consumption, and the implementation of the ISO 50001:2018 energy management system. Secondly, enhance the utilization of renewable energy in steel production by investing in solar, wind, and biomass power initiatives inside industrial zones. Thirdly, sustain low carbon pricing over the next five years to facilitate corporate transformation and mitigate the effects of CBAM. Fourthly, subsequent to this period, the carbon price ought to be modified to align with the EU ETS price to minimize CBAM cost risks and promote the development of a low-carbon economy.

For trade and markets:

Firstly, expand information availability and update CBAM legislation so that Vietnamese steel businesses may properly adapt. The State must establish a centralized consultation framework, offer technical support, and direct firms to comply with EU import criteria. Secondly, enhance bilateral and multilateral discussions with the EU to mitigate the adverse effects of CBAM on the Vietnamese steel sector. Vietnam must promote a transition plan, establish technical assistance structures, and collaborate with developing nations to achieve equitable and transparent trade. Thirdly, diversifying export markets enables the Vietnamese steel sector to mitigate its reliance on the EU and the associated risks from CBAM. Expanding into prospective markets such as Asia, the Middle East, Africa, and South America is essential for enhancing growth chances and stabilizing exports.

VI. CONCLUSION

The Carbon Border Adjustment Mechanism (CBAM) and domestic carbon pricing strategies are essential instruments for fostering green growth and sustainable development. In

Vietnam, particularly within the steel industry - a sector characterized by high emissions - these rules impose significant pressure on enterprises to innovate their technology and production methodologies.

The research findings from 2019 to 2023 indicate that CBAM significantly reduces Vietnam's steel exports, particularly those utilizing blast furnace (BF-BOF) technology, but exports from enterprises employing electric furnace (EAF) technology exhibit a minor increase. Nonetheless, the conversion rate remains constrained by substantial investment expenses and insufficient financial and technological assistance. The integration of CBAM with domestic carbon costs exacerbates the adverse effects, highlighting the apathy of Vietnamese enterprises regarding the global trend towards sustainability.

The government must formulate measures to stimulate green investment, lower funding costs, and enhance international collaboration in the transfer of clean steel technology. Organizations must actively innovate, invest in low-emission manufacturing processes, and ensure transparency in carbon data.

Research is constrained by the absence of comprehensive enterprise-level data and the inability to quantify technology conversion expenses. Subsequent research should establish a micro-database, evaluate the costs and advantages of green conversion, and model the effects of supportive policies such as carbon taxes or green credits, ultimately offering targeted recommendations for the sustainable advancement of Vietnam's steel sector.

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