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The potential effects of the implementation of the carbon border adjustment mechanism - the case of Indonesia

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ABSTRACT

The Carbon Border Adjustment Mechanism (CBAM) is one of the European Union's most ambitious climate-related trade initiatives, designed to reshape global industrial competitiveness well beyond Europe's borders. Despite its significance, empirical evidence on its economic impacts, particularly on partner countries such as Indonesia, remains limited. This study aims to address two objectives: first, to examine the potential effects of CBAM tariffs on the Gross Domestic Product (GDP) of EU trading partners; and second, to assess their implications for trade flows, sectoral adjustment, investment, and employment in Indonesia. Employing a Computable General Equilibrium (CGE) framework with the Global Trade Analysis Project Recursive Dynamic (GTAP-RD) model, the analysis provides evidence-based insights into how CBAM may reverberate through the Indonesian economy. The results show that while aggregate effects on partner countries' GDP are negligible, sectoral and distributional consequences are much more pronounced. In Indonesia, carbon-intensive industries, particularly iron and steel, face considerable adjustment pressures through declining labor demand and structural reallocation, whereas other sectors remain relatively resilient. This suggests that CBAM functions less as a macroeconomic shock than as a catalyst, exposing the vulnerability of specific industries to low-carbon trade regimes. These findings enrich ongoing policy debates by demonstrating that modest aggregate outcomes can mask substantial sectoral disruptions. For the EU, the study clarifies CBAM's external ramifications, while for Indonesia, it underscores the urgency of adaptive strategies, from technological upgrading to labor market policies, to transform potential risks into opportunities for sustainable industrial development.

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1. Introduction

Climate change is a global collective-action problem that requires joint efforts across entire economies and credible cross-border coordination (Zhu et al., 2016; Bonneuil et al., 2021; Mooris et al., 2023). In this regard, the European Union (EU) has positioned itself as a frontrunner in climate governance, most notably through the “Fit for 55” package, which aims to reduce greenhouse gas emissions by 55 % by 2030. As part of this package under the European Green Deal, the Carbon Border Adjustment Mechanism (CBAM) is one of the most recent and far-reaching policy instruments in the EU’s climate architecture.

In its primary legislation, Regulation (EU) 2023/956, and official communications, the EU explicitly frames CBAM as a climate measure to address the risk of carbon leakage and to ensure a level playing field by requiring that imports of selected carbon-intensive goods bear a carbon cost equivalent to that faced by EU producers under the EU Emissions Trading System (EU ETS). On October 1, 2023, CBAM transitioned into a phase of transitional reporting, and it will implement financial adjustments beginning in 2026, as outlined in Implementing Regulation (EU) 2023/1773. CBAM, in its conceptual framework, does not operate as a conventional tariff but rather functions as a mechanism for equalizing carbon prices.

In the transitional phase (2023–2025), importers are obligated to report embedded emissions. In the definitive phase, importers must surrender CBAM certificates priced in accordance with EU ETS allowances, with deductions for any explicit carbon price that has already been paid in the country of origin. The initial scope encompasses goods in sectors that are susceptible to carbon leakage, including iron and steel, cement, fertilizers, aluminum, hydrogen, and electricity. These design features demonstrate that CBAM is intended both to advance climate ambition and to address carbon leakage risks while remaining consistent with WTO rules (Demarest, 2023; Emily et al., 2023).

The effectiveness of this policy is still debated by the EU Parliament and the Commission, to formulate a detailed treatment. While CBAM is officially presented as a climate measure, others perceive it as disguised industry protection (Krenek et al., 2020; RECAP, 2021) or as a device to support EU competitiveness (Korpar et al., 2023). Also, there have been scholars who have highlighted that CBAM has implications concerning distributional consequences for developing and lower-income exporters (Babiker and Rutherford, 2005; Feindt et al., 2021; Tero et al., 2020;).

A growing body of literature has begun to evaluate the macro- and meso-level effects of CBAM on various economic indicators, including GDP, trade, sectoral structure, investment, employment, and welfare (see Korpar et al., 2023; Lim et al., 2021; Mattoo et al., 2012; Perdana and Vielle, 2022; Sun et al., 2023; Tarr et al., 2023; Xiaobei et al., 2022).

The existing literature frequently indicates that, while aggregate impacts are often negligible, distributional impacts can be modestly deleterious for exporters (Mattoo et al., 2012; Sun et al., 2023; Xiaobei et al., 2022). These impacts manifest in the form of modest GDP and welfare losses, trade and output reallocation with associated welfare costs (Huang et al., 2022; Martinus and Laopirun, 2023; Mealy and Teytelboym, 2022; Zhang et al., 2019), and reductions in global emissions accompanied by adverse trade effects (Mehling et al., 2019; McKibbin et al., 2018; Ameli et al., 2021; Perdana and Vielle, 2023). Several studies have reported limited average impacts, yet considerable sectoral exposure has been observed. This finding is consistent with the CGE meta-evidence that border adjustments can reduce leakage while shifting welfare from implementers to others (Acar et al., 2022; Böhringer et al., 2012;).

Indonesia is commercially exposed given its substantive trade ties with the EU, one of its top five partners in recent years. In 2020, the EU was Indonesia’s fourth-largest trading partner; conversely, Indonesia ranked as the EU’s 31st global partner and fifth within ASEAN (EEAS, 2023; Lord, 2010). We note that these rankings vary over time, with some recent statistics placing the EU as Indonesia’s fifth-largest partner. At first glance, the relatively minor shares of CBAM-covered exports in the EU market, aluminum $\leq$0.10 %, iron and steel $\leq$0.41 %, fertilizers $\approx$0.00 %, cement $\approx$0.00 % (ITC, 2017–2021), might suggest that Indonesia is only marginally exposed. However, aggregate macro figures can mask sectoral and regional adjustments for energy- and emission-intensive, trade-exposed industries (EITE). Moreover, the EU functions as a global rule-maker, the so-called “Brussels Effect”, whereby its regulatory standards diffuse across supply chains and jurisdictions (Bradford, 2012). Consequently, the avoidance of CBAM is not a viable strategy for Indonesia, as reputational and compliance risks may spill over to other export lines beyond CBAM-covered goods.

Existing evidence on CBAM’s implications for Indonesia is limited. Ramadhani and Koo (2022) contrast border adjustments with a domestic carbon tax and report small global-emissions gains but negative trade and output effects in exposed economies. Korpar et al. (2023) provide cross-country simulations and estimate modest but negative effects for Indonesia’s exports (−0.1866 %) and GDP (−0.0149 %), along with a welfare decline (−0.0136 %). While such aggregate declines may appear modest, their sectoral and employment implications are significant. Moreover, Korpar’s analysis is cross-country and aggregated, whereas this study provides a country-specific, sector-level, and dynamic perspective.

Our analysis advances this literature by focusing explicitly on Indonesia, calculating embedded carbon at the sectoral level, and implementing CBAM-consistent shocks in a recursive-dynamic CGE model (GTAP-RD). This design produces more detailed and forward-looking insights into GDP, trade, and especially sectoral employment adjustments. As a result, it strengthens the case for an Indonesia-specific assessment despite small macro shares. This article is therefore not a general review of CBAM developments but an Indonesia-specific, policy-oriented assessment of exposure, vulnerability, and prospective adjustments under stylized CBAM scenarios.

The paper pursues two aims: (i) to estimate the potential effects of CBAM-type charges on non-EU partners’ GDP and (ii) to examine Indonesia’s prospective adjustments in trade, sectoral allocation, investment, and employment. The contribution is twofold: providing current, policy-relevant magnitudes for Indonesia and benchmarking partner-country exposure while acknowledging scenario and data caveats typical of global CGE analysis.

2. Methods

This study employs a Computable General Equilibrium (CGE) framework using the Global Trade Analysis Project Recursive Dynamic (GTAP-RD) model to estimate the potential effects of the CBAM. The GTAP-RD model is an extension of the standard GTAP comparative-static framework by incorporating recursive dynamics, capital accumulation, and international capital mobility. This enables the analysis of both short- and long-run adjustments in response to policy shocks. It is particularly well-suited to CBAM analysis because it explicitly links year-to-year equilibria through investment and capital stock updates, while allowing exogenous drivers such as population, labor force, and technology to evolve (Aguiar, Corong and van der Mensbrugghe, 2020; Ianchovichina and McDougall, 2000). The overall design of the analytical approach, including data inputs, the modeling framework, and expected outputs, is summarized in Fig. 1.

The empirical foundation of the study is the GTAP 10A Database, which uses 2016 as its benchmark year and provides globally consistent input–output accounts, bilateral trade, and protection data (Aguiar et al., 2019). In its default form, the GTAP 10A Database contains 141 countries/regions and 65 sectors/industries. For tractability, these were aggregated into 16 regions (Table 1) and 35 sectors (Table 2), explicitly preserving CBAM-relevant industries such as iron and steel, aluminum, cement, fertilizers, hydrogen, and electricity. This aggregation reduces computational complexity while ensuring that the key energy- and emission-intensive, trade--exposed (EITE) sectors remain disaggregated for policy relevance.

The GTAP model relies on several core assumptions, such as perfect competition, constant returns to scale, and the Armington assumption (Armington, 1969; Bajzik et al., 2020; Devarajan et al., 2023; Francois, 1998; Hertel, 2013;). Perfect competition implies many firms producing homogeneous products, price-taking behavior, and unrestricted market entry and exit. Constant returns to scale mean that if all inputs are increased by a certain percentage, the output rises by the same percentage, with no scale effects. The Armington assumption, meanwhile, treats goods from different countries as imperfect substitutes, which is central to the way GTAP models international trade flows. While these assumptions simplify the analysis and facilitate global consistency, they may not capture all real-world complexities.

The initial effects of carbon pricing on Indonesia's industrial structure were first assessed using micro-simulations based on the

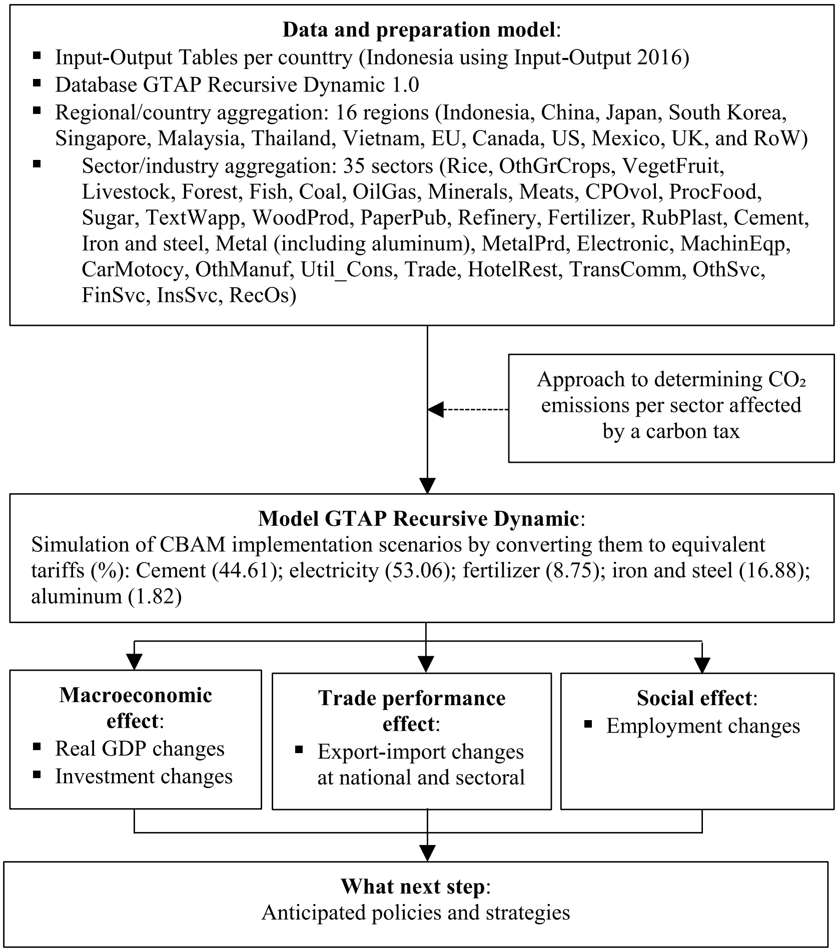

Fig. 1. Analytical framework: Data, model, and scope of analysis.

Table 1
Country and regional aggregation in the GTAP RD model.

No	Regional Aggregation (Code)	Regional aggregation in GTAP RD (Description)
1	RoW	Rest of World
2	Chn	China
3	Rasia	Rest of Asia
4	Jpn	Japan
5	Kor	South Korea
6	Rsea	Rest of Southeast Asia
7	Idn	Indonesia
8	Mal	Malaysia
9	Sgp	Singapore
10	Thai	Thailand
11	VIET	Vietnam
12	Canada	Canada
13	USA	United State
14	Mexico	Mexico
15	EU	European Union 27
16	UK	United Kingdom

Table 2
Sectoral aggregation in the GTAP RD model.

No	Sectoral Aggregation (Code)	Sectoral aggregation in GTAP RD (Description)
1	Rice	Paddy rice
2	OthGrCrops	Wheat, Cereal grains nec, Oil seeds, Sugar cane, sugar beet, Plant-based fibers, Crops nec
3	VegetFruit	Vegetables, fruit, nuts
4	Livestock	Bovine cattle, sheep and goats, Animal products nec, Raw milk, Wool, silk-worm cocoons
5	Forest	Forestry
6	Fish	Fish
7	Coal	Coal
8	OilGas	Oil, Gas
9	Minerals	Minerals nec
10	Meats	Bovine meat products, Meat products nec
11	CPOvol	Vegetable oils and fats
12	ProcFood	Dairy products, Processed rice, Food products nec, Beverages, and tobacco products
13	Sugar	Sugar
14	TextWapp	Textiles, Wearing apparel, Leather products
15	WoodProd	Wood products
16	PaperPub	Paper products, publishing
17	Refinery	Petroleum, coal products
18	Fertilizer	Chemical products, Basic pharmaceutical products
19	RubPlast	Rubber and plastic products
20	Cement	Cement products nec
21	Iron and steel	Iron products nec
22	Metal (incl. aluminum)	Ferrous metals, Metals nec, Metal products
23	MetalPrd	Metal products
24	Electronic	Computer, electronic, and optical, Electrical equipment
25	MachinEqp	Machinery and equipment nec
26	CarMotocy	Motor vehicles and parts, Transport equipment nec
27	OthManuf	Manufactures nec
28	Util_Cons	Electricity, Gas, manufacturing, distribution, water, and construction
29	Trade	Trade
30	HotelRest	Accommodation, food, and service
31	TransComm	Transport, nec, water transport, air transport, and communication
32	OthSvc	Warehousing and support activities, Real estate activities, Business services nec, Public Administration and defense, education, human health and social work, dwellings
33	FinSvc	Financial services nec
34	InsSvc	Insurance
35	RecOs	Recreational and other services

2015 Regional I–O Table (Dorband et al., 2019; Vogt-Schilb et al., 2019). As shown in Table 3, the production input structure of the five carbon-intensive industries covered by CBAM includes cement, electricity, fertilizer, basic iron and steel, and aluminum. These industries rely heavily on energy inputs, which directly influence their emission intensities. For example, cement production requires multiple energy sources, including electricity (4.4 %), coal (17.8 %), gas and geothermal energy (1.1 %), and fuel (2.4 %). Based on this structure, the embedded carbon emissions were calculated and translated into an equivalent tariff, which serves as a border adjustment ensuring that imports face a carbon cost comparable to EU domestic production (Zhu et al., 2024; Ren et al., 2023; Bellora and

Table 3
The input production structure for cement, electricity, fertilizers, basic iron and steel, and aluminum (%).

Production Input	Cement	Electricity	Fertilizer	Iron and Steel	Aluminum
Non-energy raw material					
Agriculture	0.0	0.0	2.0	–	0.0
Manufacture	8.3	1.2	9.9	7.6	1.6
Other minings	3.2	0.1	5.6	10.1	52.0
Service	15.1	18.0	9.8	13.9	7.6
Import	4.5	3.9	8.4	13.7	2.1
Energy raw material					
Electricity	4.4	0.7	0.1	6.2	0.3
Coal	17.8	21.4	1.8	4.3	0.6
Gas and geothermal	1.1	16.5	22.4	4.1	0.8
Fuel	2.4	5.6	0.9	2.9	0.5
Production factors					
Tax	0.4	0.4	2.4	0.6	0.9
Labor	15.0	7.5	9.8	16.5	5.2
Surplus (profit)	27.7	24.7	26.8	20.2	28.5
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Source: Ministry of Trade, 2023) (processed).

Fontagné, 2023).

The cost of CO_2 emissions was computed following three steps. First, carbon emissions for CBAM-covered products were derived as:

$$CE = \frac{TC}{PC} * emissions \tag{1}$$

Where *CE* is carbon emissions (ton/CO_2), *TC* is the total cost of input, and *PC* is the price of input. Second, the total carbon tax paid was calculated as:

$$Total\ carbon\ tax\ paid = CE * tariff \tag{2}$$

Finally, the tariff equivalent was obtained as:

$$Tariff\ equivalent = \frac{Total\ carbon\ tax\ paid}{Total\ of\ sales\ of\ CBAM\ product} x100\% \tag{3}$$

Notes:
CE: carbon emissions for products subject to CBAM tax (ton/CO_2)
TC: total cost of input
PC: price of input (ton/CO_2)
emissions: emissions produced by the product (ton/CO_2)
tariff: ETS average price of EUR50/ton CO_2 emissionsIn line with CBAM's design, this study clarifies that the calculation of embedded emissions primarily covers Scope 1 (direct emissions from industrial processes) and Scope 2 (indirect emissions from energy use, such as electricity, gas, and fuel). Scope 3 emissions, which include upstream and downstream supply-chain effects, are excluded due to data limitations. This focus is consistent with the transitional reporting rules of CBAM and ensures that the tariff equivalents in Table 4 can be interpreted within the official CBAM framework.

The cost of CO_2 emissions was computed following three steps (see Equations (1)–(3)). To benchmark the tariff equivalent, this study adopts an assumed EU ETS allowance price of €50 per ton of CO_2. This benchmark reflects a conservative shadow price, not a fixed tariff. While actual EUA prices have fluctuated significantly, ranging from approximately €30 in late 2020 to over €100 in early 2023, the choice of €50/tCO_2 provides consistency with early Phase IV ETS conditions and prevents overestimation of CBAM costs (TradingEconomics, 2025). The carbon price is applied directly to sectoral emission intensities to generate equivalent tariffs, aligning the methodology with the CBAM principle that charges are proportional to embedded carbon content.

Table 4 reports the estimated CO_2 emissions and equivalent tariffs for the five Indonesian sectors. Emission intensity data are

Table 4
Calculation of CO_2 emissions for sectors subject to CBAM.

Carbon emissions from the use of raw energy materials	Cement	Electricity	Fertilizer	Iron and steel	Aluminum
Electricity	4,316,055	2,830,248	91,643	4,590,819	387,181
Coal	43,001,555	207,413,672	3,359,252	7,863,055	1,784,848
Gas and geothermal	235,393	14,021,257	3,669,633	648,756	225,719
Fuel	703,516	6,697,931	200,919	641,226	186,641
Total emissions (Ton CO_2)	48,256,518	230,963,108	7,321,446	13,743,857	2,584,389
Equivalent tariff (%)	44.61	53.06	8.75	16.88	1.82

Source: Ministry of Trade (2023).

sourced from Indonesia's 2015 Regional I-O database, as integrated into the GTAP-RD framework. The analysis assumes constant sectoral technologies in the short term, meaning no new abatement options or efficiency improvements are introduced during the baseline scenario. This implies uniform technology within each sector but allows differentiation across sectors according to their distinct input structures. Such an assumption enhances transparency and provides a consistent benchmark for policy comparison, even though it may not fully capture technological heterogeneity (e.g., different steel-making routes).

In the GTAP-RD setting, investment is linked to future capital accumulation with a one-year gestation lag, while convergence in rates of return is imposed at around 9 % per annum for OECD economies, with slower adjustment for developing regions (Golub, 2008). Armington elasticities are higher in the manufactured goods ($\sigma \approx 4$–6 for sectors such as iron and steel, aluminum, and cement), lower in agriculture and food ($\sigma \approx 2$–4), and lowest in energy sectors ($\sigma \approx 1$–2) (Hertel, 1997). Factor substitution elasticities typically range from 0.2 to 1.25. These internationally calibrated values ensure comparability with existing studies, though they may not fully reflect Indonesia-specific conditions. Therefore, the results should be interpreted as indicative of directions and relative magnitudes rather than precise country-specific estimates.

The baseline scenario is explicitly defined to avoid ambiguity. It assumes a business-as-usual trajectory in which Indonesia does not adopt new domestic carbon pricing or climate policies beyond those in place in 2016, while the EU continues with its ETS but without CBAM. In comparison to this baseline, CBAM scenarios impose sector-specific equivalent tariffs, reflecting assumed carbon prices and the scope of covered products. This clarification directly addresses the need for transparency in interpreting results relative to baseline conditions.

The model evaluates effects across a consistent set of indicators—real GDP, investment, exports, imports, sectoral reallocation, and employment changes in EITE industries. At the macroeconomic level, the analysis covers GDP and aggregate investment. At the trade level, it assesses adjustments in exports, imports, and sectoral structure. At the social level, it focuses on employment effects, with particular attention to Indonesia's domestic iron and steel industries. Together, this methodological design ensures that the study provides a comprehensive and policy-relevant assessment: it benchmarks aggregate effects for EU partner countries while offering a granular, country-specific evaluation of Indonesia's exposure, sectoral vulnerabilities, and employment adjustments under CBAM-consistent scenarios.

3. Results and discussions

As a developing country with high ambition for *Indonesia Emas 2045*, Indonesia has set ambitious growth targets, aiming for an economic expansion of up to 8 % by the end of the 2025–2029 National Medium-Term Development Plan (RPJMN). To achieve this goal, industrial exports are positioned as a driver for growth. The share of goods and services exports is projected to rise from 6.95 % in 2025 to 9.50 % in 2029, supported by downstreaming, industrialization, and greater product complexity. The role of the manufacturing sector is also expected to strengthen, with its share of GDP projected to increase from 20.80 % to 21.90 % over the same period. This outlook aligns with the projected growth in foreign exchange reserves, which is expected to reach USD 189.47 billion by 2029. Recent studies reinforce the importance of export-oriented strategies: Heriqbaldi et al. (2023) demonstrate that national export promotion programs enhance competitiveness, while Tambunan (2024) highlights the critical role of strengthening export competencies among micro and small enterprises. Collectively, these findings confirm that export orientation remains central to driving economic growth and reducing unemployment and poverty.

However, this aggressive export orientation unfolds amidst rising global concerns over sustainability. The world is currently facing a *triple planetary crisis*: climate change, biodiversity loss, and pollution-driven environmental degradation (IPBES, 2019; UNEP, 2023). According to the IPCC (2022), up to 50–75 % of the global population could be exposed to life-threatening climate conditions by 2100. Indonesia is not immune to these risks: the National Disaster Management Agency (BNPB, 2025) estimates that climate-related disasters impose annual economic losses of around IDR 22.80 trillion, while more than 9000 lives were lost over the past decade. Meanwhile, air pollution has already caused approximately 4.20 million premature deaths globally each year (WHO, 2024), and Indonesia ranks among the most polluted countries in Southeast Asia (WHO, 2021). These realities underscore that sustainability is no longer optional; it is an urgent necessity.

Indonesia has responded by adopting a sustainability agenda through its Nationally Determined Contributions (NDCs), committing to reduce greenhouse gas (GHG) emissions by 31.89 % unconditionally, or up to 43.20 % with international assistance by 2030, and to achieve net-zero emissions by 2060. The fundamental challenge lies in ensuring that export-driven industrialization advances in tandem with sustainability commitments. In practice, however, these dual objectives are not always aligned: the implementation of sustainability principles often imposes additional costs on industries, which in turn may weaken export competitiveness.

In this context, the European Union's Carbon Border Adjustment Mechanism (CBAM), introduced in 2023, exemplifies the direct intersection between global sustainability measures and Indonesia's export strategies. CBAM is designed to equalize carbon costs between EU and non-EU producers while preventing carbon leakage. For Indonesia, particularly in carbon-intensive sectors such as iron, steel, and aluminum, this policy poses significant challenges. Analyzing the potential effects of CBAM using a Computable General Equilibrium (CGE) model, as undertaken in this study, is thus essential to understanding how Indonesia can safeguard its growth engine while remaining consistent with global sustainability principles.

Indonesia's readiness to respond to CBAM is shaped not only by its economic structure but also by the maturity of its domestic regulatory framework. Key legal instruments have been introduced, including Law No. 7 of 2021 on the Harmonization of Tax Regulations (HPP Law), which provides the basis for carbon taxation, and Presidential Regulation No. 98 of 2021 on the Carbon Economic Value (NEK), which establishes mechanisms for carbon trading, cap-and-trade schemes, and result-based payments. While these initiatives mark important progress, their implementation remains partial. The carbon tax, for instance, has been applied only in a very limited scope and has yet to cover carbon-intensive export sectors most exposed to CBAM, such as iron, steel, and aluminum. At the same time, robust measurement, reporting, and verification (MRV) systems are still underdeveloped, limiting Indonesia's ability to demonstrate credible carbon accounting in line with international standards. Without stronger MRV and clearer policy coordination across ministries, Indonesian exporters risk facing double burdens: paying domestic compliance costs while still being subject to CBAM tariffs in the EU. This situation underscores the urgency of accelerating regulatory reforms and institutional capacity building to safeguard export competitiveness under the tightening global carbon regime.

3.1. Potential effects of CBAM on GDP

Although CBAM is currently applied only to a limited set of products — aluminum, cement, fertilizers, iron and steel, and electricity — the effects on Indonesia's economy extend beyond their relatively small export share to the EU. These industries form the backbone of domestic production, supplying critical inputs for downstream sectors such as construction, automotive, machinery, electronics, and agriculture. An initial decline in exports therefore reverberates through forward linkages, where reduced output affects downstream users, and backward linkages, where input suppliers face falling demand. In addition, firms may scale back production not only in response to actual losses but also due to negative expectations about future competitiveness, creating a bandwagon effect that amplifies the contraction.

Empirical evidence from Indonesia supports the importance of such linkages. Nugroho (2022) shows that iron and steel, chemicals, food processing, and electricity are among the leading sectors in terms of forward and backward multipliers, while Cochrane (1990) highlights the pivotal role of fertilizers, cement, and metals in regional integration. Beyond these domestic linkages, CBAM also operates through reputational and psychological channels. Studies show that stringent environmental measures at the border can depress exports by raising compliance costs and uncertainty (Zhu et al., 2024), while the presence of environmental provisions in trade agreements can influence export structures in developing countries (Brandi et al., 2020). Moreover, the perceived environmental image of an exporting country shapes consumer responses and market access in importing countries (Thøgersen and Pedersen, 2021). Taken together, these findings explain why Indonesia's GDP contracted temporarily in 2026 despite the small direct export exposure to the EU market, as both real sectoral linkages and intangible expectations converge to generate broader economic effects (Fig. 2).

Indonesia's temporary GDP decline in 2026 can also be explained by the expenditure side of the economy. Household consumption drops in the early years (−0.0063 % in 2026) as higher production and compliance costs reduce real purchasing power, before gradually rebounding by 2032. Government spending also shows initial contraction (−0.0114 % in 2026), due to limited fiscal capacity to cushion external shocks, but gradually turns positive after 2031. In contrast, investment steadily increases throughout the period (0.0358 % in 2026 to 0.0511 % in 2040), reflecting capital shifting towards sectors less exposed to CBAM. The most significant drag comes from exports, which fall sharply at first (−0.0298 % in 2026) but begin to recover after 2035 as trade diversion and structural changes take effect. Imports, on the other hand, grow steadily (0.0156 % in 2026 to 0.0267 % in 2040), consistent with Indonesia's dependence on intermediate goods. Meanwhile, international trade margins stay negative (−0.0713 % in 2026 to −0.0361 % in 2040), indicating ongoing higher trade costs that limit overall competitiveness.

These expenditure-side dynamics suggest that CBAM's potential impact on Indonesia is transmitted not only through sectoral linkages but also through household demand, fiscal adjustment, and trade balances (Fig. 3). The continuous rise in investment indicates structural adaptation, while the delayed recovery of exports illustrates the adjustment costs of meeting stricter environmental standards. This pattern is consistent with findings by Lim and Kim (2025) and Chepeliev et al. (2025), who show that carbon border adjustments generate heterogeneous shocks across expenditure components, particularly depressing exports in the short run. Broader

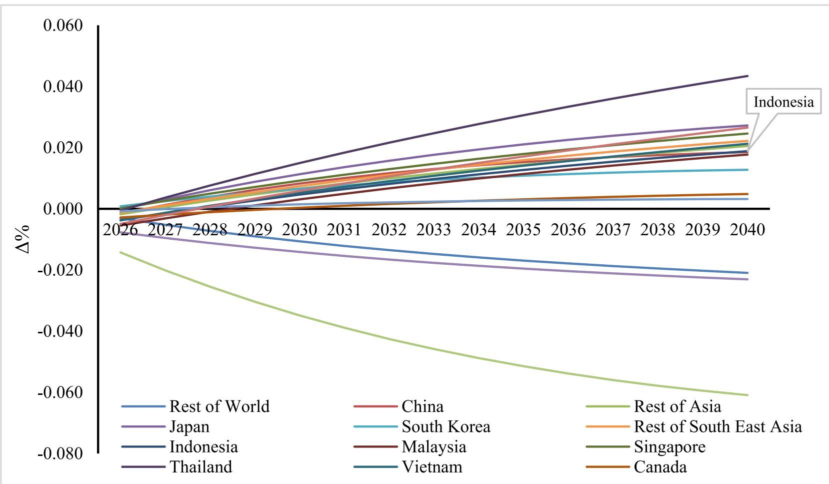

Fig. 2. Potential GDP effects of the CBAM across selected countries and regions, 2026–2040.
Source: Authors' calculation

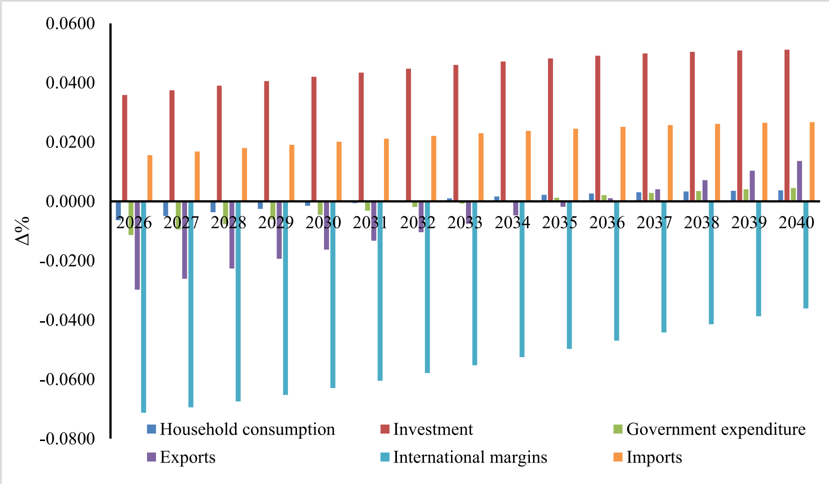

Fig. 3. Potential effects of the CBAM on Indonesia's GDP by expenditure components, 2026–2040.
Source: Authors' calculation

evidence also points to uneven effects: Abalansa et al. (2021) highlight how environmental burdens tend to be shifted disproportionately onto developing countries; Kang and Lee (2021) argue that environmental policies can stimulate green trade if institutional capacity allows adaptation; and Benzerrouk et al. (2021) emphasize the "pollution haven versus halo effect," where stricter standards may either erode competitiveness or catalyze innovation depending on domestic readiness. In this context, Indonesia's experience of temporary contraction followed by gradual adjustment reflects the dual challenge of preserving export competitiveness while advancing toward greener production.

The differentiated outcomes across countries can be explained by variations in regulatory capacity, industrial structure, and readiness for green trade. Countries such as Japan, South Korea, Singapore, and Thailand record continuous GDP gains because their manufacturing bases are less carbon-intensive and better aligned with emerging environmental standards. Kang and Lee (2021) show that environmental policies can stimulate global green trade, benefiting economies that are able to adapt swiftly to higher sustainability requirements. Conversely, Indonesia, Malaysia, and Vietnam have experienced temporary GDP losses as their export structures remain more dependent on carbon-intensive commodities, which exposes them to adjustment costs in the short run. The situation resembles what Abalansa et al. (2021) describe in the case of e-waste, where developing countries often face disproportionate burdens when global environmental responsibilities are shifted. Meanwhile, the broader dynamics also reflect the "pollution haven versus halo effect" debate: stricter environmental measures may weaken competitiveness in the short run for less prepared economies but can foster innovation and efficiency for countries with stronger institutions (Benzerrouk et al., 2021). These insights help explain why CBAM generates a U-shaped GDP effect for some countries, while others are consistently better off.

After discussing the aggregate effects on GDP, it is essential to elaborate further on the role of investment as one of the key components of output formation. Unlike household consumption and government spending, which tend to be more stable, investment is highly sensitive to shifts in trade structures and the costs of environmental compliance. This makes it a primary transmission channel

Table 5
Projected effects of the CBAM on investment across selected countries and regions (Δ%), 2026–2040.

Country/Region	2026	2030	2035	2040
Rest of World	−0.055	−0.050	−0.047	−0.045
China	0.071	0.071	0.066	0.059
Rest of Asia	0.053	0.058	0.065	0.071
Japan	0.114	0.099	0.087	0.078
South Korea	0.050	0.044	0.038	0.031
Rest of Southeast Asia	0.044	0.050	0.056	0.058
Indonesia	0.036	0.042	0.048	0.051
Malaysia	0.044	0.046	0.050	0.051
Singapore	0.041	0.048	0.054	0.057
Thailand	0.090	0.097	0.109	0.121
Vietnam	0.052	0.060	0.071	0.082
Canada	0.031	0.028	0.025	0.022
United State	0.037	0.026	0.019	0.014
Mexico	0.057	0.061	0.067	0.073
European Union 27	−0.226	−0.215	−0.199	−0.185
United Kingdom	−0.071	−0.065	−0.059	−0.057

Source: Author's calculation

through which CBAM exerts its effects. Moreover, CBAM has the potential to reshape cross-country investment flows. This aspect is particularly important because investment serves as a medium-to long-term mechanism that shapes industrial capacity and competitiveness.

The simulation results indicate that the effects of CBAM on investment are uneven across countries (Table 5). Indonesia records steady investment growth, rising from +0.036 % in 2026 to +0.051 % in 2040. Although moderate, this trend reflects the adaptive response of domestic industries that are beginning to redirect capital toward low-carbon production pathways. A similar pattern emerges in Malaysia (+0.044 to +0.051 %) and Singapore (+0.041 to +0.057 %), albeit from a smaller base. Thailand shows the sharpest increase, from +0.090 % in 2026 to +0.121 % in 2040, reflecting an aggressive strategy to attract green investment.

In East Asia, Japan maintains the highest level of investment (+0.114 % in 2026), though the figure gradually declines to +0.078 % by 2040. This outcome is consistent with Japan's position as a leader in low-carbon technologies, where initial investment is substantial but later stabilizes as its industrial base matures. South Korea shows more limited adjustment, with growth narrowing from +0.050 to +0.031 %. China records positive but slowing growth, from +0.071 % in 2026 to +0.059 % in 2040, consistent with its strategy of diversifying greenfield investments abroad to reduce exposure to CBAM (Liu et al., 2025).

By contrast, advanced economies experience contraction. The EU registers −0.226 % in 2026, remaining negative at −0.185 % by 2040. This suggests that CBAM, while intended to protect domestic industries, also undermines investment attractiveness by raising compliance costs. Similar trends are observed in the United Kingdom (−0.071 to −0.057 %) and the United States (+0.038 % in 2026, falling sharply to +0.014 % in 2040). These findings support the literature on global investment asymmetry, showing that countries with more flexible regulations or resource-based industries (such as ASEAN) become net recipients of new investment flows, while economies with stricter regimes risk losing competitiveness (Magacho et al., 2023a, 2023b; Eicke et al., 2021).

3.2. Potential effects of CBAM on trade

Based on the annual reports on the development of exports of commodities affected by CBAM in several ASEAN countries (Table 6), it is evident that these commodities have consistently contributed positively to export portfolios. In Indonesia, iron has steadily served as a major contributor to export growth. Although the trend has not always been smooth, marked by sharp fluctuations during the period of global uncertainty around 2020–2021, iron exports have nonetheless increased by approximately USD 1.1 billion over the past decade. Similarly, aluminum exports exhibited a comparable pattern, with a significant surge in 2022 before declining in the subsequent years. This indicates that Indonesia's exports are highly sensitive to shifts in the global market, where any form of trade disruption can exert a considerable impact on the country's export performance.

A similar pattern can also be observed in several other ASEAN countries, notably Malaysia, Thailand, and Vietnam. In Malaysia, aluminum has been one of the largest export contributors, with export values reaching USD 1 billion in 2022 before contracting in the following year. This reflects Malaysia's ability to capitalize on industrial demand in the aftermath of global uncertainty during 2020–2021. Thailand's performance has appeared more stable, with iron exports providing consistent contributions, complemented by aluminum, which played a secondary but sustained role. Vietnam, meanwhile, demonstrated the most striking development; its iron exports surged from less than USD 200 million in 2014 to nearly USD 3 billion in 2021, before moderating in the years that followed. This trajectory underscores the scale of Vietnam's industrial expansion, arguably the most significant among ASEAN countries.

The simulation results indicate that Indonesia's trade performance is immediately affected by the EU's CBAM. Exports decline by

Table 6
Indonesia's export to EU (thousand USD), 2016–2024.

Country	Commodity	Year (Thousand USD)								
		2016	2017	2018	2019	2020	2021	2022	2023	2024
Indonesia	Aluminum	19,073	12,769	22,135	15,187	11,094	63,710	158,084	37,150	121,954
	Cement	0	7	5	9	1	0	0	0	4
	Fertilizer	231	150	105	176	305	113	117,783	615	13,283
	Iron	108,377	134,713	309,254	478,091	308,989	1,058,534	1,127,894	745,745	1,383,846
	Electricity	0	0	0	0	0	0	0	0	0
Malaysia	Aluminum	56,143	93,045	275,903	212,478	123,370	257,793	1,011,261	860,410	653,962
	Cement	5281	3811	4638	4155	4969	2794	4607	5940	3874
	Fertilizer	85	82	103	71	106	22	773	156	164
	Iron	116,776	377,206	475,906	369,009	220,884	422,372	1,030,441	619,437	378,414
	Electricity	0	0	0	0	0	0	0	0	0
Thailand	Aluminum	11,137	17,011	29,714	44,938	45,751	66,953	73,771	36,095	23,641
	Cement	2	1	5	0	4	0	0	4	4
	Fertilizer	351	474	686	233	0	0	921	21	2
	Iron	113,369	142,474	175,630	164,484	124,254	143,706	215,112	151,166	147,748
	Electricity	0	0	0	0	0	0	0	0	0
Vietnam	Aluminum	12,242	35,302	30,812	15,496	17,575	138,645	188,382	82,048	n.a
	Cement	12,260	7860	3818	9341	13,257	21,060	13,010	21,149	n.a
	Fertilizer	806	1231	849	2117	1178	705	970	888	n.a
	Iron	162,192	413,872	535,140	478,698	484,872	2,979,270	2,294,448	2,776,031	n.a
	Electricity	0	0	0	0	0	0	0	0	n.a

Source: Trademap, 2025 (processed)

−0.030 % in 2026, reflecting the reduced competitiveness of CBAM-covered products in the EU market, before gradually recovering to +0.014 % by 2040. In contrast, imports expand steadily throughout the projection horizon, rising from +0.016 % in 2026 to +0.027 % in 2040, consistent with Indonesia's continued reliance on intermediate goods and imported inputs for domestic production. As a result, the trade balance remains persistently negative, deteriorating from −208.9 million USD in 2026 to −288.9 million USD in 2040 (Table 7).

The trajectory of Indonesia's trade under CBAM illustrates a clear adjustment mechanism. In the short run, increased compliance costs can lead to a decline in export competitiveness, resulting in a reduction in exports and a persistent negative trade balance. Over time, however, the economy gradually adapts through diversification of export markets and sectoral reallocation, allowing partial recovery in export performance. This pathway aligns with global evidence that border carbon adjustments disproportionately affect developing countries at the aggregate trade level before triggering sector-specific reconfigurations. For instance, (Chepeliev, 2021) show that CBAM depresses trade in carbon-intensive products and reshapes global trade flows, while Zhu et al. (2024) find that China's exports initially contract before rebounding as industries restructure. Similarly, Kang and Lee (2021) argue that environmental policies can foster green trade only if industrial adaptation capacity is sufficient, and Benzerrouk et al. (2021) demonstrate that compliance costs weigh more heavily on developing economies than on advanced ones. Brandi et al. (2020) further note that environmental provisions in trade agreements shift the export structure of developing countries toward greener goods.

The sectoral decomposition of Indonesia's exports under CBAM reveals a highly uneven adjustment pattern (Table 8). Carbon-intensive sectors directly covered by CBAM, cement, iron and steel, fertilizers, aluminum, and electricity, experience sharp export contractions, with iron and steel alone declining by −166.7 million USD in 2027 and further to −359.2 million USD by 2040. Fertilizers fall by −15.9 million USD in 2027 and –22.3 million USD by 2040, while cement contracts even more steeply (−35.9 million USD in 2027 and –66.5 million USD in 2040). These declines reflect not only the direct effect of CBAM tariffs but also backward and forward linkages within the domestic production system, as identified in Indonesia's input–output studies (Nugroho, 2022; Cochrane, 1990). The added carbon compliance costs erode competitiveness, limit market access in the EU, and spill over into upstream suppliers and downstream industries.

At the same time, several non-CBAM sectors register positive export growth, suggesting substitution and trade diversion effects. Coal exports increase significantly (from +9.4 million USD in 2027 to +14.2 million USD in 2040), as do CPO (from +6.2 to +12.2 million USD) and processed food (+2.2 to +3.2 million USD). Labor-intensive manufacturing, such as textiles and apparel, expands exports from +8.7 million USD in 2027 to +16.4 million USD in 2040, while electronics and machinery also post gains despite higher import dependence. This pattern illustrates how production capacity gradually reallocates toward sectors less exposed to CBAM, consistent with findings that environmental trade measures can induce restructuring and even create opportunities for greener export growth once adaptation occurs (Brandi et al., 2020; Kang and Lee, 2021; Benzerrouk et al., 2021).

Overall, these results highlight that CBAM's effects on Indonesia's trade are not confined to the directly targeted commodities. Instead, it generates broader realignment across the export portfolio, where carbon-intensive sectors bear the heaviest adjustment costs while resource-based and labor-intensive industries emerge as relative beneficiaries. This duality reflects both Indonesia's structural vulnerabilities and its capacity to adapt by redirecting competitiveness into sectors outside the CBAM scope.

3.3. Potential effects of CBAM on employment

The employment effects of CBAM in Indonesia are closely linked to sectoral output dynamics. The simulation results indicate that while aggregate changes in skilled and unskilled labor remain very small (Table 9), industry-level adjustments are more visible. Sectors directly subject to CBAM, such as fertilizers (−0.16 % in 2026 to −0.39 % in 2040), iron and steel (+7.47 % in 2026 to +7.99 % in 2040), cement (+1.97 % in 2026 to +2.27 % in 2040), and aluminum/metals (−0.30 % in 2026 to −0.68 % in 2040), display divergent patterns. Fertilizer and aluminum contract persistently, eroding employment opportunities in labor-intensive upstream activities,

Table 7
Potential effects of the CBAM on Indonesia's trade performance, 2026–2040.

Year	Export (% change)	Import (% change)	Trade balance (million USD)
2026	−0.030	0.016	−208.850
2027	−0.026	0.017	−213.416
2028	−0.023	0.018	−218.414
2029	−0.019	0.019	−223.864
2030	−0.016	0.020	−229.761
2031	−0.013	0.021	−236.109
2032	−0.010	0.022	−242.863
2033	−0.008	0.023	−249.805
2034	−0.005	0.024	−256.768
2035	−0.002	0.025	−263.673
2036	0.001	0.025	−270.179
2037	0.004	0.026	−276.190
2038	0.007	0.026	−281.299
2039	0.010	0.026	−285.657
2040	0.014	0.027	−288.863

Source: Author's calculation

Table 8
Potential effects of the CBAM on Indonesia's trade performance with the EU, 2026–2040.

Sectors	Export (Million USD)				Import (Million USD)			
	2026	2030	2035	2040	2026	2030	2035	2040
Rice	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OthGrCrops	0.23	0.16	0.12	0.10	−1.28	−1.69	−2.37	−3.23
VegetFruit	0.03	0.03	0.03	0.03	−0.05	−0.06	−0.09	−0.13
Livestock	0.01	0.01	0.01	0.01	−0.19	−0.25	−0.36	−0.51
Forest	0.01	0.01	0.02	0.02	−0.04	−0.06	−0.09	−0.14
Fish	0.02	0.02	0.02	0.03	0.00	0.00	0.00	0.00
Coal	9.26	10.04	11.82	14.23	0.00	−0.01	−0.01	−0.02
OilGas	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Minerals	7.92	8.30	8.98	9.82	−0.38	−0.50	−0.72	−1.00
Meats	0.32	0.41	0.56	0.72	−0.11	−0.13	−0.17	−0.21
CPOvol	5.83	7.43	9.76	12.19	−0.25	−0.29	−0.37	−0.47
ProcFood	2.18	2.41	2.79	3.15	−3.25	−4.21	−5.75	−7.64
Sugar	0.08	0.08	0.08	0.08	−0.21	−0.28	−0.40	−0.55
TextWapp	8.41	9.88	12.47	16.37	−1.19	−1.32	−1.46	−1.57
WoodProd	4.78	6.64	9.93	14.38	−0.25	−0.28	−0.32	−0.36
PaperPub	1.03	1.33	1.87	2.53	−5.04	−6.37	−8.26	−10.32
Refinery	0.14	0.13	0.13	0.12	−0.36	−0.44	−0.56	−0.69
Fertilizer	−15.39	−17.40	−19.77	−22.27	−13.26	−16.43	−20.90	−26.18
RubPlast	8.74	11.05	14.90	20.13	−1.08	−1.20	−1.36	−1.50
Cement	−34.32	−41.21	−52.30	−66.53	−1.04	−1.18	−1.36	−1.53
Iron and steel	−157.85	−197.18	−264.64	−359.18	−13.51	−15.31	−17.67	−20.21
Metal (incl. aluminum)	−9.11	−9.33	−9.13	−8.65	−3.46	−3.86	−4.42	−5.16
MetalPrd	3.19	3.98	5.35	7.26	−8.14	−8.19	−8.20	−8.17
Electronic	9.17	8.88	8.65	9.11	−13.69	−13.85	−13.84	−13.84
MachinEqp	5.08	6.78	9.84	14.34	−54.19	−56.92	−58.66	−59.40
CarMotocy	2.84	4.06	6.60	10.69	−27.06	−31.00	−35.52	−39.18
OthManuf	5.66	7.01	9.22	12.03	−1.46	−1.55	−1.64	−1.72
Util_Cons	0.01	0.01	0.01	0.02	−4.23	−5.27	−6.87	−8.62
Trade	0.36	0.46	0.69	1.05	−2.68	−3.50	−4.68	−5.82
HotelRest	0.37	0.42	0.53	0.67	−1.94	−2.64	−3.81	−5.29
TransComm	7.86	9.63	12.86	16.80	−9.62	−12.89	−18.09	−24.35
OthSvc	3.52	4.51	6.52	9.49	−12.30	−16.12	−21.54	−26.90
FinSvc	0.43	0.68	1.26	2.20	−1.26	−1.65	−2.16	−2.62
InsSvc	0.07	0.09	0.15	0.23	−0.89	−1.19	−1.65	−2.15
RecOs	0.61	0.81	1.20	1.75	−1.98	−2.60	−3.59	−4.67

Source: Author's calculation

Table 9
Potential effects of the CBAM on Indonesia's employment, 2027–2040.

Year	Unskilled (Δ%)	Skilled (Δ%)
2026	0.00003	0.00004
2027	0.00002	0.00006
2028	−0.00001	0.00006
2029	0.00008	0.00012
2030	0.00010	0.00015
2031	0.00008	0.00017
2032	0.00008	0.00017
2033	0.00023	0.00014
2034	0.00016	0.00017
2035	0.00016	0.00016
2036	0.00011	0.00009
2037	0.00015	0.00021
2038	0.00013	0.00018
2039	0.00014	0.00021
2040	0.00008	0.00021

Source: Author's calculation

whereas cement and iron, and steel expand, creating additional labor demand. These opposite movements help explain why aggregate employment changes appear minimal despite sharper contractions in specific subsectors. This outcome also reflects the GTAP-RD model's assumption of perfect labor mobility, whereby workers can move freely across sectors. While this is an idealized setting, it remains insightful in showing how contraction in some industries can be offset by expansion in others.

Based on labor statistics, the basic metal industry (iron, steel, and aluminum) employs about 0.16 million workers, the chemical industry, including fertilizers, employs 0.27 million workers, and the non-metallic mineral industry (cement) employs 0.64 million workers. In comparison, cement has a higher employment absorption capacity than basic metals, while fertilizers remain strategically important as labor-intensive industries in certain regions. BPS (2025) data confirm that although iron and steel record positive output growth, their absolute employment contribution is smaller, so employment effects are more pronounced in fertilizers and cement.

Spillover effects also arise in related manufacturing and services. Output in machinery and equipment (−0.98 % in 2026 to −1.39 % in 2040), electronics (−0.87 % to −1.25 %), and textiles and apparel (−0.38 % to −0.65 %) declines steadily, reflecting reduced competitiveness in energy-intensive, export-oriented industries. Since these are among Indonesia's largest formal employers, the textile industry, with 0.75 million workers and apparel with 2 million workers (BPS, 2025), even modest declines can translate into meaningful job displacements. Conversely, positive responses in minerals (+0.41 % in 2026, moderating to +0.25 % in 2040) and coal (+0.08 % to +0.02 %) help absorb some displaced workers, explaining why the contraction in unskilled labor is temporary.

Industry assessments are consistent with these dynamics. The Indonesian Iron and Steel Industry Association (IISIA, 2024) estimates that compliance under CBAM could add costs of up to €390 per ton in conventional blast furnace operations, which may reduce labor demand but at the same time incentivize a transition toward scrap-based EAF technology that requires different skill profiles. Likewise, the Indonesia Commodity and Derivatives Exchange (ICDX, 2024) points out that fertilizers and aluminum face competitiveness challenges due to insufficient carbon certification, threatening employment in those sectors. Similar to findings in Magacho et al. (2023a, 2023b, 2022) and Acar et al. (2022), these pressures suggest that CBAM may both displace workers in carbon-intensive industries and create opportunities for employment growth in greener subsectors.

In sum, the labor market effects of CBAM in Indonesia reflect a dual adjustment process: declining employment in traditional carbon-intensive exports is partly offset by new jobs in sectors able to adapt or diversify. Although the net effect remains close to neutral at the macro level, the distributional effect is uneven—job losses are concentrated in fertilizers (0.27 million workers), aluminum/iron and steel (0.16 million workers), and energy-intensive manufacturing such as textiles and apparel (a combined 2.75 million workers), while job creation is linked to cement (0.64 million workers), green steel (via Electric Arc Furnace, EAF), and mineral sectors (0.41 million workers in chemicals, rubber, and plastics as supporting supply chains). Managing this transition will require policies that promote reskilling, technological upgrading, and investment in low-carbon production, so that employment shifts contribute to a more sustainable and competitive labor market.

4. Conclusions, implications, and limitations

This study finds that although the macroeconomic effects of the CBAM on Indonesia appear modest, the short-term contraction followed by gradual recovery toward 2040 carries important strategic implications. The results indicate that Indonesia will face an initial decline in GDP during 2026–2030 before adapting through reinvestment and diversification. This highlights that the early implementation phase is a decisive period in which the resilience of Indonesia's export competitiveness will be tested.

At the sectoral level, the impact is highly uneven. Steel and cement industries still have opportunities to transform by adopting low-carbon technologies such as electric arc furnaces and green cement. In contrast, the fertilizer and aluminum industries risk a prolonged downturn without timely policy support. These findings emphasize the importance of moving beyond aggregate indicators and recognizing sectoral and regional variations that involve changes in employment, investment, and domestic production networks.

Instead of viewing the CBAM solely as a threat, Indonesia can see it as both a challenge and an opportunity for industrial transformation. Several key strategies are necessary. First, CBAM can serve as a means for market differentiation, allowing low-carbon products like green steel or sustainable textiles to access premium global markets. Second, monitoring and verification of emissions must be enhanced with reliable digital systems to ensure that reductions are recognized internationally and to prevent double carbon pricing. Third, a Carbon Adjustment Fund, financed by domestic carbon tax revenues, could support workers in vulnerable sectors while promoting retraining and adaptation.

Industrial policy should also take a spatial approach, such as creating renewable energy–based green industrial zones in regions most affected by CBAM, like fertilizer hubs in East Kalimantan and steel-producing areas in Java. Simultaneously, export diversification into environmentally certified commodities must be strengthened. The increasing trade in palm oil, textiles, and processed foods can be channeled toward sustainable markets through stricter environmental standards. Overall, these steps would transform the CBAM from a trade barrier into a driver for structural change, helping Indonesia build a more competitive, sustainable, and climate-aligned industrial sector.

This study has three main limitations. First, the data on carbon prices and sectoral input structures, while useful, may not fully represent current energy consumption and emission intensities, and the CBAM tariffs used here were based on average values that likely underestimate the dynamic nature of actual tariff adjustments. Second, the analysis is limited to five carbon-intensive industries already covered by CBAM, while the mechanism is expected to expand to more sectors, which future research should include to capture broader impacts. Third, relying on a CGE model involves simplifying assumptions, such as constant returns to scale and fixed input substitutability, which may reduce the accuracy of results; future studies should examine the sensitivity of these assumptions and consider alternative approaches to better reflect the complexity of industrial and policy responses.

CRediT authorship contribution statement

Iwan Hermawan: Writing – original draft, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carunia Mulya Firdausy:** Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Erwidodo: Writing – original draft, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Reninta Dewi Nugraheni:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Fadhlan Zuhdi:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Khoiru Rizqy Rambe:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Delima Hasri Azahari:** Writing – original draft, Methodology, Investigation, Conceptualization. **Dian Dwi Laksani:** Writing – original draft, Software, Methodology, Investigation. **Ferry Samuel Jacob:** Writing – original draft, Methodology, Investigation, Formal analysis.

Declaration of competing interest

The authors declare no conflict of interest to any individual or organizations.

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Data availability

Data will be made available on request.

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