

Finding the Sweet Spot: Carbon Pricing, Industrial Decarbonization, and the Impact of the CBAM in Indonesia

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1 Abstract

The European Union's Carbon Border Adjustment Mechanism (EU CBAM) is the first climate and trade nexus policy designed as a carbon-based tariff on imports to prevent carbon leakage. This policy is also intended to level the playing field between EU producers and foreign competitors, to incentivize decarbonization, and to accelerate the adoption of domestic carbon pricing in trading partners.

While exports of CBAM-covered commodities to the EU are not Indonesia's dominant export flow, exposure is non-trivial for certain products (notably iron & steel and aluminium), and other major economies have also considered CBAM-like policies, increasing the likelihood of broader trade-related carbon constraints. Moreover, Indonesia's production emissions intensity in several CBAM-relevant sectors remains above EU averages and CBAM benchmark values, particularly in iron & steel (Indonesia 4.00 tCO₂/t-product vs EU-average 1.10) and cement (Indonesia 0.62 vs EU benchmark 0.492), implying a competitiveness challenge but also a decarbonization opportunity.

By employing GTAP-E and database version 11, this study assesses the macroeconomic, sectoral, distributional, and emission-reduction implications of the EU CBAM for Indonesia and contrasts them with those of domestic carbon pricing and industrial subsidies for decarbonization scenarios. It further explores the "sweet spot" range of carbon prices that can improve emissions outcomes while minimizing GDP impacts.

Overall, EU CBAM is projected to have a relatively modest near-term macroeconomic impact on Indonesia, but it creates clearer incentives for industrial decarbonization and exposes competitiveness risks for emissions-intensive production. The risk profile may increase over time if (i) the methodology for carbon content calculation becomes more stringent and (ii) CBAM coverage expands beyond current commodities.

Policy implications follow a three-part logic consistent with the presentation's framing: (1) reduce embedded emissions through industrial decarbonization using green subsidy to lower CBAM

obligations; (2) implement credible domestic carbon pricing to reduce CBAM cost adjustments; and (3) pursue international cooperation/coalition approaches that balance emissions reductions with competitiveness and common but differentiated responsibilities (CBDR) considerations.

Within Indonesia's domestic policy space, the modeling results suggest that raising carbon pricing toward USD 20–25/tCO₂e may represent a pragmatic “sweet spot” that improves climate outcomes with comparatively lower GDP impacts than higher price levels.

Keywords: carbon border adjustment mechanism, computable general equilibrium model, climate policy, trade policy

2 Background

In an effort to combat climate change globally, the European Union (EU) implemented the Carbon Border Adjustment Mechanism (CBAM) in 2023. This policy essentially places a carbon tariff on certain imported goods, aiming to reduce carbon leakage and put a fair price on the carbon emissions of the products (European Commission 2024). It is also aimed at incentivizing countries outside the EU to adopt stricter decarbonization regulations.

While the ultimate goal of CBAM is laudable, its potential impact on developing countries remains a significant concern. It is unfair to expect these emerging markets to bear the same burden as developed countries in mitigation by common, but differentiated, responsibilities (Perdana & Vielle 2022; Davidson Ladly 2012). Developing countries often lack the infrastructure and resources to implement stringent environmental regulations at the same pace as developed nations. Concerns exist that policies like CBAM could disproportionately burden these economies, potentially leading to job losses and decreased export competitiveness (Zhong & Pei 2024; Liang et al. 2016; Bassi & Yudken 2011; Böhringer et al. 2015). However, the potential impact of EU CBAM on developing countries is not well documented.

Indonesia has imported almost all CBAM product categories in 2021, except electricity that is still consumed domestically. One of Indonesia's comparative advantages is its metal products, with a revealed comparative advantage (RCA) of 1.65 (WITS 2021). Moreover, Indonesia become one of the largest iron and steel exporters behind China, Germany, Japan, and South Korea in 2022. CBAM products account for US\$19 billions of Indonesia's export to EU. The exported products include cement, fertilizer, iron and steel, and aluminum. Iron and steel become a product category with the largest value compared to other CBAM products, followed by aluminum, fertilizer, and cement consecutively.

To analyze the potential impact of CBAM on Indonesia, this study uses a hybrid computable general equilibrium (CGE) model. This model provides a comprehensive framework for assessing the national macroeconomic effects of international climate-related trade policies like EU CBAM on the Indonesian economy. This model combines a global model through the Global Trade Analysis Project (GTAP) database, Indonesia's Extended Social Accounting Matrix, and the flow of input energy. Moreover, this model is equipped with a carbon tax module at the domestic level which provides us with the ability to explore potential climate-related policy response.

Through utilizing this CGE model, we aim to quantify the potential consequences of the implementation of the recently established EU CBAM for Indonesia. This includes exploring the implication for Indonesian economy and carbon emissions reductions. Usually, the indicators that are examined in studies on CBAM are its effect on carbon leakage, competitiveness, and social welfare. However, this paper will not be discussing about the effect of CBAM on carbon leakage because we are going to focus more on the national macroeconomic effect of CBAM on Indonesia.

This paper will then be divided into several sections: a brief review of EU CBAM policy, update on the most recent literatures covering the potential impact of CBAM, introduction to the model, results and discussion, followed by conclusions and policy implications.

3 Literature Review

3.1 EU's CBAM Policy

As time goes by, climate-related provisions are more likely to be integrated in trade policies. Starting in 1989, EU was the first to introduce references to the greenhouse effect in its trade policy (Berger, Brandi, Bruhn 2017). Now, one of the most recent climate-related trade policy is the Carbon Border Adjustment Mechanism. It is a policy that is recently implemented by the European Union which aims to reduce carbon leakage that potentially shift the carbon emission outside of EU and dissipate EU's decarbonization effort. Besides that, it also serves as a tool to level the playing field between countries with and without carbon pricing policy, and the differences in the carbon pricing across region (Zhong & Pei 2024; Cosbey et al. 2019). Through this policy, certain imported goods, namely cement, iron and steel, aluminum, fertilizer, hydrogen, and electricity, will be charged a carbon tariff.

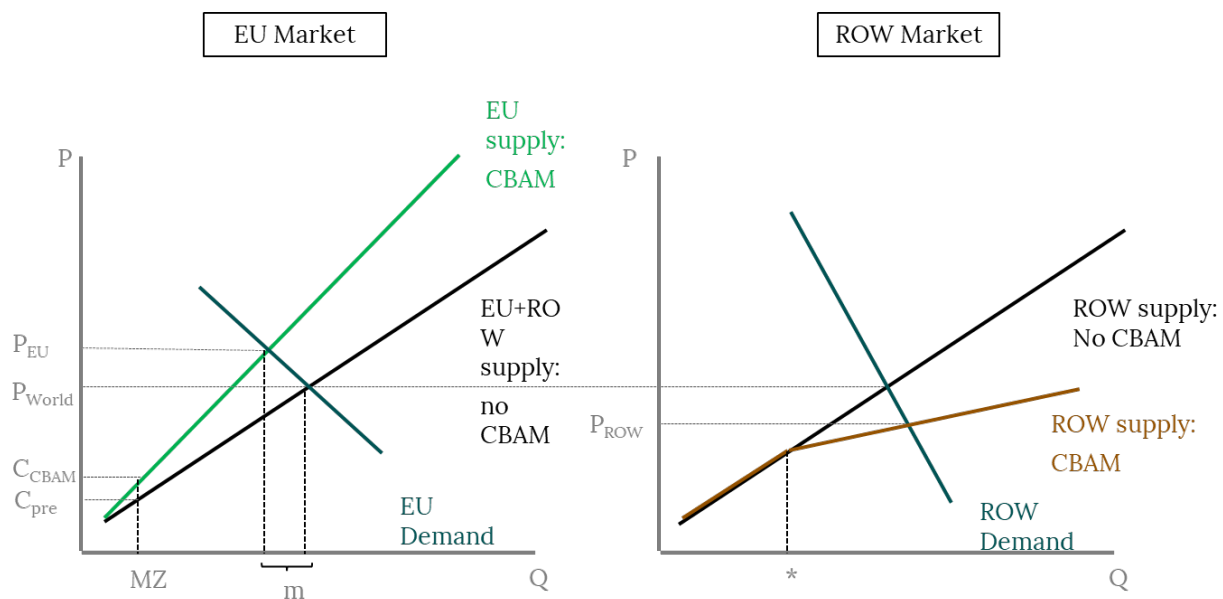
The carbon tariff that is imposed by EU CBAM depends on each exporter's carbon pricing regime. The price that importers have to pay equals to the calculation of the EU Emission Trading System (ETS) weekly average carbon price (European Commission 2024). However, if the exporting countries has already implemented a carbon pricing scheme, the tariff would be decreased based on the domestic carbon price. Hence, the higher the carbon price, the lesser EU CBAM's carbon tariff. Through this policy, EU CBAM is also intended to be a tool to put pressure on other

countries in adopting a decarbonization policy, especially those with emission-intensive trade-exposed (EITE) industries.

3.2 Theoretical Framework

The economic mechanism underlying the CBAM can be understood through a partial-equilibrium trade model that distinguishes between the EU market and the rest-of-the-world (ROW) market for CBAM-covered commodities (Wolfram, 2025). In the absence of a border carbon adjustment, both markets are integrated at a single world price (P_{World}), where domestic supply and demand in each region clear simultaneously. The EU and ROW supply curves jointly determine the equilibrium quantity traded, and producers in carbon-intensive exporting countries face no additional cost disadvantage relative to EU-based producers.

The introduction of CBAM alters this equilibrium by imposing an additional cost on imports into the EU that reflects the carbon content of the product and the gap between the exporter's domestic carbon price and the EU ETS price. This effectively shifts the supply curve faced by EU importers upward — from the pre-CBAM combined supply to a new, higher-cost EU supply curve that incorporates the CBAM levy. Consequently, the price in the EU market rises from P_{World} to P_{EU} , while the price received by ROW exporters falls to P_{ROW} as demand for their carbon-intensive output declines. The resulting price wedge ($P_{EU} - P_{ROW}$) represents the incidence of the carbon border adjustment shared between EU consumers and ROW producers.



Assume m capacity competitive after point $*$.

Within this framework, three key effects emerge. First, the pre-CBAM cost of compliance (C_{pre}) — reflecting the existing carbon pricing in the exporting country — is augmented by the CBAM-

induced cost (CCBAM), raising the total compliance burden on ROW exporters to the EU. Second, a marginal zone (MZ) emerges in the supply curve where producers whose costs fall between the old and new equilibria face competitive pressure. Some of these producers, particularly those at the margin of emission intensity, may find it profitable to reduce emissions rather than pay the CBAM levy. Third, beyond a critical threshold — the point at which the marginal producer's cost equals the CBAM-adjusted price — competitive capacity shifts from carbon-intensive to cleaner production. This threshold, denoted as the competitive capacity point, represents the level at which CBAM effectively redirects production incentives toward decarbonization.

This theoretical model provides the foundation for the empirical analysis conducted in this study. The supply-curve shifts and price divergence described above are operationalized through the hybrid CGE framework, where the CBAM tariff enters as an additional import duty calibrated to the carbon content and pricing differential of each exporting country. The partial-equilibrium intuition — that CBAM simultaneously raises costs for carbon-intensive exporters while creating incentives for emission reduction — is tested against the general-equilibrium interactions captured by the GTAP-based model.

3.3 Previous Studies on the Effect of CBAM

The vast majority of literature on the effect of the EU's CBAM is documented in the context of developed countries. The context that is commonly explored is the economic and environmental impacts within the EU itself ((Magacho et al. 2024; Chepeliev 2021; Chen et al. 2020; Krenek et al. 2020; Kuusi et al. 2020). However, developing countries are inadequately represented and the effect is sometimes underestimated (Magacho et al. 2024; Eicke et al. 2021; Zhong & Pei 2021). In general, there are two divisions of methods that are widely used in studies on CBAM based on the quantitative approach used. In a non-quantitative study, a game theoretical method is a common approach to see the effect of implementing CBAM. However, a game theory model cannot represent the decision making of various countries in the real world and it cannot compare many policy designs (Zhong & Pei 2021). Hence, a more quantitative approach becomes the method that is frequently used to model the effect of CBAM. The models include a computable general equilibrium (CGE) model or input-output analysis.

The implication of CBAM is something important to note for countries with high carbon emission due to the design of this policy that targets carbon-intensive imported products. However, there are inconclusive results from studies related to the effectiveness of CBAM on carbon leakage and competitiveness that relate to changes in production output. One of the reasons is due to the differences in the policy designs and economic characteristics of the regions (Zhong & Pei 2024). Regarding carbon leakage, previous studies using the Global Trade Analysis Project (GTAP) database have shown that the implementation of CBAM could reduce carbon leakage by 6% on average (Branger & Quirion 2014; Larch & Wanner 2017; Chateau et al. 2022). As for the

competitiveness effect, previous studies documented those countries affected by CBAM, namely the implementing country's trading partners that have EITE industries, experienced negative competitiveness effect (Zhong & Pei 2024; Liang et al. 2016; Bassi & Yudken 2011; Böhringer et al. 2015). The indicators that are often looked at when examining the competitiveness of CBAM are export volume, output, profitability, and gross domestic product (GDP).

Whereas the impact of CBAM on social welfare, it usually depends on the design of the policy itself, whether it is implemented partially (either import tariff or export rebate) or fully (Zhong & Pei 2024). In many studies, a poorly designed CBAM tends to create unintended costs, e.g., an increasing administrative cost, a higher price for certain products, and an international trade dispute (Eicke et al. 2021). Literatures showed that there are ambiguous evidence related to the effect on welfare. For example, an import-tariff-only CBAM has lower global welfare costs compared to the fully implemented one (Lanzi et al. 2012) and other studies prove otherwise (Mattoo et al. 2013; Böhringer et al. 2014).

For the least developing countries (LDCs), EU CBAM affects their competitiveness through a loss in exports and welfare (Perdana & Vielle 2022). Through a diminishing exports, implementation of this policy may harm EU's LDCs trading partners to a large extent if there is not any mitigation in their national development strategies (Perdana & Vielle 2022; Mealy and Teytelboum 2020; Ameli et al. 2021). Another study by Chepeliev (2021) proves in a similar manner that a developing country and EU's trading partner such as Ukraine suffers from a decrease of export to EU in CBAM products, namely electricity, ferrous metals, and chemical products. This study also shows that there is a limited negative effect in welfare from EU CBAM that developing countries and regions such as China, India, and Southeast Asia suffer from a diminishing per capita income. On the other hand, EU CBAM may bring a positive impact for developing countries' investment (Perdana & Vielle 2022).

3.4 Domestic Carbon Pricing as A Policy Response

For regions or countries with EITE industries that exploit brown energy sources, a CBAM implemented by their trading partner increases the cost due to the sharp increase in carbon price (Keen et al. 2021). CBAM is also sometimes seen as a form of "green protectionism" for the implementing country that shift the burden to developing countries that often lack of decarbonization effort (Eicke et al. 2021; Babiker & Rutherford 2005; Droege 2011; Evenett & Whalley 2009). Hence, CBAM could act as a coercion for developing countries to adopt a more stringent climate policy, and one of such policy is domestic carbon pricing. A study by Zhu et al. (2020) performs a simulation of China's response to a carbon tariff by the United States, and it shows that China's carbon tax against American carbon tariffs results in fluctuation in China's GDP and greatly impacts high-carbon industries.

Carbon pricing provides an explicit value of greenhouse gasses (GHGs) emission in the form of price per ton CO₂ equivalent (tCO₂e). This approach helps reducing the external cost from carbon emission of production activity by shifting the burden from public to the emitters. By having such policy, industries would be forced to adopt a greener production process and countries would be able to have a flexible and effective quantitative measure in reducing emission (UNFCCC 2023).

In practice, there are two approaches commonly used in carbon pricing: market-based and non-market based. An example of market-based instruments are the Emission Trading System (ETS) and carbon crediting mechanism (World Bank 2023). In an ETS, there is an emission limit attached to certain entities and these entities are provided with tradable emission units that they can utilize to fulfil their compliance requirements. Whereas in carbon credit mechanism, entities are given a tradable certificates which symbolizes their emission reduction. A carbon tax is an example of carbon pricing instrument that is non-market-based. It charges a fee on the emissions created.

Indonesia has recently enforced a carbon pricing policy through both approaches. Through Law no. 7/2021 about Harmonization of Taxation Regulation, the government of Indonesia set the carbon tax at IDR30,000/tCO₂e (approximately US\$2/tCO₂e). This regulation is currently imposed only on coal power plants, but is expected to be expanded to other sectors such as sanitation, agriculture, forestry, and other carbon-intensive ones in the following years. Whereas for a market-based carbon pricing, Indonesia has just established its carbon trading platform in the late 2023. The current carbon trading policy only regulates power plants and forestry sector. This set of policy is made to spur Indonesia's progress in achieving its nationally determined contribution (NDC) 2030.

4 Methods and Data

4.1 Methods: Hybrid-CGE

In this study, we tried to develop a hybrid CGE model by combining the GTAP and national CGE models with an additional of energy input features. Concerning the national model, we combine the concept of electrical technology explicitness from the bottom-up model and the conventional top-down model (or standard CGE model). Hence, it is expected that this hybrid-CGE model can integrate various types of energy technologies as a mediation of reconciliation between techno-economic perspectives 'bottom-up' and macroeconomics – which is usually called 'top-down' (Wing 2008).

Additional features and modifications incorporated into the hybrid CGE model include the following:

- i. Modifications were made to distinguish the nested structure between energy and non-energy production sectors, namely by allowing the possibility of substitution between energy commodities and production factors and also substitution between energy commodities. This modification was made according to studies conducted by Hudson and Jorgenson (1974), Berndt and Wood (1975), and Griffin and Gregory (1976) who made estimates with econometric models. Based on the regression results, it is concluded that energy can be substituted with labor and capital factors. Next, in the CGE model, we classify the relationship between production volume activity (including prices) and commodity supply (including prices) for each type of industry. For example, in the fossil and non-energy sectors, only one-to-one production links between activities and commodities produced are allowed. However, for the oil refinery industry, a single-to-multiple production relationship is allowed i.e. the oil refinery sector produces a wide range of final energy products. Then, for the electricity sector, multi-to-single production relationships are allowed, namely various types of power plants only produce one electricity commodity.
- ii. An equation model for carbon emissions and its carbon tax features was added to analyze the impact of carbon taxes on the burning of fossil energy sources by the industrial sector, energy consumption for households, and governments. However, this model equation does not apply to emissions produced by the agricultural sector and deforestation.

4.1.1 CO2 Emission Calculation and Carbon Tax Module (Satellite Model)

We assume that the use (absorption) of fossils and their refined products (petroleum) increases CO2 emissions due to their combustion. This absorption includes: (i) fossil (and petroleum) inputs in industry-wide production processes; and (ii) final consumption of fossil (and petroleum) by households and governments. However, due to limited information, we exclude emissions resulting from the agricultural sector – i.e. land use change – and deforestation.

4.2 Data Constructions and Simulations

4.2.1 Calculation of EU CBAM Tariff

To calculate the EU CBAM tariff, we divided the estimated CBAM certificate value with the export value of a certain product. The CBAM certificate value is then determined by the carbon content for each CBAM product and carbon pricing in a certain country. To calculate the carbon content, we need the export value data of a specific product and its carbon intensity. For the export value, the source of the data is retrieved from the World Integrated Trade System (WITS) by the World Bank, whereas for the carbon intensity, it is from the Global Carbon Project. However, the carbon intensity is on the country level, and we cannot obtain a product-specific carbon intensity due to the limitation of data. We also need to calculate the difference between the carbon price of a country and the EU ETS's weekly average carbon price, since it is the basis of the EU CBAM price certificate. After getting the carbon intensity of a certain product in a country and the difference

between a country's carbon price, we can then calculate the EU CBAM certificate value (see appendix 1).

4.2.2 Data Constructions for CGE Model

This study uses two datasets of Global Analysis Trade Project Environment (GTAP-E) and Indonesia's Social Accounting Matrix (SAM) or *Sistem Neraca Sosial Ekonomi* (SNSE) published by Statistics Indonesia (BPS). According to BPS (2011), the SAM is a data framework that summarizes various economic and social variables of a country at a certain time in a comprehensive and integrated manner. Thus, SNSE is not only able to describe the economic and social conditions of the community but also able to describe the relationship between these economic and social variables. That linkage, for example, is between economic growth, employment and income distribution.

As a comprehensive and integrated data framework system, SNSE covers a wide range of economic and social data consistently because it ensures the balance of transactions in each balance sheet contained therein. SNSE is also modular because it can connect various economic and social variables, so that the relationship between these variables can be shown and explained. The relationship between balance sheets in the SNSE Framework 2008 is shown in Table 1.

Table 1: Relationships Between Balance Sheets in the SNSE Framework

Income	Expenditure					
	Factors of Production	Institution	Production sectors	Capital	International trade	Total
Factors of Production			Allocation of value added to factors of production		Income of factors of production from foreign countries	Income of factor of production
Institution	Income allocation of factors of production to institutions	Transfer among institutions			Transfer from foreign countries	Income of institutions
Production sectors		Final demand	Intermediate demand	Physical investment	Export	Output
Capital		Savings			loan from foreign countries	Accumulated income

International trade	Income allocation of factors of production to foreign countries	transfer to foreign countries	import, indirect tax (net)	loan to foreign countries		Income from foreign countries
Total	Expenditure of factors of production	Expenditure of institutions	Input	Accumulated expenditure	Expenditure from foreign countries	

Source: Statistics Indonesia (2011)

In this study, SNSE data was used to calibrate the CGE model built in the framework of looking at the impact of EU CBAM implementation on the Indonesian economy. The CBAM mechanism will add tariffs or import duties on imported goods that in the process emit high carbon emissions (European Commission 2024). CBAM will increase tariffs or import duties on imported goods that emit high carbon emissions. In the first phase, the types of products applied by CBAM, namely aluminum, iron and steel, cement, fertilizer, and electrical energy. Then the next phase will potentially be developed for other products that allegedly produce carbon emissions from the EU and non-EU.

However, the types of CBAM product classifications as described above have not been categorized in the Indonesian SNSE Table. Thus, it is necessary to adjust the SNSE Indonesia Table published by BPS in 2008 to include CBAM products in the context of the CGE model. In addition, adjustment is also necessary to include input factors of energy into the production systems and to put the data into a more relevant context. The steps of the SNSE adjustment are done by the following conditions:

- Adjustment of transaction value in SNSE Table 2008 to the newest data available (Input-Output Table 2016) using the household consumption expenditure per type of commodity.
- Mapping the commodities covering CBAM products under the SNSE products. In addition, use the share value obtained by the percentage of Indonesian exports to look at the share values of CBAM products in aggregated sectors.
- Disaggregation of various energy products, both fossil and renewable types, in the SNSE Table Extension 2016.

In addition to SNSE, this study also uses some secondary data sourcing from GTAP *Database*. We use the latest version of GTAP (version 11), published in 2023 consisting of 76 sectors and 160 regions.

Furthermore, we aggregated the number of countries and economic sectors into 26 countries/regions and 18 economic sectors for this study. The aggregated countries consist of the members of the European Union (27 countries), members of the G20 and key partner countries in ASEAN (Malaysia, Philippines, Singapore, Thailand and Viet Nam). Meanwhile, sector selection is carried out based on industrial commodities related to CBAM policies that will be

implemented by the European Union. More detailed country aggregations of GTAP baseline data can be seen in Table 2, while the aggregated sectors can be seen in Table 3.

Table 2. GTAP Country Aggregation

No.	Country	No	Country
1	Argentina	14	Russia
2	Australia	15	Saudi Arabia
3	Brazil	16	South Africa
4	Canada	17	Turkey
5	China	18	United Kingdom
6	France	19	USA
7	Germany	20	Rest of EU
8	India	21	Malaysia
9	Indonesia	22	Philippines
10	Italy	23	Singapore
11	Japan	24	Thailand
12	Mexico	25	Viet Nam
13	Korea Republic	26	Rest of World

Source: GTAP version 11

Table 3. GTAP Commodities Aggregation

No	Sector	No	Sector
1	Grain Crops	11	Mineral Products
2	Meat & Livestock	12	Ferrous Metal
3	Forestry & Fishery	13	Computer & Electronic
4	Coal	14	Electric & Machinery
5	Oil & Gas	15	Automotive
6	Other Mining	16	Other Manufactures
7	Process Food	17	Utility & Construction
8	Textiles	18	Transport & Communication services
9	Leather & wood products	19	Other Services
10	Chemical Products		

Source: GTAP version 11

Regarding the policy simulation process, we utilized the tariff on imports of certain products from the country of origin to the destination country ($tms / source-spec. change in tax on imports of i from r into s$).

In the **first scenario**, we established additional import tariffs imposed by the European Union on selected products (such as iron & steel, fertilizers, and cement) from each country (region). For Indonesia, the resulting tariff hike due to the CBAM policy amounts to 1.82 percent. Detailed information regarding the range of tariff adjustments under CBAM for each country that we utilized in this simulation can be found in Appendix 1. The **second scenario** looks at the impact of CBAM policy with the introduction of carbon pricing policies in Indonesia. In this scenario, the EU's import tariffs from Indonesia on selected CBAM products amounts to 1.79 percent. The **third scenario** illustrates the transition of CBAM policy impacts from the GTAP model to the Indonesian National model, utilizing trade and investment variables as shock factors. The **fourth scenario** in this simulation evaluates the effects of CBAM on the national model alongside with the carbon tax set at US\$2 per ton CO₂e in Indonesia.

5 Results and Discussions

5.1 Impact of CBAM on Indonesian Economy

The CGE model is used to assess the impact of CBAM on the Indonesian economy. As discussed in previous literature, CBAM's primary objective of mitigating carbon leakage poses potential adverse effects on developing countries. In the Indonesian context, the implementation of CBAM appears to have a limited influence on the national economy. Table 4 below illustrates how the increase of tariffs on selected products such as iron and steel, cement, and fertilizers leads to a total reduction of Indonesia's exports by 0.1%. Furthermore, its impact on Indonesia's GDP is notably marginal, standing at a mere 0.0002%.

Table 4. Impact of EU CBAM and Carbon Tax on Macroeconomic Indicators (%)

Indicators	1 st Scenario	2 nd Scenario
Trade balance, \$ US million (change)	-268.826	-271.34
Welfare \$ US million (change)	-36.2496	-35.2352
CPI (price index)	0.0115	0.0122
GDP	0.00020	0.00019
Investment	0.0833	0.0842
Volume of imports	0.014	0.0154
Volume of exports	-0.1014	-0.1021
Government expenditure	0.0074	0.0083
Household consumption	0.0071	0.008

Source: Author's calculation

Certainly, several factors contribute to the limited impact of CBAM on Indonesia's economy. Firstly, the scope of products subject to tariff adjustments under CBAM policies is narrow, which are primarily based on the calculation of domestic carbon prices from the EU ETS. Initially, only the power sector and energy-intensive industries like cement, steel, aluminum, and fertilizers are subject to CBAM tariff adjustments.

Secondly, Indonesia's relatively modest share of exports to the European Union positions it as a low-risk country in terms of CBAM implementation, as classified by Eicke et al. (2021). This is evident in Indonesia's economic ties with the EU, with exports to the EU concerning CBAM products only accounting for a small percentage of 1% of Indonesian GDP. In addition, exports of iron and steel from Indonesia to the EU, amounted to only 3.8%. This figure is notably lower compared to Indonesia's export proportion of the same products to China, which stands at 67%.

Thirdly, Indonesia's carbon intensity profile is relatively low (Andrew & Peters 2023; Bolt & Van Zanden, 2020), a pivotal factor in EU ETS calculations and the subsequent tariff adjustments under CBAM policy. Our calculation indicates that CBAM policy implementation would marginally raise EU import tariffs from Indonesia by 1.82%, significantly lower than several other developing nations such as China and South Africa (see appendix 1).

Although the repercussions on Indonesia's GDP and international trade are modest, CBAM policy still results in welfare losses of approximately US\$ 36 million. This reduction in welfare primarily stems from reduced production in sectors subject to CBAM tariffs, including chemicals (-0.38%), ferrous metals (-0.096%), and mineral products (-0.02%) (see Table 5). Moreover, the welfare decline in Indonesia is also due to diminished consumer surplus resulting from heightened price indices. The combination of reduced sectoral production and increased international prices contributes to an overall uptick in price indices in Indonesia, requiring higher consumer expenditures to maintain previous utility levels and thus diminishing social welfare.

Table 5. Impact of EU's CBAM on Industrial Output

Sector	1 st Scenario	2 nd Scenario
Grain Crops	-0.0045	-0.0048
Meat & Livestock	0.0038	0.0037
Forestry & Fishery	0.0098	0.0098
Coal	-0.0816	-0.082
Oil & Gas	-0.0176	-0.018
Other Mining	-0.0227	-0.0223
Process Food	-0.0058	-0.0063
Textiles	-0.065	-0.069
Leather & wood products	0.0234	0.0224

Chemical Products	-0.3896	-0.3814
Mineral Products	-0.0204	-0.0196
Ferrous Metal	-0.0964	-0.0965
Computer & Electronic	-0.0137	-0.0183
Electric & Machinery	0.1026	0.0987
Automotive	0.0847	0.0828
Other Manufactures	0.0276	0.0239
Utility & Construction	0.0663	0.067
Transport & Communication services	0.0024	0.0023
Other Services	0.0061	0.006

Source: Author's calculation

Apart from its impact on the Energy-Intensive Industries, CBAM policy also has indirect effects on production across various sectors in Indonesia. One interesting aspect to observe is the decline in production within the Grain Crops and Processed Food sectors. These sectors are affected due to CBAM's imposition of additional tariffs on the fertilizer sector, which serves as a crucial input for agriculture. Although the reduction in production for these products is not substantial, it does highlight CBAM's potential to increase food insecurity.

Another notable outcome is the increased production witnessed in the electric machinery and automotive equipment sectors. This uptick in output is attributed to the reallocation of production factors from sectors directly impacted by CBAM policy. Considering Indonesia's relative comparative advantage in these sectors (electronic, manufacture, & transportation), this surge in production has spurred investment growth (as depicted in Table 4) and contributed positively to Indonesia's GDP trajectory. Hence, it is important to note that CBAM may not directly have a positive impact on Indonesia's GDP, it is the reallocation of factors of production from sectors with lower comparative advantages to those with higher ones that drive Indonesia's GDP growth.

5.2 Impact of CBAM on Indonesian Emissions

An area of concern discussed in numerous literatures regarding CBAM is its systemic implications on the economy without a significant reduction in carbon emissions (UNCTAD 2021). CBAM is viewed as a costly and less efficient tool for emission reduction, although it can serve as an effective strategy for enforcing sustainable growth (Li & Zhang 2012). Similar conclusions are drawn in this study as well. Despite its limited economic impact on Indonesia, CBAM policy does not drive a substantial reduction in carbon emissions within the country (see table 6, 3rd scenario). Utilizing the combination of the GTAP and hybrid CGE models (Anderson, Cockburn, Martin 2010; Horridge & Zhai 2006), simulations from this model indicate that the implementation of CBAM would only lead to 1.04% reduction in carbon emissions in Indonesia.

Nevertheless, this reduction in CO₂ emissions also signifies CBAM's potential in mitigating carbon leakage.

These findings resonate with existing literature highlighting how CO₂ exports from developing nations only account for a small proportion of the final demand in the European Union. Even for countries with robust economic ties to the EU like Mozambique, their CO₂ contribution remains below 1% of the total final demand in the EU (Perdana & Vielle 2022). Similarly, India's CO₂ exports to the EU account for roughly 1% (Lowe 2021). Moreover, these findings also align with the UNCTAD's (2021) report, emphasizing that CBAM's impact would marginally reduce CO₂ emissions by 0.8 to 1.3 percentage points, thereby underscoring the need for supplementary instruments such as carbon taxes to exert a more pronounced influence on global carbon emission reduction efforts.

Table 6. Impact of CBAM and Indonesia's Carbon Tax on Indonesia's Carbon Emissions

Institutions	% change of total CO ₂	
	3 rd Scenario	4 th Scenario
Household	-15,35	-0,04
Firms	-0,01	-0,06
Total	-1,04	-0,06

Source: Author's calculation

The subsequent scenario analyzed in this study involves integrating a carbon tax component into the emission function within the model. The simulation assesses the concurrent impacts of the carbon tax alongside CBAM policy. The carbon tax, a non-market instrument, is currently being developed by the Indonesian government to support the achievement of its NDCs aimed at reducing greenhouse gas emissions. As depicted in Table 6 (4th scenario), the reduction in CO₂ emissions is less pronounced when the carbon tax is introduced into the model. This outcome presents an anomaly compared to some literature suggesting that carbon tax has a greater CO₂ emission reduction impact than CBAM.

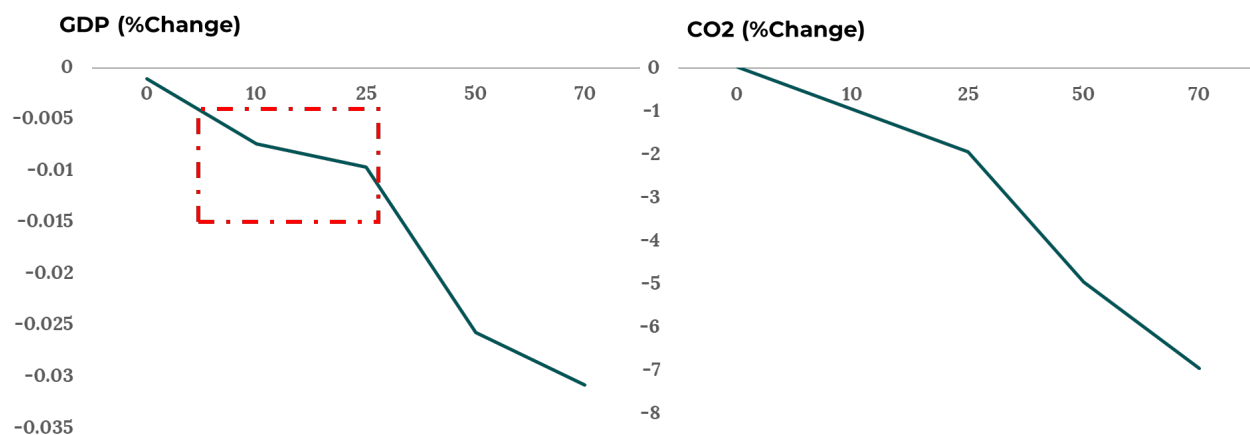
Several factors may contribute to this result. First, it is important to note that the emission function, based on a satellite model in this study, solely calculates emissions from energy sources. Industries reliant on fossil-based energy tend to have higher emissions, thus experiencing a more substantial carbon tax burden. This is evident in Table 6, where there is a further decrease of CO₂ emission by firm's post-implementation of the carbon tax policy.

However, households do not exhibit a significant reduction in emissions. While households bear the carbon tax cost, their energy consumption is comparatively lower than that of firms for industrial input purposes. Moreover, households receive government budget support after the government gains additional fiscal revenue from the carbon tax. This boost in household consumption contributes to the failure to achieve further emission reductions.

Meanwhile, the carbon tax's impact on industries also fails to offset the use of fossil-energy to achieve overall emission reductions. This is partly due to the relatively low carbon tax rate set by the government at US\$ 2 per ton CO₂. This rate is notably lower than developing countries like the European Union, which has set carbon prices at around US\$ 96 per ton CO₂ (World Bank, 2023). The low carbon tax rate maintains the affordability of fossil-based energy inputs compared to new and renewable energy sources, thereby not incentivizing companies to transition to alternative energy inputs (push factor). Additionally, this study solely focuses on the carbon tax's impact without considering policy interventions or incentives for environmentally friendly energy. By incorporating simulations of policy instruments such as tax reductions or technology transfers for green energy, the attractiveness to invest in green energy investment, facilitating a faster transition to new and renewable energy sources (pull factor).

5.3 Sensitivity Analysis

The preceding analysis established that Indonesia's current carbon tax rate of US\$2 per ton CO₂e is too low to achieve meaningful emission reductions, particularly when operating alongside the EU CBAM. A natural policy question follows: what carbon tax rate would optimize the trade-off between economic cost and environmental benefit? To address this, we conduct a sensitivity analysis by simulating the model under five carbon tax scenarios — US\$0, US\$10, US\$25, US\$50, and US\$70 per ton CO₂e — and examining the resulting changes in GDP and CO₂ emissions.



The simulation results reveal a clear non-linear relationship between the carbon tax rate and its macroeconomic and environmental outcomes. At the baseline of no carbon tax (US\$0), GDP experiences a negligible decline of 0.001% attributable solely to the CBAM effect, while CO₂ emissions marginally increase by 0.03%. Introducing a carbon tax of US\$10 per ton CO₂e produces a GDP contraction of 0.007% alongside a CO₂ reduction of 0.96%. At US\$25 per ton CO₂e, GDP declines by 0.010% while CO₂ emissions fall by 1.94%. However, at higher rates the economic costs escalate disproportionately: a US\$50 carbon tax generates a GDP loss of 0.026%

with CO₂ reductions of 4.96%, and at US\$70, the GDP contraction reaches 0.031% against emission reductions of 6.96%.

These results suggest the existence of a policy "sweet spot" in the range of US\$10 to US\$25 per ton CO₂e. Within this band, the marginal emission reduction per unit of GDP loss is most favorable — the economy achieves approximately 70% of the emission reduction observed at US\$50, but at less than 40% of the economic cost. Beyond US\$25, the diminishing marginal returns become apparent: doubling the carbon tax from US\$25 to US\$50 yields an additional 3.0 percentage points of CO₂ reduction but costs an additional 0.016 percentage points of GDP. By contrast, the increment from US\$10 to US\$25 achieves a comparable emission gain of approximately 1.0 percentage point for only 0.003 percentage points of additional GDP loss.

The sweet spot range of US\$10–25 per ton CO₂e also carries practical policy significance for Indonesia. At the lower bound of US\$10, the carbon tax would represent a fivefold increase from the current rate of US\$2 — substantial enough to signal policy commitment and begin incentivizing industrial decarbonization, yet modest enough to avoid disruptive economic adjustment. At the upper bound of US\$25, the rate approaches the levels adopted by several middle-income economies and would meaningfully reduce Indonesia's CBAM exposure, as the higher domestic carbon price narrows the gap with the EU ETS price that forms the basis of the CBAM levy. Furthermore, a carbon tax within this range would generate additional fiscal revenue that could be recycled into green energy subsidies or technology transfers, creating the "pull factors" that the base model's carbon tax simulation lacked.

This sensitivity analysis underscores a central finding of the study: while an excessively low carbon tax — such as Indonesia's current US\$2 rate — fails to generate meaningful emission reductions, an excessively high tax imposes disproportionate economic costs on a developing economy. Policymakers seeking to align Indonesia's climate commitments with its economic development objectives should target the US\$10–25 range as an initial benchmark, with the possibility of gradual escalation as industrial decarbonization technologies mature and the economy adjusts.

5.4 Limitations

One of the main challenges in constructing this study is related to data availability. The carbon intensity data used as the basis for formulating CBAM tariffs in this study is national-level data due to the absence of sectoral data. This results in uniform CBAM tariffs across sectors. Furthermore, the CBAM tariffs employed in this study may be underestimated, particularly given the higher carbon intensity levels in energy-intensive sectors compared to other sectors.

Regarding data availability, the emission levels considered in this study pertain solely to energy emissions, neglecting emissions from product sectors. Utilization of sectoral emission data, not just energy inputs, for a comprehensive analysis of the carbon tax's impact should be a concern for future research.

Another limitation relates to the CGE-based model, which is commonly used in literature to assess the potential impacts on economic structures due to shocks in exogenous factors. Future research must delve deeper into the assumptions inherent in CGE models, such as constant return to scale, substitutability of input factors, and imperfect elasticity of imported goods, to assess the impact of environmental policy instruments. This is particularly crucial in understanding the substitutability dynamics between energy-intensive sectors, less-intensive energy sectors, and its input factors.

Furthermore, it is imperative to establish a linkage between international and national models in future studies. This linkage will enable a sequential assessment of the impacts of environmental policy initiatives at both international and domestic levels, providing a more comprehensive understanding of their effects.

6 Conclusion and Policy Implications

In an effort to foster decarbonization agenda, the European Union (EU) has introduced the Carbon Border Adjustment Mechanism (CBAM) to combat carbon leakage and encourage non-EU countries to adopt more stringent decarbonization measures. However, this policy in which aimed at ensuring a level playing field, has raised concerns about its adverse economic effects on developing nations like Indonesia.

This paper seeks to analyze the potential impact of the CBAM policy on Indonesia's economy. Utilizing the GTAP model alongside a national hybrid CGE, our study shows that the implementation of CBAM, targeting an energy-intensive sectors, would yield a relatively modest impact on Indonesia's economic landscape. Specifically, an additional 1.82% import tariff imposed by the EU on Indonesian products would marginally reduce overall exports by 0.1% and minimally affect Indonesia's GDP by 0.0002%. Several factors contribute to this limited impact, including Indonesia's comparatively lower exposure levels and less carbon-intensive production processes compared to other nations.

Despite these findings, it is imperative to note certain nuances from our simulations. The scenarios examined align with current EU regulations (European Commission 2024), where CBAM is applied to energy-intensive sectors. Consequently, the economic repercussions of CBAM vary significantly and depends on each country's level of exposure, which remains relatively low for Indonesia. The anticipated shift in economic burdens resulting from CBAM implementation, a

focal point in existing literature, does not emerge as a concern within Indonesia's economic context.

Nevertheless, Indonesia's risk exposure to CBAM may evolve due to two key factors. First, potential adjustments in carbon content calculation methodologies could escalate tariff adjustments under CBAM. Currently, EU ETS calculations only consider direct product-related carbon emissions, but an inclusion of indirect carbon emissions from a product's value chain would augment CBAM tariffs. Second, the expanded coverage of CBAM beyond energy-intensive sectors could heighten Indonesia's exposure, considering Indonesia's export proportion to the EU is 8.4% of total exports and contributes 1.6% to Indonesia's GDP.

Furthermore, it is also important for developing nations like Indonesia to be cautious of additional consequences stemming from the CBAM policy. One of these concerns is the potential adoption of CBAM measures by EU partner nations. The economic strain resulting from CBAM's implementation could diminish their level of competitiveness, which prompt these partners to adopt similar measures. Recent analyses by Magacho et al. (2024) show that Indonesia will be vulnerable to economic disruptions when China adopt a comparable CBAM policy.

In addition to economic impacts, the simulations conducted in this model have not been able to demonstrate the effects of CBAM on reducing Indonesia's carbon emissions. Only a 1% decrease in Indonesia's total CO₂ emissions can be attributed to the CBAM policy. This finding is consistent with several other studies indicating that CBAM has a limited impact on carbon emission reduction efforts. Additionally, the introduction of domestic carbon taxes has not resulted in a significant reduction in carbon emissions in Indonesia. However, the modest decrease in carbon emissions does indicate that CBAM policies can help mitigate carbon leakage.

Meanwhile, there are various complementary policies that could support global emission reduction efforts. One option is to use the funds generated from CBAM tariffs to invest in clean energy projects in developing countries. Perdana & Vielle (2021) argue that such complementary policies could substantially reduce carbon emissions without imposing additional welfare burdens on developing countries or the EU. Moreover, these additional policies could assist developing countries to comply with CBAM requirements and accelerate the transition to renewable energy sources.

Furthermore, domestic policies must also contribute to reducing carbon emissions. Market-based initiatives like carbon trading and non-market policies such as carbon taxes need immediate implementation by the Indonesian government. To effectively achieve greenhouse gas emission reduction targets and support the goal of achieving net-zero emissions by 2060, carbon trading or carbon tax policies should encompass a wider range of sectors beyond just energy. Additionally, the pricing for carbon control measures must be increased from their

current levels. Setting a low price at US\$2 per ton CO₂, as it was intentionally plan by the government, only encourages companies to purchase certificates to offset their carbon emissions rather than investing in and transitioning to renewable energy sources.

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8 Appendix

8.1 Appendix 1: EU CBAM Tariff

One of the limitations of this study is that there is no difference in carbon intensity for different commodities within the same country. Due to this drawback, the tariffs for all CBAM commodity

categories are all the same, when it should be different depending on the carbon price regulation and each carbon intensity.

Table 7: EU CBAM Tariff for Scenario 1

Country	Carbon intensity (kgCO ₂ e/US\$)	Carbon price (US\$/tCO ₂ e)	EU CBAM tariff
Argentina	0.22	3.34	2.04%
Australia	0.34	10.64	2.90%
Brazil	0.16	0	1.54%
Canada	0.35	48.03	1.68%
China	0.57	8.15	5.01%
United Kingdom	0.15	88.13	0.12%
Indonesia	0.19	0	1.82%
India	0.29	0	2.78%
Japan	0.23	2.17	2.16%
Korea, Rep.	0.34	11.24	2.88%
Mexico	0.23	4.07	2.11%
Malaysia	0.34	0	3.26%
Philippines	0.16	0	1.54%
Russian Federation	0.47	0	4.51%
Saudi Arabia	0.41	0	3.94%
Singapore	0.12	3.77	1.11%
Thailand	0.26	0	2.50%
Turkey	0.25	0	2.40%
United States	0.3	0	2.88%
Vietnam	0.39	0	3.74%
South Africa	0.65	8.93	5.66%
Rest of World	0.32	3	2.98%

Source: Author's calculation

In the second scenario, the tariffs for every country except Indonesia remains the same because there is no change in the carbon price. For Indonesia, the implementation of the carbon pricing regulation slightly decreases the EU CBAM tariff from 1.82% to 1.79%.

Table 8: EU CBAM Tariff for Scenario 2

Country	Carbon intensity (kgCO ₂ e/US\$)	Carbon price (US\$/tCO ₂ e)	EU CBAM tariff
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Argentina	0.22	3.34	2.04%
Australia	0.34	10.64	2.90%
Brazil	0.16	0	1.54%
Canada	0.35	48.03	1.68%
China	0.57	8.15	5.01%
United Kingdom	0.15	88.13	0.12%
Indonesia	0.19	2	1.79%
India	0.29	0	2.78%
Japan	0.23	2.17	2.16%
Korea, Rep.	0.34	11.24	2.88%
Mexico	0.23	4.07	2.11%
Malaysia	0.34	0	3.26%
Philippines	0.16	0	1.54%
Russian Federation	0.47	0	4.51%
Saudi Arabia	0.41	0	3.94%
Singapore	0.12	3.77	1.11%
Thailand	0.26	0	2.50%
Turkey	0.25	0	2.40%
United States	0.3	0	2.88%
Vietnam	0.39	0	3.74%
South Africa	0.65	8.93	5.66%
Rest of World	0.32	3	2.98%

Source: Author's calculation

8.2 Appendix 2: Construction of CGE Model

Below will be described in detail the concept of CGE hybrid model construction used for energy policy analysis. As mentioned above, this hybrid model adds equation model features to detect energy flows including emission equation features and associated carbon taxes. Furthermore, other equation block models are identical to the principles of the standard CGE model which include equations of economic agent behavior systems, transfers between institutions, production sectors and linkages between industries, balance of savings and investment and substitution of international trade commodities (exports and imports).

4.1.1. Production Sector Behavior

To capture industry characteristics specific to the energy sector, we separate energy and non-energy production sectors. For the non-energy sector, energy substitution between fuel types and subsequent substitution between production factors and fuels (composite energy and production

factors) is permitted. But on the contrary, for the energy sector, for example the fossil energy sector and the refinery industry, Leontief assumptions are used (complementary) between energy fuel commodities and production factors.

The assumption of a substitution relationship between energy composites and capital factors (not labor) was chosen to indicate the existence of new technologies in the type of capital goods that affect the occurrence of energy substitution and energy saving. Thus, optimization of producer behavior for both the energy and non-energy sectors is assumed based on the constraints of composite bonding of energy and capital fuel inputs.

Furthermore, for the electricity sector, following the approach of the Wing model (2006), namely the hybrid model, which is a combination of *top-down* and *bottom-up models* to represent various types of power generation technology in the industrial sector (activity). Thus, the effect of technological substitution on the power generation industry can be analyzed. According to Wing (2006), this hybrid CGE model design can provide more accurate calculation results, especially for the substitution of fossil energy plants with plants from renewable energy sources.

4.1.1.1. Behavior of the Non-Energy Production Sector

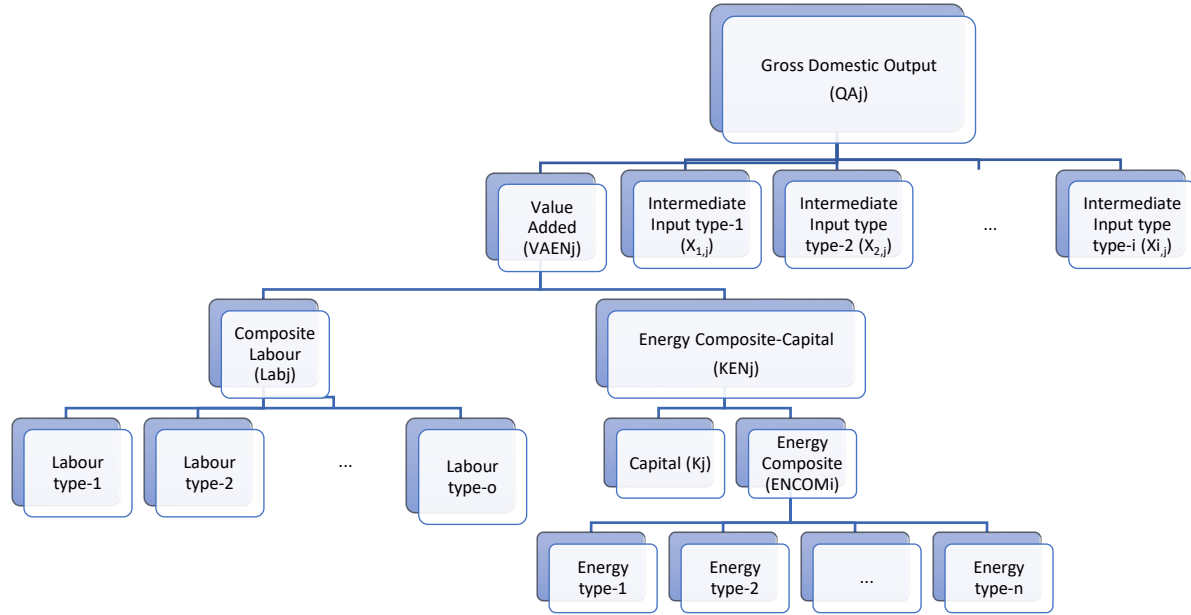
The energy industry sector is based on SNSE BPS statistical data in 2018, namely: food type agricultural sector; other types of agriculture; animal husbandry and livestock products; forestry and hunting; Fishing; other mining and quarrying materials; food, beverages and tobacco; spinning, textiles, clothing and leather; wood and wood products; paper, printing, conveyance, metal goods, and other industries; construction; trade; restaurant; Hospitality; land freight; air, water and communication freight; transportation and warehousing support services; banks and insurance; real estate and services of the Company; government and land, education, health, film and other social services; and individual, household and other services. The economic behavior of the non-energy production sector based on the "cage" structure is shown in Figure 1.

In general, any non-energy industry will produce output by processing intermediate goods and factors of production. It is assumed that producers will minimize such costs by technological constraints of production in the context of perfectly competitive markets. Production technology functions are explicitly specified with CES functions to define decisions on the choice of optimal input combinations. The degree of substitution of this combination depends largely on the value of the elasticity of substitution between each input. However, because this study did not perform regression estimation to calculate the value of the elasticity coefficient, the value was taken from existing references.

The model structure for the non-energy industrial sector is actually identical to the standard CGE model structure. The only difference lies in the possibility of substitution between types of

energy and substitution between composite energy and capital factors. It is assumed that the set of non-energy industrial sectors is denoted by $j \in NE \subset A$, $NE \cap Energy = \emptyset$

Figure 1: "Cage" Production Structure for Non-Energy Industry ($j \in NE \subset A$)



Source: Author Modification

Based on Figure 1, at the top level, the domestic output of non-energy industries results from the Leontief (or complement) production function between intermediate raw materials and combined value-added aggregates and composite energy (). If is gross domestic output; symbolizes the element of the intermediate commodity, excluding energy commodity inputs (), used in non-energy industries to-; symbolizes intermediate inputs from non-energy-to-commodities, used by non-energy-to-industries; symbolizes the minimum coefficient required of input between non-energy to- to produce 1 unit of ; symbolizes the minimum coefficient required from to produce 1 unit of ; symbolizes the price of ; and represents the final composite price of the non-energy commodity to-. It is assumed that the industry will produce through minimization of input costs from and through Leontief's production function: $VAEN_jQA_jii \in NEC \subset C, NEC \cap Energy = \emptyset jX_{i,j}ijax_{i,j}iQA_java_jVAEN_jQA_jp_j^{VAEN}VAEN_jp_i^ZijQA_jX_{i,j}VAEN_j$

Top stage:

$$\min_{VAEN_j, X_{i,j}} C_j = p_j^{VAEN} VAEN_j + \sum_{i \in NEC \subset C} p_i^Z X_{i,j}, \quad j \in NE \subset A \quad (1')$$

Subject to:

$$QA_j = \min\left(\frac{X_{i,j}}{ax_{i,j}}, \frac{VAEN_j}{ava_j}\right), \quad i \in NEC \subset C, \quad j \in NE \subset A \quad (2')$$

Equation (2') implies that ; and. The re-expression of equation (1') is as follows:

$$ax_{i,j}QA_jVAEN_j = ava_jQA_j$$

$$C_j = \left(p_j^{VAEN}ava_j + \sum_{i \in NEC \subset C} p_i^Z ax_{i,j}\right)QA_j, \quad j \in NE \subset A$$

The incentive rate for production activity to- () is added to the index price of agar . So that the relationship equation becomes as follows:

$$X_{i,j} = ax_{i,j}QA_j, \quad i \in NEC \subset C, \quad j \in NE \subset A \quad (1)$$

$$VAEN_j = ava_jQA_j, \quad j \in NE \subset A \quad (2)$$

$$(1 + subA_rate_j)p_j^{QA} = p_j^{VAEN}ava_j + \sum_{i \in NEC \subset C} p_i^Z ax_{i,j}, \quad j \in NE \subset A \quad (3')$$

Next, the variables are redefined into the average incentive for all production activities; and the rate of subsidies for specific types of production activities (), so that the following relationship can be obtained:

$$subAArate = \frac{1}{card(A)} \sum_{j \in NE \subset A} sub_rateA_j$$

$$subA_rate_j = subAArate (subArate_j), \quad j \in NE \subset A$$

Thus, equation (3') can be reconstructed into:

$$\left(1 + (subAArate) (subArate_j)\right)p_j^{QA} = p_j^{VAEN}ava_j + \sum_{i \in NEC \subset C} p_i^Z ax_{i,j}, \quad j \in NE \subset A \quad (3)$$

Equation (3) represents the unit cost for the to- industry to produce output () obtained from the total weighting of the jQA_j Value Added-Energy Composite price with the intermediate commodity.

The relationship between the activity volume of production (including prices) and the volume of related supply commodities (including prices) is defined as follows:

$$Q_i = \sum_{j \in NE \subset A} TRANS_Coef_{j,i} Q_{A_j}, \quad i \in NEC \subset C \quad (4)$$

$$P_j^{QA} = \sum_{i \in NEC \subset C} TRANS_Coef_{j,i} P_i^Q, \quad j \in NE \subset A \quad (5)$$

where:

$TRANS_Coef_{j,i} = \frac{Q_{j,i}}{Q_{A_j}}$, is the Input-Output coefficient; and

$Q_{j,i}$: The output of non-energy industrial production to- to become non-energy to-commodity. j i

For non-energy industrial structures, a *one-to-one relationship* is assumed i.e. production activity produces only one type of related commodity, so that $TRANS_COEF_{j,i} = 1$

In the second stage, non-energy industries j are assumed to initiate the combined cost of inputs from energy-capital composites and labor composites in the Cobb-Douglas production function to produce aggregates from value-added energy composites. $()$. and is the price of labor composites and energy-capital composites of non-energy to-industry; and is the sum of labor composites and energy-capital composites of non-energy to-industry; is the $VAEN_j P_j^{LAB} P_j^{KEN} j LAB_j KEN_j j \delta_{LAB,j} share$ parameter of the composite of non-energy industrial labor to- ($;$ is the $j0 \leq \delta_{LAB,j} \leq 1$) $\delta_{KEN,j} share$ parameter of non-energy industrial composites to- ($;$; and is an efficiency parameter. Thus, cost minimization from non-energy industries to- can be defined into: $j0 \leq \delta_{KEN,j} \leq 1$) $\delta_{LAB,j} + \delta_{KEN,j} = 1$ $sva_j VAEN_j$

Second stage:

$$\min_{Lab, KEN} (P_j^{LAB} LAB_j + P_j^{KEN} KEN_j), \quad j \in NE \subset A$$

Constraints:

$$VAEN_j = sva_j LAB_j^{\delta_{LAB,j}} KEN_j^{\delta_{KEN,j}}, \quad \delta_{LAB,j} + \delta_{KEN,j} = 1, \quad j \in NE \subset A \quad (6)$$

The solution to the above problem is the amount of demand from energy-capital composites and labor composites as follows:

$$KEN_j = \delta_{KEN,j} \frac{P_j^{VAEN}}{P_j^{KEN}} VAEN_j, \quad j \in NE \subset A \quad (7)$$

$$LAB_j = \delta_{LAB,j} \frac{P_j^{VAEN}}{P_j^{LAB}} VAEN_j, \quad j \in NE \subset A \quad (8')$$

The index price of value added represents the cost per unit of VAEN production and is obtained from the sum of combinations of labor composite and energy-capital composite prices: P_j^{VAEN}

$$P_j^{VAEN} = \frac{P_j^{LAB} LAB_j + P_j^{KEN} KEN_j}{VAEN_j}, \quad j \in NE \subset A \quad (9')$$

Furthermore, to measure price variations in each industry, we made adjustments as follows:
 $P_j^{LAB} = PDIST_j^{LAB} P^{LAB}$

Where is the adjustment factor of the labor composite and the aggregate price of the labor composite that will determine the price level of the labor composite activity. Assumed.
 $PDIST_j^{LAB} P^{LAB} P^{LAB} = 1$

Thus, based on the above definition, the equation (8' – 9') can be reexpressed to:

$$LAB_j = \delta_{LAB,j} \frac{P_j^{VAEN}}{PDIST_j^{LAB} P^{LAB}} VAEN_j, \quad j \in NE \subset A \quad (8)$$

$$P_j^{VAEN} = \frac{PDIST_j^{LAB} P^{LAB} LAB_j + P_j^{KEN} KEN_j}{VAEN_j}, \quad j \in NE \subset A \quad (9)$$

Under the conditions of Walras's Law, equation 9 is excluded from the CGE model to maintain a balance between the total number of equations and the number of endogenous variables. Thus, the identity of the receipt-expenditure account in the balance system can be obtained.

At the third stage, the specification of two types of aggregation is carried out. The labor composite is determined from the CES function for the type of labor with cost minimization problems. is the workforce of the ke- type used in the non-energy industry to- ; is the wage of the labor of the ke-kind; is the $L_{o,j}ojp_o^L o\gamma_{o,j}share$ parameter of the to- type of labor used in non-energy industries to- (is the efficiency parameter of the composite of labor used in the non-energy to- industry; and is the substitution parameter of ($oj0 \leq \gamma_{o,j} \leq 1$); $sl_j j\beta_j L_{o,j} - 1 \leq \beta_j \leq \infty$, $\beta_j \neq 0$)

Third Stage (Left Side):

$$\min_{L_{o,j}} \sum_{o \in LBR} p_{o,j}^L L_{o,j}, \quad j \in NE \subset A$$

Constraints:

$$LAB_j = sl_j \left\{ \sum_{o \in LBR} \gamma_{o,j}^{1+\beta_j} L_{o,j}^{-\beta_j} \right\}^{-\frac{1}{\beta_j}}, \quad j \in NE \subset A \quad (10')$$

Solutions to the amount of labor demand for non-energy industries to:

$$L_{o,j} = \left(\frac{\gamma_{o,j}}{s l_j^{\frac{\beta_j}{\beta_j+1}}} \right) LAB_j \left(\frac{P_{o,j}^L}{P_j^{LAB}} \right)^{\frac{-1}{\beta_j+1}}, \quad o \in LBR, \quad j \in NE \subset A \quad (11')$$

The price index of the industrial labor composite () is obtained from the total weighted of wages per type of labor to (): $P_j^{LAB} P_o^L$

$$P_j^{LAB} = \frac{\sum_{o \in LBR} p_{o,j}^L L_{o,j}}{LAB_j}, \quad j \in NE \subset A \quad (12')$$

If the elasticity of the substitution is , then . $\sigma_j^L \beta_j = \frac{1}{\sigma_j^L} - 1$

Next, for the adjustment of labor wages for each industry, we define additional variables, and , so that: . is an adjustment factor for wages per type of labor and is the aggregate wage of all types of labor. So that the multiplication of the two variables will determine the level of wages per type of labor. $p_o^L PDIST_{o,j}^L p_{o,j}^L = PDIST_{o,j}^L p_o^L PDIST_{o,j}^L p_o^L p_{o,j}^L$

Based on SNSE-Energi table data, the total labor supply is calculated from the total labor demand in domestic industries and those working abroad:

$$\sum_{j \in A} L_{o,j} + L_{o,ROW} + LU_o = LS_o, \quad o \in LBR, \quad ROW \in INS$$

It is assumed that there is no unemployment ; so that the aggregate wage of the type of labor can be calculated as: $LU_o p_o^L = \frac{\text{total labour type value in SAM}}{LS_o}$

Assumed and . So where and . $p_{o,j}^L = 1 P_{o,ROW}^L = 1 p_{o,j}^L = \frac{SAM(o,j)}{L_{o,j}} SAM(o,j) = L_{o,NE} SAM(o, ROW) = L_{ROW_o}$

To ensure there is no difference, a gap test is carried out as follows:

$$Cost_gap(o,j) = PDIST_{o,j}^L p_o^L L_{o,j} - SAM(o,j)$$

Thus, based on this definition, the equation (10' – 12') can be rewritten to:

$$LAB_j = s l_j \left\{ \sum_{o \in LBR} \gamma_{o,j}^{1+\beta_j} L_{o,j}^{-\beta_j} \right\}^{-\frac{1}{\beta_j}}, \quad j \in NE \subset A,$$

$$\sum_{o \in LBR} \gamma_{o,j} = 1, \quad \beta_j = \frac{1}{\sigma_j^L} - 1 \quad (10)$$

$$L_{o,j} = \left(\frac{\gamma_{o,j}}{\beta_j} \right)_{sl_j^{\frac{\beta_j}{\beta_j+1}}} LAB_j \left(\frac{PDIST_{o,j}^L P_o^L}{PDIST_j^{LAB} P^{LAB}} \right)^{\frac{-1}{\beta_j+1}}, \quad o \in LBR, \quad j \in NE \subset A \quad (11)$$

$$PDIST_j^{LAB} P^{LAB} LAB_j = \sum_{o \in LBR} PDIST_{o,j}^L P_o^L L_{o,j}, \quad j \in NE \subset A \quad (12)$$

One of the above equations still has redundancies. Thus, based on the conditions of Walras' Law, we chose to eliminate equation 10 from the equilibrium model specification.

Furthermore, aggregates of energy-capital composites are determined assuming the *Cobb-Douglas* production function under the cost minimization problem. and is the price of the energy composite and capital of the non-energy industry to-; and is a composite energy input and capital in non-energy industries to-; is the share parameter of energy composites from non-energy industries to (; is the share parameter of capital in non-energy industries to- (; ; and is the efficiency parameter of the composite energy-capital to-. Thus, the problem of non-energy industries in minimizing the cost of aggregate energy-capital is as follows: $P_j^{ENCOM} P_j^K j ENCOM_j K_j j \chi_{ENCOM,j} 0 \leq \chi_{ENCOM,j} \leq 1) \chi_{K,j} 0 \leq \chi_{K,j} \leq 1) \chi_{ENCOM,j} + \chi_{K,j} = 1$ $sken_j j j$

Third Stage (Right Side):

$$\min_{ENCOM,K} (P_j^{ENCOM} ENCOM_j + P_j^K K_j), \quad j \in NE \subset A$$

Constraints:

$$KEN_j = sken_j ENCOM_j^{\chi_{ENCOM,j}} K_j^{\chi_{K,j}}, \quad \chi_{ENCOM,j} + \chi_{K,j} = 1, \quad j \in NE \subset A \quad (13)$$

The solution of the above problem yields the -th industry demand for energy composite and capital:

$$ENCOM_j = \chi_{ENCOM,j} \frac{P_j^{KEN}}{P_j^{ENCOM}} KEN_j, \quad j \in NE \subset A \quad (14)$$

$$K_j = \chi_{K,j} \frac{P_j^{KEN}}{P_j^K} KEN_j, \quad j \in NE \subset A \quad (15')$$

Price index of capital-energy composite is the unit cost of capital-energy composite production and is obtained from a weighted sum combination of price of energy composite and capital: P_j^{KEN}

$$P_j^{KEN} = \frac{P_j^{ENCOM} ENCOM_j + P_j^K K_j}{KEN_j}, \quad j \in NE \subset A \quad (16')$$

Here, we introduce the terms of capital rent adjustment to obtain the specific capital rent across -th non-energy industries. Thus, we need to define the additional variables: and such that: where is the adjustment factor of capital rent, and is the aggregate capital rent which together determine the -th industry's level of capital rent, . $jP^K PDIST_j^K P_j^K = PDIST_j^K P^K PDIST_j^K P^K jP_j^K$

Based on the SAM-Energy data set, total supply of capital stock is obtained from sum of capital demand to activities and rest of world (ROW) () as follows: K_ROW

$$KS = \sum_{j \in NE \subset A} K_j + K_ROW$$

We assume there is no unemployed capital, . Thus, the aggregate capital rent is obtained as: $KU = 0P^K = \frac{\text{total capital value in SAM}}{KS}$

However, due to lack information on real (physical) capital stock at specific activity () and rest of world (ROW) () in the given year of SAM-Energy, we then assume that: $K_{NE}K_ROW$

$$P_j^K = \frac{SAM(K, j)}{K_j} \text{ and } P_{ROW}^K = 1$$

where . Thus, is equal to 1. To test these relationships, in the model we estimate the cost gap, which should be zero: $SAM(K, j) = K_j P_j^K$

$$Cost_GAP(K, j) = PDIST_j^K P^K K_j - SAM(K, j)$$

4.1.1.2. CO₂ Emission Calculation and Carbon Tax Module (Satellite Model)

This chapter explains the application of carbon taxes and the calculation of carbon emission content¹. We assume that the use (absorption) of fossils and their refined products (petroleum) increases CO₂ emissions due to their combustion. This absorption includes: (i) fossil (and petroleum) inputs in industry-wide production processes; and (ii) final consumption of fossil (and petroleum) by households and governments. However, due to limited information, we exclude emissions resulting from the agricultural sector – i.e. land use change – and deforestation.

4.1.1.3. CO₂ emissions calculation

¹ Based on Allan, *et al* (2008), the calculation of carbon emissions is only based on the equivalent CO₂ content and does not calculate the level of emissions from non-CO₂ – for example emissions from methane, sulphuric acid, carbon monoxide emissions – which are caused by complicated emission identification methods that are closely related to combustion conditions and the type of technology used.

According to McDonald and Thierfelder (2008), the CGE model built on this study will be incorporated with CO₂ emissions. In this model, commodity fuel inputs (primary fossil and refinery final product), denoted as i , are used by the in-house industry. Thus, the total CO₂ emissions, expressed as ton units, resulting from burning fossil energy for each industry (j), are obtained from the multiplication between emission factors as follows:

$$CO2FIRM_j = \sum_{i \in \{fuel\ types\} \subset energy \subset C} CO2FAC_i \cdot X_{i,j}, \quad j \in A$$

On the other hand, the total CO₂ emissions resulting from fossil fuel consumption by households and governments are derived from the equation below:

$$CO2INS = \sum_{i \in \{fuel\ types\} \subset energy \subset C} CO2FAC_i \cdot \left(\sum_{h \in H} CH_{i,h} + CG_i \right)$$

Where $CO2INS$ is the total CO₂ emissions; i is an element of a subset of fossil fuel commodity types; and h in order is the fuel consumption of households and governments. $CO2INS = \sum_{h \in H} CH_{i,h} + CG_i$

Because there are no published emission factor standards, in this study the emission factor per fuel type refers to the *Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories* (2006).² To calculate the total CO₂ emissions in Indonesia, information for consumption volume from fossil fuels is obtained from the source *Handbook of Energy and Economic Statistics of Indonesia* (HEESI) KESDM (2016). Table 9 shows the data of emission factors ($CO2FAC_i$) and oil fuels volume sales (CG_i) for Indonesia in year of 2008 $TonCO_2/TJ$.³

Table 9: CO emission factor² and Fossil Fuel Sales

No.	Fuel Type	CO ₂ emission Factor ($TonCO_2/TJ$)	Volume Sales (Terajoules (TJ))
1.	Bioethanol	70.80	7,096.72
2.	Biodiesel	70.80	13,190.11
3.	Coal	94.60	458,466.31
4.	Petroleum	73.30	2,187,141.07
5.	Kerosene	71.90	280,375.41
6.	Liquid Natural Gas (LNG)	64.20	1,394.87
7.	Natural Gas	56.10	208,771.97
8.	'Pertamax' Type of fuel oil	69.30	10,571.66

² Available on <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html>

³ We convert the unit of oil fuels volume (Kilo liters) to Tetra Joule (TJ) so that the total emissions can be calculated.

9.	Non-subsidized LPG	63.10	96,160.52
10.	Other Petroleum Products	73.30	176,335.08
11.	Subsidized Biodiesel	70.80	19,785.16
12.	Subsidized Biodhanola	70.80	1,560.05
13.	Subsidized fuel oil ('Premium')	69.30	682,208.69
14.	Subsidized diesel fuel oil	74.10	931,479.67
15.	Subsidized LPG	63.10	313,148.78

Source: IPCC (2006); Handbook of Energy and Economic Statistics of Indonesia, Ministry of Energy and Mineral Resources (2008).

Thus, the total CO₂ emissions generated from economic activities in Indonesia are obtained from the total emissions generated from the burning of fossil fuels by all industries, households and governments as follows:

$$CO2TOTAL = \sum_{j \in A} CO2FIRM_j + CO2INS$$

4.1.1.4. CO₂ Emission Tax Model

Government revenue from the CO₂ emission tax levy is derived from the following equation:

$$IGCO2 = TAXCO2.CO2TOTAL$$

$$= TAXCO2 \sum_{i \in \{fuel\ types\} \subset energy \subset C} \left(\sum_{j \in A} CO2FIRM_{i,j} + \sum_{h \in H} CO2H_{i,h} + CO2G_i \right)$$

$$IGCO2 = TAXCO2.CO2TOTAL$$

$$= TAXCO2 \sum_{i \in \{fuel\ types\} \subset energy \subset C} \left(\sum_{j \in A} CO2FIRM_{i,j} + \sum_{h \in H} CO2H_{i,h} + CO2G_i \right)$$

Where $IGCO2$ is the total government revenue derived from CO₂ emission taxes; (Rp/ton $COTAXCO2_2$) is the total tax value of CO₂ emissions from each emission resulting from the combustion of every fossil fuel in the to- j industry; $CO2H_{i,h}$ is CO₂ emissions resulting from fossil fuel consumption in households; $CO2G_i$ is CO₂ emissions resulting from public consumption of fossil fuels.

In other words, government revenue on carbon emission taxes is equivalent to *ad valorem* taxes on fossil fuels consumed by industry, households and governments as follows:

$$IGCO2 = \sum_{i \in \{fuel\ types\} \subset energyc \subset C} p_i^Z \left(\sum_j TAXFUEL_{i,j} X_{i,j} + \sum_{h \in H} TAXFUEL_{i,h} CH_{i,h} + TAXFUEL_{i,gov} CG_i \right)$$

Where is the index price of each fuel and is $p_i^Z TAXFUEL_{i,user}$ the *ad valorem* tax for the entire economic agent. Thus, the relationship between and can be expressed as follows: $TAXCO2 TAXFUEL_{fuel,user}$

$$TAXFUEL_{i,j} = \frac{TAXCO2.CO2FIRM_{i,j}}{p_i^Z X_{i,j}}, \quad i \in \{fuel\ types\} \subset energyc \subset C,$$

$j \in A$

$$TAXFUEL_{i,h} = \frac{TAXCO2.CO2H_{i,h}}{p_i^Z CH_{i,h}}, \quad i \in \{fuel\ types\} \subset energyc \subset C, \quad h \in H$$

$$TAXFUEL_{i,gov} = \frac{TAXCO2.CO2G_i}{p_i^Z CG_i}, \quad i \in \{fuel\ types\} \subset energyc \subset C, \quad gov \in INS$$

The expression of the equation model above shows that the amount of carbon tax is not only based on the level of carbon content in each type of fuel, but also influenced by the price and volume of fossil fuel consumption.

In the industrial sector, to implement a carbon tax for CO2 emissions resulting from burning fossil fuels, at the lower stage of the production structure for non-energy industries a rearrangement is carried out by adding carbon tax variables as follows:

$$X_{i,j} = \left(\frac{\kappa_{i,j}}{sen_j^{\frac{\phi_j}{\phi_j+1}}} \right) ENCOM_j \left(\frac{(1 + TAXFUEL_{i,j}) p_i^Z}{P_j^{ENCOM}} \right)^{\frac{-1}{\phi_j+1}}, \quad i \in energyc \subset C,$$

$j \in NE \subset A$

where:

$TAXFUEL_{i,j} = 0$ if $i \in \{non - fuel\ types\} \subset energyc \subset C$,

$j \in NE \subset A$; and $TAXFUEL_{i,j} \neq 0$ if $i \in \{fuel\ types\} \subset energyc \subset C$,

$j \in NE \subset A$

The index price of the energy composite () is obtained from the total weighting of energy prices

(): $P_j^{ENCOM} p_i^Z$

$$P_j^{ENCOM} = \frac{\sum_{i \in \text{energyc} \subset C} (1 + TAXFUEL_{i,j}) p_i^Z X_{i,j}}{ENCOM_j}, \quad j \in NE \subset A$$

For the fifth industry that uses fossil energy commodities as raw materials, for example the petroleum refinery industry, the following rearrangement is carried out: j

$$(1 + (subAArate)(subArate_j)) p_j^{ENCOM} = \sum_{i \neq oil \in \text{energyc} \subset C} (1 + TAXFUEL_{i,j}) p_i^Z ax_{i,j},$$

$$j \in \text{fossil} \subset \text{energy} \subset A$$

Where:

$$TAXFUEL_{i,j} = 0 \text{ if } i \in \{\text{non} - \text{fuel types}\} \subset \text{energyc} \subset C,$$

$$j \in \text{fossil} \subset \text{energy} \subset A;$$

$$\text{and } TAXFUEL_{i,j} \neq 0 \text{ if } i \in \{\text{fuel types}\} \subset \text{energyc} \subset C, \quad j \in \text{fossil} \subset \text{energy} \subset A$$

Then for the electricity industry sector is also added to the production structure as follows: $TAXFUEL_{i,j}$

$$X_{i,j} = \left(\frac{\kappa_{i,j}}{\frac{\phi_j}{sen_j \phi_j^{j+1}}} \right) ENCOM_j \left(\frac{(1 + TAXFUEL_{i,j}) p_i^Z}{P_j^{ENCOM}} \right)^{\frac{-1}{\phi_j^{j+1}}}, \quad i \in \text{energyc} \subset C,$$

$$j \in \text{conv} \subset \text{elect} \subset \text{energy} \subset A$$

where:

$$TAXFUEL_{i,j} = 0 \text{ if } i \in \{\text{non} - \text{fuel types}\} \subset \text{energyc} \subset C,$$

$$j \in \text{conv} \subset \text{elect} \subset \text{energy} \subset A;$$

$$\text{and } TAXFUEL_{i,j} \neq 0 \text{ if } i \in \{\text{fuel types}\} \subset \text{energyc} \subset C,$$

$$j \in \text{conv} \subset \text{elect} \subset \text{energy} \subset A$$

The index price of composite energy is obtained from the total weighting of various types of energy prices () as follows: p_i^Z

$$P_j^{ENCOM} = \frac{\sum_{i \in \text{energyc} \subset C} (1 + TAXFUEL_{i,j}) p_i^Z X_{i,j}}{ENCOM_j},$$

$$j \in \text{conv} \subset \text{elect} \subset \text{energy} \subset A$$

In household institutions, it is subject to the following household request functions: $TAXFUEL_{i,h}$

$$(1 + TAXFUEL_{i,h}) P_i^Z CH_{i,h} = CH_share_{i,h} EH_h, \quad i \in C, \quad h \in H$$

where:

$TAXFUEL_{i,h} = 0$ if $i: \{non\ fuel\ types\} \in energy \subset C$; and

$TAXFUEL_{i,h} \neq 0$ if $i: \{fuel\ types\} \in energy \subset C$

For government institutions, it is incorporated into the public expenditure model as follows: $TAXFUEL_{i,gov}$

$$EG = \sum_{i \in C} (1 + TAXFUEL_{i,gov}) P_i^Z CG_i + \sum_{i \in C} (subQArate)(subQrate_i) P_i^Q Q_i \\ + \sum_{j \in A} (subAArate)(subArate_j) P_j^{QA} QA_j + \sum_{in \in INS} TR_{in,gov}$$

where:

$TAXFUEL_{i,gov} = 0$ if $i: \{non\ fuel\ types\} \in C$; and

$TAXFUEL_{i,gov} \neq 0$ if $i: \{fuel\ types\} \in C$

4.1.2. Government Behavior

In principle, the model of government behavior built on this study is identical to the standard CGE model. The only difference lies in the addition of a carbon tax as explained above.

Thus, in this hybrid CGE model, the model of government behavior is expressed as follows. On the acceptance side, the mathematical model built is:

$$IG = \sum_{i \in C} (vatArate)(vatrate_i) P_i^Q Q_i + \sum_{i \in CM} (tarifArate)(tarifrate_i) P_i^M M_i \\ + \sum_{in \in INS} TR_{gov,in} + TAXCO2.CO2TOTAL \quad (111)$$

Where is the total government revenue; is $IG(vatArate)(vatrate_i)$ the *ad valorem* tax of the gross domestic supply; is the rate of tariffs of imported commodities; and is government revenue through transfer from institutions. $(P_i^Q Q_i)(tarifArate)(tarifrate_i)(P_i^M M_i)TR_{gov,in}$

On the government expenditure side, the model built is:

$$EG = \sum_{i \in C} (1 + TAXFUEL_{i,gov}) P_i^Z CG_i + \sum_{i \in C} (subQArate)(subQrate_i) P_i^Q Q_i \\ + \sum_{j \in A} (subAArate)(subArate_j) P_j^{QA} QA_j + \sum_{in \in INS} TR_{in,gov} \quad (112)$$

$$CG_i = CGIN_i \overline{CGADJ}, \quad i \in C \quad (113)$$

$$TR_{h,gov} = TRG_share_{h,gov} TRG_barCPI, \quad h \in H, gov \in INS \quad (114a)$$

$$TR_{in,gov} = TRG_share_{in,gov} TRG_bar, \quad in \neq h \in INS \quad (114b)$$

Government saving is defined () as follows:SG

$$SG = IG - EG \quad (115)$$

Where is the total public expenditure; is government spending on goods and services; is the rate of subsidies distributed by the government for domestic supply commodities (); is the rate of subsidies distributed by the government for industrial activities (business entities) (); is the transfer of government to institutions; is the issuance of government initials for the to- commodity $EGCG_i(subQArate)(subQrate_i)P_i^Q Q_i(subAArate)(subArate_j)P_j^{QA} QA_j TR_{in,gov} CGIN_i$; $TRG_share_{in,gov}$ is the proportion of government transfer payments to institutions; and is the total transfer payments. TRG_bar

4.1.3. Consumer Behavior

The specification model in this study to define household behavior is identical to the standard CGE model. The only difference lies in: i) the addition of *an ad valorem TAXFUEL_{i,h}* fuel tax to the household demand function; and ii) the household income factor from natural resources from fossil mining activities.

So that the source of household income is expressed in the following equation:

$$IH_h = IHL_h + IHK_h + IHRES_h + \sum_{in \in INS} TR_{h,in}, \quad h \in H \quad (116)$$

$$IHL_h = \sum_{o \in LBR} IHL_share_{h,o} P_o^L \left(\sum_{j \in A} PDIST_{o,j}^L L_{o,j} + L_{o,ROW} \right), \quad h \in H \quad (117)$$

$$IHK_h = IHK_share_h P^K \left(\sum_{j \in A} PDIST_j^K K_j + K_{ROW} \right), \quad h \in H, \quad ROW \in IN \quad (118)$$

$$IHRES_h = IHRES_share_h P^{RES} \left(\sum_{j \in fossil \subset A} PDIST_j^{RES} RES_j + \sum_{j \in renew \subset A} PDIST_j^{RES} RES_j \right), \quad h \in H \quad (119)$$

Where is the total income of the to-household; is the income factor of household capital to-; is household income from natural resource factors; is transfer income from households from institutions; is the $IH_h IHK_h IHRES_h TR_{h,in} IHL_share_{h,o}$ share of household income from

labor donations; is the IHK_share_h share of household income from capital factors; is the $IHRES_share_h$ share of household income from natural resource factors; is the supply of foreign workers working in domestic industry; and is the supply of foreign capital used in domestic industry. $L_ROW_K_ROW$

Because the government levies i) household income tax (assumed to be the transfer of household institutions to the government); ii) tax on CO2 emissions for fossil fuels, resulting in the following household net income: DIH_h

$$DIH_h = IH_h - TR_{gov,h} - TAX_{CO2} \sum_{i \in \{fuel\ types\} \subset energy \subset C} CO2H_{i,h}, \quad h \in H, \quad gov \in INS \quad (120)$$

where are CO2 emissions emitted by combustion from fuel consumption by households. $CO2H_{fuel,h}$

Household transfers to institutions other than government are specified in equation (121a); and a household transfer that counts as a household transfer to the government is specified in equation (121b).

$$TR_{in,h} = TRH_share_{in,h} DIH_h, \quad in \neq gov \in INS, \quad h \in H \quad (121a)$$

$$TR_{gov,h} = (HAtaxrate)(Htaxrate_h) IH_h, \quad h \in H \quad (121b)$$

Where is the $TRH_share_{in,h}$ share of the transfer of household payments to the institution; and is the rate of household income tax. $(HAtaxrate)(Htaxrate_h)$

Furthermore, the household's net income () minus household transfer payments to the institution generates: $ADIH_h$

$$ADIH_h = DIH_h - \sum_{in \neq gov \in INS} TR_{in,h}, \quad h \in H \quad (122)$$

The average constant propensity of *household saving* is shown in equation (123), where this portion is assumed to be endogenously adjusted (equation 124).

$$SH_h = sh_ratio_h ADIH_h, \quad h \in H \quad (123)$$

$$sh_ratio_h = sh_rin_h(1 + sh_dum_h sh_adj), \quad h \in H \quad (124)$$

Where is household SH_h saving; is the average propensity sh_ratio_h saving of the household; is the initial value of the average household saving propensiveness ; if , for example there is no change in the $sh_rin_h sh_rin_h sh_dum_h = 0$ $sh_ratio_h = sh_rin_h$ saving ratio; if allowed to

adjust i.e. to the condition is the endogenous adjustment parameter of $.sh_dum_h = 1sh_ratio_h sh_adjsh_ratio_h$

Thus, the household budget allocation for final commodity consumption () is obtained from actual net income minus $EH_h saving$ () (equation (125)). SH_h

$$EH_h = ADIH_h - SH_h, \quad h \in H \quad (125)$$

Then variables will be added to the household query function model. Thus, by solving the optimization problem of the Cobb-Douglas satisfaction function, the resulting solution is expressed in the equation below: $TAXFUEL_{i,h}$

$$(1 + TAXFUEL_{i,h})P_i^Z CH_{i,h} = CH_share_{i,h} EH_h, \quad i \in C, \quad h \in H \quad (126)$$

where:

$TAXFUEL_{i,h} = 0$ if $i: \{non\ fuel\ types\} \in energy \subset C$; and

$TAXFUEL_{i,h} \neq 0$ if $i: \{fuel\ types\} \in energy \subset C$.

4.1.4. Consumer Price Index (CPI)

Based on the standard model, CPI is calculated based on the total index price of households (equation 127) obtained from the homogeneity relationship of the final commodity price to - (equation 128). i

$$PI_h = \prod_{i \in C} (P_i^Z)^{CH_share_{i,h}}, \quad h \in H \quad (127)$$

$$CPI = \sum_{h \in H} w_h PI_h \quad (128)$$

Where is the weighting of commodities purchased by households to- $w_h h$

4.1.5. Enterprise Behaviour

The company's revenue () is derived from total capital lease receipts (), fixed natural resources () and transfers from institutions () as shown in the following equation: $IBIBKIBRESTR_{b,in}$

$$IB = IBK + IBRES + \sum_{in \in INS} TR_{b,in} \quad (129)$$

$$IBK = IBK_share P^K \left(\sum_{j \in A} PDIST_j^K K_j + K_{ROW} \right), \quad ROW \in INS \quad (130)$$

$$IBRES = IBRES_share P^{RES} \left(\sum_{j \in fossil \subset A} PDIST_j^{RES} RES_j + \sum_{j \in renew \subset A} PDIST_j^{RES} RES_j \right) \quad (131)$$

Where $IBRES_share$ is the share of income from capital and natural resources. Thus, the company's net income is expressed as follows:

$$DIB = IB - TR_{gov,b}, \quad gov \text{ and } b \in INS \quad (132)$$

Where $TR_{gov,b}$ is a transfer of payments to the government or corporate income tax:

$$TR_{in,b} = TRB_share_{in,b} DIB, \quad in \neq gov \in INS \quad (133a)$$

$$TR_{gov,b} = (Btaxrate)IB, \quad b \in INS \quad (133b)$$

The deduction of the company's net income by its income tax will be the actual net income as follows:

$$ADIB = DIB - \sum_{in \neq gov \in INS} TR_{in,b} \quad (134)$$

Company saving (SB) is assumed to be equal to actual net income as follows:

$$SB = ADIB \quad (135)$$

4.1.6. Rest of the World (ROW)

Total outflow transactions from abroad are obtained from total imports, institutional transfers abroad and foreign income on factors of production (foreign labor and foreign capital):

$$IROW = \sum_{i \in CM} P_i^M M_i + \sum_{in \in INS} TR_{ROW,in} + \sum_{o \in LBR} RL_share_o P_o^L \left(\sum_{j \in A} PDIST_{o,j}^L L_{o,j} + L_{o,ROW} \right) + RK_share P^K \left(\sum_{j \in A} PDIST_j^K K_j + K_{ROW} \right), \quad ROW \in INS \quad (136)$$

Where $IROW$ is the total foreign income; M_i is the total import of the commodity; $TR_{ROW,in}$ is the transfer of foreign income from the institution; CM is the set of imported commodities; and o is the foreign labor to- and foreign capital used domestically.

On the other hand, total expenditure (inflow transactions) abroad () is obtained from the total amount of exports (), payments of foreign transactions to domestic institutions (), costs of factors of production (wages of labor and capital) from domestic to abroad:

$$EROW = \sum_{i \in CE} (1 + TarifCBAM) P_i^E E_i + \sum_{in \in INS} TR_{in,ROW} + \sum_{o \in LBR} P_o^L L_{o,ROW} + P^K K_{ROW},$$

(137)

Where is CE the set of export commodities.

Transfer of foreign payments to institutions () obtained from a fixed proportion of total foreign payments ():

$$TR_{in,ROW} = TRW_share_{in,ROW}(EXR)TROW_bar, \quad ROW \in INS \quad (138a)$$

$$TR_{ROW,ROW} = 0 \quad (138b)$$

Where is the share of payment transfers from abroad to institutions; and is the exchange rate (Rp/US\$).

Overseas saving is determined from the residue between foreign outflow and inflow transactions:

$$SROW = EROW - IROW \quad (139)$$

Furthermore, the relationship between domestic and foreign currencies for export and import commodities:

$$P_i^E = (EXR)P_i^{EW}, \quad i \in CE \quad (140)$$

$$P_i^M = (EXR)P_i^{MW}, \quad i \in CM \quad (141)$$

Where and sequentially are the import and export prices of commodities in the form of foreign currency (exogenous); and and sequentially the import and export prices of commodities in the form of Rupiah currency.

4.1.7. Investment

The total demand for investment from the next commodity i is as follows:

$$CINV_i = CINVIN_i(1 + INVADJ), \quad i \in C \quad (142)$$

Where is the initial investment demand for the to-commodity; is the index of change in investment ($CINVIN_i i INVADJ INVADJ=0$ if the investment is constant; conversely if the investment is allowed to adjust endogenously).

Walras' identity is then determined from the *saving-investment* balance as follows:

$$WALRASRES = \sum_{h \in H} SH_h + SB + SG + SROW - \sum_{i \in C} P_i^Z CINV_i \quad (143)$$

Where is the residue of Walras. $WALRASRES$

4.1.8. The Armington's Aggregations

Furthermore, for the Armington() aggregation between the demand function of imported and domestic commodities is specified as follows: Z_i

$$Z_i = sz_i \left(\delta_{mi}^{1+\Phi_i} M_i^{-\Phi_i} + \delta_{di}^{1+\Phi_i} D_i^{-\Phi_i} \right)^{-\frac{1}{\Phi_i}},$$

$$i \in CM \cap CD, \quad \Phi = \frac{1}{\sigma^Z} - 1, \quad \sigma^Z > 1 \quad (144)$$

$$M_i = \left(\frac{\delta_{mi}}{sz_i^{\frac{\Phi_i}{1+\Phi_i}}} \right) Z_i \left\{ \frac{\left((1 + (tarifArate)(tarifrate_i)) P_i^M \right)^{-\frac{1}{1+\Phi_i}}}{P_i^Z} \right\}, \quad i \in CM \cap CD \quad (145)$$

$$D_i = \left(\frac{\delta_{di}}{sz_i^{\frac{\Phi_i}{1+\Phi_i}}} \right) Z_i \left\{ \frac{P_i^D}{P_i^Z} \right\}^{-\frac{1}{1+\Phi_i}}, \quad i \in CM \cap CD \quad (146)$$

The index price of the final commodity (obtained from the following equation: P_i^Z)

$$P_i^Z Z_i = (1 + (tarifArate)(tarifrate_i)) P_i^M M_i + P_i^D D_i, \quad i \in CM \cap CD \quad (147)$$

For cases where the industry does not absorb imported raw materials, the relationship can be expressed as follows:

$$Z_i = D_i, \quad i \in CD \ \& \ \checkmark CM \quad (148)$$

$$P_i^Z = P_i^D, \quad i \in CD \ \& \ \checkmark CM \quad (149)$$

For the transformation of export and domestic commodities it is stated as follows:

$$Q_i = sq_i \left(\omega_{e,i}^{1-\mu_i} (E_i)^{\mu_i} + \omega_{d,i}^{1-\mu_i} (D_i)^{\mu_i} \right)^{\frac{1}{\mu_i}}, \quad i \in CE \cap CD,$$

$$\mu = \frac{1}{\sigma^q} + 1, \quad \sigma^q > 0 \quad (150)$$

However, for cases where the industry carries out only domestic commodity production it is expressed in the equation below:

$$Q_i = D_i, \quad i \in CD \ \& \ \checkmark CE \quad (151)$$

$$E_i = \frac{\omega_{ei}}{sq_i^{\mu_i/\mu_i-1}} Q_i \left\{ \frac{P_i^E}{(1 + (vatArate)(vatrate_i) - (subQArate)(subQrate_i))P_i^Q} \right\}^{\frac{1}{\mu_i-1}},$$

$$i \in CE \cap CD \quad (152)$$

$$D_i = \frac{\omega_{di}}{sq_i^{\zeta_i/\zeta_i-1}} Q_i \left\{ \frac{P_i^D}{(1 + vat_i - subQ_i)P_i^Q} \right\}^{\frac{1}{\zeta_i-1}}, \quad i \in CE \cap CD \quad (153)$$

Price index of domestic commodity products (obtained from the following relationship: P_i^Q)

$$(1 + (vatArate)(vatrate_i) - (subQArate)(subQrate_i))P_i^Q Q_i = P_i^D D_i + P_i^E E_i,$$

$$i \in CE \cap CD \quad (154)$$

Because of Walras' condition, equation 150 is excluded from the model specification.

For cases where the industry produces only domestic commodities the relationship is as follows:

$$(1 + (vatArate)(vatrate_i) - (subQArate)(subQrate_i))P_i^Q = P_i^D,$$

$$i \in CD \text{ \& \text{ICE}} \quad (155)$$

4.1.9. Market Clearing

Market clearing conditions to obtain a market balance between supply and demand for the entire market are as follows:

$$Z_i = \sum_{h \in H} CH_{i,h} + CG_i + CINV_i + \sum_{j \in A} X_{i,j}, \quad i \in C \quad (156)$$

Market clearing conditions for factors of production:

$$\sum_{j \in A} K_j + K_{ROW} + KU = KS, \quad ROW \in INS \quad (157)$$

$$\sum_{j \in fossil \subset A} RES_j + \sum_{j \in renew \subset A} RES_j + RESU = RESS \quad (158)$$

$$\sum_{j \in A} L_{o,j} + L_{o,ROW} + LU_o = LS_o, \quad o \in LBR, \quad ROW \in INS \quad (159)$$

Where KS is the total supply of capital; $RESS$ is the total supply of natural resources; KU is unused (excess) capital stock; LU_o is the total unemployment of the kenis labor ke-; and LS_o is the total supply of labor of the to-type.

4.1.10. Closures

The *closure* options on this developed CGE model are as follows. For *the closure* of factors of production, it is assumed that the capital stock and types of labor are mobilized throughout the industrial sector with constant rents and wages. The balance of the labor market is obtained from the adjustment of the unemployment rate; and for capital market equilibrium obtained from adjustments to the rate of capital rent. Furthermore, for *saving-investment closure* follows the assumption of exogeneity of *saving* institutions. Thus, actual commodity investments will adjust to reach an equilibrium point. For the open economy model, the assumption of Indonesia's exchange rate regime is flexible but saving foreign affairs is constant so that the deficit (surplus) of outgoing and incoming transactions becomes balanced. Lastly, for fiscal balance, it is assumed that the entire net tax rate is exogenous but *public saving* is endogenous to obtain fiscal balance.

For some additional *closures*, it is done to equalize the total of mathematical equations and the number of variables, among others, as follows. Fuel taxes for activities and institutions are constant; total supply of natural resources () constant; and the rent of fossil natural resources () is constant; However the demand for natural resources () will adjust to acquire clearing markets. However, we assume no unused resources () and the price of aggregated resources () adjusts to ensure overall market clearing.

$$RESSPDIST_j^{RES} RES_j RESU = 0 P^{RES}$$