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Assessing the Emission Reduction Policies on Global Value Chains: The Renewable Energy Policy Framework

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Abstract: To mitigate climate change problems, a low-carbon renewable energy policy is needed. Evaluating the impact of these problems on global value chains is essential to ensure an effective transition to sustainable economic development. This study analyzes the impact of emission reduction policies on Global Value Chains (GVC) using the Global Trade Analysis Project-Energy (GTAP-E) model by addressing three fundamental research questions. First, how does the implementation of B40 renewable energy policy combined with carbon tax affect Indonesia's energy sector output and carbon emissions? Second, to what extent does this policy influence Indonesia's participation in GVC, particularly in the crude palm oil (CPO) industry? Third, what are the implications for economic growth and social welfare? Our analysis focuses on the CPO sector, considering Indonesia's position as the world's largest producer and its potential for sustainable biofuel production through clean technological processes. The results of this study show that the policy effectively reduces carbon emissions through decreased fossil fuel production while promoting renewable energy adoption. It significantly increases Indonesia's forward GVC participation in the CPO sector, enhancing value addition and international competitiveness. Furthermore, the policy generates positive impacts on economic growth and social welfare. This study emphasizes the importance of international policy coordination and the crucial role of technological innovation in achieving sustainable economic development for a low-carbon economy and strengthening Indonesia's position in the global value chain.

Keywords: emission reduction; renewable energy; carbon tax; crude palm oil; global value chains; GTAP-E

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1. Introduction

The issue of climate change has received significant attention at the global level in recent decades. The leading cause of climate change is the increase in greenhouse gas (GKR) emissions, which seriously impact the environment and human well-being [1,2]. Many economic activities use energy, which can lead to increased CO_2 emissions and the greenhouse effect [3,4]. Indonesia is the fourth most populous country after China, India, and the United States, and it is one of Southeast Asia's most significant energy users. Due to rapidly increasing energy consumption and depleting fossil fuel production, Indonesia has been a net oil importer since 2004. The policy on using biodiesel as a substitute for fossil fuels was first launched in 2006 to mitigate these challenges. Starting in 2020, the Indonesian government issued a mandatory biodiesel program called B30, making Indonesia achieve a record as the highest biodiesel implementer in the world [5]. The advantage of using palm oil-based biodiesel compared to other vegetable oils is that palm oil-based biodiesel can be produced sustainably [6].

In the Southeast Asian region, Indonesia has the most significant energy consumption [7]. Economic activity is increasing with the development of international trade.

Currently, the linkage, specialization, and growth of trade between countries are captured in the GVC [8,9]. Indonesia's involvement in GVC activities has caused Indonesia's role in the world energy market to increase significantly [7]. Dependence on fuel oil consumption (biofuel) is still high, while domestic fuel oil production is limited, so countries still depend on imports. On the other hand, the tension of the trade war between the United States and China and the geopolitical crisis have further increased world oil prices and disrupted the global trade supply chain [10–12]. To address this challenge, many countries, including Indonesia, are committed to reducing greenhouse gas emissions through renewable energy policies and increasing trade between countries through trade liberalization [1,13,14].

Renewable energy policies are implemented in the context of emission mitigation to solve climate change problems while fulfilling the commitments made at the Conference of Parties 28 in 2023, which aim to reduce Greenhouse Gas (GHG) emissions by 31.89% (Nationally Determined Contribution) in 2030 [15]. To realize this, the government, through the Regulation of the Minister of Energy and Mineral Resources of Indonesia number 9 of 2023, approved the use of renewable energy by implementing a policy of using 40% vegetable oil as a diesel or biodiesel mixture (B40); this will continue to be upgraded to B50, namely the use of 50% vegetable oil as a diesel mixture, so that it is more efficient and environmentally friendly [16].

Biodiesel is amber yellow, is based on mono alkyl esters from plants/animals, and is similar to diesel but environmentally friendly. B20 renewable energy has been mandatory since 2018 in Indonesia. As the world's largest producer of CPO, Indonesia needs to increase the use of CPO as energy [16–18]. This effort can reduce diesel imports and trade balance deficits.

To achieve the emission reduction target, a carbon tax should be implemented. Based on Pigou's (1920) externality theory, carbon emissions are a negative externality that impact the environment [19]. By implementing this carbon tax, Indonesia is on par with developed countries that have implemented carbon tax policies, including the United Kingdom, Japan, and Singapore. This carbon tax is determined by the mandate of Law Number 7 of 2021 concerning the Harmonization of Tax Regulations.

Studies on the impact of liberalization on the ability of sectors in various countries' economies to achieve a general balance with the Global Trade Analysis Project (GTAP) model have been carried out extensively, but the use of GTAP-E to analyze the impact of renewable energy policies on GVC activities to create green manufacturing is still limited [20]. Previous research analyzed GHG emission reduction policies with the implementation of B20 and B30 renewable energy [21]. Therefore, this study aims to analyze the impact of GHG emission reduction policies, with the implementation of renewable energy policies using the GTAP-E approach, on countries' participation in the Global Value Chain.

The remainder of this article is structured as follows: The literature review is introduced in Section 2. The methodology is explained in detail in Section 3, while the empirical results and discussion are presented in Section 4. The final section concludes with significant findings and policy recommendations.

2. Literature Review

Global climate change caused by increased greenhouse gas (GHG) emissions is one of the biggest challenges facing people around the world today. GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (N_2O), are gases that cause heat in the atmosphere, causing the greenhouse effect and global warming. Studies show that human activities, especially the use of fossil fuels and deforestation, have significantly increased the concentration of GHGs in the atmosphere since the industrial era began [1,2].

The government applies renewable energy policies to reduce GHG emissions by replacing fossil energy sources with cleaner and more sustainable ones. Using renewable energy sources through biofuels from CPO is a key strategy in reducing dependence on fossil fuels and mitigating GHG emissions [22]. Indonesia, as the world's largest producer of CPO, has significant potential to develop a CPO-based biofuel industry that is processed through biotechnology [23]. One of the main policies is using CPO as a biofuel in the form of biodiesel. The implementation of the B40 policy, which mixes 40% vegetable oil with diesel, is expected to reduce dependence on diesel imports, reduce the trade balance deficit, and support the transition to a green economy [16,18]. The B40 policy mandates that every liter of diesel fuel sold in Indonesia must contain 40% biodiesel (400 mL of biodiesel per liter of blended fuel). This volumetric standard applies uniformly across all diesel fuel sales in Indonesia, with compliance verified through established testing protocols. This volumetric blending requirement ensures a consistent biodiesel content across all diesel fuel sales, supporting emission reduction goals [24].

2.1. Emission Reduction Policy and Low-Carbon Economy

The transition to a low-carbon economy has become a global goal in climate change mitigation efforts [25]. Emission reduction policies, especially those focused on the energy sector, play a central role in achieving greenhouse gas (GHG) emission reduction targets, as agreed by countries worldwide at the Conference of Parties [26].

Implementing this policy involves various instruments, including carbon taxes, cap-and-trade systems, and incentives for renewable energy. Carbon taxes have proven effective in internalizing the external costs of carbon emissions and encouraging low-carbon technological innovation. Meanwhile, cap-and-trade systems such as the EU Emissions Trading System (EU ETS) have shown potential to reduce emissions in the industrial and energy sectors cost-effectively [27].

Indonesia's B40 renewable energy policy aims to achieve a 30% reduction in CO_2 emissions following the Conference of Parties 28 of 2023, and this will continue to be adjusted based on Nationally Determined Contributions. This policy can be carried out through the imposition of a carbon tax. A carbon tax is a policy instrument imposed on CO_2 emissions to provide economic incentives to companies and individuals to reduce their emissions. This tax increases the cost of fossil fuel production, encourages a switch to cleaner energy sources, and reduces inefficient energy consumption. Several countries have implemented carbon taxes as part of their strategies to reduce GHG emissions and achieve climate targets [3,20].

The imposition of a carbon tax provides a strong signal that drives the development of carbon markets, technological innovation, and more efficient, low-carbon, and environmentally friendly investments [28]. In the development context, state revenue from carbon taxes can be used to increase development funds, invest in environmentally friendly technologies, or support low-income communities through social programs. For the initial stage, starting 1 April 2022, the carbon tax will be applied to the coal steam power plant sector using a tax mechanism based on emission limits (cap and trade) at a rate of IDR 30,000 (equivalent to USD 1.91) per tCO_2e. It will be reviewed for an increase of around 5% or the achievement of emission reductions according to the COP 28 agreement in 2023. The conversion to USD uses the average exchange rate of USD 1 = IDR 15,700 during the implementation period. This rate means that Indonesia's carbon tax is lower than developed nations like Japan (USD 2.40), but comparable to other emerging economies in Southeast Asia such as Vietnam (USD 1.80) per tCO_2e.

2.2. Global Value Chains (GVC) and Environmental Policy

Integrating environmental policies into GVCs is becoming increasingly important as global awareness of sustainability grows [29]. Global Value Chains (GVCs) are a network of stages of production for goods and services, from product design to the distribution of goods to end consumers, which are produced and assembled in different countries or across international borders. Calculating a country's participation in the GVC refers to the decomposition of exports, as proposed by Zhi Wang et al. [30].

Zhi Wang et al. [30] classify added value into three main categories, namely (a) added value produced and consumed domestically, (b) the added value inherent in the export or import of final products, and (c) the added value inherent in intermediate exports or imports. Only the added value associated with the trade in intermediate goods is included in the GVC calculation. Forms of participation in GVC can be through forward and backward linkage. From a forward-linked perspective, a country can supply domestic added value by exporting intermediate products to other countries. On the other hand, from a backward-linked perspective, intermediary inputs from different countries are used to produce final goods and services. If forward GVC participation is higher than backward GVC participation, the sector is more actively involved in upstream production activities [31].

Implementing environmental policies in the context of GVC also has important implications for countries in the world. On the one hand, strict environmental standards can hinder participation in the GVC. On the other hand, it can also encourage technological upgrading and the long-term improvement of competitiveness. Increasing added value in the industry, especially in the context of CPO, can strengthen a country's position in the GVC [32]. Low-carbon renewable energy policies can encourage innovation, competitiveness, and participation in global value chains, contributing to economic growth and people's well-being. In addition, this policy can reduce energy import dependence so that it can improve trade balance [33]. In line with global climate action initiatives, Indonesia actively participates in the Mission Innovation Program (MI), which is in line with global climate action initiatives. Indonesia has committed to doubling its clean energy R&D investments by 2025. This commitment aligns with Indonesia's renewable energy policy framework, particularly in advancing biofuel technology and implementing the B40 program. Indonesia's participation in MI's Clean Energy Materials Innovation Challenge has mainly supported advances in biofuel development, including improvements in palm oil-based biodiesel production efficiency [34]. Increased added value in the CPO industry can be achieved by developing high-value derivative products, such as oleochemicals and next-generation biofuels. This can increase export revenues and contribute to reducing emissions through fossil fuel substitution [8].

For CPO products, the Indonesian government has high levels of trade cooperation with India [8]. Trade liberalization can increase trade transactions between the two countries and other trading partner countries. This policy can improve production efficiency and encourage the adoption of clean technologies through technology transfer and knowledge spillovers.

Recent studies show that coordination between trade and environmental policies is crucial in achieving sustainable development goals [28]. One study showed that implementing renewable energy policies in Thailand promoted biofuels and could reduce dependence on fossil fuels and improve energy security [35]. Meanwhile, research in Vietnam that implemented carbon taxes and renewable energy policies succeeded in reducing CO_2 emissions and supporting economic growth [14]. Another study found that fuel subsidies to reduce CPO price volatility have become a costly instrument, so some European countries are implementing climate finance policies to lower greenhouse gas emissions (GHGs) and promote changes in the energy system that support the replacement of fossil sources with renewable sources [23,32].

3. Methodology

3.1. GTAP Database

This study uses the GTAP model to analyze the impact of reducing GHG emissions through implementing a carbon tax in connection with implementing B40 renewable energy in the Indonesian economy. The database of the GTAP model includes data on the input–output of each country's economy, bilateral trade flows, transportation costs, tax and tariff information, and all other data consisting of Social Accounting Matrices (SAMs) and elasticity parameters. SAMs describe the flow of income and expenditure in a national economy over a while, usually one year. SAMs report the value of all goods and services produced and the revenue generated from their sales. In addition, SAMs describe household income and expenses, government tax revenues and costs, investment savings and expenses, and international trade. The SAM database contains fuel substitutions and provides a complete account of revenue and expenditure from carbon taxes and the more specific treatment of carbon emissions trading. Computable General Equilibrium (CGE) model databases typically use data from official national accounts. The second component of the CGE model database presents elasticity parameters that explain the response of producers and consumers if there is a change in prices and revenues [36,37]. The model's production function parameters determine sectoral responses to policy changes. We employ substitution elasticities between primary factors, with higher values assigned to manufacturing sectors and lower values to agricultural sectors. The elasticity between domestic and imported intermediates reflects the empirically observed trade responsiveness in energy markets. Energy substitution elasticities in production are significant for our analysis.

Consumption behavior in the model is governed by carefully calibrated parameters. The income elasticity for energy products captures the energy demand's varying responsiveness to income changes across different consumer groups. Trade relationships are modeled using Armington elasticities for energy goods and export transformation elasticities, capturing the imperfect substitutability between domestic and foreign goods.

The concept of analysis using GTAP begins with a standard database, and then there are shocks associated with the calibration process of obtaining a new balance database. The difference in change is the impact of the policy. In recent years, the GTAP model and database have expanded significantly to increase the utilization of biofuels and incorporate the potential of biofuels as a substitute for petroleum products. The modified database includes data on the production, consumption, and trade of biofuels, including grain-based ethanol, sugarcane ethanol, and biodiesel from oilseeds, as well as data on biofuel by-products. Its use affects the environment through CO_2 emissions and the greenhouse effect because energy is an important commodity in economic activities. This expansion was necessary to capture the increasing importance of biofuels in global energy markets and their unique characteristics in terms of production, trade, and environmental impacts. The modified GTAP database incorporates the detailed disaggregation of the biofuel sector. This detailed representation enables the more accurate analysis of policy impacts across the entire biofuel value chain [38]. The methodology has undergone rigorous peer review and stakeholder consultation to ensure its robustness and relevance for policy analysis.

3.2. GTAP Model

The GTAP model used was version 11, referencing 2017, which includes 160 regional units, 65 sectors, and 8 production factors [39]. The data were aggregated from 160 regions into several regions and 65 commodities into 8 commodity sectors (Table 1).

Table 1. Regional and sectoral aggregations.

Regional Aggregation	Sectoral Aggregation
Indonesia	Crude Palm Oil
India	Coal
ASEAN	Oil
East Asia	Gas
European Union	Energy-intensive industries
Rest of World	Manufacture
	Electricity
	Other industries

Source: Summarized according to GTAP database (GTAPagg).

The GTAP model was built in 1992 by Purdue University, constructed from the Australian IMPACT model, and implemented using GEMPACK version 12. This study used general equilibrium analysis to examine the links between energy, economy, trade, and the environment. The Computable General Equilibrium (CGE) approach is the most appropriate methodology for analyzing the impact of broad economic policies, such as energy taxes.

The GTAP is a global economic model used to analyze international trade, environmental policies, and other global economic issues. The production structure in the GTAP model plays a crucial role in determining how inputs are used to generate outputs in various sectors of the economy around the world. The GTAP model's assumptions are perfect competition and constant scale [22,36]. This results in dynamic adjustment processes not being explicitly captured. Assuming the full employment of factors and perfect factor mobility within regions enables a precise analysis of resource real-location effects. In trade relations, we employ the Armington and small-country assumptions for price-taking behavior, which is particularly relevant for analyzing Indonesia's position in global energy markets. The GTAP model can be developed into a GTAP-E model capable of solving the climate change problem by including carbon emissions from fossil fuel combustion and providing a mechanism with which to trade these emissions internationally. The agent behavior generated in the model was analyzed using the general equilibrium demand elasticity that summarized the combined effects of the new model specification. On the producer side, the production function is characterized by the constant elasticity of substitution (CES), and the elasticity of substitution for all production inputs is constant on the household side. The GTAP-E model formulates a carbon tax function to consume carbon-gas-emitting commodities such as petroleum and gasoline. Thus, this model can be considered one of the most powerful CGE models for studying energy-related problems.

The production structure in the GTAP-E model uses the Constant Elasticity of Substitution (CES) production function to allow substitution between various inputs [36,40]. This function allows for changes in the proportion of input usage based on relative price changes. The inputs consist of primary and secondary inputs. The primary inputs include labor, capital, land, and natural resources, while the secondary inputs are the goods and services used to produce other goods or services. It contains raw materials, energy, and inputs, among others. Labor inputs are divided into two categories: skilled and unskilled labor. Capital includes investments in the machinery, buildings, and other infrastructure used in production. Land inputs are the primary inputs to the agricultural sector. Meanwhile, natural resources include oil, gas, and the minerals used in production.

The production structure in the GTAP-E model follows a tiered production structure [40]. The first level is the substitution between capital, labor, and land. Capital, labor, and land can be substituted for each other by using the functions of CES. The degree of substitution depends on the elasticity of the substitution set in the model. The second level is the substitution between energy and non-energy inputs. At this level, energy inputs such as electricity and fuel can be substituted for non-energy inputs. The CES function is used to capture these substitutions. The third level includes substitutions between energy sources. At this level, various energy sources, such as oil, gas, and coal, can be substituted for each other. This model considers the different substitution elasticity for each pair of energy sources.

The GTAP-E model uses an input–output matrix to ensure that the total number of inputs used in production equals the total number of outputs produced. The matrix covers all sectors of the economy and shows the relationship between inputs and outputs across sectors. The GTAP-E model allows for the analysis of policy effects such as tariffs, subsidies, and carbon taxes. The impact of this policy is analyzed based on changes in the relative prices and input substitutions in the production structure. The GTAP-E model includes international trade, where goods and services are traded between countries. The production structure of this model allows for an analysis of how changes in trade policies and tariffs affect production and the balance of trade between countries.

3.3. Measuring Global Value Chains

A country's participation in the GVC measures how much added value is inherent in a country's exports. The proper method for calculating the contribution of added value and distribution of intermediate export goods is to use the decomposition of gross exports proposed Wang et al. [30]. The decomposition of gross exports of the sector is a direct application of the Leontief standard decomposition, and can be stated as follows [30,41]:

$$X = (I - A)^{-1} Y \quad (1)$$

The above equation shows the relationship between production and final demand, where X and Y are the vectors of gross output and final demand, respectively, provided by the economy sector, and I is an N × N identity matrix. A is the N × N matrix of the input coefficient. We disaggregated each country's gross output by rearranging the final demands of both countries into a matrix format based on sources and destinations. This decomposition is distinguished by the forward and backward linkages [12]. The backward linkage approach measures the share of FVA used to produce a country's export goods to total world exports. Meanwhile, the forward linkage approach measures the ratio of DVA embedded in intermediate exports to total world exports.

Country participation in GVC in terms of backward linkage through the GTAP-E approach is measured through the following equation [33,39,42]:

$$GVCB_{(i,s,r)} = \sum_i \sum_r \left[viwcif_{(i,s,r)} \right] / vxwfob_{(s)} \quad (2)$$

Meanwhile, the country's participation in GVC from the forward linkage perspective is measured through the following equation:

$$GVCF_{(i,s,r)} = \sum_i \sum_s \left[\left[vxwfob_{(i,s,r)} \right] \left(1 - \left(\frac{\sum_i \text{viwcom}_{(i,s)}}{\sum_i \text{vxwcom}_{(i,s)}} \right) \right) \right] / vxwfob_{(s)} \quad (3)$$

where $GVCB_{(i,s,r)}$ is the backward global value chain participation value of commodity i by country s from country r. $GVCF_{(i,s,r)}$ is the forward global value chain participation value of commodity i by country s from country r. $viwcif_{(i,s,r)}$ is the value of commodity imports i by country s from country r. The *viwcif* variable indicates how much a country uses foreign inputs in its export production. Next, $vxwfob_{(s)}$ is the total export value from country s to the rest of the world. The *vxwfob* variable indicates that country r exports intermediate inputs used in other countries' export production. Variable $viwcom_{(i,s)}$ is the total value of commodity imports i by country s from all over the world. Meanwhile, $vxwcom_{(i,s)}$ is the total export value of commodity i from country s to the rest of the world. The comparison between $viwcom_{(i,s)}$ and $vxwcom_{(i,s)}$ shows the proportion of foreign added value in a country's total exports. It measures the extent to which a country's exports depend on import inputs or added value coming from other countries.

3.4. Simulation Scenario Design

The GTAP-E model is an economic equation model that uses actual economic data to assess how the economy may react to changes in policy, technology, or other external factors. With the help of this model, several economic energy policy scenarios can be analyzed. In connection with the Indonesian government's commitment to complying with the Conference of Parties (COP) 28 in 2023 and reducing Greenhouse Gas (GHG) emissions in order to overcome the problem of global climate change, the scenario is designed by implementing a carbon tax increase of 5% per year [37,43]. This policy is combined with the policy of reducing Indonesia's CPO import tariff by 2.5%, which was imposed by India as Indonesia's largest trading partner, to see the effect of the policy on the energy sector and the country's participation in the GVC. The provisions of this Indian import tariff have been in effect since 11 September 2021, according to an official statement from the Department of Revenue Ministry of Finance of India.

4. Empirical Results and Discussion

This section discusses the results of the overall analysis of the impact of emission reduction policies, in the framework of renewable energy policies, on the energy sector, macroeconomic conditions, and Global Value Chains using the GTAP-E model database [39].

4.1. Energy Sector

Implementing CO_2 emission reduction policies in the framework of renewable energy policies can be achieved by imposing carbon taxes [3,20]. The government's plan to implement the B40 renewable energy policy in Indonesia has resulted in a change in output in the energy sector. Table 2 shows the percentage change in the price level and output of the energy sector in Indonesia. The renewable energy policy for reducing CO_2 emissions, carried out through a carbon tax of Rp30,000.00 (equivalent to USD 1.91) per ton of CO_2 with an increase of 5% per year to achieve the target of reducing GHG emissions by 31.89%, will increase the energy prices and production costs and thus reduce the amount of energy produced [43]. This energy sector includes coal, crude oil, and natural gas, which can potentially contain amounts of high carbon [14]. The increase in the carbon tax resulted in an increase in the coal price index by 0.03%, crude oil prices by 0.13%, and natural gas prices by 0.05%. On the other hand, there was a decrease in coal production by 0.004%, a decrease in crude oil production by 0.008%, and a decrease in natural gas production by 0.017%. Reducing energy sector production can reduce CO_2 emissions [14,22,43].

Table 2. Changes in output in the energy sector.

Sector	Market Price (% Change)	Output (% Change)
Coal	0.0323	−0.0035
Oil	0.1289	−0.0080
Gas	0.0525	−0.0167
Energy-intensive industries	−0.0087	−0.0002
Manufacture	0.0134	−0.0028
Electricity	0.0126	−0.0051
Other industries	−0.0013	0.0008

Source: Simulations of GTAP-E mode.

On the other hand, this policy can also reduce the production of different energy sectors, such as energy-intensive industries (minerals, chemicals, rubber, plastic products, metals), manufacturing, and electricity. This condition can lead to green manufacturing, enabled by the use of clean processes in the production process. This is possible because businesspeople are starting to pay attention to environmental aspects in their production activities. In addition, the revenue generated from the carbon tax can be reinvested in the energy sector, including improvements in the extraction and processing of coal, oil, and gas. Improvements in extraction technology and infrastructure can improve production efficiency. This CO_2 emission reduction policy is important for realizing environmental goals and a green economy [26,37,44].

4.2. Macroeconomic Impacts

The impact of emission reduction policies on Indonesia's macroeconomic variables can be seen in Table 3. The implementation of this policy increased the Gross Domestic Product level by 0.0006%. This GDP enhancement operates through multiple reinforcing channels. The direct effects manifest through increased investments in renewable energy infrastructure, particularly in the biofuel industry's expansion. Implementing the B40 policy catalyzed significant capital formation in biofuel production facilities, creating new value chains and strengthening existing ones. Simultaneously, indirect effects emerge through technology spillovers from clean energy adoption, contributing to broader productivity improvements across sectors. As a bio-diesel fuel substitute for fuel oil, the CPO price index increased by 0.0409%. This price adjustment reflects the market's response to increased domestic demand for biofuel feedstock while maintaining equilibrium, without triggering significant inflationary pressures. The price movement also indicates successful value addition in the CPO sector. The implementation of renewable energy as a commitment to reducing emissions by 31.89% following the Paris Agreement, through the implementation of a carbon tax, resulted in an increase in terms of trade (TOT) in Indonesia by 0.0881%. This is mainly due to greater investment in clean energy technologies [44].

Table 3. Macroeconomic conditions.

Variables	Unit	Value
Gross Domestic Product	%	0.0006
World price indexfor CPO	%	0.0409
Terms of Trade	%	0.0881
Welfare	US$ million	0.031
Trade balance	US$ million	1,905,577.714

Source: Simulations of GTAP-E mode.

The increase in TOT will increase the competitiveness of Indonesian exporters in their trading partner markets. The larger the plant material used for renewable energy, the more that the imposition of a carbon tax will provide a significant margin [37]. The application of renewable energy will increase the TOT by 0.0881%. This is related to the use of primary energy in Indonesia, where CPO as a B40 fuel mixture is used most. The government's efforts continue to create added value by increasing the dominance of downstream palm oil product exports so that domestic palm oil producers can innovate and create new products in the palm oil industry.

The level of public welfare is measured by the equivalent variation (EV) value, which sees changes in people's welfare if there are government policies such as an increase in carbon tax [45]. The results of the study show that the rise in EVs due to carbon taxes is USD 0.031 million. Emission reduction policies through carbon taxes can lead to an increase in people's welfare. This is due to consumers benefiting from more stable energy prices and improved environmental quality, while producers benefit from new market opportunities and technological advancements.

The renewable energy policy, which aimed to reduce emissions through carbon taxes, caused a trade balance surplus of USS 1,905,577.714 million. A trade balance surplus can increase the competitiveness of renewable energy technologies and reduce dependence on fossil fuel imports. Increased renewable energy consumption can help balance carbon emissions and reduce the gap between production-based emissions and consumption. This shift reduces carbon transfer and encourages the production and export of renewable energy technologies, thus contributing to a positive trade balance [13,46]. Decentralized energy markets and carbon trading within the energy community can facilitate efficient energy use and reduce carbon emissions, further improving the trade balance by encouraging renewable energy exports.

4.3. Global Value Chains in the Crude Palm Oil Industry Sector

Implementing a carbon tax policy to reduce CO_2 emissions, combined with the policy of reducing import tariffs on CPO from Indonesia, imposed by India as the largest trading partner, can significantly increase added value in the CPO industry sector. The results of this study show that the increase in added value in Indonesia's CPO industry is 1.5828%, while in India, it is 0.8657%, and in ASEAN countries, it is 2.1770% (Table 4). This increase is possibly in connection with the downstream policy implemented by the primary sector in order to increase added value. This can increase Indonesia's CPO value-added trade with trading partner countries or increase the country's participation in GVC [28,30]. On the other hand, the increase in added value did not occur in East Asian countries and the European Union because these countries already have high added value in the production of export goods. The value of countries participating in GVCs in the CPO sector is high from the forward GVC perspective. Indonesia has a GVCF participation value of 0.59 and a GVCB participation value of 0.41.

Table 4. Global value chains in the CPO industry.

Variables	Indonesia	India	ASEAN	East Asia	EU
Value added in industry CPO (% change)	1.5828	0.8657	2.1770	−0.0337	−0.0435
Firm price of value added (% change)	−0.0082	−0.0115	−0.0010	0.0065	0.0115
Export CPO (% change)	0.0890	0.1968	0.1142	0.1247	0.1342
Backward global value chain participation (GVCB)	0.4100	0.1153	0.0906	0.2877	0.2183
Forward global value chain participation (GVCF)	0.5899	0.8846	0.9093	0.7123	0.7817
Aggregate export CPO (% change)	−0.811	−0.162	0.344	0.019	−0.011
Aggregate export price index (% change)	−0.003	0.037	0.006	0.010	0.013
Gross domestic product (% change)	0.001	−0.009	0.005	0.007	0.014
Trade balance (USD million)	1,905,577.71	457,005.81	650,737.10	11,795,876.57	45,421,141.33
Regional household income (% change)	0.0003	−0.0118	0.0039	0.0064	0.0132
EV (USD million)	0.031	1.001	0.244	0.822	0.587

Source: Simulations of GTAP-E mode.

Similarly, India has a GVCF participation value of 0.88 and a GVCB participation value of 0.12 (Table 4). This finding suggests that GVCF dominates GVCB [12]. This is also the case for other country groups. This suggests that Indonesia, India, and other countries utilize domestic resources more than foreign resources.

The policy of reducing emissions in the renewable energy framework has increased domestic demand for palm oil as a raw material for biodiesel production. To meet this demand, Indonesian palm oil producers can increase production, resulting in a surplus of production available for export. Increasing the production capacity can make it easier to meet domestic and international demand. The results of the study show that the value-added price of CPO production has decreased by 0.0082%. Along with increasing biodiesel production under the B40 policy, economies of scale can reduce the overall cost of palm oil production. This can make Indonesian CPO more competitive in the global market and increase the country's participation in GVC [18].

Carbon emission reduction policies to create a clean environment in the long term while meeting the COP 28 agreement in 2023 can be carried out by implementing a carbon tax. Implementing a carbon tax incentivizes producers to adopt cleaner technologies and practices to reduce emissions [28]. Compliance with these regulations can improve Indonesia's palm oil environmental image, making it more attractive to countries such as India, China, and other East Asian countries, as well as EU countries that are increasingly paying attention to sustainable practices in their import policies [47].

As other countries will also implement carbon taxes and renewable energy policies, Indonesia's more cost-effective production methods, supported by renewable energy policies, can make Indonesian CPO more competitive in the international market [13,45]. Implementing carbon tax policies to reduce CO_2 emissions and trade liberalization policies can increase CPO exports from Indonesia and trading partner countries. The increase in CPO exports from Indonesia, India, ASEAN countries, East Asia, and the European Union was 0.0890%, 0.1968%, 0.1142%, 0.1247%, and 0.1342%, respectively. This was supported by a decrease in the aggregate export price index of Indonesian CPO by 0.003% (Table 4). Implementing this policy can lead to the production of higher added value and sustainable palm oil products [5].

With stricter environmental regulations and the transition to renewable energy, Indonesian palm oil producers can focus on improving the quality of their products to meet international sustainability standards. The transfer of most palm oil production to domestic biodiesel production based on the B40 policy can positively impact the trade balance of Indonesian CPO and trading partner countries. Indonesia's CPO trade balance experienced a surplus of USD 1,905,577.714 million, while India's CPO trade surplus was USD 457,005.810 million. India's approach offers particularly relevant insights given similar developmental challenges. Their E20 ethanol program, integrated with rural development initiatives and agricultural sector support, has reduced oil imports while boosting rural employment [48]. India's distributed production model has enhanced implementation success in diverse geographical contexts, providing valuable lessons for Indonesia's archipelagic implementation challenges. The CPO trade balance of the ASEAN, East Asia, and the European Union group also shows a trade balance surplus (Table 4). The need to meet renewable energy policy mandates encourages producers to produce more efficiently. The CPO trade balance of the ASEAN, East Asia, and the European Union group also shows a trade balance surplus (Table 4). The need to meet renewable energy policy mandates encourages producers to produce more efficiently. Increased efficiency can reduce the overall cost per palm oil unit, making Indonesian CPO competitive.

Implementing a carbon tax incentivizes producers to implement cleaner and more sustainable practices [28]. This shift could enhance the global reputation of Indonesia's palm oil and appeal to markets such as India and other groups of increasingly sustainability-conscious countries. As Indonesian CPO producers adapt to carbon taxes and renewable energy policies, they can develop products with higher added value to increase the country's participation in GVC. Furthermore, this policy can increase household income by 0.0003% and ultimately improve the welfare of the people of Indonesia and trading partner countries. Table 4 shows that the EV values of Indonesia, India, ASEAN countries, East Asia, and the European Union are USD 0.031 million, USD 1.001 million, USD 0.244 million, USD 0.822 million, and USD 0.587 million, respectively.

5. Conclusions and Policy Recommendations

To overcome the problem of climate change, the Indonesian government has issued a policy to reduce emissions by establishing a carbon tax within the renewable energy policy framework. On the other hand, international trade is currently captured in Global Value Chains (GVCs). The participation of Indonesia and several developing countries that are trading partners is still relatively low regarding backward GVC participation. This study aims to analyze the impact of carbon tax policies, meant to reduce GHG emissions to fulfill the commitment the government made at the 28th Conference of Parties (COP) 2023, on the energy sector in Indonesia using the GTAP-E model. In addition, this study also analyzes the impact of emission reduction policies on state participation in GVC, especially in the CPO sector. This study simulates the impact of a 5% annual increase in carbon tax to reduce GHG emissions to achieve net zero emissions and sustainable economic growth, and a 2.5% reduction in CPO import tariffs by Indonesia's largest trading partner, India.

The results of the study show that policy scenarios produce economic and environmental benefits, namely a decrease in carbon potential and an increase in the added value of production in the CPO industry to increase value-added trade and countries' participation in GVC. The results of the study show that forward GVC participation dominates backward GVC participation in Indonesia and its trading partner countries. In addition, the results of the study show that these policies can improve community welfare and economic growth.

Emission reduction policies in the renewable energy framework can potentially increase the prospects of the fuel economy in the future. The successful implementation of the B40 policy requires substantial modifications to existing production facilities and distribution networks. Many biofuel processing facilities require extensive upgrades to handle higher blend ratios, while storage and distribution systems need modernization to maintain fuel quality standards. The transition to higher biodiesel blends demands substantial upfront investments, which many small and medium enterprises struggle to secure. For this reason, the government needs to create added value for downstream palm oil products so that domestic palm oil producers can develop the CPO processing industry by innovating and creating new products in the palm oil industry sector with a clean technology process. In addition, the government needs to encourage increased investment in R&D and innovative technologies to improve production's added value to increase profitability, state participation in GVC, and overall biodiesel sustainability. This can be realized if all interested parties participate actively, such as producers, distributors, consumers, and policymakers.

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