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Analysis of the Relationship between International Trade and Carbon Border Adjustment Mechanism

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Abstract The European Union (EU) Carbon Border Adjustment Mechanism (CBAM) is a crucial tool that aims to connect carbon reduction commitments with international trade. It encourages countries to align their carbon emissions with EU standards, design reasonable carbon taxation systems, and stimulate investment in clean technologies to achieve global decarbonization goals. The implementation of CBAM in 2026 will have a direct impact on the global supply chain, including Taiwan's export-oriented enterprises. This article aims to explore the relationship between the CBAM and international trade. CBAM not only encourages countries to demonstrate their commitment to carbon reduction and align their carbon emissions with EU standards, but it also guides governments in designing reasonable carbon taxation systems and incentivizes businesses to invest in clean technologies to achieve global decarbonization goals. This study uses a regression model to analyze how international trade and other economic variables relate to CO_2e emissions of multinational companies in Taiwan. The findings reveal strong positive associations between Taiwan's carbon emissions and variables like metal production, construction, fixed investment, land value tax, steel industry profitability, and annual export trade growth rate. Conversely, a significant negative association is observed in variables like electronic component production, number of employees in power machinery manufacturing, and Indices of Consumer Price in Taiwan area-food away from home. This indicates that Taiwan's electronic, semiconductor and power machinery industries have effectively achieved environmental benefits through the adoption of cleaner production technologies. Overall, this research contributes to facilitating low-carbon transformations within businesses and the formulation of policies that attract international orders, highlighting the importance of CBAM in promoting global sustainability.

Keywords: *carbon border adjustment mechanism, export trade, fixed investment, consumer price index, electronic components industry*

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1. Introduction

1.1. Research Background

International trade is a vital driver of global economic growth [1]. Globalization, which has been prevalent for over two decades, has enabled the closer integration of diverse geographical regions, varied commodities, cultures, and social perspectives through interconnected supply chains. This has resulted in increased value addition to products and rapid economic growth [2]. Climate change is a globally recognized issue of concern [3]. Continued climate deterioration will lead to decreased crop yields worldwide and will also become a long-term factor contributing to rising prices [4]. The international community is increasingly recognizing the necessity of reducing greenhouse gas emissions to mitigate climate change [5]. When it comes to addressing climate change, no country can afford to stand on the sidelines [6]. To achieve the goal of net-zero emissions by 2050 outlined in the Paris Climate Agreement, it is necessary to go beyond macroeconomic policies and include actions by businesses in international trade to reduce carbon emissions [7].

The European Union (EU) proposed "European Commission, 2019" a roadmap for action from 2020 to 2023, with the goal of achieving carbon neutrality by 2050. This roadmap includes the implementation of various environmental sustainability policies and sets a reduction target of at least 55% by 2030 compared to 1990 levels, ultimately reaching carbon neutrality by 2050 [8]. Furthermore, if substantial efforts are not made to limit emissions, this growth trend will continue to persist [9]. To address the comprehensive impact of climate change on the global economy, the EU passed the Carbon Border Adjustment Mechanism (CBAM) in April 2023. This mechanism sets carbon prices on targeted imported products such as coal, liquefied natural gas, and steel. It is expected to contribute to a reduction in global carbon

emissions. However, orders and industries from high-carbon cost countries may relocate to countries with lax environmental regulations and lower carbon costs, resulting in a situation of carbon leakage [10]. This can undermine the effectiveness of the EU's efforts to improve the climate. Therefore, governments should actively pursue coordinated approaches involving all stakeholders and promote international cooperation to address climate change, while considering the economic realities of the global market. The Russian invasion of Ukraine has triggered an ongoing crisis that highlights the world's excessive reliance on fossil fuels, pushing the global energy and living costs into a critical situation [11]. Climate change has transformed from a future challenge to a present-day threat, affecting not only the well-being of individuals but also posing real and immediate risks to society [12].

1.2. Research Purposes

In pursuit of necessities such as food, clothing, shelter, transportation, education, and recreation, human beings have overlooked the carbon emissions resulting from these activities. This has disrupted the natural carbon cycle, which had achieved equilibrium since ancient times, leading to intensified global climate change and posing a threat to sustainable human development [13]. Previous research on household carbon emissions has not adequately explored the relationship between carbon emissions and daily lifestyles. However, in response to the need for adjustments based on living expenses, some countries have taken action to incentivize energy efficiency and emissions reduction. Examples include the UK's Carbon Reduction Commitment Energy Efficiency Scheme, Tokyo's Emissions Trading Scheme, and Performance Achievements and Trading Scheme [14]. In 2020, a total of 853 companies worldwide implemented Internal Carbon Pricing (ICP), with an additional 1,159 companies stating their intentions to implement ICP [15]. COP27 was held at the end of 2022, and over 130 countries globally have announced their commitment to achieve net-zero carbon emissions before 2050. As a result, there is increasing attention to cross-border approaches to carbon pricing, with many countries considering international trade measures to address "carbon leakage". Most countries aim to address this issue by providing exemptions, offsets of carbon tax, or quotas of carbon emissions to affected industries.

To achieve the goal of net-zero carbon emissions, the EU has proposed the CBAM, which aims to create a level playing field by imposing CBAM charges on goods imported into the EU [16]. The consensus among countries regarding the imposition of carbon fees has led to increased production costs, which businesses are likely to pass on to consumers, thereby driving up prices [17]. This article aims to explore the relationship between the CBAM and international trade. CBAM not only encourages countries to demonstrate their commitment to carbon reduction and align their carbon emissions with EU standards, but it also guides governments in designing reasonable carbon taxation systems and incentivizes businesses to invest in clean technologies to achieve global decarbonization goals.

Due to the implementation of CBAM, which involves balancing environmental and trade policy objectives, it is a complex issue. The effectiveness of such measures in reducing global emissions is still subject to debate and requires international cooperation to ensure its success. Taiwan's government now seeks ways to balance economic development and environmental issue and to avoid erosion of the tax base. From the government's perspective, it examines the root causes of Taiwan's carbon emissions, monitors international tax system development trends, and incentivizes industries to innovate their "green" emission reduction technologies, thus achieving a win-win situation for all parties involved. These ideas, as well as our ability to translate them into empirical studies, can be a source of information and inspiration for academics and practitioners.

2. Literature

2.1. International Trade and CO_2 Emissions

The relationship between CO_2 emissions and international trade is complex. International transportation accounts for approximately 33% of the global trade-related emissions and over 75% of emissions in major manufacturing sectors [18]. International trade plays a significant role in driving CO_2 emissions through various pathways. It is considered an important factor in explaining CO_2 emissions [19]. The CBAM is an international trade policy that imposes tariffs on carbon-intensive imported goods. It aims to create a level playing field for manufacturers within the EU and incentivize investment in clean technologies. CBAM represents a new form of obligatory green trade trend, promoting international equality, reciprocal cooperation, and corporate social responsibility. Its goal is to achieve net-zero emissions [20]. Firstly, international trade can lead to an increase in the production of goods and services, resulting in higher energy use and CO_2 emissions. This is especially true for industries such as manufacturing that are energy-intensive and often rely on fossil fuels for production.

Secondly, with the cross-border transportation of goods, international trade can contribute to increased emissions associated with transportation. Air freight, maritime shipping, and land transportation are energy-intensive modes of transport that typically rely on fossil fuels. As international trade volume grows, the demand for transportation also increases, leading to higher emissions. [21]. Thirdly, international trade can also generate indirect emissions from the output of traded goods. For example, a country specializing in steel production may import iron ore from another country, resulting in emissions associated with the production and transportation of the iron ore. Similarly, a country specializing in electronic products may import semiconductors and other components from other countries/regions, leading to emissions related to the production and transportation of these components.

2.2. Taiwan's Response to the CBAM Policy

As countries worldwide strive to promote net-zero emission policies to combat the threats of global warming and climate change, providing appropriate transition support measures to affected industries or stakeholders becomes an important task in policy formulation. Taiwan, as a member of the international community, is committed to fulfilling its obligations under the Paris Agreement and other international climate change treaties. On the other hand, Taiwan is a trade-oriented nation, with exports consistently accounting for around 60% of its GDP. To 2021, exports to Europe amounted to approximately $28.17 billion, representing 8% of the total trade volume [22].

The top ten exports of Taiwan to the EU include electrical machinery, mechanical appliances, vehicles, and steel products. For carbon-intensive goods, importers need to procure specific and objectively verifiable CBAM certificates based on the carbon emissions of their products to enter the EU market. Among the 158 steel products manufactured in Taiwan and exported to the EU, management measures are implemented, and exporters must obtain a certificate of origin issued by the International Trade Bureau before the goods are released. Over 80% of businesses in Taiwan have not yet conducted carbon footprint assessments. Taiwan is included in 212 out of the 248 items regulated by CBAM, with a value of 24.5 billion NT dollars, mainly in steel and aluminum products. Preliminary estimates suggest that CBAM implementation will increase export costs by 600 million to 4.7 billion NT dollars. To 2022, Taiwanese exports to the EU subject to the CBAM amounted to approximately 1 billion USD, with steel, accounting for 950 million USD. Although Taiwan's carbon emissions from steel production are significantly lower than those of China and India, they are still higher than those of advanced countries such as the United States, Canada, and the EU in East Asia, and compared to Japan and South Korea [22].

The EU will begin a trial of the CBAM in October 2023, with full implementation scheduled for 2026. In the initial stage, the focus is on data collection, and importers are only required to submit carbon emission-related reports without paying the carbon border tax. Therefore, regulated industries in Taiwan have several months of preparation time. According to estimates by the Ministry of Economic Affairs, there are 248 items subject to CBAM regulation, with Taiwan accounting for 212 of them, totaling around 24.5 billion New Taiwan (NT) Dollars. The regulated industries include cement, fertilizers, steel, aluminum, and electricity, representing 3.6% of the total EU exports. Steel products are particularly affected. In the future, the central government will announce medium and long-term case plans to assist small and medium-sized enterprises in achieving their net-zero transformation goals. The National Development Council, together with the Environmental Protection Administration (EPA), Ministry of Economic Affairs, Ministry of Transportation, Financial Supervisory Commission, Ministry of Labor, Ministry of the Interior, National Science Council, and Council of Agriculture, will promote twelve key strategies to expand central and local cooperation, public-private partnerships, and international collaboration [23]. Due to most businesses in Taiwan being small and medium-sized enterprises (SMEs) (currently nearly 1.6 million, accounting for approximately 99% of all businesses), the government has proposed the "SMEs Overall Competitiveness Enhancement Program," which will allocate 95 billion NT Dollars for carbon emission reduction over a period of five years starting from 2022. Please refer to Table 1 for the corresponding timeline.

Table 1. Taiwan Sustainable Development Path

Schedule planning (Listed and OTC)	Individual companies under investigation	Completion of the investigation of subsidiary companies in consolidated financial statements	Completion of certification for individual companies	Completion of certification for subsidiary companies in the consolidated financial statements
Capital Exceeding NT$ 10 Billion and Steel and Cement Industries	2023	2025	2024	2027
Listed and OTC Company with a Capital of NT$ 5-10 Billion	2025	2026	2027	2028
Listed and OTC Companies with a Capital of NT$ 5 Billion or less	2026	2027	2028	2029

Source: Financial Supervision Commission (2023)

After the Climate Change Adaptation Act comes into effect, Taiwan's EPA will develop relevant subsidiary regulations in the second half of 2023 regarding the imposition of carbon fees. These regulations will include amendments to inventory registration procedures, management of inspection and certification organizations, carbon fee collection and rates, voluntary emission reduction plans, voluntary emission trading mechanisms, and carbon footprint procedures [24]. Starting from January 2024, emitters will be required to calculate their annual emissions for the latest reporting year, and by the end of January 2025, they will need to report their quarterly carbon emissions from the previous year for carbon fee imposition. Currently, the industries subject to greenhouse gas inspection and reporting include power generation, steel manufacturing, petroleum refining, cement production, semiconductor manufacturing, and LCD panel manufacturing, with a threshold of annual emissions exceeding 25,000 metric tons of CO_2e.

In the face of changing international trade norms and the evolving global supply chain landscape following the Covid-19 pandemic [25]. Taiwan and the United States have launched the U.S.-Taiwan Initiative on 21st-Century Trade. According to the initiative, there will be a focus on supporting the environment and climate action. In addition to promoting the implementation of environmental protection regulations, other factors beyond efficiency will be considered. The Ministry of Economic Affairs and relevant government units will assist in evaluating energy management systems and establish ISO50001, introduce high-efficiency energy-saving technologies and counseling, SMEs carbon inventory counseling and corporate carbon reduction counseling, product environment Footprint analysis, technical assistance for

greenhouse gas exchange projects, etc., to accompany the industries go through net-zero transformation smoothly [26].

3. Methodology

Climate change will result in disruptions to environmental sustainability, economic growth, social development, and energy supply [27]. Therefore, in view of this, this study aims to encompass the variables that affect the business models of Taiwanese multinational corporations due to the current economic development in Taiwan and the impact of CBAM.

3.1. Sample

This study uses the export and CO_2 emissions (CO_2e) of Taiwan from 2011 to 2021 as data for analysis. As mentioned above, Taiwan's economy is export-oriented, with a significant focus on contract manufacturing, primarily in the manufacturing sector. The electronics industry holds a leading position globally in terms of contract manufacturing and exports. This economic development model based on manufacturing also suggests that industrial processes may contribute to higher carbon emissions [28]. Therefore, utilizing databases such as the World Bank, International Monetary Fund (IMF), International Energy Agency (IEA), and Taiwan Economic Journal (TEJ), Taiwan's sample is used for analysis.

3.2. Model and Variables

Carbon emissions are generally measured in terms of carbon dioxide equivalent (CO_2e). CO_2e/GDP is an indicator used to assess the carbon intensity of an economy, representing the amount of carbon emissions produced per unit of economic output (GDP). The research aims to explore how CBAM affects the operational models of multinational companies in Taiwan, such as product pricing and export strategies. This variable holds economic significance as it is also one of the indicators (Indicator 9.4.1) for the United Nations Sustainable Development Goals.

Based on this, the empirical model in this study takes CO_2e/GDP as the dependent variable and includes variables such as industry employment, fixed investment, government tax revenue, financial investment, and export trade as independent variables (Table 2. Variables). The research model is referenced from studies by Liddle (2018) [29] and Hasanov et al. (2018) [30].

The model is represented as Equation (1):

$$\begin{aligned} CO_2e/gdp_\tau = {} & \lambda_1 Export\ growth_\tau + \lambda_2 Metal\ output_\tau \\ & + \lambda_3 Metal\ dividend_\tau + \lambda_4 Electronic\ output_\tau \\ & + \lambda_5 Eemploy_\tau + \lambda_6 Fixed\ invest_\tau \\ & + \lambda_7 Land\ tax_\tau + \lambda_8 Dine\ out_\tau + \varepsilon_\tau \end{aligned} \quad (1)$$

Equation (1) has 8 control variables. The Independent variable is the annual change rate of the export value (*Export growth*), and the export commodities include such things as functionality, design, pricing, packaging and after-sales service. They must conform to international standards and meet customer demands, while highlighting Taiwan's innovative capabilities and quality assurance. With all countries focused on growing the economy and expanding export sales, Taiwan is no exception. Consequently, this study forecasts that the annual growth rate of export trade will show a significant positive correlation with CO_2e/GDP.

As Taiwan's pathway to achieve net-zero emissions by 2050 involves four major transformations, namely "energy transition," "industrial transition," "lifestyle transition," and "social transition," this study focuses on the "lifestyle transition" aspect, which includes promoting low-carbon diets and other aspects of daily consumption [31]. The Consumer Price Index (CPI), which is generally used to observe and measure changes in the prices of goods and services from the perspective of product demand. It is an important indicator for measuring product demand trends and inflation, and it is also a crucial data point for central banks in formulating monetary policies. Therefore, the CPI in Taiwan area-food away from home (*Dine out*) constitutes a part of the independent variables of the model of this study, and it is estimated that it will show a very significant negative correlation with CO_2e/GDP.

Taiwan's electronics industry represented 54.8% of manufacturing in 2021, indicating that Taiwan's industrial structure is focused on the electronics industry [28]. In addition to incorporating the electronics production index (*Electronic output*) into the research model, Taiwan's exports to the European Union, primarily consist of electronic products that require a substantial number of raw materials and technology for production (*Eemploy*). Therefore, the research model also includes variables such as employment figures in the electronic and machine industries. These industries are vital for Taiwan and have a high level of international competitiveness.

The self-sufficiency rate of raw materials and energy is insufficient in Taiwan, as the required materials must rely on imports. Based on this, the study anticipates a highly significant negative correlation between *Electronic output* & *Employment* and CO_2e/GDP.

Table 2. Variables

Variable	Explanation
CO_2e/GDP	The Carbon Emissions per unit of GDP
Export growth	Annual Change Rate of Export value
Metal output	Industrial Production Index-Fabricated Metal Products Manufacturing
Metal dividend	Yield of Steel & Iron
Electronic output	Industrial Production Index-Other Electronic parts and Components Manufacturing Not Elsewhere Manufacturing
Eemploy	Employees on Payrolls of Electrical machinery, supplies& equipment manufacturing & repairing.
Fixed invest	Gross Fixed Investment
Land tax	Total of Land Value-Added Tax
Dine out	Indices of Consumer Price -Food Away from Home

Steel is the backbone of industry, and the ability to melt steel represents a nation's potential in the industrial sector. Steel production is a key component of Taiwan's industrial sector, and it plays a vital role in supporting various industries, such as construction, manufacturing, and infrastructure development. With the expansion of industrial operations, demand for steel to support construction projects, machinery manufacturing and other

sectors is increasing. This increase in steel production results in a rise in carbon emissions. However, steel production processes are known to be energy-intensive and often result in significant carbon emissions. The growth of Taiwan's economy leads to increased demand for steel, both domestically and for export purposes. Therefore, as steel production (Metal output) and (*Metal dividend*) increases, it is expected to contribute to higher levels of CO_2e/GDP.

The share of fixed investment in GDP rose to 27.6% in 2022, reaching the highest level in Taiwan since 1994 [28]. On the other hand, fixed investment (*fixed invest*) refers to the investment made by businesses and individuals in acquiring production equipment, factories, and other materials or intangible assets to improve their productivity and economic efficiency. During the process of fixed investment, there will also be corresponding carbon emissions. When companies increase their fixed investment, the employment level within the company is likely to increase as well, as it provides information about the health of the labor market and financial investment in the economic entity. Consequently, this study predicts a very significant positive correlation between fixed investment (*fixed invest*) and CO_2e/GDP.

Total of land value-added tax (*Land tax*) is a policy measure implemented in Taiwan to address environmental concerns and promote sustainable development. It incentivizes efficient land use and discourages speculative activities, which can lead to increased carbon emissions. Due to the characteristic of Taiwan's real estate market being prone to rapid increases and slow declines, this study anticipates a highly significant positive correlation between the land value-added tax and CO_2e/GDP.

4. Results

As the EU adopts CBAM, Canada and the United Kingdom are also exploring similar mechanisms. Under the trend of carbon reduction and net-zero goals, the increasing carbon pricing measures and the accompanying CBAM have significant impacts on international trading activities. The most apparent effect of CBAM implementation is that European consumers will face higher prices for imported goods. Additionally, as CBAM is gradually implemented, industries will face a reduced quota of tax-free carbon emissions, which will further increase production costs. By examining the exports of five high-risk products with carbon leakage potential, namely fertilizers, cement, steel, aluminium, and power equipment, as regulated by the EU during the trial phase (refer to Tables 3-6), we investigate the potential effects of CBAM on Taiwan's industrial exports.

The summarized data on Taiwan's export trade are as follows:

4.1. Top 10 Export Destinations for CBAM Products from Taiwan

The Harmonized System (HS) is a standardized coding system developed by the World Customs Organization (WCO). It serves to quantify and manage the tariff rates applicable to the import or export of various commodities. The first six digits of the HS code are universally accepted in a variety of countries. In recent years, Taiwan has benefited from emerging technology applications, resulting in increased global exports. The highest export value comes from electrical machinery and its parts (HS85), accounting for over 50% of the total export value. The second highest is machinery and its parts (HS84), with a share of 13.2%. The remaining categories have a share of less than 5%. Regarding the countries targeted by Taiwan's export of products regulated by the CBAM, Table 3 shows that in the past 6 years, Taiwan's global export trade in CBAM-regulated products has been primarily focused on regions outside of Europe.

Table 3. Major Countries for Taiwan's CBAM Product Exports (in Thousand US Dollars)

Year	China	USA	Japan	Vietnam	South Korea	India	Hong Kong	Thailand	Malaysia	Australia
2016	13,011,955	5,641,181	2,741,238	2,306,116	1,383,430	1,167,521	1,622,253	1,328,185	1,132,647	776,756
2017	15,574,815	6,440,527	3,291,475	2,769,062	1,864,237	1,345,065	1,833,222	1,418,751	1,327,040	875,691
2018	17,314,310	6,847,733	3,852,035	3,279,914	1,984,829	1,760,474	1,875,178	1,483,177	1,472,945	1,029,787
2019	13,654,923	6,456,245	3,635,516	3,277,571	1,590,583	1,519,244	1,516,144	1,289,525	1,236,138	779,176
2020	12,775,590	6,216,596	3,017,055	2,903,918	1,331,180	1,157,040	1,401,448	1,111,339	1,004,922	771,218
2021	17,224,408	9,561,856	4,106,112	4,141,836	2,198,969	2,127,805	1,677,412	1,675,183	1,536,596	1,284,735

Source: Ministry of Finance

4.2. Taiwan's Exports to the EU

Prior to the Covid-19 pandemic, the proportion of motorcycle and bicycle components imported from Taiwan by the European Union exceeded that long-distance equipment such as laptops and graphics cards. However, due to changes in commuting habits caused by the pandemic, along with environmental considerations and government subsidy policies, there has been a surge in demand for electric bicycles among Europeans. This has led to continued strong sales of Taiwanese electric bicycles in the European Union, making them the second-largest imported goods. Table 4 illustrates the trade situation of Taiwanese products exported to the EU over the past 6 years.

Germany, one of the largest economies in the EU, is also an important trading partner for Taiwan. Taiwanese exports to Germany include information technology, machinery, and automotive parts, among other electronic products. The Netherlands serves as a vital gateway for Taiwan's exports to Europe, with the port of Rotterdam being the largest port in Europe. Taiwanese products exported to the Netherlands are often re-exported to other EU countries. Major export products include electronics, machinery, and chemicals. France receives Taiwanese exports of electronics, machinery, textile products, and consumer electronics.

Table 4. Taiwan's Exports to the EU (Million US dollars)

Year	Germany	Netherlands	Italy	Belgium	France	Spain	Poland	Sweden	Hungary	Czech
2016	5,897	4,469	1,860	1,138	1,542	876	780	579	524	405
2017	6,429	4,972	2,027	1,370	1,707	1,026	889	614	532	452
2018	7,058	5,856	2,328	1,500	1,667	1,249	993	615	499	462
2019	6,522	5,863	1,979	1,405	1,521	1,194	899	634	579	454
2020	6,039	6,047	1,608	1,438	1,283	1,037	863	565	606	521
2021	8,173	8,079	2,566	2,738	1,585	1,612	1,242	770	728	529

Source: Ministry of Finance.

4.3. CBAM Product Exports to Major Countries in the EU

The EU imposes relevant fees on importers of high carbon leakage products under CBAM. However, Table 5 presents the trade situation of Taiwan's exports to the EU for CBAM-regulated products in the past 6 years, with Germany being the largest importer followed by the Netherlands. Although Taiwan is an export-oriented country, as shown in Table 5, the major exports to the EU are "manufactured goods" rather than the "raw materials" (cement, fertilizers, steel, iron, aluminum) subject to initial regulation under CBAM. Therefore, in terms of CBAM content, most exported goods from Taiwan do not fall under the regulated category, resulting in minimal impact on Taiwanese companies.

Table 5. CBAM Product Exports to Major Countries in the EU (Thousands of US dollars)

Year	Germany	Netherlands	Belgium	Italy	Spain	France	Poland	Sweden	Denmark	Portugal
2016	771,334	616,309	331,869	523,107	240,434	209,171	153,521	151,647	86,040	34,724
2017	833,781	709,914	616,462	625,009	345,981	235,457	197,656	166,771	104,410	44,082
2018	956,632	784,058	708,255	782,272	519,407	262,461	224,163	176,184	99,379	64,958
2019	797,984	738,393	456,258	587,212	437,772	239,524	205,100	177,844	107,321	76,453
2020	719,179	623,164	405,150	377,229	331,990	187,699	156,265	156,818	92,047	46,507
2021	987,628	1,129,104	1,389,146	906,286	672,425	238,383	214,502	237,739	161,922	118,701

Source: Ministry of Finance.

4.4. Exports of CBAM-regulated products from Taiwan to the EU

Due to the prevailing low-carbon trend in the EU, Taiwan primarily exports products such as information and communication technology, electronic goods, and transportation equipment to Europe. In the future, the main CBAM-regulated items will be raw materials such as cement, fertilizers, steel, iron, and aluminum. Steel and its products will constitute the majority (approximately 12%) of exports to Europe, followed by aluminum and its products (approximately 0.4%). Therefore, Taiwan's future exports of steel, cement, aluminum, and related products to the EU will be subject to CBAM regulations and face the risk of carbon border taxes. As shown in Table 6, Taiwan's major exports still consist of information and communication technology and electronic goods.

Table 6. Taiwan's CBAM-regulated Products are Sold to the EU (Thousands of US Dollars)

Item	Chemicals	Plastic, Rubber	Textiles	Metal a	Electronic	Mechanical	Motor	Communication	Transportation	Optics Equipment	Minerals
2016	2,861	1,558	901	4,096	19,041	3,887	1,686	41,323	3,196	2,468	83
2017	3,275	1,666	1,155	4,754	21,280	4,191	1,871	50,069	3,560	2,461	164
2018	3,177	1,683	1,279	5,511	20,460	4,211	1,672	50,182	3,591	2,016	82
2019	2,471	1,731	1,236	4,452	20,983	3,560	1,602	49,625	3,783	1,857	69
2020	2,215	1,951	1,146	3,988	24,104	3,276	1,627	56,881	4,134	1,686	42
2021	2,578	2,548	1,340	7,566	29,047	4,606	2,063	66,041	6,222	1,919	85

Source: Ministry of Finance.

From Table 6, it is evident that Taiwan's exports to the EU are dominated by electronic and metal products, both of which require many raw materials and technology for production. Electronic components, including integrated circuits, printed circuits, and diodes, are vital industries in Taiwan. Only Taiwan possesses a complete industrial ecosystem and extensive research and manufacturing experience, making it highly competitive internationally. Semiconductor chips have become a strategic resource that dominates the global competition, influencing the rise and fall of international powers, with Taiwan playing a critical role in the global semiconductor supply chain. Consequently, the research model incorporates the electronic component production index (*Electronic output*) as a final variable.

4.5. Taiwan's CO_2 emissions

Carbon emissions tax is an important measure to incentivize businesses to innovate "green" emission reduction technologies [2]. Therefore, the novelty of this study lies in considering the cost-benefit assessment items of the government in formulating carbon emission policies, such as government tax revenue and financial indicators, which are incorporated. From Table 7, Taiwan's carbon dioxide emissions per unit of gross domestic product (CO_2e/GDP) ranged between 0.234 and 0.306 from 2011

to 2021, still higher than Germany's 0.14 but comparable to Canada's 0.29 and Ukraine's 0.31. Moreover, there has been a decreasing trend in these emissions over the years, including the latest available data in 2021. Taiwan's export growth rate (*Export growth*) reached its highest at 23.871 in 2021, while in 2011, the global economy was still recovering from the 2008 financial crisis, and the Eurozone debt crisis was unfolding. Taiwan has experienced multiple natural disasters, including typhoons Nanmadol and Nesat. Climate change poses significant risks to supply chains, including increased frequency of climate change and natural disasters, leading to transportation delays, infrastructure damage, and disruptions in the flow of goods and services. Economic uncertainty and reduced consumer demand have also impacted Taiwan's export growth. Therefore, Taiwan must actively introduce new international requirements related to carbon emissions, environmental standards, and sustainable practices in line with the international trend of mandatory green trade. This can help mitigate regulatory risks, ensure legality, and enhance supply chain resilience.

Table 7. Descriptive Statistics Table

Variable	Min	Max	Mean		S.D.
			Statistic	Std.Error	
CO_2e/GDP	0.234	0.306	0.272	0.007	0.023
Export growth	0.940	23.871	8.875	2.245	7.446
Metal output	98.310	110.940	103.294	1.377	4.566
Eemploy	563	643	607	8	28
Fixed invest	312	459	372	13	45
Land tax	336	338	337	0.221	0.732
Metal dividend	1.460	8.010	3.873	0.561	1.862
Dine out	90.330	109.460	102.390	1.839	6.098
Electronic output	83.970	181.550	114.139	10.755	35.670

From Table 8, it can be understood that there is a significant positive correlation between the formation of real fixed investment in construction (*Fixed invest*) and the production of electronic and related component products (*Electronic output*) as well as the number of personnel engaged in the industry (*Eemploy*). This corresponds to the current industrial development trend in Taiwan. To achieve the goal of net-zero carbon emissions, Taiwan typically involves transitioning from fossil fuels to renewable energy, which can reduce dependence on traditional energy sources vulnerable to price fluctuations and geopolitical tensions, thereby enhancing supply chain resilience. In Taiwan, the construction industry should focus on enhancing energy security and reducing supply chain disruption risks by adopting renewable energy as part of its fixed investment.

In terms of daily living, the correlation coefficient of the CPI for eating out is also positively correlated with the two previous factors. This indicates that there are reasons behind Taiwan's dominance in the global semiconductor and electronics industries, and it comes at the expense of workers sacrificing their own dining happily with their families. Therefore, the government should actively strive for "good health and social welfare" for workers, "dignified labor and economic growth," and "reduced domestic and international inequality" to align with the international Sustainable Development Goals (SDGs).

On the other hand, there is a significant negative correlation between the formation of fixed investment (*F*ixed invest) and the collection of land value tax (*Land tax*). This indicates that the current tax policy in Taiwan is not particularly friendly or supportive towards the development of the electronic industry capable of achieving net-zero carbon emissions. The government should actively amend laws and create a favorable investment environment.

Table 8. Variable Correlation Coefficients

Variable	Co_2e/GDP	Fixed invest	Metal output	Eemploy	Dine out	Electronic output	Yield	Land tax	Export
Co_2e/GDP	1.000								
Fixed invest	−0.984***	1.000							
Metal output	−0.494	0.548**	1.000						
Eemploy	−0.868***	0.840***	0.301	1.000					
Dine out	−0.722***	0.702***	0.447*	0.686***	1.000				
Electronic output	−0.851***	0.883***	0.578**	0.529**	0.488*	1.000			
Metal dividend	0.582**	−0.612**	−0.636**	−0.468*	−0.512*	−0.441*	1.000		
Land tax	0.739***	−0.782***	−0.556**	−0.413	−0.360	−0.815***	0.559**	1.000	
Export growth	−0.500*	0.559**	0.322	0.546*	0.411	0.461*	−0.427*	−0.244	1.000

***, **, and *represents at the 1%, 5%, and 10% significance levels.

4.6. Regression Analysis

From an export perspective, Taiwan remains a significant producer of high-tech industrial components. Despite the breakdown of globalization, it still does not affect the importance of Taiwan's manufacturing and technology industries in the global trade market. However, export trade growth depends on various factors such as industry, country of origin, and type of exported products. Given that industries related to electronic components like semiconductors in Taiwan prioritize sustainable operations, companies that prioritize sustainability are more likely to achieve lower carbon emissions earlier. For example, using renewable energy and reducing waste can help minimize a company's environmental impact and carbon footprint. Additionally, companies' products and services have a competitive advantage in the international market as more consumers become aware of sustainability and are willing to pay a premium for sustainably produced goods.

According to Table 9, the Adj R-squared value of 0.999 indicates that the variability of the dependent variable, carbon dioxide emissions per capita of GDP, can be adequately explained by the relationships among the variables. The regression P-values approaching 0 indicate that the selected variables in this analysis model have a highly significant influence on carbon dioxide emissions

per capita of GDP. The empirical results show that Taiwan's carbon emissions (Co_2e/GDP) are significantly negatively correlated with the electronic component production index, employment in the power machinery and equipment manufacturing sector, and CPI dining-out index. On the contrary, Taiwan's carbon emissions (Co_2e/GDP) show a highly significant positive correlation with the metal products production index (Metal output), fixed investment in construction (*Fixed invest*), land value-added tax (*Land tax*), and yield of the steel industry (Metal dividend), while exhibiting a significant positive correlation with the export trade growth rate (*Export growth*).

Table 9. Regression Analysis

Variable	Coefficient
Export Growth	0.2186**
	(6.6355)
Metal output	0.7735***
	(12.0474)
Eemploy	−0.0011***
	(−18.7943)
Fixed invest	0.001***
	(11.7935)
Land tax	0.0148***
	(13.4191)
Metal dividend	3.3072***
	(14.4204)
Dine out	−1.1339***
	(−15.6208)
Electronic output	−0.8726***
	(−18.0966)
Adj R^2	0.9994
F-statistic	2234.54
Prob(F-statistic)	0.0004

Dependent Variable: Co_2e/GDP; p-values are in parentheses); ** $p < .05$;*** $p < .01$.

5. Discussions

When international trade operates through the global value chain, the relationship between carbon emissions reduction and employment is no longer a zero-sum game [31]. The empirical results show that the three variables of industrial production index-electronic component manufacturing, motor, material and equipment manufacturing and maintenance employees, CPI-outside food expenses and so on all show a very significant negative correlation with CO_2e/GDP.

According to the Environmental Kuznets Curve (EKC) hypothesis as economies develop and industrialize, pollution and carbon emissions initially increase. Studies in this sector have consistently shown that carbon emissions go up as production increases. This is due to the use of energy-intensive processes, like manufacturing, which require large amounts of electricity and contribute to carbon emissions. However, above a certain level of economic development and technological progress, companies are becoming more aware of environmental concerns and implementing policies and technologies that reduce carbon emissions [32]. When companies play an active role in reducing carbon emissions, this can create unemployment for existing employees. The EKC hypothesis is confirmed when the aggregate GDP growth is considered, considering the improvement of the overall economic conditions of the countries regardless of the economic structure and role of industrialization [33].

From Table 9, it can be inferred in the context of Taiwan's industrial development, in terms of environmental benefits and creating employment opportunities, it is complementary to the electronics industry in Taiwan. Given the energy-intensive nature of the industry, the electronics industry faces some challenges. Nevertheless, Taiwan plays a crucial role in the global semiconductor supply chain, with Taiwan Semiconductor Manufacturing Co. (TSMC) being the world's leading semiconductor manufacturer with the largest market share. TSMC has already implemented advanced carbon reduction technologies and environmental awareness, resulting in effective energy consumption and emission reduction within the industry.

International trade is how national patterns of production and consumption can decouple within a country [34]. This becomes an important issue to take into consideration when looking at the relationship between economic growth and environmental impact. Over time, environmental issues have become increasingly important and sustainable development has been encouraged. From the perspective of Table 9, it is evident that carbon emissions and the Indices of Consumer Price in the Taiwan Area for food away from home exhibit a significant negative relationship. Implementing sustainable practices in the restaurant industry in Taiwan can explain this unexpected finding.

As a result, many restaurants have adopted environmentally friendly practices, such as sourcing local ingredients, reducing food wastage and implementing energy efficiency measures in Taiwan. These efforts have been successful in reducing the carbon emissions associated with outdoor food, despite an increase in the CPI. In addition and changing consumer preferences and government initiatives aimed at promoting sustainable choices have contributed to the negative relationship between carbon emissions and the ICP for food away from home. More and more individuals are opting for local, organic, and environmentally friendly products, which could have reduced the food service industry's carbon footprint in Taiwan. It was pointed out from [35] that CO_2 emissions do not decline with increasing per capita income and that better environmental quality may be a result of increased ability to consume energy efficiently. This studies consistently reveal a significant negative correlation, which challenges traditional theories.

This observation contradicts previous theories and comparisons in the literature. One prominent theory supporting the positive relationship between carbon emissions and the CPI for food away from home is the income elasticity of demand. This theory suggests that as individuals' income rises, they tend to spend a larger portion of their budget on dining out, contributing to higher carbon emissions associated with the food service industry [36]. It is important to note that while the findings contradict previous theories, they provide

valuable insights into the potential effectiveness of sustainable practices in mitigating carbon emissions.

Daily lifestyle not only reflects individual differences in sustainable living but also systematic household differences in carbon emissions. Liu, Shryane, and Elliot (2023) found that an energy-saving lifestyle significantly reduces carbon emissions from the residential fuel use [37]. The empirical evidence shows a highly significant negative correlation between Taiwan's CPI (*Dining-out*) and CO_2e/GDP, indicating that restaurants heavily rely on low-carbon cooking techniques and locally sourced ingredients. This reflects the uniqueness of Taiwan's dining habits compared to other countries, such as the Shilin Night Market.

In most developing countries, renewable energy still cannot compete with the cost of electricity generation based on fossil fuels in terms of the trade competition. Therefore, when compared to various measures supporting the deployment of renewable energy, government fiscal tools can be considered the most promising tool in emerging economies [38]. According to the regression analysis in Table 9 shows that there is a very significant positive correlation between the industrial production index-metal product manufacturing, OTC-steel production, total fixed investment, total land value-added tax and carbon emissions in Taiwan. On the other hand, the revenue from the Land value-added tax can be allocated for environmental protection efforts, such as reforestation, preservation of natural habitats, and restoration of degraded ecosystems, which contribute to carbon offsetting and reduction in the future.

Therefore, the Taiwanese government will impose a certain amount of tax on land value to prevent excessive expansion of urban land values, promote mixed-use development of assets, reduce the demand for long-distance commuting and related carbon emissions. However, implementing *Land value-added tax* in Taiwan will primarily affect the construction industry. *Land value-added tax* can indirectly impact environmental outcomes by altering land use patterns, promoting sustainable development, and incentivizing eco-friendly practices. *Land value-added tax* can encourage landowners to effectively activate land and deter real estate speculation.

6. Conclusions

Our research aims to highlight key changes that will inform future research orientations. Despite the changes in international trade over time, Taiwan has always maintained a strong trade relationship with EU countries. To address global climate change, the government should formulate climate change adaptation strategies, manage, and reduce greenhouse gas emissions, fulfill its responsibility in protecting the global environment, and implement intergenerational justice, environmental justice, and a just transition to ensure sustainable development of the country. Taiwan will adhere to relevant regulations such as the Climate Change Response Act and implement carbon pricing mechanisms to reduce the risks associated with the EU CBAM. Therefore, the most common barrier to achieving industry targets is financial obstacles, which are not necessarily related to the size of the companies but rather the risk aversion in implementation or long investment payback periods [39].

To accelerate compliance with international standards in an effective manner, the government needs to guide businesses towards sustainable and environmentally sound practices through policy. It is also crucial for businesses to proactively shoulder their social responsibility and further reduce carbon emissions. Therefore, the government should lead by example in legislating and regulating carbon reduction measures for domestic enterprises, providing the public with clear guidelines and regulations to follow.

This study explores the impact of CBAM on Taiwan's industrial development. First, referring to the export statistics from the Customs Administration, Ministry of Finance, from 2016 to 2021, the data for the five categories of products with the highest carbon leakage risk regulated by the EU, namely fertilizers, cement, steel, aluminum, and power equipment, indicate that Taiwan's exports of products targeted for CBAM regulation were mainly directed to regions outside of Europe, and the products exported to the EU were primarily "manufactured products" rather than the "raw materials" (cement, fertilizers, steel, iron, aluminum) subject to initial regulation. Therefore, the impact on Taiwanese companies is minimal.

The empirical results of this study confirm that Taiwan's industrial development during the sample period is conducive to promoting carbon reduction efforts and has played a role in increasing employment. In terms of environmental benefits and job creation, it has provided Taiwan's electronics industry with an advantage in international competition. Therefore, this paper not only demonstrates that the Taiwanese government has actively strengthened investment and operations in green energy through the establishment of green energy policies, particularly in the construction and steel industries, but also provides empirical evidence that Taiwan's electronics and power equipment industries, despite being energy-intensive, have been given attention and implemented measures to reduce energy consumption and emissions. During the sample period, besides improving energy efficiency and adopting cleaner production technologies, the Taiwanese government has set specific emission reduction targets for industries such as electronics and electrical equipment manufacturing and actively facilitated cooperation between businesses, government, and academic institutions to conduct comprehensive carbon footprint assessments to identify the main emission sources and guide policy formulation to improve areas of business operations.

Through technological innovation and the development of green and clean energy technologies, Taiwan aims to reduce carbon emissions. Given the international cooperation between governments and businesses to enhance carbon-related product regulations and standards and reduce tensions in international trade, it is essential to promote international convergence of emission standards through a universal carbon price [20]. Therefore, the Taiwanese government has completed legislation and established rigorous environmental regulatory systems to impose fines and tax adjustments on high-polluting companies, aiming to punish high-pollution and low-

efficiency practices and encourage the private sector to shift towards environmentally friendly and low-carbon industries.

Because accessing resources such as fossil fuels has been crucial in the past, but renewable energy technology and industrial development will be key in the future, renewable energy is altering the geopolitics of energy [40]. Countries that fail to achieve the 'Fit for 55' target may face significant consequences, such as economic penalties for non-compliance, which could be substantial [41]. Although the main human source of greenhouse-gas emissions is the combustion of fossil fuels for energy generation, non-energy emissions contribute more than a third of the total greenhouse-gas emissions worldwide. To keep global warming below 1.5 degrees Celsius, as recommended by the Intergovernmental Panel on Climate Change (IPCC), diets must change. However, future schemes should be modelled on a national level and be culturally acceptable [42].

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