Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2022/2023

The Impact of Carbon Border Adjustment Mechanism (CBAM) on China

By

Ge Gao

Acknowledgments

First and foremost, I would like to express my greatest gratitude to my supervisor, Dr. Michele Acciaro. The thesis topic is motivated by his excellent classes and valuable suggestions. He has provided helpful guidance about the thesis's writing and methodology and supported me promptly when I encountered data obstacles during my thesis writing. I always liked the fundamental ideas, insights, and helpful presentation skills in his vivid classes. And I respect his professionalism and golden attitude from my heart.

Besides, the MEL program allows me to expand my career horizons, obtain a wealth of new knowledge from many outstanding professors and lecturers, and meet an array of exceptional colleagues. I appreciate discussing ideas and collaborating with them. It's been a memorable adventure, and I'm grateful for that.

Furthermore, I'd also like to thank Renee, Matha, and Felicia from the MEL office. They demonstrate professionalism and support MEL students in various ways, convoy the MEL trip with safety and joy.

Last, I want to thank my family for continually trusting in me, respecting my decisions, and standing by me wherever they are.

Abstract

Given the context of elevated inflation and an urgent need for economic restoration following the COVID-19 crisis, policymakers, economists, scientists, and researchers across various nations continue to face significant challenges in addressing climate change. Their endeavors involve substantial efforts to unravel the complex interplay between political economy, sustainable goals, and green levels in different countries.

Being at the forefront of environmental legislation, Europe has implemented the Carbon Border Adjustment Mechanism (CBAM) to reconcile trade and climate considerations, building upon its extensive carbon emissions trading system. [1] The previous scholarly study has extensively investigated the effects of the CBAM policy on various countries and specific sectors, analyzing its implications through legal, economic, and environmental lenses. However, research is still being conducted regarding potential strategies for dealing with the policy and its specific impacts on different industries concerning the CBAM.

Under such background, it is meaningful to investigate the impacts on China as one of the EU (European Union)'s biggest trade partners and its possible strategies. This study undertakes a comprehensive analysis of policies about environmental protection. It calculates carbon tariffs as analogous to conventional taxes by the MRIO model and integrates them into GTAP models to analyze their potential theoretical economic impacts. This research also examines the effects of carbon tariffs imposed by the EU on China's export industries, employing comparative analyses with selected countries to gain further insights.

The study derived from the simulation analysis suggests that adopting the European Union's taxation policy targeting high-carbon goods under CBAM negatively affected several dimensions of China and some developing countries' economies. Specifically, for China, implementing this policy led to a reduction of 7.1% in GDP, a decrease of 0.3% in export trade, and a decline of $1528.04 million in social welfare. The adverse effects were identified when bilateral taxation was implemented between the EU and China, and there are even more negative impacts on social welfare and exports when compared to doing nothing. In addition, there are small positive effects on China's and some developing countries' carbon emissions. Still, to some developed countries like the EU, the US, and more, CBAM will lead to more carbon emissions. Furthermore, the study suggests that it becomes imperative for China to foster the growth of its domestic carbon market and advance its green technology. Additionally, China must enhance contact with the European Union and the rest of the world to become a green community and actively seek more effective solutions.

Table of Contents

Acknowledgments I
Abstract III
Table of Contents IV
List of Tables VI
List of Figures VIII
List of Abbreviations IX
1. Introduction 1
1.1 Problem Identification 4
1.1.1 Carbon Emission 4
1.1.2 Fairness Concerns 6
1.2 Research Question 7
1.3 Structure of the Thesis 9
2. Literature Review: 11
2.1 Global Climate Change 13
2.1.1 Climate Change Status Quo 13
2.1.2 Climate Target 14
2.2 CBAM 15
2.2.1 CBAM Introduction 15
2.2.2 Problems and Obstacles 18
2.3 Trade 19
2.3.1 Trade between China and the EU 19
2.3.2 Trade in Relevant Sectors 20
3. Carbon Policies and Status 22
3.1 EU Policies 24
3.2 China Policies 25
3.3 Gaps and Obstacles 32
4. Methodology 34
4.1 Theoretical Foundation 34
4.1.1 MRIO Model 34

4.1.2 Global Trade Analysis Project model (GTAP) 34
4.2 Modelling Introduction 35
4.2.1 Data Aggregation 35
4.2.2 Scenarios Setting 38
4.2.3 Measure Embedded Carbon Emissions 39
5. Results and Data Analysis 42
5.1 Changes in the Output of the Different Sectors (China only) 42
5.2 Change in the Export of the Different Sectors (China only) 43
5.3 Export 44
5.4 GDP 45
5.5 Social Welfare 46
5.6 Carbon Emissions 47
5.7 Scenarios Discussion 48
5.8 Limitation of the model 49
6. Results and Recommendations 51
6.1 Results 51
6.2 Recommendations 51
7. Conclusions 54
Bibliography 56
Appendices 61

List of Tables

Table 1	Top 10 Countries Exporting Major Carbon-intensive Products into the EU (Billion in USD)	20
Table 2	Carbon Cost of Global Emissions Trading Systems (2021-2022)	23
Table 3	The EU “Fit for 55” Policies	24
Table 4	The Policies in China regarding Carbon Emissions	26
Table 5	Countries Setting	35
Table 6	Factors Change in % During 2014-2020	36
Table 7	Factors Change in % During 2020-2025	36
Table 8	Sectors Setting	38
Table 9	Scenarios Setting	39
Table 10	Input-Output Table of Selected Countries	39
Table 11	Changes in the Output of Different Sectors (China only)	42
Table 12	Changes in the Export of Different Sectors (China only)	43
Table 13	Changes in the Export by Countries	44
Table 14	Changes in the GDP	46
Table 15	Changes in the Social Welfare	47
Table 16	Changes in the Carbon Emissions	48
Table 17	Embedded Carbon Emissions for each Sector and Country	61
Table 18	Carbon Tariffs for each Sector and Country (EU import / Carbon- Intensive industries only)	64
Table 19	Total Output of Final Goods	65
Table 20	Carbon Emission intensity C_i for each Sector and Country	69

List of Figures

Figure 1	Yearly Emission in Million Mt CO_2, 1960-2021, Top 10 Global Emitters	5
Figure 2	Total Goods: EU Top Import Partners 2022	19
Figure 3	World Major Carbon Tools Distribution [17]	22
Figure 4	Worldwide Major ETS Allowance Price [42]	23
Figure 5	China ETS Allowance Price in Regions [42]	30
Figure 6	Exporters (Share of the EU's Importers of CBAM-coved Products) [57]	72
Figure 7	China's Foreign Trade Dependency = Total Merchandise Import and Export	73
Figure 8	Changes in the Output of Different Sectors (China only)	74
Figure 9	Changes in the Export of Different Sectors (China only)	74
Figure 10	Changes in the GDP	75
Figure 11	Changes in the Social Welfare	75
Figure 12	Changes in the Export	76
Figure 13	Changes in the Carbon Emission	76
Figure 14	Price and Coverage across ETSs and Carbon Taxes [17]	77

List of Abbreviations

CBAM	Carbon border adjustment mechanism
CBDR	Principle of common but differentiated responsibilities
SDT	Special and Differential Treatment
CCUS	Carbon capture, utilization, and storage
EITE	Energy-intensive, trade-exposed
ETS	Emissions trading system
FYP	Five-Year Plan
GATT	General Agreement on Tariffs and Trade
GHG	Greenhouse gas
MEPS	Minimum energy performance standards
SCM	Agreement on Subsidies and Countervailing Measures
WTO	World Trade Organization
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
ECIU	Energy and Climate Intelligence Unit
EU	European Union
GDP	Gross domestic product
ETS	Emissions trading system
CO_2	Carbon dioxide
COP	Conference of the Parties
CEA	Chinese Emission Allowance
CCER	Chinese Certificate Emission Reduction
LDCs	Least Developed Countries
VER	Voluntary Emission Reduction
ESG	Environmental, Social, and Governance
CSG	Carbon, Social, and Governance
TCC	Transparency, Consistency, and Comparability Framework
SMEs	small and medium-sized Enterprises
RGGI	Regional Greenhouse Gas Initiative
EGD	European Green Deal
ECFGA	Deep and Comprehensive Free Trade Area
BTAs	Border Tax Adjustments
MRV	Monitoring, Reporting, and Verifying
OECD	Organization for Economic Co-operation and Development Nations
EEA	European Economic Area
CEPII	French Institute for International Economics

1. Introduction

Climate change is a global problem that has already raised many countries' attention. Global warming may lead to many natural disasters, such as ocean acidification, intense heat waves, rising sea levels, and weighty rainfall, threatening lives and global economic development. Carbon dioxide emission, the primary source of greenhouse gases, is the key index to evaluate climate change. In the year 2021, the world total generated 37,124 $MtCO_2$; top-ranked are China (11,472), the US (5,007), India (2,709), the Russian Federation (1,755), and Japan (1,067). [2]

To decrease carbon emissions and achieve sustainable goals, many countries established policies according to the Paris Agreement, set their carbon emission goals, and built carbon markets. Taking the lead in addressing the climate-changing issue, the EU started the EU Emission Trading System (ETS) as a critical tool, the world's first primary carbon market, and remains the biggest. The carbon emission allowance can be traded in the market [3]. However, with the different phases and carbon prices in various markets, the market raises a risk – "carbon leakage." [1] This phenomenon occurs when industries move their polluting manufacturing to countries with less strict climate standards or when products from the EU are substituted with imports with higher carbon emissions. Thus, the EU wants to keep the industry and trade partners outside Europe on the same page in the same direction and proposed a tool- Carbon border Tax Adjustment (BTA) to decrease carbon leakage. In July 2021, the European Commission union presented the new renewable energy policy system CBAM - Carbon Border Adjustment Mechanism. [4] The plan was launched and activated in 2023 Jul, initially focusing on six vital carbon-intensive sectors. However, this policy still faces many challenges from other countries. Some people doubt it is a kind of bilateral protectionism and may not spur the EU's green ambitions.

It is essential to understand the impact of CBAM on each country. As a robust economic system, Europe has emerged as a leader in shaping global institutional norms and is instrumental in formulating many frameworks. However, avoiding the Brussels effect and establishing scientifically grounded implementation methods constitutes a pivotal concern. The EU must ensure a seamless transition while averting socio-economic upheaval, safeguard employment security, preserve undisturbed supply chains, foster enterprise growth, and ensure equitable distribution, which are paramount considerations. It is vital to protect the interests of vulnerable groups; government support, energy bill rebates through efficiency enhancements, and ongoing policy optimization are all matters necessitating contemplation. Throughout implementation, policymakers must consider the risks of morphing into a form of veiled trade protectionism or engendering localized heat island effects that impact the overarching trade and economic milieu must be mitigated.

In addition, China's EITE industry's carbon intensity is significantly higher than the same industry in developed countries. Researching the impact of CBAM on EITE and countermeasures will help balance emission reduction goals and protect industrial competitiveness while reducing the effects of output fluctuations on the EITE industry and reducing the harm caused by possible trade protectionism. Boasting a substantial industrial production capacity, China must attend to the repercussions of policy influences and redouble efforts in energy conservation and emission reduction during its energy transition while remaining attuned to the trade implications stemming from CBAM and taking sustainability leadership in developing countries.

Recent studies conducted on the CBAM have shown significant findings. CBAM can significantly influence international trade, potentially leading to reconfiguring trade patterns and supply networks. The primary objective of lowering carbon emissions exhibits potential. However, it requires diligent oversight to mitigate the risk of carbon leakage, resulting in firms relocating to nations without similar policies, negating the intended reductions in emissions. Furthermore, the effects of the CBAM differ across various businesses, presenting more significant difficulties for sectors with higher carbon emissions. The importance of efficient coordination of foreign policies cannot be overstated to prevent trade conflicts and maintain stability in the market. The results mentioned above highlight the complexities in formulating policies related to CBAM, considering factors such as trade, environmental considerations, and industrial dynamics. Furthermore, these findings provide opportunities for further investigation into the impacts and efficacy of CBAM. The potential threats can be mitigated by adopting a proactive climate policy and transitioning towards an economic structure more aligned with climate-friendly practices. [5] What’s more, to evaluate if it has become an inevitable trend to impose a carbon tariff and pay extra costs for excessive carbon emissions, a study finds that in reaction to the energy crisis, governments had limited opportunities to reduce greenhouse gas emissions by turning back emissions trading schemes (ETSs) or carbon taxes policies. Even suggested that an incentive system, rather than BTAs, would be more successful in promoting the broader adoption of eco-friendly fuels and technology.[6]

Moreover, some theoretical research and analyses support CBAM's effectiveness in fair competition, carbon leakage prevention, and reducing global welfare costs, contingent on policy design and the implementing economy. Carbon leakage prevention relies on policy stringency. While more coverage, broader products, and higher CBAM prices help, correlations vary for competitiveness and welfare. Tailored policies are vital, considering local economic traits. The EU's CBAM raises fairness concerns and compatibility with the global climate policy architecture. Addressing these challenges remains crucial for CBAM's successful implementation.[7]
Some research studies highlight the importance of customizing policy approaches that consider economic and geopolitical circumstances to optimize the effectiveness of the CBAM.[8]

However, scholarly investigations are scarce concerning viable tariff approaches and addressing the policy impact. Considering the trade, geopolitical, and sustainability policies aspects, this study investigates the current carbon policy status to measure the gap. By using the GTAP model, analysis of the impact of CBAM on the major global trading countries with the EU, production, trade, economy factors, and the possible impact industries, such as Energy-Intensive and Trade-Exposed industries (EITE), substitutes to those industries, downstream industries and trade and logistics industries, and others. In addition, this research proposed possible suggestions to minimize the negative impact on China's economy.

There are three primary research objectives for this thesis. First, this study aims to gain insight into the potential challenges of implementing the CBAM policy using qualitative research methods. Second, this study aims to conduct a policy analysis to examine the existing environmental protection policies in China and Europe. It will explore the potential direction and propose a more proactive climate policy in China, explicitly focusing on energy-saving and emission-reduction efforts. Drawing upon the preceding discourse, this analysis suggests possible tax frameworks for three scenarios of the CBAM policies. It aims to examine the repercussions and obstacles associated with diverse tax policies, as well as China's resistance to implementing a carbon tax, about its industrial sector, macroeconomic conditions, and carbon emissions. Simultaneously, other reference countries will be incorporated to facilitate a comparison analysis to evaluate the fairness and equity of the CBAM policy.

According to the analysis of different carbon tariff distribution methods based on the inevitable implementation of CBAM, in three scenarios, a. the EU takes half of the import carbon tariff on carbon-intensive products, b. the EU charges all of the import carbon tariff and no tariff waiver to be allowed, and c. China will take half of the carbon tariff based on one hypothesis that posits that importers and exporters must adopt a responsive approach towards climate change obligations influenced by considerations of trade equality. According to the simulation results, the planned adoption of CBAM is expected to mitigate China's production levels within specific sectors, especially for those carbon-intensive industries, thus exerting an overall influence on its export activities and the overall GDP. The implementation of more stringent carbon levies would result in more substantial reductions. However, the impact will be mitigated if China convinces the EU to pay a portion of the carbon tax. However, at the same time, it does not help on the social welfare and the overall export. In addition, CBAM does little help with global carbon emissions, as some countries increase carbon emissions while others will increase the carbon emission rate. Furthermore, considering the overall economy in selected countries, CBAM will benefit some developed nations, such as the US and the EU, but not some developing countries like China, India, Russia, and so forth.

With the following suggestions, the study advises that China needs to investigate if CBAM, during the transition, can ensure there will be no upheaval in the economic landscape and then become a tool of protectionism; ensure employment security and a pro-trade environment; ensure supply chains remain undisturbed, and upheld the equitable distribution. The principle of making the biggest polluters bear the highest costs will be sustained and improve the local carbon market China ETS and Chinese Certificate Emission Reduction (CCER) market. Chinese government support will be extended, and energy funding and discounts will incentivize efficiency improvements to optimize policies continuously. Though CBAM places cost pressures on businesses with significant carbon emissions, China can also use CBAM to boost the competitive advantage of low-carbon companies and encourage the development of green technologies. Effective macroeconomic regulation and policy necessitate close communication and cooperation between nations to investigate more scientifically based carbon reduction methods. A failure to do so will increase the burden on businesses and the economic pressure on consumers, exacerbate unilateralism and protectionism, resulting in the Brussels effect. The author believes that while Europe demonstrates its resolve and leadership in energy efficiency and emission reduction under the "Fit for 55" framework, [9] it should also take into account the different development needs and industrial structures of developing countries and assume greater responsibilities by implementing legislation and policies in a more scientifically rational manner. Carbon leakage concerns the domestic economy and is crucial to achieving carbon emission goals. Only when all countries and trade attendees devote themselves to strengthening the scientific carbon emission systems, and technologies can lead to a win-win result rather than seek ways to benefit or escape from the policy loopholes.

1.1 Problem Identification

1.1.1 Carbon Emission

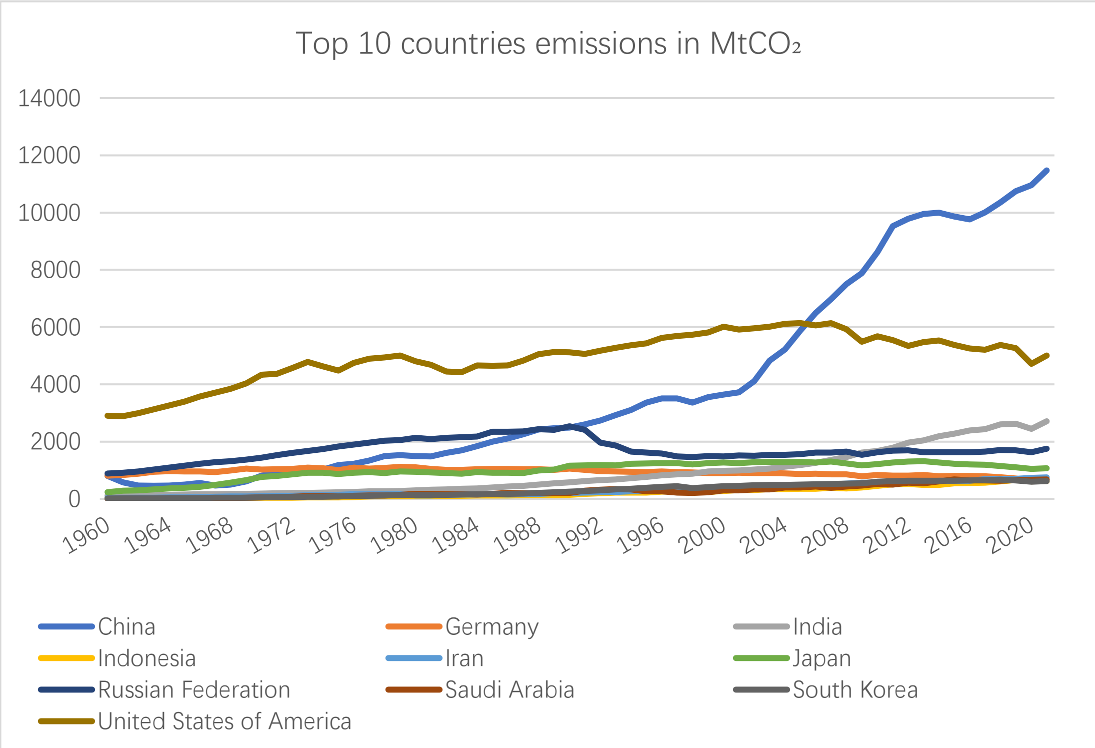
According to the Climate Change 2023 Synthesis report, the global surface temperature has risen by 1.1 degrees Celsius between 2011 and 2020, primarily due to carbon dioxide and methane emissions of greenhouse gases. The significant influence of human civilization's rapid advancement in the past century on climate change surpasses the impact of natural variations observed throughout the preceding several hundred thousand years. [10]

Increased extreme temperatures due to global warming and ecosystem destruction have harmed human health and urban infrastructure and wreaked devastation on ecosystems. It has a wide-ranging and permanent effect. It is undeniable that humans must take action to prevent the climate from deteriorating, as this has implications for human health, urban safety, the harmonious development of ecosystems, and the future of economic activities and biology. The impact and significance of surviving are profound.

The CO_2 emission sector is the area of focus. Figure 1 presents the top ten nations in terms of CO_2 emissions. Global emissions were dominated by the United States and Europe long into the 20th century. By the year 1900, emissions originating from these two regions were over 90% of the total emissions. This dominance continued into

1950, with these regions collectively contributing to more than 85% of annual emissions.[11] The data indicates that carbon emissions in most countries exhibit a relatively consistent trend from 1961 to 2021. However, after 1992, it is noteworthy that China demonstrated a significant increase in carbon emissions. Several factors may contribute to industrialization and economic growth, such as population expansion, extensive infrastructure development, and diversification of energy sources. According to the analysis, the combined emissions of the United States and Europe constitute slightly under 1/3 of the total global emissions. [11]

Figure 1: Yearly Emission in Million Mt CO_2, 1960-2021, Top 10 Global Emitters



Resource: Author collected from *https://globalcarbonatlas.org/emissions/carbon-emissions/*

To address the global warming problem, in pursuit of the overarching goal to stabilize atmospheric greenhouse gas concentrations, the Conference of the Parties 15 (COP15) agreement acknowledged the scientific consensus advocating the limitation of global temperature rise to below 1.5 or 2 degrees, guided by principles of fairness and within the framework of sustainable development.[12]

To strengthen the global response to the threat of climate change, in the context of sustainable development, the Paris Agreement raised to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change. [13] To address the global warming problem, in pursuit of the overarching goal to stabilize atmospheric greenhouse gas concentrations, in Article 4.1, parties Acknowledging the extended time required for developing country Parties to reach their peak emissions, it is essential to implement swift reductions by the most up-to-date scientific knowledge subsequently. This approach aims to attain a state of equilibrium between human-induced greenhouse gas emissions from sources and their removal through sinks during the latter half of this century. Such efforts are to be undertaken with fairness in mind within the framework of sustainable development. [13]

Under the efforts in different regions towards sustainable goals, as per the World Bank report "State and Trends of Carbon Pricing 2022" findings, 71 nations and areas have adopted carbon pricing schemes. Moreover, there were notable positive developments in 2021, wherein the utilization of global carbon pricing mechanisms and the corresponding carbon prices witnessed a surge of 60% compared to the figures recorded in 2020. This surge resulted in a cumulative value of $84 billion. As of July 2022, collecting 68 carbon sensors constituted an estimated 23% of global greenhouse gas emissions. [14] As the world's leading emitter of CO_2 and the largest developing nation, China should take responsibility for carbon emissions. Thus, investigating China's carbon progress and possible ways to tackle global regulations is essential.

1.1.2 Fairness Concerns

With the global warming problem becoming severe, CBAM's introduction by the EU raises fairness concerns, reflecting an international dispute over mitigation responsibility distribution. The use of carbon tariffs has been taken into the public spotlight as a pivotal role in preserving justice and a catalyst to boost the green revolution.

The main centrepieces of global trade are North America, Europe, and Asia. The CBAM has raised concerns among the EU's trade partners. And more and more problems can be found over time in various aspects:

1. The different carbon emission levels due to development requirement

A previous study found that fossil fuel-derived carbon emissions serve as a direct indicator of socioeconomic progress. The use of fossil fuels, which generate many carbon emissions, has a strong positive correlation with employment rates, industrialization, urbanization, and per capita GDP. [15] Reducing carbon emissions will, therefore, impact developing nations' socioeconomic progress. The economy's growth and poverty reduction are the top priorities of the least developed countries (LDCs), which may call for more use of fossil fuels than the developed countries and result in a relatively high level of carbon emission. If in line with the same standards of emission of EU, it means to quench the development for the LDCs.

2. Various industrial structures

The destruction of the environment is a consequence of industrial revolution-induced modernization. Among the industries, the secondary sector has a more significant detrimental influence on the environment than the primary and tertiary industries, so the CBAM-covered products almost belong to these industries. One of China's plans- the "Belt and Road Initiative," aimed to accelerate industrialization in developing nations along the Belt and Road. Many developing countries still need to improve infrastructure and manufacturing to improve their economy. Moreover, many developing nations rely on exporting those products, which may cause more CO_2 emissions. The interaction between secondary industry and economic growth increases environmental efficacy in developed countries while decreasing it in developing countries.[16] Besides, China and India still predominantly depend on conventional thermal power sources as production resources. In contrast, other European countries, such as Germany, the Netherlands, France, Denmark, Switzerland, and Sweden, have primarily relied on renewable energy sources. The different industry structures may result in an unfair carbon emission environment.

3. The carbon cost and the capability to bear the carbon reduction cost

According to a report by the World Bank, carbon pricing exhibits variations across different nations in Figure 2[17], making it challenging to implement a uniform carbon import tax based on a single standard. In numerous developing countries, the combination of inexpensive labour and abundant material resources has significantly diminished the profitability of products. For businesses with minimal profits, adding carbon tariff costs that do not align with their operations will undoubtedly impose significant cost pressures, which is also unfair. This predicament is also particularly concerning since certain countries continue to grapple with food scarcity, exacerbating the problem further. The perceived inequity is also evident in green technologies and innovation capabilities.

4. The proper and mature carbon policies and regulations (will discuss this in the chapter in session 3.4.)

Thus, different development process requires different standards and policies. The LDCs need more Carbon Emission Levels to support to develop green technologies and adjust to the other standard carbon rules- EU's CBAM; otherwise, it will cause a Mattew effect. Due to the cumulative advantage, the developed countries will be more likely to attain tremendous success. Furthermore, this contributes to the wealth disparity between the developed and undeveloped.

1.2 Research Question

This study delves into the complex landscape of the CBAM, a European Union (EU) policy initiative designed to prevent carbon leakage and encourage environmental responsibility to solve related concerns. CBAM is a pivotal measure intended to level the playing field regarding global carbon emissions. Yet, it may raise significant problems and complex challenges for the EU and its trade partners. This thesis will dive from two perspectives: the questions raised from CBAM per se and the economy-related impacts.

Sub-Questions:

CBAM policy: understanding CBAM, such as what is CBAM at its essence, and what prompted the European Union to develop this innovative policy? Fundamentally, it is essential to comprehend the fundamental concepts, policy particulars, and distinctive characteristics that define CBAM. Furthermore, part 3 of the thesis will answer the following questions about CBAM that have been presented:

1. Why is it necessary, and to whom is it essential to investigate the topic?

2. Possible outcomes: With CBAM taking the spotlight, what are different countries' attitudes towards it, and what measures can be taken under such strict rules?

3. What are China's ecological policies, and where are they in terms of development?

4. What is the trade situation between China and Europe regarding carbon-intensive products subject to the CBAM?

5. Equity in Carbon Tariffs: Should the burden of enforcing carbon tariffs be distributed according to consumption patterns, or should it rest entirely on the place of export goods' manufacture? How closely does CBAM adhere to WTO (World Trade Organization) principles?

6. Global Carbon Pricing: Is it reasonable to benchmark carbon tariffs for developing nations against carbon prices established by developed countries such as the EU? Who has the authority to establish carbon pricing, and who will ultimately endure the financial burden of CBAM's implementation?

7. Would CBAM unambiguously fulfill its primary purpose of preventing carbon leakage and protecting domestic competitiveness?

Economy impact-related questions will be answered in chapters 4 and 5 of the thesis:

1. Economic influences: This is the particularly intriguing part. It included but was not limited to what changes in the EU and China's economies would the CBAM bring about once it goes into effect? How will it reorganize complex value chains, affecting EITE sectors? The possible impact on trade is China's trade surplus and the EU's trade deficit.

2. Analytical Modeling: What modeling approaches adequately represent CBAM's multidimensional effects to reveal their nuances? How to ensure the data accuracy, and how to choose the variables.

3. Innovative Substitution: Implementing CBAM may promote product substitution in carbon-intensive industries such as iron and steel, aluminum, cement, electricity, and fertilizers, adding complexity to the market. How will this impact downstream sectors and reverberate across the supply chain?

4. Mitigation Strategies: In an era of global cooperation and heightened environmental awareness, what strategies can be developed to ensure equitable distribution of CBAM's burden, with a particular emphasis on developing nations? How can the revenue generated by carbon tariffs be distributed fairly?

5. Impact on China's Economy: In a shifting global economic landscape, could CBAM inadvertently exacerbate economic challenges in the EU's major trading countries?

This study sets out to analyze the complexities of CBAM and provides a thorough understanding of its multifaceted effects on economics. In keeping with the framework of CBAM, it aims to piece together possible solutions for peaceful coexistence while considering the various effects on both EU and non-EU countries. It also looks at the broader effects of CBAM on international collaboration, sustainable development, and trade.

1.3 Structure of the Thesis

Chapter 1 includes an introduction, problem identification, the research questions, and the structure of the thesis sessions for the thesis. This sector aims to provide a concise overview of the primary research objective of CBAM and the underlying motivation for the significance of researching the impacts of CBAM on China.

Chapter 2 is the part of the background introduction. This sector establishes the basic knowledge of the thesis. It introduces the concepts and variables under climate change, CBAM, and trade factors about the existing knowledge. It presents the theoretical perspectives to formulate further methodology hypotheses in different scenarios. In addition, it explores the prevailing trade conditions and pertinent trade facts within the purview of the CBAM. Furthermore, it also discusses the obstacles and arguments surrounding CBAM and concludes with an evaluation of the effectiveness of the CBAM.

Chapter 3 includes an in-depth examination of the policy analysis of the subject matter. It provides the most updated policy news and evaluates the carbon market differences between the EU and China. Furthermore, it delivers suggestions regarding the differences and the green path status.

Chapter 4 contains methodology approach. This sector introduced what modeling approaches can adequately represent CBAM's multidimensional effects, how to define the data strategy, and provide the calculation methods for the measurement of embedded carbon emissions.

Chapter 5 provides the model outputs results from Chapter 4 and analysis to answer the sub questions about the economic effects. Meanwhile, this chapter states the limitations of the model.

Chapter 6 summarizes the main results and provides the policy recommendations to answering the main questions.

Chapter 7 is the conclusion of the entire study. It summarizes the major findings and the results and give the answers for sub-research questions.

2. Literature Review:

With the closing carbon neutral goals, all trade parties are becoming more aggressive to expedite their carbon emission process. By the conclusion of State and Trends of Carbon Pricing 2022 [14], 89 nations had adopted net-zero commitments, with 13 countries accounting for almost 86% of world emissions. These commitments entail setting goals for the dates achieving net-zero emissions from 2035 to 2060.[18][19] However, the situation could be more positive. The recent emissions gap report by the United Nations Environment Programme emphasizes that achieving the collective objective of restricting global temperature rise to 1.5°C will be unattainable without an urgent and extensive global economy restructuring.[20] Under such a background, human beings will pay for the carbon price sooner or later to make the world better, cleaner, and more sustainable, from regions to countries to firms and individuals. Meanwhile, developing countries need economic and future development, so there is a trade-off between current and forward consumption. As one of the major developing countries, China needs to focus on the CBAM policies.

Much existing literatures have raised the impacts of the CBAM on trade, economics, carbon emission efficiency, and legal problems. A study based on the GTAP model shows that deploying the CBAM throughout the EU may provide diverse outcomes across different member states. The probable consequences of this scenario may result in adverse effects on the welfare of the United States while yielding beneficial outcomes for China, Russia, the European Union, and other nations. The implementation of CBAM has the potential to decrease carbon emissions inside China, Russia, and the United States while simultaneously leading to a rise in emissions within the European Union and other nations.[21] However, another study in 2021 found that the global distribution of impacts caused by BTA is unequal.[22] Moreover, it has been proved by lots of studies that CBAM will face many obstacles and put some developing countries at a disadvantage. The potential to restrict market entry conditions for developing nations and incentivize environmentally sustainable practices may challenge developmental considerations. [35]

From an economic standpoint, experts are skeptical about the CBAM's efficacy in mitigating carbon leakage. Previous studies have demonstrated that a more considerable carbon content coverage, a more comprehensive product range, and higher prices for the CBAM contribute to more effective prevention of carbon leakage. The correlation, however, is not always reliable when preserving domestic competitiveness or cutting back on the expense of global welfare. CBAM on exports, as opposed to full CBAM or CBAM on imports alone, may better maintain local competitiveness. [23] Besides, the imposition of emission coverage for carbon tariffs is determined following the regulations set forth by the World Trade Organization (WTO) due to the limitations on implementing carbon pricing adjustments on imported goods originating from industries not subject to the domestic carbon tax.[24]

Owing to the diversity of the multilateral trading system, trade discrimination may occur and result in a trade war. Furthermore, future redistribution issues may be triggered by CBAM, as the introduction of carbon tariffs will increase European fiscal revenue while the costs will be borne predominantly by consumers as policy implementation advances and free carbon allowances decrease.

From the perspective of evaluating the efficiency of carbon leakage and the environmental protection measures, the capacity of CBAM to effectively mitigate carbon leakage is constrained, resulting in an inequitable impact on nations. Implementing CBAM, in the presence of varying carbon pricing and policy designs, can potentially mitigate carbon leakage by 9-25%. Furthermore, the overall decrease in global emissions resulting from CBAM is estimated to be in the field of 10-36Mt, which accounts for a mere 0.03-0.12% of global emissions.[25]

Additionally, from the perspective of an academic investigating the geographical distribution of carbon emissions from 1122 multinational corporations, there needs to be more empirical data supporting the notion that implementing ETS results in carbon leakage by international firms. Implementing the ETS reduces greenhouse gas emissions by multinational corporations operating within the EU and extends its impact to multinational corporations outside the EU.[26] Furthermore, from a study evaluating GTAP for the countries, there are minor impacts of the CBAM on emission reductions outside the EU.[27]

From a legal perspective, climate change is a global issue that requires all stakeholders' collective efforts to adhere to global trade regulations. There are three primary frameworks of corporations that critics may utilize to support the argument for the CBAM policy. These frameworks include the 1997 Kyoto Protocol, the 2016 Paris Agreement, and the GATT/WTO rules, namely the principles of "Most-Favored-Nation Treatment," "National Treatment," and "Non-Discrimination Principle." [13][28][29]

- The Paris Agreement has advised all participating nations to produce, share, and uphold successive nationally decided contributions defining their expected outcomes because the carbon peaking will take longer for less wealthy countries. Governments are expected to execute internal emission reduction measures to meet the targets outlined in these contributions. After that, they are expected to implement rapid reductions by the best available research. (Article 4 II)[13]
- According to the Kyoto Protocol, advanced nations are more responsible for reducing carbon emissions than less developed nations. It usually entails enacting stricter environmental protection rules and regulations inside their boundaries, focusing primarily on sectors with significant carbon emissions. As a result, businesses from wealthy countries frequently relocate their high-carbon production facilities to developing nations with laxer restrictions due to considerations of production ease.[28]
- By Article 1 of the General Agreement on Tariffs and Trade (GATT), also referred to as the principle of most-favored-nation treatment, any benefits, favors, or

exemptions granted to the importation of products from one member country must be equally and unconditionally provided to identical commodities imported from all other member countries.[29] Giving CBAM an exception within the World Trade Organization (WTO) framework may deliver practical challenges to maintaining the "common but differentiated responsibilities" CBDR principle between developed and developing states. It might increase the probability of developed countries implementing carbon emission fees as barriers against developing nations.

Based on these rules, a study found that while CBAM aims to facilitate the development of green manufacturing capabilities, it has the potential to integrate the principles of Common but Differentiated Responsibilities (CBDR) and Special and Differential Treatment (SDT) to ensure equity. Nevertheless, it is essential to acknowledge the potential for CBAM to encounter criticism like that directed towards the 'Trade and Development' Chapter of the General Agreement on Tariffs and Trade (GATT), which implies the possibility of unequal treatment despite nominal equality.[30]

However, although much research raises the problems, few studies observe the nations' responses to the bilateral carbon tariff regulation. With the implementation of CBAM, questions have been raised concerning the possible ways for importers to put export carbon tariffs, as the establishment of a bilateral carbon tariff has the potential to enhance the global cost-effectiveness of climate policy and promote the equitable distribution of the burden of international climate protection efforts.[31] Besides, another study also found that countries heavily relied on exporting energy items may find it more beneficial to implement retaliatory tariffs instead of accepting the European Union's unilateral levies.[32]

Based on the mentioned issues that may be faced in the previous studies, this thesis focuses on exploring the obstacles that CBAM may face and the possible impacts on China by different measurements of the carbon tariff charge of CBAM. The possible contribution to this thesis is 1. To analyse China's most updated policies during the transition period to tackle Climate change issues. 2. To explore the impacts of BTAs on different sectors in China. 3. To provide a comparative analysis of CBAM may change the economic factors in major discussed countries or regions. 4. To evaluate the possible way that China responds to the BTAs to the bilateral carbon tariff regulation.

2.1 Global Climate Change

2.1.1 Climate Change Status Quo

Despite the denial by some people, it is evident that climate change is indeed occurring. The Synthesis Report, published by the Intergovernmental Panel on Climate

Change (IPCC) in March 2023, unequivocally affirmed that anthropogenic activities are the predominant driver of climate change. [61]

Based on NASA global climate change data, till 2022, the CO2 increased by 420 parts per million; the Global temperature has increased 1.1 centigrade since preindustrial; the Methane increase 1923.6 parts per billion; Arctic Sea ice minimum extent decrease 12.6% OER DECADE SINCE 1979; Ice sheets decrease 424 billion metric tons per year; sea level increase 4 inches since January 1993; Ocean warming increase 345 zettajoules since 1955.[65]

The escalating global changes pose a growing challenge in adjusting to climate change, particularly for economically disadvantaged nations. Meanwhile, numerous species and ecosystems have reached or surpassed their thresholds of adaptability. [62] It has an impact on human health simultaneously. Outdoor air pollution is responsible for causing the deaths of around 8.7 million individuals annually, while approximately 3.8 million individuals die annually due to interior (home) air pollution.[63]

In 2020, natural gas, oil, and coal combustion accounted for 22%, 32%, and 44% of worldwide carbon emissions, respectively. China and the United States jointly accounted for 45% of global fuel combustion emissions, with the European Union, India, the Russian Federation, and Japan following suit. [64] With these changes, governments, scientists, environmental organizations, and policymakers are all trying to figure out ways to solve the problems.

2.1.2 Climate Target

During the 2015 Paris Climate Conference, a consensus was reached among 196 contracting parties, establishing the Paris Agreement. The primary objective of this agreement was to facilitate the coordination and implementation of measures to address global climate change beyond the year 2020.[33] The primary aims of the deal were to establish a framework for constraining the rise in global temperatures to a maximum of 2 degrees Celsius, with an additional aspiration to maintain it below 1.5 degrees Celsius.[13] Achieving carbon neutrality by the mid-21st century is imperative to effectively mitigate global warming and adhere to the recommended threshold of 1.5 degrees Celsius, as proposed by the Intergovernmental Panel for Climate Change (IPCC).

The Climate Neutral Now Initiative is among a range of initiatives introduced by the United Nations Framework Convention on Climate Change (UNFCCC) governing body to enhance climate action by involving non-party stakeholders, including sub-national governments, enterprises, organizations, and individuals.[12] The achievement of global carbon neutrality, wherein the balance between carbon emissions and their absorption or offset is maintained, is a crucial objective highlighted in the report of the IPCC. To effectively mitigate the worst impacts of climate change and adhere to the target of restricting global warming to below 2 degrees Celsius, this state of carbon neutrality must be attained by around 2070. To limit global warming to 1.5 degrees Celsius, it is imperative to achieve carbon neutrality by approximately 2050.[34]

According to data provided by the Energy & Climate Intelligence Unit (ECIU) in September 2023, a total of 42 countries, such as Germany, Italy, the United States, and New Zealand, have implemented legislative measures to attain their objectives of achieving net-zero emissions and carbon neutrality. What's more, a total of 51 nations, namely China, India, Singapore, and Brazil, have been classified in the status of "In policy document"; The "Declaration / Pledge " phase currently encompasses a total of eight countries, which include South Africa and Estonia and so forth; moreover, a total of 59 countries, such as Mexico and Indonesia, are currently in the status of "Proposed / In discussion."[59] An increasing number of countries are incorporating the concept of "carbon neutrality" into their national goals, which involves setting specific timelines for reaching carbon neutrality and implementing a range of legislative measures and action plans to enhance energy efficiency and reduce emissions. The measures include but are not limited to: The Mexican ETS is scheduled to commence its operational phase in the year 2023; The Australian parliament has enacted legislation to incorporate crediting into its pre-existing safeguard system on July 1, 2023, to transition into a rate-based ETS; New Zealand has announced its intention to implement a pricing mechanism for agricultural carbon emissions starting in 2025; The EU has reached a consensus to construct a distinct ETS by the year 2027. This new system would encompass emissions from buildings and road transport, as well as small energy and industry installations that are currently not covered by the existing EU ETS; The EU intends to enhance its current ETS by including maritime transportation starting in 2024; and the implementation of the CBAM and so forth.[17]

2.2 CBAM

2.2.1 CBAM Introduction

Implementing the EU ETS, which imposes carbon prices primarily on the domestic market within the EU, has increased the danger of carbon leakage. Because carbon leakage occurs when enterprises based in the EU relocate their manufacturing and capital investments to nations with less stringent carbon emission regulations and prices, this change is in response to the rising costs of emission quotas and the progressive reduction of free quotas. [1]

To address this issue and promote carbon competitiveness equitably, some OECD nations proposed the CBAM. The mechanism would establish responsibility for specific categories of commodities imported into the EU. It would be applied to those products imported into the EU with integrated emissions priced below the EU carbon price aligned with the ETS standard. The CBAM was passed and went into force on

May 17, 2023. To offer enterprises and other nations stability and legal certainty, the CBAM will be implemented progressively. [1]

The CBAM introduced by the EU is a significant instrument to establish an equitable cost for the carbon emissions generated in some carbon-intensive products imported into the EU. The implementation of CBAM coincides with the reduction of free allowances allocated through the EU Emissions Trading System (ETS), facilitating the EU industry's transition towards decarbonization. [1]

Aims:

The CBAM generally aims to promote environmentally cleaner industrial processes in nations outside the EU. [1] besides, there are two major purposes:

1. As one of the policies of EU Green Deal-"Fit for 55" climate policy package, the CBAM is the tool to adjust carbon emissions to achieve carbon neutrality by 2050.
2. Avoid carbon leakage
   If more carbon price the EU firms will pay locally, those firms will relocate the carbon-intensive production to regions with no or little carbon price or tax. In this case, European production and output will suffer, and the attempts to reduce GHG emissions globally will be finally undermined, which cause carbon leakage. Using import tariffs, the CBAM mechanism is intended to reduce the risk of carbon leakage by ensuring that the costs of carbon offsets for goods imported into the European Union are equal to or higher than the costs of carbon trading incurred for identical items through the ETS method.

Timeline:

Applicable importers are not obliged to pay carbon tariffs during the transition period from October 1, 2023, to January 1, 2026, but they are expected to submit precise carbon emission data for reference. After the transitional period and starting from 1 January 2026, importers will officially begin to pay for the financial adjustment while presenting "CBAM certificates" simultaneously. [1]

In addition, starting in 2026, the European Union (EU) will gradually reduce free allowances by 10% annually until they are eliminated by 2035. After the conclusion of the transition period, the EU will evaluate the operation of the CBAM and determine whether to expand the extent of products covered. [1]

Scope Accounting:

The accounting scope of CBAM encompasses direct and embedded carbon emissions, particularly concerning specific items. The category of direct carbon emissions includes the emissions that arise from the production process, irrespective of the production site, and includes emissions from utilizing heating and cooling. Embedded carbon emissions refer to the indirect emissions from power consumption during the industrial process. Companies that are obligated to comply with the CBAM must ascertain the appropriate parameters for conducting calculations. It entails adhering to the specified categories and fulfilling the stipulated criteria in the annex. Utilizing the draft provides a degree of adaptability in the computation of embedded emissions. In Article 7 of the original text of CBAM, only the products with direct emissions and those with embedded emissions need to be reported. [1]

Report Method:

Effective from Oct 1st, 2023, the CBAM during the transition period, firms do not have to pay for the carbon tariffs; however, they must provide the carbon emission report. During the inaugural year of implementation, organizations can choose from three distinct reporting approaches: a. utilizing the European Union's novel methodology, b, adopting an analogous system from a third country, or employing reference values as the basis for reporting. On January 1, 2025, exclusive acceptance will be granted solely to the EU method. [1]

Coverage:

The CBAM will apply initially limited to six main carbon-intensive sectors at a high risk of leaking carbon: Aluminium, Cement, Electricity, Fertilisers, Hydrogen, and Iron and Steel.

Besides, after the transition period, the EU wants to gradually expand the scope of regulation to include high-carbon products such as organic chemicals and plastics in the mechanism, aiming to bring all products covered by the EU carbon market under rule by 2030. [1]

Tax Deductions:

Carbon tariffs can be reduced or exempted in two methods, as specified by CBAM regulations: First is the mutual recognition of national-level carbon trading systems, comparable to Switzerland's linkage of its carbon market to the EU ETS; the second method is to recognize carbon tariffs offsets at the commodity transaction level. Importers can reduce their tax liability by declaring that a portion or all of the carbon costs associated with their imported products have been paid in the country where they are produced. [1]

For the first deduction condition, Article 5 of the CBAM draft specifies the prerequisite for exemption from CBAM obligations, which stipulates that the EU ETS must cover the product's country of origin or have a carbon emission trading system with prices aligned with the EU ETS. Several countries, such as Iceland, Liechtenstein, Norway, and Switzerland, or territories such as Büsingen, Helgoland, and so forth, will be exempted from purchasing CBAM certificates because they satisfy the criteria above.[58] Thus, products from these countries will not be required to immediately acquire CBAM certificates, whereas products from other countries may not enjoy this benefit. This scenario does not, however, appear plausible for China.

Carbon Emission Calculation:

According to the rules of CBAM, importers during the transition period have to report the embedded carbon emission in their imports, which include the direct and indirect

emissions. Here, direct Emissions refer to the emissions that arise from the production processes of commodities. And indirect Emissions refers to the emissions that arise from the generation of power, which is utilized in the production processes of commodities, irrespective of the geographical origin of the electricity consumed. [1]
Thus, that is the carbon emissions in the entire life cycle of the product calculated.

Process:
The CBAM system will operate as follows: EU importers will purchase carbon certificates equivalent to the carbon price that would have been paid per the EU's carbon pricing regulations. In contrast, if a non-EU producer can demonstrate that they have already paid the price for the carbon used in the production of imported goods in an additional nation, the importer in the EU can deduct the complete cost associated with the carbon. [1]

2.2.2 Problems and Obstacles

Carbon leakage refers to the phenomenon wherein implementing carbon reduction measures in one region or country increases carbon emissions in another province or country. One phenomenon observed is the industrial outflow, wherein corporations from the EU opt to transfer their operations to nations with more relaxed climate legislation. Second, "carbon dumping" may occur when high-carbon items from abroad displace low-carbon EU products in the market. Among the consequences of carbon emissions are: a) The global net greenhouse gas emissions are experiencing an upward trend rather than a decline in the context of climate change. b) The Impact on the EU economy includes industry damage and decreased employment.
However, some scholars doubt this mechanism will work efficiently, and many developing countries and economists have questioned whether this rule is fair as it is against the CBDR rule.

With the starting of CBAM effective and the potential risk of involving more related products in the mechanism, problems may come. Shouldn't the consumer side bear the cost? As the exporters in developing countries transit energy-intensive products to the European Union or resource-scarce regions, they pay for the price - potentially sacrificing the environment while retaining emissions domestically, effectively becoming a pollution haven for the receivers. With increasingly stringent emission reduction requirements, producers have already shouldered the responsibility and obligations due to production, yet still need to pay more on the carbon emissions in EU standard carbon price.

Admittedly, global warming is not one party’s issue but the whole world’s. Due to natural resource allocation, every party should pay the bill for the product's physical movement requirement. Producers take the duty, and so do consumers.

In the previous studies, CBAM may face challenges from several countries.[35] Even though it is for all of the nations that will import to EU, it is more or less concentrated on some critical rising economies as several reasons introduced in the previous introduction. Due to the high proportion of outbound business with those carbon-intensive products, a multidimensional index shows that Belarus, China, Egypt, Kazakhstan, Iran, India, Russia, UAE, USA, and Ukraine may strongly oppose the policy; the major economies like the USA, China Russia, and India might fight CBAM through WTO; relatively small economies such as Vietnam, Ukraine and Morocco and more may oppose it driven by the carbon intensity of their energy supply. These all call for a more rational method to support the development of greater capacity for innovation and energy transition. [35]

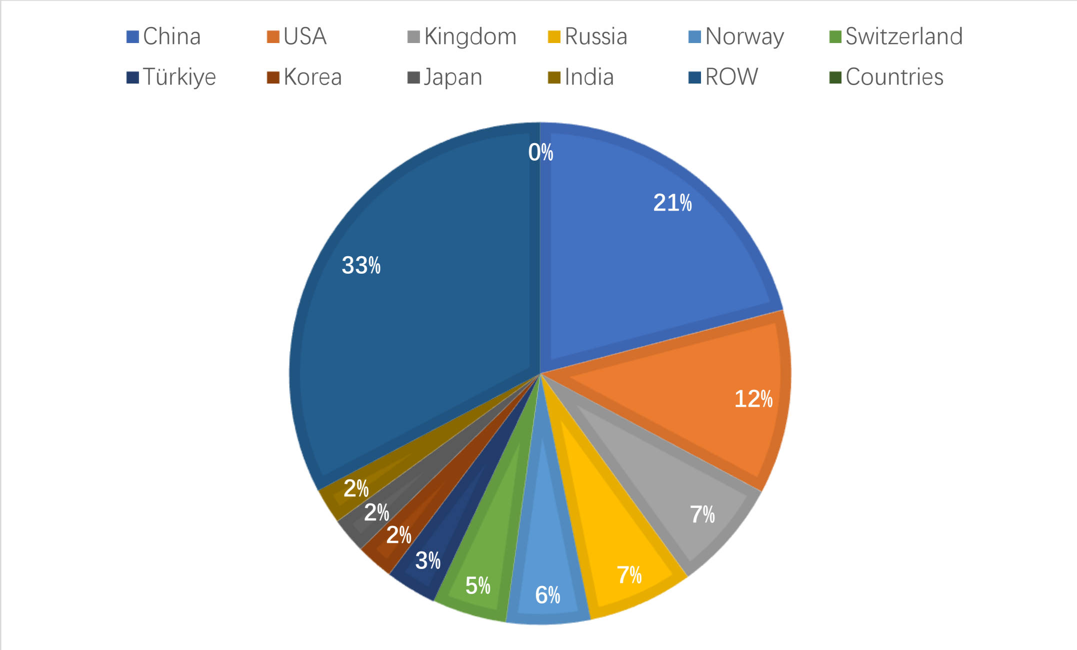
In conclusion, carbon leakage may become an import discrimination. Carbon leakage is caused by inconsistencies in timelines and programs of climate policies and emission reduction plans in different countries, that is, different phases of developing the status of both economy and sustainability. There is no one-size-fits-all solution to deal with such a problem. Mishandling the policy may lead to the willingness to achieve carbon emission goals and incur a trade war, which impacts the global economy and the supply chain in the long term.

2.3 Trade

2.3.1 Trade between China and the EU

Due to the manufacturing effectiveness and the products' favorable price, China has become the biggest exporter. According to the data from the China General Administration of Customs (Figure 7), China’s foreign trade dependency will be beyond 30% in 2020-2022 and reach more than 60% in 2006, 2007, and 2008.
According to EUROPA, in 2022, China ranked as the primary trading partner for the EU, accounting for EUR 626,304 million in import trade value, representing a significant share of 21% among all countries. The countries that follow in the top 10 rankings are the USA, the United Kingdom, Russia, Norway, Switzerland, Turkey, South Korea, Japan, and India. [36] According to the China General Administration of Customs (2023), a trade surplus exists between China and the EU. In 2022, the nation's trade surplus had a notable expansion of 31 percent compared to the previous year, reaching a value of USD 876.91 billion. This figure represents the most outstanding trade surplus recorded since the commencement of data collection in 1950. [37]

Figure 2. Total Goods: EU Top Import Partners 2022



Resource: author collected from EUROPA.[41]

According to the China Securities report, in 2022, the proportion of China's exports to the European Union accounted for 15.63% of its overall export volume.[66] Based on the latest data extracted from China's 2018 input-output table, it has been observed that the combined carbon emissions, encompassing both direct and indirect emissions, associated with China's exports to the European Union amounted to 80.5937 million tons. Notably, industries that fall under the purview of the CBAM accounted for approximately 19.091% of this cumulative emissions figure. [66]

2.3.2 Trade in Relevant Sectors

To understand the significance of investigating China and conducting comparative analyses with other global areas, one must familiarize oneself with the pertinent industries and critical stakeholders. Based on the data obtained from the UN Comtrade database, TOP 10 presents the trade value of nations that are most likely to be affected.

Table 1. Top 10 Countries Exporting Major Carbon-intensive Products into the EU. (Billion in USD)

Country	Aluminum	Cement	Electricity	Fertilizer	Iron and Steel	Total
China	4.2	0	0	0.1	15.1	**19.4**
Russian Federation	2.8	0	0.7	1.7	5.9	**11.1**

Turkey	1.8	0.1	0.1	0.1	7.4	**9.5**
India	0.5	0	0	0	4.1	**4.6**
USA	1	0	0	0.1	3.4	**4.6**
Rep. of Korea	0.3	0	0	0	4	**4.3**
Ukraine	0	0	0.4	0.1	3.8	**4.3**
Serbia	0.3	0	0.5	0.1	1	**2**
Brazil	0	0	0	0	1.8	**1.9**
United Arab Emirates	1.5	0	0	0	0.3	**1.8**

Resource: UN Comtrade database [32]

According to the summary, China maintains the highest ranking in CBAM-related products, with a share of 19.4%. Among all sectors, the Iron and Steel, and Aluminum industries exhibit the highest percentage, accounting for 15.1% and 4.2% of the total value. According to the research from CITIC, the four primary sectors (steel, aluminum, fertilizer, and cement) accounted for less than 1.33% of total Chinese exports to the EU in 2020. They take the percentage of total exports from China's steel, aluminum, fertilizer, and cement industries, which account for 11.25%, 5.55%, 1.02%, and 0.07% of total exports, respectively. The relative influence of the steel and aluminum industries appears to be more significant than that of the fertilizer and cement industries, as indicated by the import data from the European Union. When a carbon price of EUR 80 per ton is considered for imports, the carbon tariffs imposed on the abovementioned industries will represent 17%, 20%, 17%, and 31% of their respective trade values.[38] Moreover, the situation will be worse if there is an expansion in the product area. Thus, even if the sow is not that high in China’s overall export, the impacts are more significant, which may be the reason for the high carbon emissions in those industries, and this thesis will explain more in the result session.

In conclusion, from the previous studies, it’s evident that trade has a crucial role in fostering the economic advancement of emerging economies.[39] China needs to formulate corresponding export carbon tariffs for high-energy-consuming products based on its trade conditions, depending on its related policies and regulations and the collaborations and trade negotiations between trading countries. In this thesis, the author starts with the policy analysis and discusses possible ways to analyze the CBAM impacts.

3. Carbon Policies and Status

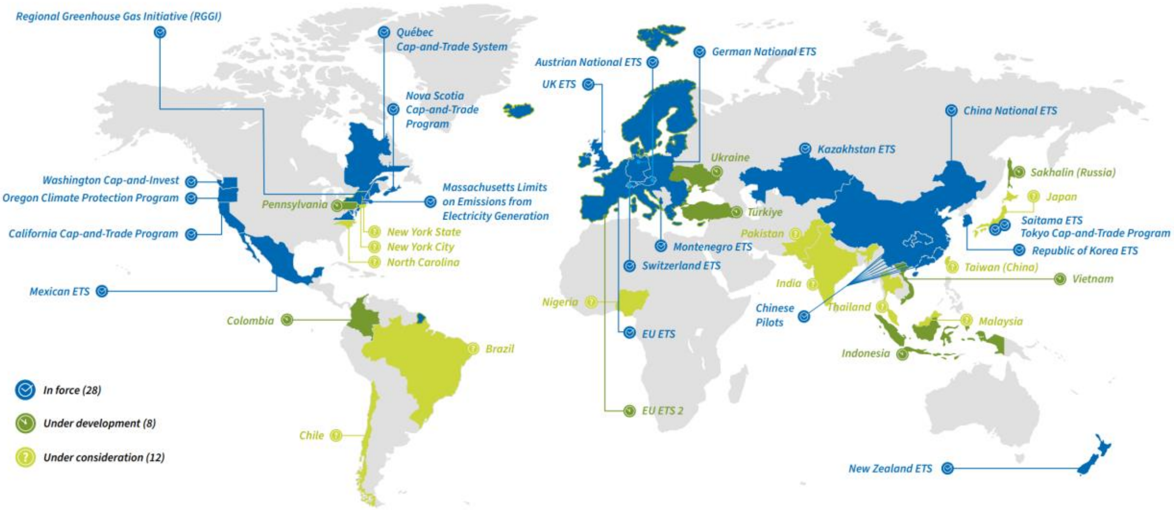
With several new measures and coverage expansions, the overall amounts of implemented instruments rose to 73, covering approximately 23% of the world's total greenhouse gas (GHG) emissions.[17]

After that, many nations have established goals of achieving carbon neutrality to alleviate climate change's impacts. In 2020, several prominent economies, like Germany and Canada, declared their intentions to achieve carbon neutrality by the year 2050. [3] China, the foremost contributor to worldwide carbon emissions, has pledged to attain carbon neutrality by 2060. As of 2020, over 100 nations have declared promises to achieve carbon neutrality. [40]

There are several policy measures for reducing carbon emissions: 1. Issuing a carbon tax as a levy imposed on CO_2 emissions, payable based on energy consumption. 2. Creating a carbon market to facilitate carbon emissions trading using CO_2 as a commodity by providing carbon quotas (Chinese Emission Allowance - also known as CEA) - entities and individuals lawfully acquire emission rights that can be traded and used as indicators for significant emitters to offset their greenhouse gas emissions.

According to the World Bank Group report- State and Trends of Carbon Pricing 2023[17], the world's primary carbon market is listed in Figure 3:

Figure 3. World Major Carbon Tools Distribution [17]



Resource: World Bank 2023

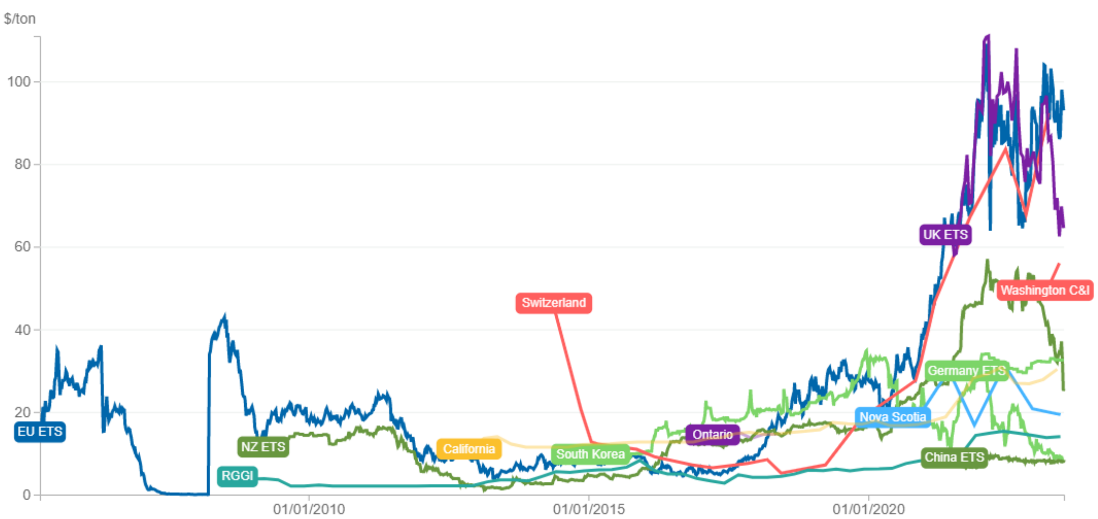
It is clear that the carbon market is spreading globally and still expanding in Figure 3. The author also gathered several important carbon emission markets based on the ICAP real-time data in Table 2:

Table 2. Carbon Cost of Global Emissions Trading Schemes (2021-2022)

Jurisdiction	Average Carbon Price (USD)	Scope
EU ETS	67.13	40% of EU emissions come from power, industry, and flights in the EEA.
California Cap-and-Trade Program	25.25	accounts for 80% of emissions from industry and fossil combustion.
China ETS	7.6	The power sector only covers 4 billion tons of CO_2 emissions.
South Korea ETS	19.97 (2022 Jan-Oct)	Power, industry, domestic aviation, garbage, and buildings contribute 66% of total emissions.
UK ETS	83	The UK ETS includes energy-intensive sectors, power, and aviation in the UK and EEA, accounting for one-third of GHG emissions.
Germany ETS	31	The ETS applies to all petroleum suppliers and distributors and complements the EU ETS.
RGGI	12.64	A partnership of ten states in the Northeastern United States encompasses 20 percent of the region's emissions from the electricity sector.

Resource: author collected and calculated from the "ICAP Allowance Price Explore" (https://icapcarbonaction.com/en/ets-prices)

Figure 4. Worldwide Major ETS Allowance Price [42]



Resources: ICAP https://icapcarbonaction.com/en/ets-prices

From Figure 4 and Table 2, it is evident that carbon prices vary with the ETS from different countries, and the market entry time varies from countries. In prominent global emission trading systems, namely the EU ETS and UK ETS, a comparatively

elevated carbon price of approximately $100/ton and $65/ton was observed until June 30, 2023. Conversely, the recently established China ETS exhibited a lower carbon price, hovering around $10/ton on the same day. Compared with the EU, the US, and some developed countries, the Chinese Carbon market remains in its infancy. The carbon price system is incomplete, and the trading market is limited mainly to the power sector and still needs to cover more comprehensive EITE.
The graphical representation underscores the substantial divergence in carbon prices across different countries, with disparities exceeding tenfold. This variability is attributable to distinct regional policies, economic performance, and industrial landscapes, resulting in divergent carbon pricing within a jurisdiction.

The huge gap between China and the EU, according to Professor Xiliang Zhang, director of the Institute of Energy, Environment, and Economics of Tsinghua University, in an interview with the reporter of “National Economic News”: “Although the outcome of the negotiations between China and the EU is unpredictable, there will be no situation where Chinese carbon price will be raised exceptionally high in response to the carbon tariff issue. A country's carbon price should be related to the marginal cost of abatement corresponding to the country's emission reduction targets. Differences in emission reduction goals, development stages, and economic structures of different countries will lead to differences in marginal emission reduction costs.” [67]

3.1 EU Policies

The European Commission, on July 14, 2021, approved a series of legislative measures known as "Fit for 55" under the framework of the European Green Deal. "Fit for 55" pertains to the European Union's objective of achieving a minimum 55% reduction in net greenhouse gas emissions by 2030. The proposed package seeks to align European Union legislation with the objective set for the year 2030. The package included but was not limited to the following:

Table 3. The EU “Fit for 55” Policies

EU Emissions Trading System (EU ETS)	It is bolstering the EU Emissions Trading System (EU ETS) to reduce emissions for trading industries by 62% by 2030.
Reduce energy sector methane emissions.	EU energy sector methane emission reduction rules in December 2021
Land Use and Forestry (LULUCF)	For EU members not included in the EU ETS or the Land Use, Land Use Change, and Forestry (LULUCF) sector, the emission reduction target has been raised from 29% to 40%.
Alternative Fuels Infrastructure	It is accelerating the construction of alternative fuel and electric vehicle charging infrastructure.

Carbon Border Adjustment Mechanism (CBAM)	It establishes CBAM, the equivalent of placing carbon tariffs on imported products.
Social Climate Fund	To provide investments and support measures to vulnerable households, microenterprises, and transportation users. The EU budget will support the fund with external earnings up to €65 billion.
RefuelEU Aviation and FuelEU Maritime	To encourage sustainable aviation fuels, to call airlines to use electric and biofuels to reduce carbon emissions. They supported using low-carbon or renewable fuels in ships and airplanes and mandated that they cut greenhouse gas emissions by up to 75% by the year 2050.
Energy performance of buildings	To revise the energy performance of buildings directive to increase energy efficiency in EU buildings by 2030 and beyond.
Carbon Dioxide Emission Standards for Cars and Trucks	To lower car carbon dioxide emissions (by establishing new regulations) and discontinue the sale of cars with internal combustion engines by 2035.
Energy Taxation	To implement energy taxation.
Renewable Energy	To increase from the previous target of 32% to above 40% by 2030 for the share of renewable energy.
Energy Efficiency	The updated EU energy efficiency directive is expected to lower the EU's overall energy usage by 11.7% by 2030.

Resource: author collected from EUROPA.[41]

The EU carbon market is the world's largest and most active one. It covers broad industries and regions, and the allocation is gradually shortened. As an instrument for handling CO_2 emissions, the European Union Emissions Trading System (EU ETS) was initiated in 2005 to regulate GHG emissions from power generation, industrial activities, and aviation inside the European Economic Area (EEA). This comprehensive scheme encompasses approximately 40% of the total emissions produced within the European Union. At present, the domestic carbon market holds the distinction of being the largest in the world. Moreover, it runs with the Cap and Trade system.[42]

3.2 China Policies

As the most significant carbon emission country and one of the major manufacturing factories in the world, if China's long-term development strategy relies on conventional energy sources such as coal power and oil, it may not be sustainable in the long run. It may not align with the principles of sustainable development. Given its substantial population and significant volume of commerce, China, the most populous developing nation, assumes the role of a responsible considerable power. It must contribute to the global climate change and safeguard the global environment.

On September 22nd, 2020, President Xi Jinping of China put up a proposition of dual–carbon goals, wherein China sets a target to reach the peak of its carbon dioxide (CO_2) emissions by 2030 and endeavors to achieve carbon neutrality by 2060.[43] This holds considerable importance for global collaborative efforts in addressing climate change.

China, the foremost emitter of carbon globally, accounted for 32% of worldwide carbon emissions by the conclusion of 2020. The country has implemented measures and regulations to accelerate the transition towards a more sustainable pathway in response to the significant carbon emission challenges and forthcoming dual-carbon targets. By the conclusion of 2020, there has been a notable success in managing the magnitude of greenhouse gas emissions, resulting in a reduction of 18.2% compared to the levels seen in 2015 and a substantial decrease of 48.1% in the emissions recorded in 2005.[40]

Moreover, in July 2023, the "Opinions on Promoting Dual Controls of Energy Consumption and Gradually Shifting to Dual Controls of Carbon Emissions" published, established and implemented a dual control system for total energy consumption and intensity, which effectively promoted the substantial improvement of China's energy utilization efficiency and the continuous decline of carbon dioxide emission intensity. Gradually shift from dual control of energy consumption to dual control of carbon emission. Regarding the carbon policies, the author gathered the regulations and laws in Table 4:

Table 4. The Policies in China regarding Carbon Emissions

Policies and Actions	Issuance Time	Key Contents
Green certificates and green energy policies	2006	Promotes the widespread use of sustainable energy sources and mitigates the reliance on non-renewable fossil fuels to reduce carbon emissions effectively.
National Climate Action Plan	2016	"13th Five-Year Plan (FYP)" and "Carbon Peaking Action Plan" set the carbon reduction targets by promoting clean energy development and energy efficiency.

Green Finance Policies (multiple)	2016	Provide multiple financial goals and institutions such as bonds and credit to support related green projects.
China Emission Trade System	2017	Creates a carbon market where emitters can buy and sell emission credits.
Ten Major Actions for Carbon Peaking	2020	Introduced actions to achieve carbon peaking goal, such as transitioning to green and low-carbon energy, enhancing energy efficiency for carbon reduction and improved efficiency, achieving carbon peaking in the industrial sector, attaining carbon peaking in urban and rural construction, promoting green and low-carbon transportation, leveraging circular economy for carbon reduction, fostering innovation in green and low-carbon technology, and so forth.
Global Warming Response Action Plan	2020	Set "Dual carbon" goals: Aim to peak CO_2 emissions by 2030 and achieve carbon neutrality by 2060.
Carbon Market Development	2021	Launched carbon emission trading market; set up trading rules, emission allocation plans, and sectors that will cover and gradually cover in the future.
14th Five-Year Action Plan (14F Plan)	2021	A set of steps about the energy system, including "The 14th Five-Year Plan (FYP) for Renewable Energy Development", the essential steps for the clean and efficient use of coal, and other green projects such as green transportation projects, and so forth.
Electric Vehicle Policies	2021/2022	Promote electric vehicle sales and usage with policy support by offering financial subsidies, exempting from purchase tax, and the related.
Carbon Emission Data Monitoring and Reporting	2022	enforced the reporting of carbon emissions data by companies and industries with high emissions.
Notice on Achieving Full Coverage of Green Power Certificates for	2023	Clarifies that green certificates are the only documentation attesting to the environmental qualities of renewable

Renewable Energy and Promoting the Consumption of Renewable Energy Electricity		energy sources and the only way to track the amount of renewable energy produced and consumed. Improve green certificate transactions, increase the use of green electricity, achieve complete coverage of renewable energy sources, and broaden the scope of application of green certificates.
Taiwan Carbon Rights Exchange officially unveiled	2023	The carbon rights exchange will allow the Taiwan area to keep up with the international trend of net-zero transformation.

Resources: author gathered from the Ministry of Ecology and Environment of the People's Republic of China [44]

- China ETS

China ETS officially started in 2021. Jul.16 with the carbon price of CNY48/ton and more than 2100 power generation companies, emitting over 26,000 tCO_2 and about 4.5 billion t CO_2 per year—over 30% of China's total GHG emissions.[45] The carbon exchange market has expanded to 8 provinces, including Beijing, Shanghai, Guangzhou, Shenzhen, Tianjin, Chongqing, Hubei, and Fujian. It's one of the benchmarks for moving forward to a greener future and achieving Chinese "dual carbon" goals. By setting the carbon emission goals and an exchange mechanism, China ETS aims to encourage enterprises to decrease carbon emissions and to develop a low carbon economy growth. Like EU ETS, China ETS is a cap-and-trade market that sets carbon emission quotas for related industries and companies, and the allocation gradually decreases with time. Setting up the carbon market allows companies with different carbon quota requirements to purchase and sell emission quotas as an adjustment tool. If beyond the percentage, companies should pay the extra fee according to the carbon price; the involved companies must also report the emission data regularly and be tracked for accurate emission data. [14]

In 2021 and 2022, China's Ministry of Ecology and Environment allowed emission-controlled companies to use their 2019-2020 carbon emission quotas in the following period (2021-2022) and for carbon market transactions. [68] The initial compliance phase of the national carbon market ran from January 1 to December 31, 2021, and covers 2,162 entities, requiring emission-controlled firms to meet their 2019-2020 emission quotas. Notably, compared with the first compliance cycle, the second compliance phase has lower emission baselines, reducing free allowances for power generation companies. Suppose the total carbon emissions of the regulated enterprises for two years are higher than the allowances they have been allocated for free. In that case, they must make up the gap by purchasing allowances in the national carbon market. If the emissions are lower than the quota, the quota can also be sold in the national carbon market to obtain income.

Even though it only covers one primary industry- the power sector, according to the report 2022 China Carbon Pricing Survey [46], as the cement and steel industries are designed to be the critical EITE, they are most likely to be included in the China ETS in the year 2024. In 2023, the three major industries, steel, petrochemicals, and construction materials, were officially discussed and proposed during the government conferences. Carbon prices may gradually increase simultaneously, with more initiatives likely to be included in the system and strengthened policies.

As of Aug 23, 2023, China's daily closing carbon price reaches CNY 74.76/ton in the national carbon emission quota listing agreement (CEA), an increase of 2.79% compared with the previous day. This set a new high price since the opening of the Chinese national carbon market. Even though it’s far lower than the EU carbon price, which is around EUR80/ton, the overall trend is firmly upward, and with the second carbon emission compliance period of the national carbon market approaching which means the concentrated release of carbon quota demand, and with the CBAM effective day is arriving, they will further boost the rise of carbon prices. According to the "2022 China Carbon Price Survey Report" [46] published by consulting firm ICF, the survey participants in the national carbon market also exhibit a positive long-term outlook on carbon prices within China's carbon market.

In addition, in March 2022, China’s Ministry of Ecology and Environment updated monitoring, reporting, and verifying (MRV) guidelines to enhance data accuracy by using the facts and the knowledge gained from the previous compliance period.[69]

- CCER Chinese Certificate Emission Reduction

Moreover, in 2023, China announced the plan to relaunch the construction of the national voluntary greenhouse gas emissions trading market - CCER- to support the development of the green economy and the service sector after being suspended for six years.

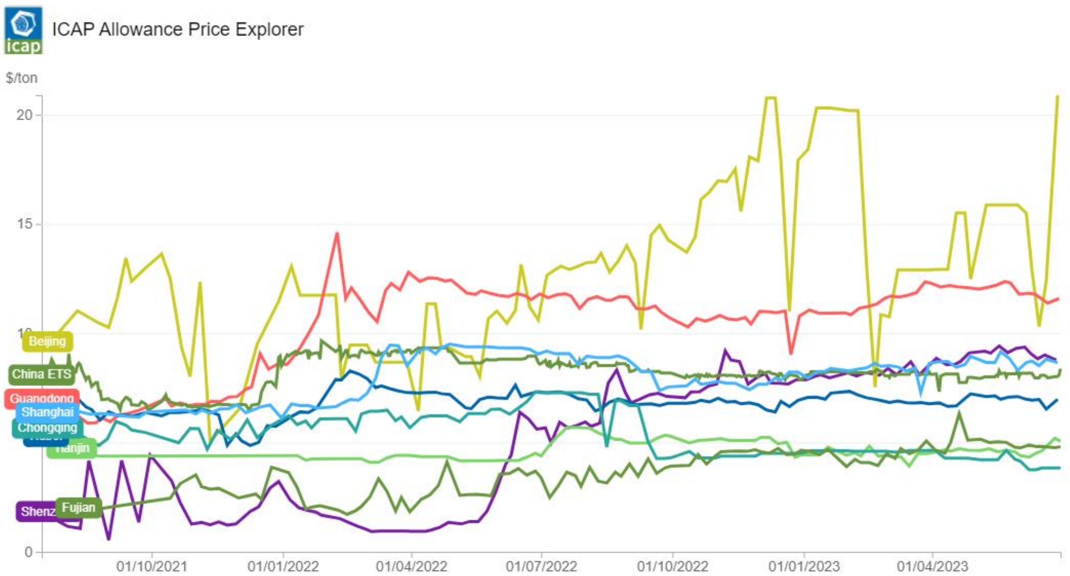
CCER is derived from CER, which originated from the CDM initiative during the Kyoto Protocol era. It refers to the utilization of capital and technology by developed nations to invest in renewable energy projects in developing countries to obtain greenhouse gas emission rights, which can be used to offset their carbon emission indicators. Reduce the financial burden on businesses, CCER initiatives can be developed by voluntary emission reduction enterprises (non-control enterprises). CCERs can be sold to corporations with high carbon emissions to offset up to 5% of their carbon allowances. In collaboration with the Netherlands, China completed its first CDM initiative in 2002. The cooperation project was the Huitengxile wind farm project in Inner Mongolia, which, at the time, was the largest wind farm project in Asia. Later, due to a decrease in cooperation projects, China shifted its focus to domestic CCER, and most transactions no longer involved a developed nation. Still, it's the nation's responsibility to facilitate the fulfillment of domestic carbon reduction objectives. However, in 2017, the National Development and Reform Commission suspended the submission of the CCER project due to the small market transaction volume and irregularities in some projects.[47]

The previous studies show China's carbon trading system can experience cost savings due to the CCER scheme.[48] In the shortcoming, more EITE products will be added to China's carbon market, and the demand for CCER will continue to grow. The growth of the carbon market in China, along with the influence of the CBAM, is expected to lead to a substantial increase in the demand for CCERs. This heightened demand is anticipated to be crucial in supporting China's emissions trading scheme by reducing the costs associated with transitioning to more energy-efficient practices.

As additional industries become engaged in the China ETS and green policies and initiatives are reinforced, producers will inevitably become more aware of the importance of carbon emission management. This entails developing future reduction or trade plans, ensuring the accuracy of carbon data, conducting verification processes, and exploring avenues for enhancing production technologies. An analysis of green technology in China states that environmental-related technologies in China experienced a notable increase from 1990 to 2011, aligning with the growth patterns observed in both research and development (R&D) expenditures as a percentage of gross domestic product (GDP) and GDP per capita.[49]

Meanwhile, China needs to strengthen policy regulation and control for the carbon market. Carbon leakage may happen in countries, regions, industries, and companies. China ETS was initiated in 2021 and only covered the electricity industry until August 2023. With the growing setup of different provinces, carbon quotas and green electricity can be traded to offset and clear some carbon prices. By doing so, the carbon emissions of key companies can quickly transfer to non-key emitters, leading to “carbon leakage.” According to International Carbon Action Partnership ICAP data, ETS allowance prices of China ETS pilots, which covered Beijing, Shanghai, Guangzhou, Shenzhen, Tianjin, Chongqing, Hubei, and Fujian, shown in Table 5, it is clear that even different region has remarkable gaps of the carbon price, with more industries involving, China should further focus on this field and create an equally green market.

Figure 5. China ETS Allowance Price in Regions



Recource: https://icapcarbonaction.com/en/ets-prices

- Shortages:

Meanwhile, the China carbon market still has some obstacles and shortages. 1. The carbon emissions market in China remains in its initial phase of advancement. In contrast to advanced economies such as Europe and the United States, China's trading mechanism still needs time to ascertain its efficacy by expanding more industries into the carbon market. 2. Carbon costs are still too low to reach the USD 40-80 range, which, according to the Stern-Stiglitz High-Level Commission on Carbon Prices, is the ideal carbon price to achieve “2 degrees Celsius”. 3. The growth of China's carbon trading market, which may have gradually assumed attributes akin to those of a commodity and financial instrument, could contribute to ambiguity in legal definitions. Hence, it is imperative to swiftly adjust industry-specific laws and regulations to meet these evolving circumstances effectively. 4. The nascent stage of the carbon futures market has led to a restricted array of derivative offerings about carbon allowances. From a market standpoint, carbon futures, considered crucial carbon products, can alleviate information asymmetry, bolster market liquidity, and offer advice for spot markets. Nevertheless, China has considerable potential for further advancement in this aspect.

To conclude, in the present time, thousands of emission reduction initiatives have been approved by the government, which contributed over 50 million tons of reduced emissions. Even though the carbon market was only recently launched, it has already absorbed 32.73 million tons of carbon emissions allowances, indicating its efficacy to some degree.[50] Propelled by both internal and external factors, the voluntary certificate emission reduction trading market and the carbon emission trading market collectively form a comprehensive carbon trading system, accompanied by various subsequent policies. Consequently, China is undeniably making progress towards achieving its dual carbon goals and trying to keep up with European initiatives for environmental protection. Meanwhile, China must prioritize the balance between pushing the status of green policy exploration and the risks it may face. Focusing on developing topics within the CBAM and TCC Framework is vital. Additionally, China should evaluate its vulnerability to environmental obstacles from foreign policies concerning ESG (Environmental, Social, and Governance) and CSG (Corporate Social Responsibility and Sustainability).

3.3 Gaps and Obstacles

According to the calculation for the CBAM fee:

CBAM fee = (EU ETS carbon price - carbon price of exporting country) x (product carbon emissions-free emission quota obtained by EU companies with similar products)

The free emission quota will gradually reduce to zero. As a result, two significant factors actually affect the payment of CBAM: the difference between the EU carbon price and the domestic carbon price and the product's carbon emissions.

To conclude, an effective policy to stimulate the increase of carbon prices to minimize the carbon price gap between the EU, China and green technology can decrease domestic carbon emissions.

However, a previous study found that China's ETS pilot policy drops the firms' green patents percentage by a remarkable 9.3%, primarily affecting non-state-owned companies and SMEs. Due to the cash flow shortage and revenue reduction, firms opt for short-term production reductions rather than pursuing long-running carbon emissions reduction goals by green technological upgrading, which hurts R&D and technical transformation.[51]

In addition, the investigation conducted by UNCTAD reveals that the simulation of a carbon price of 44 Euros effectively addresses the issue of carbon leakage, resulting in a reduction of leakage data from 13.3% to 5.2%. This finding slightly deviates from the previous study [25], which reported a lower reduction rate. However, it is necessary to note that implementing carbon tariffs primarily addresses carbon leakage concerns but may not be as effective in motivating global emissions reduction, as the majority of carbon emissions may still originate from within the EU.

Furthermore, the profitability of several firms in China, particularly those categorized as small and medium-sized, is insufficient to accommodate the elevated carbon pricing. The imposition of a high carbon price can significantly impact the viability of SMEs, potentially resulting in their insolvency. As the tax scope is expanded, increasing producers and organizations will incur supplementary costs, exacerbating the adverse consequences and inflicting substantial harm on the broader macroeconomic environment. Hence, it might be argued that hasty modifications and uncritical comparisons to the benchmarks set by Western nations will harm China's economic progress. China must strive to achieve a harmonious equilibrium that aligns with its current growth stage. In doing so, it should effectively address trade policies that deviate from its established development principles while concurrently enhancing communication channels to foster the sound progression of trade.

When developing countries export products that require much energy to the European Union or other regions that are short on resources, they risk jeopardizing the environment's health. At the same time, these countries keep their emissions levels high locally, essentially turning themselves into a pollution shelter for more developed countries. Producers are already shouldering the duty and liabilities that stem from production despite emission reduction criteria becoming increasingly strict. Indeed, the party doing the exporting ought to pay for it.

Based on those related methods, questioned about the effectiveness of carbon emission and the risk to impact the benefit of exporters, some people raised the idea that producers and consumers should pay the corresponding cost for carbon emissions equally. Doing so will benefit from no limits to: 1. Promote global emission reduction and encourage awareness of consuming and producing low-carbon products in the trade process to avoid the burden of carbon tariffs. 2. Stimulate global technological innovation; consumers will also invest in green technology innovation of producers in disguise, improve production processes, and increase international cooperation, thereby Reducing carbon emissions. 3. Ensure fairness; producers and consumers will pay for the price to avoid carbon leakage risks.

In summary, the ineffective implementation of carbon pricing in various national policies and stages may hinder the advancement of green transformation. The CBAM may not effectively address the issue of carbon leakage and the imperative to incentivize other nations to reduce greenhouse gas emissions simultaneously. There is no one-size-fits-all solution to dealing with carbon leakage. If CBAM is implemented, exporters and importers must devise a fair method for allocating costs and managing green revenue. Based on the technique, producers and consumers must bear equal responsibility for the financial burden associated with carbon emissions. This analysis will set up one scenario according to the premise that implementing CBAM carbon tariffs is inevitable. It will also explore the various strategies for allocating this tax fairly and reasonably while examining its potential future implications.

4. Methodology

This study employs the MRIO and GTAP models of the ramifications of carbon emissions. It investigates how products with varying degrees of embedded carbon emissions affect China within the framework of CBAM policies. This chapter addresses queries about models and their associated impacts, as outlined in the sub-questions.

4.1 Theoretical Foundation

4.1.1 MRIO Model

Input-output analysis, also called interindustry analysis, is a quantitative method for investigating the intricate relationships between inputs and outputs in various sectors of the global and national economies. An eminent American economist, Wassily Leontief, pioneered this general equilibrium-based analysis method in the previous century. It is a valuable tool for addressing economic issues in the actual world. Due to their unique ability to account for the interdependencies between industries, input-output tables are one of the most widely used instruments in economic analysis.[52]

The remarkable aspect of these tables is their inclusiveness, as they depict the interactions between various economic sectors and products across many nations. These are especially useful because they comprehensively comprehend the economic sectors' consumption and production interactions and dependencies. In this thesis, the author utilizes this model to calculate the implicit carbon emissions associated with industry sectors and macroeconomic factors in multiple countries.

4.1.2 Global Trade Analysis Project model (GTAP)

The author uses GTAP to analyze the impact of this problem. As one of the computable general equilibrium models, GTAP is a global trade analysis project. The GTAP model was created by Professor Thomas Hertel (1993) of Purdue University in the United States.[53] The model above is founded upon the general equilibrium model of neoclassical economics and relies on comprehensive data about economic activities at the level of individual countries or regions. The closed world economy is formed by integrating many worldwide entities, including governments, producers, households, banks, and trade. In this particular framework, it becomes possible to carry out policy simulations to examine alterations in production levels, price levels, GDP, trade, and social welfare across different sectors of the economy for each country or area, all within the context of diverse policy scenarios.

This study employs the most recent iteration of the GTAP10 database, published in 2019, along with the GTAP-E database, which includes the carbon emission data. This database has comprehensive production, prices, and trade information for 144 nations and regions spanning 65 industries. The simulations were performed utilizing the Rungtap software, and the results were afterward compared and examined for discussion in different BTA methods.

4.2 Modelling Introduction

To model the effects of policies, this chapter first recompiles the multi-regional input-output tables in GTAP into eleven regions based on the import countries with high carbon-emission products import rate to the EU: China (CHN), the United States (USA), Russia (RUS), India (IND), South Korea (KOR), the European Union (EU), Turkey (TUR), Ukraine (UKR), Brazil (BRA), and Saudi Arabia (SAU), then choose the 13 leading industrial sectors further to evaluate the carbon emission rate and industry analysis. By recursing the variable data- GDP, Capital, Population, and skilled and unskilled labor from 2014-2020 and 2020-2025, the author outputs the base data in the year 2025 from GTAP. Second, the recompiled multiregional input-output tables are then used to calculate the embedded carbon emissions between these selected regions across various sectors, and the carbon tariff rates are subsequently determined for further shocks in the three scenarios.

The empirical GTAP model is subsequently utilized to simulate the effects of the different carbon tariff policies on the selected region’s sectors' outputs. This simulation evaluates the impact of the CBAM on China's GDP, export fluctuations, carbon emissions, and social welfare and, what’s more, investigates the effects on China’s different sectors. The Rungtap model simulates the policy's impact on various industries and countries, yielding insights into the policy's potential sectoral and national-level consequences.

4.2.1 Data Aggregation

Countries selection- To enhance the precision and specificity of the quantitative simulation analysis utilizing the GTAP model, redefining the geographical regions and economic sectors was imperative. To conduct a more comprehensive evaluation of the ramifications of the European Union's carbon pricing, the author opts to include nations on the overall carbon-intensive products imports to the EU nations in Figure 6 and move out those that may potentially be exempted due to credit recognition agreements (UK, Norway, Switzerland). The selected 11 sectors encompassed in this study include China (CHN), United States (USA), Russia (RUS), India (IND), South Korea (KOR), European Union (EU), Turkey (TUR), Ukraine (UKR), Brazil (BRA), Saudi Arabia (SAU), and the rest of the world (ROW) as Table 5.

Table 5. Countries Setting

Country(countries)	Group
China（CHN） US（USA） Russia (RUS）	

India（IND）	
South Korea（KOR）	
The EU（EU）	France, Germany, Italy, Netherlands, Belgium, Luxembourg, Denmark, Ireland, Greece, Portugal, Spain, Austria, Sweden, Finland, Malta, Cyprus, Poland, Hungary, Czech Republic, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Romania, Bulgaria, Croatia
Turkey（TUR）	
Ukraine（UKR）	
Brazil（BRA）	
Saudi Arabia（SAU）	
Rest Of the World	Other countries

Source: Aggregated data from the GTAP database.

Data recursion: As the CBAM officially issued carbon tariffs in 2026, the author set the base year in 2025 and gathered the data resources about the population, GDP, capital stock, skilled and unskilled labor across different countries from 2014 to 2025 obtained from the French Institute for International Economics (CEPII) and after using GTAP to modifying the changing of the population, GDP, capital, skilled and unskilled labor shown in Table 6 and 7, got the base scenario data resources for future shocks.

Table 6. Factors Change in % During 2014-2020

Country	GDP	Capital	Population	Skilled labor	Unskilled labor
CHN	0.47	0.62	0.01	0.14	0.00
USA	0.12	0.15	0.04	-0.13	-0.01
RUS	0.04	0.02	0.00	-0.26	0.00
IND	0.60	0.51	0.07	-0.02	-0.05
KOR	0.17	0.27	0.00	0.00	0.01
EU	0.10	0.10	0.01	0.04	0.02
TUR	0.35	0.42	0.08	-0.02	-0.04
UKR	-0.12	-0.16	-0.03	-0.21	0.01
BRA	-0.03	0.09	0.05	0.04	0.03
SAU	0.22	0.35	0.12	0.06	0.01
ROW	0.15	0.18	0.10	0.02	-0.01

Table 7. Factors Change in % During 2020-2025

Country	GDP	Capital	Population	Skilled labor	Unskilled labor
CHN	0.33	0.42	0.00	0.18	0.04
USA	0.05	0.12	0.02	-0.13	-0.01
RUS	0.05	0.04	-0.02	-0.29	0.00

IND	0.46	0.49	0.07	0.00	-0.01
KOR	0.09	0.18	-0.02	0.08	0.03
EU	0.02	0.09	-0.01	0.05	0.02
TUR	0.19	0.26	0.05	0.00	0.00
UKR	-0.10	-0.10	-0.03	-0.23	0.00
BRA	0.04	0.09	0.04	0.05	0.06
SAU	0.16	0.26	0.09	0.02	0.02
ROW	0.11	0.15	0.07	0.03	0.01

Industries selection- According to CBAM principles, starting in 2026, the EU would impose carbon levies on imported high-carbon products, initially confined to six selected industries (here, mainly choose the industries that may impact China). Following the GTAP categories, the author has classified these items into a comprehensive set of 13 groups from a1 to a13, shown in Table 8(including the five primary energy sectors a9-a13 not discussed in the thesis), four EITE related sectors, and also takes into account for two substitutes and the downstream industries that may be impacted, one trade and logistics industries, and one group of other industries as illustrated in Table 8. Apart from the five primary energy sectors, these can be categorized into four main groups: carbon-intensive industries, substitute or downstream groups, logistics and trade, and others.

Four carbon-intensive sectors impacting the CBAM are worth focusing on: Cement, Iron and Steel, Fertilizers, and Aluminum. These sectors primarily encompass industries with substantial carbon emissions. Another group encompasses downstream sectors: car manufacturing, machinery manufacturing, and construction. Additionally, within alternative product sectors, a category includes wood, rubber, and plastic products. Furthermore, the author has conducted a distinct categorization of the commerce and logistics sector, encompassing maritime and air transportation, to evaluate overall trading impacts.

The discussion of partial substitutes, downstream products, and trade is critical because, in an analysis of international economic exchange, production materials, and raw materials are constantly flowing and interacting with one another, and changes in any aspect can have ripple effects that impact supply chains, societal welfare, employment, and asset allocation. In addition, the discussion of partial substitutes, downstream products, and logistics is relevant because of the interaction between production materials and raw materials. For example, steel and aluminum production may influence subsequent industries such as construction, aircraft, automotive, shipbuilding, and industrial manufacturing. Cement may affect the housing and construction industries. At the same time, fertilizers may involve a variety of other industries, including plastics, coatings, and chemical products, because of the certainty that a number of the effects will eventually be reflected in trade and logistics. All of these reshapes will ultimately result in a domino effect across the economic system, which will have far-reaching repercussions for employment, economic growth, and the general welfare of society.

Table 8. Sectors Setting

Sector.	No.	Description
Mineral(cement)	a1	Mineral, mineral products
Ferrous metals (Iron and Steel)	a2	ferrous metals
Metals (Aluminum)	a3	Metals, metal products
Chemical products (Fertilizers)	a4	chemical products
Downstream industries	a5	Machinery and equipment, motor vehicles and parts, transport equipment, manufactures, construction
Substitute	a6	wood products, rubber, and plastic products
Trade and logistics	a7	Trade, Transport (air and ocean), warehousing
Others	a8	(Crop and food, textiles and wearing apparel, leather products, thesis and publishing, essential pharmaceutical products, computer, electronic and optic, electrical equipment, water, service, and so forth.)
Energy	a9	Coal
	a10	Oil
	a11	Gas
	a12	Petroleum, coal products
	a13	Electricity

4.2.2 Scenarios Setting

The author establishes one base scenario and three simulation scenarios using the preceding discussion as a foundation. Setting the European Union's carbon price benchmark at USD 80 per ton is based on an analysis of carbon price variations and the carbon price scenario for 2022. China’s carbon price is USD 10 based on the same logic. This benchmark has been nominated for facilitating calculations. Based on the carbon taxation pricing regulations, which involve deducting the carbon fees already paid by the producing country, and the premise of equal obligation for both the importing and exporting parties to pay carbon emission fees, the author has established three simulated scenarios as follows:

Baseline Scenario: During the transition period, the baseline scenario anticipates no carbon tariffs for both importer and exporter.
Scenario 1: In this scenario, after the EU and China negotiation, Europe is willing to, as an importer, contribute 50% of the carbon levy. We compute this fee based on an approximate average of $80 per ton, so $40 per ton EU will take after deducting the carbon fees already paid by enterprises in China ($10). As a result, Europe levies carbon costs of $30 per ton.
Scenario 2: This scenario implies that Europe imposes all carbon fees on relevant importing parties by the ETS carbon price, without exceptions. This policy deducts the carbon tax businesses have already paid in their home country. Therefore, the importing parties must pay carbon fees of $70 per ton.
Scenario 3 assumes that while Europe charges the total carbon price, China charges European importers only half of the carbon price, resulting in Europe charging $70 per ton and China charging $35 per ton.
The final scenarios are listed in Table 9:

Table 9. Scenarios Setting

Scenarios (USD$)	Baseline Scenario	Scenario 1	Scenario 2	Scenario 3
Carbon Price (EU)	0	30	70	70
Carbon Price (CN)	0	0	0	35

4.2.3 Measure Embedded Carbon Emissions

To analyze the impacts of CBAM, it is essential to have carbon tariff and emission data based on industries specifically designed to investigate in-depth results further. Because the GTAP or GTAP-E software does not include a category for carbon tariffs, the author converts them into conventional taxes to evaluate their impact on various scenarios.

First, an input-output model is constructed based on selected countries and industries. This model can represent the economic relationships between various sectors and various nations. Here, the author uses this as a basis for calculating the embedded carbon emissions between various sectors in different countries to evaluate the collection of carbon tariffs under multiple scenarios.

Table 10. Input-Output Table of Selected Countries

		Intermedia output					Final output					Total output
Intermedia input		CHN	…	EU	…	ROW	CHN	…	EU	…	ROW	
	CHN	Z_{11}	…	Z_{16}	…	Z_{113}	f_{11}	…	f_{16}	…	F_{113}	X_1
	…	…	…	…	…	…	…	…	…	…	…	…
	EU	Z_{61}	…	Z_{66}	…	Z_{613}	f_{61}	…	f_{66}	…	f_{613}	X_6

	…	…	…	…	…	…	…	…	…	…	…	…
	ROW	Z_{131}	…	Z_{136}	…	Z_{1313}	f_{131}	…	f_{136}	…	f_{1313}	X_{13}
Imported industrial input		V_1	…	V_6	…	V_{13}						
Total production		X_1	…	X_6	…	X_{13}						

Based on the MRIO model, the input-output relationships between various economic sectors can be described as follows:

$$X = AX + Y \text{ (Equation 4.1)}$$

X represents the total output of each sector of the economy of SN*1. A is the direct consumption matrix of SN*SN, and Y is the final demand vector of SN*1.

The intermediate input of a product can be interpreted as the input of raw materials or other goods and services utilized in the production of the product but not included in its ultimate composition. They may come from both domestic and import. Therefore, matric A can be divided into domestic direct consumption coefficient matrices A_d and import direct consumption coefficient matrices A_m. To calculate the embedded carbon emission of one country, here the author only involved A_d. Consequently, Equation (4-1) can evolve to:

$$X= A_dX+Y \text{ (Equation 4.2)}$$

Thus, after conversion:

$$X = (I – A_d)^{-1} Y \text{ (Equation 4.3)}$$

Here, A represents the direct consumption coefficient matrix, including every element $a_{ij} = x_{ij} / x_j$, which means how many products from sector i are required as inputs to produce a single unit of product j. $(I – A_d)^{-1}$ represents the inverse matrix of Leontief. X is the matrix of total output, while Y is the matrix of final products containing additional final products.

Input-output analysis has been widely used to investigate the relationship between carbon dioxide (CO_2) and international trade. To construct the total carbon emission coefficient, the author therefore introduces the direct carbon emission coefficient C, thus:

$$EC=C_i (I – A_d)^{-1} Y \text{ (Equation 4.4)}$$

Each element, C, carbon emission intensity, represents the amount of carbon dioxide emissions per unit of product i output. It can be represented by the quotient of the overall production of sector i divided by the sector's total CO_2 emissions shown in Table 20. Finally, the formula for the hidden carbon in export trade for specific sector i in each country can be determined by:

$$EC_i = C_i (I - A_d)^{-1} Y^{ex} \text{ (Equation 4.5)}$$

Furthermore, as the CBAM is not levied as a tax on exported items, but rather functions as a fiscal contribution based on the carbon emissions associated with those imported products. To calculate the EU import carbon tariffs by different sectors, the author uses the carbon price product that will charge in different scenarios (CP_x) and EC_i got in last step, then divide by the imports value (at market prices) P^{im} , then get the related carbon tariffs for further shock in different scenarios—got the results shown in Table 17 and Table 18.

$$CT = CP_x * EC_i / P^{im} \text{ (Equation 4.6)}$$

5. Results and Data Analysis

The results are generated in this chapter by using the different carbon tariffs calculated by MRIO in different scenarios in GTAP.

5.1 Changes in the Output of Different Sectors (China only)

The implementation of carbon tariffs may prompt producers to curtail production due to cost constraints, reallocate production towards alternative replacements, or seek out alternative trade partners. Alternative industries have the potential to yield advantageous outcomes and enhance productivity. The abovementioned phenomenon is expected to significantly influence downstream or upstream industries, owing to its inherent intuitiveness. However, it is worth noting that carbon tariffs can incentivize reallocating domestic production resources, such as labor costs, from sectors that face higher tax burdens to less impacted sectors. This might result in a moderate increase in domestic production for the latter sectors—the result or outcome of a process or calculation.

Conversely, adopting carbon tariffs will engender a heightened corporate focus on carbon emissions, thereby the adoption of new energy sources, the proliferation of green energy, and technological advancements. Exporters that have been impacted will actively enhance collaboration with domestic green environmental protection enterprises and technology firms and implement additional strategies to address the potential decline in exports. Ultimately, it is anticipated that the output of these sectors will experience growth rather than a drop, as they have demonstrated more adaptability to the new emission reduction and energy-saving environment following the implementation of green innovation. That will be the best situation and the result of carbon tariffs from the emission target perspective.

Table 11: Changes in the Output of Different Sectors (China only)

Sectors	**Scenario 1**	**Scenario 2**	**Scenario 3**
a1- Mineral(cement)	-0.137	-0.267	-0.262
a2- Ferrous metals (Iron and Steel)	-0.187	-0.378	-0.374
a3- Metals (Aluminum)	0.000	-0.010	-0.011
a4- Chemical products (Fertilizers)	-0.161	-0.349	-0.331
a5- Downstream industries	0.026	0.055	0.053
a6- Substitute	0.032	0.067	0.063
a7- Trade and logistics	-0.003	-0.006	-0.006
a8- others	0.013	0.028	0.027

Based on the data presented in Table 11, the influence on various industry sectors in China is contingent upon the escalation of carbon pricing, with a direct correlation between the carbon tariff standard and its effects. However, in Scenario Three, the impact experiences a minor drop when China implements similar taxation measures. Besides, the export of industries a1- mineral, a2- ferrous metals, a4- chemical products, and a7-Trade and logistics from China to the European Union (EU) has experienced negative impacts, especially for a1- mineral, a2- ferrous metals and a3-metals. That's because these sectors included EITE industries- Aluminum, Cement, Fertilizers, and Iron and Steel- primarily encompass industries with substantial carbon emissions. Furthermore, it is noteworthy that the magnitude of the influence exerted by a2-ferrous metals is the greatest across all examined scenarios, especially in scenario 2, where the output impact reached -37.8%. This is because China's export of a2-ferrous to Europe represents a substantial proportion of its total exports, leading to a comparatively more significant influence on output.

Of the variables mentioned above, a2-ferrous metals exert the most significant impact. Interestingly, a3-metals exhibits minimal influence, possibly due to the trade between Russia and the EU experiencing some negative implications due to the Russian-Ukrainian war. In addition, for the majority of sectors, scenario 2 experienced the worst situation except for a5- Downstream industries, a6- Substitute, and a8- others, and it is evident that because in such a scenario, the carbon tariff is the highest, then most EITE industries decrease in output, thus benefit for the substitutes and those industries did not involve to the CBAM. Except for a7- Trade and logistics sector output decrease, other enterprises not engaged in CBAM may have positive output due to implementing CBAM.

5.2 Changes in the Export of Different Sectors (China only)

Table 12. Changes in the Export of Different Sectors (China only)

Scenarios	Scenario1	Scenario2	Scenario3
a1- Mineral(cement)	-21.029	-40.726	-40.712
a2- Ferrous metals (Iron and Steel)	-17.309	-35.056	-34.815
a3- Metals (Aluminum)	0.526	0.762	0.669
a4- Chemical products (Fertilizers)	-9.425	-20.488	-20.498
a5- Downstream industries	1.541	3.192	3.105
a6- Substitute	1.209	2.543	2.388
a7- Trade and logistics	0.625	1.240	1.230
a8- others	0.890	1.801	1.770

When examining the matter of exports, it is imperative to analyze multiple facets. This is because exports do not solely pertain to the movement of products from China to

Europe; instead, each alteration in one trade chain has the potential to impact other trade chains. From the export standpoint, several industries have exhibited indications of nearly equivalent output changes. The implementation of carbon tariffs has thus far been limited to Europe, while other nations have yet to adopt such measures. Consequently, this carbon taxation discrepancy may increase the export activities of different regions. Based on the data presented in Table 12, it is evident that the exports of the three high-carbon emission industries (a1- mineral, a2- ferrous metals, and a4- chemical products) exhibit a decline as the carbon tariff is raised. Notably, sector a1- mineral experiences the most pronounced impact, particularly in the second scenario, with a reduction of -40.73%, and scenarios 1 and 3, with a negative effect with numbers -21% and -40.71%, respectively. Implementing a carbon price is expected to significantly affect industries with substantial carbon emissions. Furthermore, it should be noted that in the context of Scenario 3, China's imposition of an additional export carbon tariff will inevitably result in adverse consequences for its exports. It is essential to acknowledge that any form of taxation will inevitably be passed on to trade exports to a certain degree.

Conversely, in the case of industries that have not been subjected to taxation, exports have a favorable outcome, with the downstream sector of a5, encompassing machinery production, vehicle and spare parts manufacturing, and construction, emerging as particularly lucrative. In the second scenario, an increase of 3 percentage points was observed in growth. The a7 trade and logistics industry has demonstrated a beneficial influence, as seen by significant increases in the overall export volume. Specifically, the export volume has experienced growth rates of 62%, 124%, and 123% in three distinct situations. Nevertheless, based on the analysis of Scenario 3, it becomes evident that the implementation of bilateral taxation has predominantly negative consequences across various situations. Specifically, harmful effects are observed in industries subject to taxation, while even industries exempt from taxation experience detrimental impacts, particularly concerning exports. However, it is essential to note that the taxed industries warrant further discussion. In industries characterized by high carbon emissions and subject to significant tax burdens, the extent of his savings on exports is relatively modest.

5.3 Export

Table 13. Changes in the Export by Countries

Countries	Scenario 1	Scenario 2	Scenario 3
CHN	-0.032	-0.066	-0.071
USA	0.003	0.005	0.004
RUS	-0.005	-0.018	-0.018
IND	-0.038	-0.093	-0.091
KOR	0.003	0.005	0.009
EU	0.014	0.036	0.031
TUR	0.014	0.027	0.027
UKR	0.010	0.017	0.016

BRA	-0.003	-0.008	-0.008
SAU	-0.027	-0.064	-0.061
ROW	-0.001	-0.003	-0.002

Based on the chart depicting the impact of three distinct scenarios on various countries, to China, the export will be negatively impacted by the CBAM, showing the result -3.2%, -6.6%, and -7.1% in scenarios 1, 2, and 3. Notably, the second scenario, characterized by the European Union's implementation of substantial carbon tariffs on these countries, exhibits the most significant impact among the three scenarios. In addition, in Scenario 3, it is evident that China's imposition of higher tariffs will impact its exports, per the principles of economics. The data exhibits a continuous decline, transitioning a decrease of 0.05% from Scenario 2 to Scenario 3. The trade will undoubtedly be harmed by increasing taxes from export and import countries. If the goal is to enhance the growth of exports, it may not be prudent to persist with the imposition of carbon tariffs on exports.
EU will be the most beneficial union with the increasing number of 1.4%, 3.6%, and 3.1% on export, especially for scenario 2, due to most manufacturing countries burden the same amount of carbon tariffs and decreased export, and finally in favor of the EU export.
Apart from China, Russia, India, Brazil, Saudi Arabia, and several other nations are associated with negative consequences. At the same time, the United States, South Korea, Europe, Turkey, and Ukraine are linked to positive outcomes. Remarkably, India will decrease the most in export sessions in Scenario 2, with a high number of -9.3%.

The devaluation of exports can indicate a nation's diminished trade activity and decreased competitiveness of its goods, resulting in diminished foreign currency revenues and a deceleration of economic growth. Consequently, there is a decline in the rate of employment, GDP, and welfare. The data presented in Table 13 indicates that most developing nations continue to experience varying losses. While the magnitude of the losses may not be substantial, this data nevertheless holds some reference relevance.

5.4 GDP

As a significant producer, China has always maintained its position as a prominent exporter due to its ability to offer cost-effective products, operate an efficient supply chain, and demonstrate high production efficiency. Moreover, China has always relied significantly on foreign commerce due to this factor. The percentage reached a peak of 64.2% in the year 2006 (Figure 7). China generates a substantial trade surplus annually, exporting significant goods to various nations worldwide. This surplus accounts for around 1% of the country's gross national product. Trade has a significant impact on GDP. Therefore, the impact on GDP and trade are positively correlated to some degree.

Table 14. Changes in the GDP

Countries	Scenario 1	Scenario 2	Scenario 3
CHN	-0.015	-0.031	-0.030
USA	0.007	0.016	0.017
RUS	0.001	-0.001	-0.001
IND	-0.017	-0.041	-0.040
KOR	0.004	0.009	0.010
EU	0.023	0.050	0.048
TUR	0.010	0.020	0.020
UKR	0.010	0.016	0.016
BRA	0.005	0.011	0.011
SAU	-0.021	-0.049	-0.046
ROW	0.003	0.006	0.006

Regarding the effect of the simulation outcomes on the exports of various nations, some parallel patterns that resonate with the preceding findings in export can be observed. The GDP for China in different scenarios decreased by 1.5%, 3.1%, and 3%, respectively. According to economic knowledge, the components of GDP: Y = C + I + G + NX [56], which means GDP is a result of the function of C (consumption), I (investment), G (government purchases), and NX (net exports), thus, here it may be the crucial consequences for the decrease in net export reflect the last session discussed.

The imposition of carbon tariffs, denoted as CBAM, would have detrimental consequences for China, India, Saudi Arabia, and Russia. Notably, the most severe outcome arises from the European Union's implementation of carbon tariffs across the board, resulting in a 0.049% reduction in Saudi Arabia's GDP in Scenario 2. Meanwhile, it is noteworthy that countries such as the United States and South Korea have experienced minimal impact and even observed certain growth levels.

This observation suggests that the imposition of higher carbon prices disproportionately disadvantages developing nations while exerting minimal influence on affluent countries. In three distinct scenarios, Europe's GDP is projected to grow by 2.3%, 5%, and 4.8%. This result further substantiates the notion that implementing the CBAM policy is likely to result in a certain degree of inequality and is not beneficial to the economic advancement of developing countries. The plausibility of this potentially being an additional manifestation of trade protectionism must be considered, as it may further burden developing nations and go against the principle of equitable development. Moreover, Saudi Arabia will impact the most in the GDP session.

5.5 Social Welfare

Table 15. Changes in the Social Welfare

Countries	Scenario 1	Scenario 2	Scenario 3

CHN	-729.372	-1505.653	-1528.039
USA	140.496	308.762	310.036
RUS	-54.110	-130.762	-129.102
IND	-123.092	-295.065	-290.044
KOR	7.815	19.895	25.827
EU	483.030	853.455	756.578
TUR	9.656	18.396	18.237
UKR	2.064	2.355	2.445
BRA	6.183	11.443	12.611
SAU	-29.192	-67.689	-65.467
ROW	-47.061	-158.371	-136.476

(Data in USD million)

The social welfare system encompasses a range of institutional arrangements for fulfilling human needs and promoting well-being within a given society. These arrangements include conceptual frameworks, material resources, organizational structures, and trained personnel. In conjunction with the economic, political, and educational systems, it functions as a mechanism for upholding the regular functioning of society.

The result table reveals a substantial decline in China's social welfare across all three scenarios, shown as -$729.37, -$1505.65, and -$1528.04 million.
Furthermore, it is worth noting that countries such as Russia, India, and Saudi Arabia have also made substantial reductions in their respective areas of concern. For instance, in three scenarios, India demonstrated -$123.09, -$295.07, and -$290.04 million.

Nevertheless, compared to the other countries, it can be observed that the United States, South Korea, the EU, Turkey, Ukraine, and Brazil exert favorable influences on social welfare, especially for the EU in scenario 3, which demonstrated a significant growth 756.578 $US million, and that is the benefit from the industries reshoring and tax income. Turkey and Ukraine, as developing countries, can benefit from the CBAM in social welfare, maybe because of the friendly trade environment among Europe under several collaborations such as EGD (European Green Deal), ECFGA (Deep and Comprehensive Free Trade Area), and so forth.

This further substantiates the unequal outcomes of the CBAM policy in terms of social welfare, particularly when considering the disparities between developed and developing nations. In the second scenario, it is notable that the gap between China and Europe reaches a maximum of $2359.1 million. In conclusion, the result again proved the inequality of the CBAM policy and the potential negative effect on developing countries, and China will impact the most in the welfare session.

5.6 Carbon Emissions

Table 16. Changes in the Carbon Emission

Countries	Scenario1	Scenario2	Scenario3
CHN	-0.045	-0.091	-0.089
USA	0.003	0.008	0.008
RUS	-0.015	-0.04	-0.039
IND	-0.033	-0.079	-0.078
KOR	-0.001	-0.003	0.001
EU	0.055	0.123	0.118
TUR	0.007	0.012	0.012
UKR	0.01	0.008	0.008
BRA	0.007	0.014	0.014
SAU	-0.03	-0.068	-0.066
ROW	0.001	0.002	0.002

From the standpoint of carbon emissions shown in Table 16, the outcomes of the CBAM strategy may not be entirely satisfying.
The carbon emissions in China have experienced corresponding changes of -0.045%, -0.091%, and -0.089% in response to three distinct scenarios wherein the EU unilaterally enforces varying CBAM measures, and China reacts. This finding suggests that implementing CBAM exerts a certain degree of constraint on carbon emissions within China with relatively little impact.

China, Russia, India, and Saudi Arabia are all associated with negative export consequences, thus reflecting a decrease in carbon emissions. Moreover, among the several scenarios, Scenario 2, which charged the highest carbon tariffs, can be identified as the most severe influence. South Korea may also have a positive carbon emission influence, but only in specific scenarios (1 and 2).

Nevertheless, the US, EU, Turkey, Ukraine, Brazil, and ROW will increase carbon emissions. It is evident that an increase in tax collection by the European Union does not necessarily lead to a reduction in carbon emissions for all countries. It also contradicts the initial objective of the European Union to implement a CBAM.

5.7 Scenarios Discussion

In Scenario 1, wherein the European Union willingly undertakes 50% of the carbon tariff burden, it is undoubtedly the most advantageous outcome for China. Nevertheless, this assertion only holds when considering Europe from multiple aspects.

In the second scenario, wherein the European Union enforces CBAM without any corresponding retaliatory actions from China, there are negative consequences for China and many developing nations such as India, Russia, and Saudi Arabia. In contrast, some developed countries like the US, South Korea, and the EU experience some advantages, and the EU benefits more than all. The discussion aspects almost double the digit compared to those in scenario 1.

In the third scenario, China's imposition of retaliatory taxes exhibits a marginal impact on the output and trade exports of different industries within the country compared to the second scenario. However, this impact is not deemed to be statistically significant. This phenomenon could be attributed to the fact that the associated products constitute a minor fraction of China's total exports. Conversely, it yields a marginal increase in China's Gross Domestic Product (GDP). The observed phenomenon can be attributed to the redirection of linked products, which have been negatively affected by the impact of exports, into the home market. As a result, there is an increase in domestic purchasing power. Nevertheless, decreased exports' impact mitigates the decline's overall magnitude. However, it is essential to note that this phenomenon negatively affects society's overall well-being. Moreover, Scenario 3 does not have a favorable outcome regarding emissions reduction for China and Europe compared to Scenario 2. Consequently, implementing retaliatory taxation would not be a sensible action for China.

Compared to advanced nations such as Europe, the United States, and Japan, China initiated its industrialization process at a comparatively delayed stage. When formulating policy, Europe must consider the diverse levels of industrialization and the variable degrees of progress in green energy technology across different countries. For carbon-emitting nations, inhibiting their trade development is not conducive to their growth and the possibility of achieving carbon neutrality. Implementing a fair taxation plan is important in mitigating adverse effects on exports, social welfare, and GDP for all parties involved. Implementing a consistent tax rate on all importing countries, based on EU carbon pricing rules, may have detrimental effects on the interests of developing nations and result in undesirable scenarios of reciprocal taxation.

5.8 Limitation of the model

First, the GTAP model is a relatively static model, and it is challenging to capture some dynamic effects that may exist in trade changes, such as black swan events, trade sanctions, and other geopolitical influences. Secondly, the simulation and part of the data in this thesis are recursively based on CEPII Data forecasts; actual elements may differ from estimated values. Thirdly, the three scenarios simulated in this thesis are based on projections, and the accurate taxation method may vary. Forth, due to the industries categories in GTAP, the specific carbon-intensive industries cannot precisely be the same as the products covered in CBAM policies; this may cause a variation compared with the actual situation. Another limitation is that this article only considers the case of bilateral tariffs between the EU and China. The real-world problems could be more complicated than this. If there are other possibilities, the results will also impact the economy and trade differently, and it is another field for future research.

6. Results and Recommendations

6.1 Results

From the previous discussion, in the scenario of the EU imposing carbon tariffs unilaterally, it can be observed that China's GDP, exports, and welfare decrease, and this reduction tends to widen as the tariff standards increase. The situation is similar for developing countries like Russia, India, and Saudi Arabia. However, the condition differs for developed countries like the EU and the US. Those countries demonstrate a positive outcome for trade and some macroeconomic factors.

The scenarios discussed in this thesis suggest that China may experience varying positive effects on carbon emissions. Moreover, the impact on countries such as Russia, India, and Saudi Arabia is the same. This result is the same as in the previous study. [25] To some degree, CBAM may contribute less to global carbon emissions. To effectively reduce carbon emissions, it would be advisable for these countries to prioritize developing and implementing their green technologies and policies, such as CCUS. However, it is anticipated that carbon emissions will increase in the United States, European Union, Turkey, Ukraine, Brazil, and other countries around the globe. So, the policy has limited influence on worldwide carbon emissions.

The implementation of carbon tariffs by CBAM is expected to result in a decline in China's domestic production for industries such as a1- Cement, a2- Iron and Steel, a3- Aluminum, a4- Fertilizers, and a7- Trade and logistics. Export reflects the same trend except a7 trade and logistics sectors turn positive as it is an overall index for all the industries and export countries (downstream and other sectors growth). The degree of reduction will escalate with the implementation of more stringent carbon tariff regulations, and little mitigate the influence when China chooses to let the EU pay for some of the carbon tariffs as a carbon consumer.

In conclusion, implementing CBAM carbon tariffs can be considered a trade protection mechanism that prioritizes environmental sustainability. However, it is essential to note that these levies have faced opposition from both the WTO and developing nations, especially China. The simulation results indicate that the strategy will benefit wealthy countries such as the European Union, the United States, and South Korea while not benefiting some emerging countries. Hence, certain nations express their opposition to this particular policy. Despite observing a small degree of carbon emission reduction in nations such as China, Russia, India, and Saudi Arabia, it is crucial to acknowledge and address the significant trade implications associated with this phenomenon, which warrant considerable attention and worry. Suppose China reciprocates by imposing half of the carbon tariffs on the EU as consumers. In that case, the performance may not meet the anticipated standards, which will worsen the trade and the producers' benefits.

6.2 Recommendations

Prior research has demonstrated that a more significant proportion of low-carbon energy sources, like some new energies, is associated with a higher probability of reaching a carbon peak. This probability increases when the ratio exceeds 35%, and the GDP per capita falls between $20,000 and $35,000.[60] Based on a recursive study of historical data on GDP growth, China's per capita GDP is projected to exceed $20,000 by 2030. Consequently, to attain carbon peak and subsequent carbon neutral objectives, China needs to adopt measures from two perspectives: GDP growth and Green-energy enhancement and transition.

To begin with, it is imperative to proactively advocate for adopting alternative energy sources, curtail the consumption of coal, accelerate the development of environmentally friendly energy technologies and carbon markets, and optimize the utilization of low-carbon energy sources during the transition period. This should be accompanied by efforts to mitigate carbon emissions from high-carbon energy sources.

Moreover, China needs to build effective communication channels with its European counterparts to engage in meaningful discussions regarding taxation and mitigation techniques, aiming to identify more rational approaches. Furthermore, it is imperative to have a proactive approach to monitoring the green energy legislation and trade policies related to environmental conservation across different nations. Besides, enhancing the examination of worldwide green energy endeavors and fostering cooperation among trade alliances could mitigate the impact of unilateral policy demands and adverse consequences. Implementing these policies is essential in facilitating the anticipated expansion of GDP and trade.

On the other hand, the analysis of the simulation outcomes reported in this thesis demonstrates that implementing reverse taxes in Scenario 3 yields adverse consequences for China and Europe. Hence, it is imperative for China and other developing nations characterized by significant carbon emissions in their export activities to exercise caution and be attentive to potential emerging obstacles in the form of green trade barriers.

In conclusion, a comprehensive strategy encompassing international cooperation and aggressive domestic actions to balance trade and the achievement of green goals is vital in effectively tackling carbon emissions and making meaningful contributions towards global environmental objectives. The successful mitigation of carbon emissions necessitates proactive and voluntary measures by nations with high emissions levels. China ought to assume a leadership position as a significant participant in the manufacturing sector and a notable contributor to carbon emissions. China has the potential to set a precedent in the formulation of effective emission reduction policies, both in the short-term and long-term, and needs to positively discuss with the EU the solution to make the trade equal and set up funding by using the carbon tariffs to support the global green projects and energy supports. This entails enhancing the efficacy of the domestic carbon trading market, progressively broadening the purview of carbon-emitting sectors, establishing carbon prices customized to its specific circumstances, overseeing market implementation, imposing more stringent penalties, bolstering investments in green finance, and aligning with global carbon trading markets.

7. Conclusions

From the perspective of various industries, macroeconomic factors, and carbon emissions, this study examines the probable consequences of the Carbon Border Adjustment Mechanism policy, mainly focusing on China. By doing policy analysis and using the MRIO and GTAP model to do the simulation and comparison analysis with nations that may be impacted, the author found it becomes evident that the CBAM policy is more functional in trade and economic influence and does little help to the environment, it has the potential to behave as a manifestation of green protectionism. Implementing this policy has notable negative consequences for China and certain developing countries and will benefit some developed countries and the countries with preferential policies with the EU.

The findings from the simulation analysis indicate that the implementation of the European Union's taxation policy on high-carbon items had adverse effects on various aspects of China's economy, including its GDP, export trade, and social welfare with the number of -7.1%, -0.3% and $-1528.04 million. These negative impacts were observed both in the case of unilateral taxation by the EU and in scenarios where a mutual tariff was applied. Moreover, in the context of mutual tax, the adverse effects on export trade and social welfare were further aggravated with -7.1%, -0.3%, and $-1528.04 million. Thus, bilateral carbon tariffs would not significantly help in this CBAM case.

The CBAM policy poses a potential threat. Nonetheless, it concurrently serves as a catalyst for the green growth of the countries involved. It raises the awareness that all the nations that will export to the EU need to pay attention to carbon emissions and global warming and also put green policies into practice in high-carbon emission countries. To China, up to Sep 2023, it speeds up the green energy transition by all means and has gradually expanded the carbon trading market. The surrounding projects have already proven this function.

The most important thing for China is effectively achieving its dual carbon objectives and balancing China's trade cooperation with carbon emissions. It requires contemplating Sino-European energy transition cooperation and domestic energy resilience and flexibility. It involves developing the green finance industry, increasing green financing, decreasing support for high-carbon initiatives, and providing ample funding for technological innovations in low-carbon businesses. Meanwhile, China must also increase the data's traceability to facilitate efficient feedback for the global energy transition and adequate progress and diversify integration into international multilateral carbon policies. Taking those measures to accomplish dual carbon goals can enhance trading competitiveness, increase commerce with the EU, minimize policy impacts of CBAM on the economy, and cooperate through environmental and energy sustainability.

Regardless of perspective, using only the EU standard one-size-fits-all method for collecting carbon tariffs is unscientific and unjust. Importers should also bear the duty of carbon-intensive usage in trade exchanges and actively assume the responsibility and benchmarking role of sharing advanced green technologies to create a fair and green trade environment. All countries should scientifically attain environmental goals based on typical development standards. Protectionism and unilateralism are the only outcomes of aggressive tax policies. The problem of global climate requires a global solution. To achieve a dynamic equilibrium between the economy and the environment, each trade participant and final consumer must shoulder the responsibilities within their capacities; it requires active coordination and communication among national governments, the amicable implementation of policies within a particular space of flexibility, the establishment of a transnational energy internet to monitor carbon changes in real-time and coordinate actions, the solution from WTO to initiate the Subsidies and Countervailing Measures Agreement(SCM) measures to ensure the equality and the strengthening of cooperation and incentives to form a virtuous circle on the path to sustainable development rather than as a reason for exacerbating trade discrimination.

Bibliography

[1] Europe Commission . (2023). *EUROPEAN COMMISSION DIRECTORATE-GENERAL TAXATION AND CUSTOMS UNION GUIDANCE DOCUMENT ON CBAM IMPLEMENTATION FOR INSTALLATION OPERATORS OUTSIDE THE EU*. https://taxation-customs.ec.europa.eu/system/files/2023-08/CBAM%20Guidance_non-EU%20installations.pdf

[2] Atlas, G. C. (2021). *Carbon Emissions*. Global Carbon Atlas. https://globalcarbonatlas.org/emissions/carbon-emissions/

[3] Commission, european. (n.d.). *EU Emissions Trading System (EU ETS)*. Climate.ec.europa.eu. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en#a-cap-and-trade-system

[4] European Commission. (2021, July 14). *Carbon Border Adjustment Mechanism: Questions and Answers*. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/qanda_21_3661

[5] Acar, S., Aşıcı, A. A., & Yeldan, A. E. (2021). Potential effects of the EU's carbon border adjustment mechanism on the Turkish economy. *Environment, Development and Sustainability*, *24*(6), 8162–8194. https://doi.org/10.1007/s10668-021-01779-1

[6] Bao, Q., Tang, L., Zhang, Z., & Wang, S. (2013). Impacts of border carbon adjustments on China's sectoral emissions: Simulations with a dynamic computable general equilibrium model. *China Economic Review*, *24*, 77–94. https://doi.org/10.1016/j.chieco.2012.11.002

[7] Zhong, J., & Pei, J. (2023). Carbon border adjustment mechanism: a systematic literature review of the latest developments. *Climate Policy*, 1–15. https://doi.org/10.1080/14693062.2023.2190074

[8] Steenbrink, F. (2022). *Impact of the Carbon Border Adjustment Mechanism An economic and geopolitical assessment of the German- Chinese aluminium trade flows*.

[9] Europe, U. (2021). *Fit for 55: Delivering on the proposals*. Commission.europa.eu. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en

[10] Trisos (south Africa, Romero, J., Dodman, D., Geden ; Bronwyn, O., & Wei, H. ; H.-O. P. ; Y.-M. (2023). Amjad Abdulla (Maldives), Edvin Aldrian (Indonesia), Ko Barrett (United States of America), Eduardo Calvo (Peru), Carlo Carraro (Italy). In *Zinta Zommers (Latvia)), Siri Eriksen*. Pakistan. https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

[11] Ritchie, H., & Roser, M. (2021). *CO_2 emissions*. Our World in Data. https://ourworldindata.org/co2-emissions

[12] Climate Neutral Now. (2021, March 26). *Newsroom.unfccc.int*. https://unfccc.int/climate-neutral-now

[13] *PARIS AGREEMENT (mm UNITED NATIONS 2015*. (n.d.).

[14] Bank, W. (2022). State and Trends of Carbon Pricing 2022. In *openknowledge.worldbank.org*. Washington, DC: World Bank. https://openknowledge.worldbank.org/entities/publication/a1abead2-de91-5992-bb7a-73d8aaaf767f

[15] Zhu, J., Zheng, T., & Fang, J. (2013). Carbon Emissions and Socio-economic Development. *Science and society*, https://doi.org.10.19524/j.cnki.10-1009/g3.2013.02.001
[16] Muhammad, S., Pan, Y., Agha, M. H., Umar, M., & Chen, S. (2022). Industrial structure, energy intensity and environmental efficiency across developed and developing economies: The intermediary role of primary, secondary and tertiary industry. *Energy*, *247*, 123576. https://doi.org/10.1016/j.energy.2022.123576
[17] Bank, W. (2023). State and Trends of Carbon Pricing 2023. *Openknowledge.worldbank.org*. https://doi.org/10.1596/39796
[18] *IEA,* based on identified pledges in the law, proposed legislation, policy documents, and oral pledges.
[19] Net Zero Tracker. (2023, March 12). Global Net Zero Coverage: Net Zero Numbers [Press Release]. Retrieved from https://zerotracker.net/.
[20] UNEP. (2022, October 21). *Emissions Gap Report 2022*. UNEP - UN Environment Programme. https://www.unep.org/resources/emissions-gap-report-2022
[21] Chepeliev, M. (2021b). Possible Implications of the European Carbon Border Adjustment Mechanism for Ukraine and Other EU Trading Partners. *Energy RESEARCH LETTERS*, *2*(1). https://doi.org/10.46557/001c.21527
[22] Eicke, L., Weko, S., Apergi, M., & Marian, A. (2021). Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism. *Energy Research & Social Science*, *80*, 102240. https://doi.org/10.1016/j.erss.2021.102240
[23] Zhong, J., & Pei, J. (2023b). Carbon border adjustment mechanism: a systematic literature review of the latest developments. *Climate Policy*, 1–15. https://doi.org/10.1080/14693062.2023.2190074
[24] Bierbrauer, F., Felbermayr, G., Ockenfels, A., Schmidt, K., Südekum, J., & Kiel. (2021). *A CO_2-border adjustment mechanism as a building block of a climate club*. https://www.econstor.eu/bitstream/10419/232523/1/1752576446.pdf
[25] Sun, X., Mi, Z., Cheng, L., Coffman, D., & Liu, Y. (2023). The Carbon Border Adjustment Mechanism is inefficient in addressing carbon leakage and results in unfair welfare losses. *Fundamental Research*. https://doi.org/10.1016/j.fmre.2023.02.026
[26] Dechezleprêtre, A., Gennaioli, C., Martin, R., Mirabelle Muûls, & Stoerk, T. (2019). *Searching for carbon leaks in multinational companies*. https://doi.org/10.25561/17965
[27] Chepeliev, M. (2021a). Possible Implications of the European Carbon Border Adjustment Mechanism for Ukraine and Other EU Trading Partners. *Energy RESEARCH LETTERS*, *2*(1). https://doi.org/10.46557/001c.21527
[28] Nations, U. (1997). *Kyoto Protocol.* United Nations.
[29] WTO. (2019). *The General Agreement on Tariffs and Trade (GATT 1947)*. Wto.org. https://www.wto.org/english/docs_e/legal_e/gatt47_01_e.htm
[30] Venzke, I., & Vidigal, G. (2022). Are Trade Measures to Tackle the Climate Crisis the End of Differentiated Responsibilities? The Case of the EU Carbon Border Adjustment Mechanism (CBAM). *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4013767
[31] Böhringer, C., Fischer, C., Rosendahl, K. E., & Rutherford, T. F. (2022). Potential impacts and challenges of border carbon adjustments. *Nature Climate Change*. https://doi.org/10.1038/s41558-021-01250-z

[32] Lim, B., Hong, K., Yoon, J., Chang, J.-I., & Cheong, I. (2021). Pitfalls of the EU's Carbon Border Adjustment Mechanism. *Energies*, *14*(21), 7303. https://doi.org/10.3390/en14217303
[33] *United Nations. (2020).Yearbook of Global Climate Action 2020 Marrakech Partnership for Global Climate Action Global Climate Action Global Climate Action*. (n.d.). https://unfccc.int/sites/default/files/resource/2020_Yearbook_final_0.pdf
[34] European Parliament. (2019, March 10). *What is carbon neutrality and how can it be achieved by 2050?* Europa.eu. https://www.europarl.europa.eu/news/en/headlines/society/20190926STO62270/what-is-carbon-neutrality-and-how-can-it-be-achieved-by-2050
[35] Overland, I., & Sabyrbekov, R. (2022). Know your opponent: Which countries might fight the European carbon border adjustment mechanism? *Energy Policy*, *169*, 113175. https://doi.org/10.1016/j.enpol.2022.113175
[36] *European Commission Directorate-General for Trade European Union, Trade in goods with China*. (n.d.). https://webgate.ec.europa.eu/isdb_results/factsheets/country/details_china_en.pdf
[37] *Chinese foreign trade in figures - Santandertrade.com*. (n.d.). Santandertrade.com. https://santandertrade.com/en/portal/analyse-markets/china/foreign-trade-in-figures
[38] CIRS. (2022, July 19). *A Further Step to the EU Carbon Tariff - Regulatory News - Chemicals - CIRS Group*. Www.cirs-Group.com. https://www.cirs-group.com/en/chemicals/a-further-step-to-the-eu-carbon-tariff
[39] Shao, X., Zhong, Y., Liu, W., & Li, R. Y. M. (2021). Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. *Journal of Environmental Management*, *296*, 113189. https://doi.org/10.1016/j.jenvman.2021.113189
[40] Wu, X., Tian, Z., & Guo, J. (2022). A review of the theoretical research and practical progress of carbon neutrality. *Sustainable Operations and Computers*, *3*, 54–66. https://doi.org/10.1016/j.susoc.2021.10.001
[41] European Council. (2022). *Fit for 55*. Www.consilium.europa.eu. https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
[42] User, I. (n.d.). *International Carbon Action Partnership (ICAP)*. International Carbon Action Partnership. https://icapcarbonaction.com/en/ets-prices
[43] huaxia. (2020, September 23). *Xi Focus: Xi announces China aims to achieve carbon neutrality before 2060 - Xinhua | English.news.cn*. Www.xinhuanet.com. https://www.xinhuanet.com/english/2020-09/23/c_139388764.htm
[44] Ministry of Ecology and Environment of the People's Republic of China. (n.d.). *Ecological and environmental policy*. Www.mee.gov.cn. Retrieved September 10, 2023, from https://www.mee.gov.cn/ywgz/zcghtjdd/sthjzc/
[45] Hub, Iisd. S. K. (2021, July 19). *Trading Begins under China's National ETS | News | SDG Knowledge Hub | IISD*. https://sdg.iisd.org/news/trading-begins-under-chinas-national-ets/
[46] Environmental Defense Fund. (2023). *2022 China carbon pricing survey*.
[47] Xue, Y. (2022, January 31). *China to relaunch voluntary emissions reduction plan. Here is why it is important*. South China Morning Post.

https://www.scmp.com/business/article/3165425/what-china-certified-emission-reduction-scheme-and-why-it-important
[48] Li, L., Ye, F., Li, Y., & Chang, C.-T. (2019). How will the Chinese Certified Emission Reduction scheme save cost for the national carbon trading system? *Journal of Environmental Management*, *244*, 99–109. https://doi.org/10.1016/j.jenvman.2019.04.100
[49] Wang, Q., Qu, J., Wang, B., Wang, P., & Yang, T. (2019). Green technology innovation development in China in 1990–2015. *Science of the Total Environment*, *696*, 134008. https://doi.org/10.1016/j.scitotenv.2019.134008
[50] Ministry of Ecology and Environment of the People's Republic of China. (2022). *The First Compliance Period Report National Carbon Emissions Trading Market*. Retrieved from https://www.mee.gov.cn/ywgz/ydqhbh/wsqtkz/202212/P020221230799532329594.pdf.
[51] Chen, Z., Zhang, X., & Chen, F. (2021). Do carbon emission trading schemes stimulate green innovation in enterprises? Evidence from China. *Technological Forecasting and Social Change*, *168*, 120744. https://doi.org/10.1016/j.techfore.2021.120744
[52] Thijs Ten Raa, & Ebrary, I. (2010). *Input-output economics : theory and applications : featuring Asian economies*. World Scientific.
[53] Center for Global Trade Analysis. (n.d.). *About GTAP: GTAP History*. Www.gtap.agecon.purdue.edu. Retrieved September 10, 2023, from https://www.gtap.agecon.purdue.edu/about/history.aspx
[54] Lu, Z. (2013). *Analysis of the Impact of the EU Carbon Border Adjustment Mechanism on Steel and Cement Export Trade*.
[55] Simola, H. (2021). *CBAM! -Assessing potential costs of the EU carbon border adjustment mechanism for emerging economies Bank of Finland, BOFIT Bank of Finland Institute for Emerging Economies*.
[56] N Gregory Mankiw, & Taylor, M. P. (2015). *Economics*. Cengage Learning.
[57] Kardish, C., Mattia, M., Mattia, M., & Hall, M. (2021, August 20). *Which countries are most exposed to the EU's proposed carbon tariffs?* Resource Trade. https://resourcetrade.earth/publications/which-countries-are-most-exposed-to-the-eus-proposed-carbon-tariffs
[58] European Union. (2023). *REGULATION (EU) 2023/956 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 10 May 2023 establishing a carbon border adjustment mechanism (Text with EEA relevance)*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0956
[59] Energy & Climate Intelligence Unit. (2023). *Net Zero Tracker*. Energy & Climate Intelligence Unit. https://eciu.net/netzerotracker
[60] Zhang, Z., & Zhang, Y. (2023). Study on Carbon Peak and Carbon Sink Capacity in Major Carbon Emitting Countries Worldwide. *Forest Resources Management*.
[61] IPCC. (2023). *AR6 Synthesis Report: Summary for Policymakers Headline Statements*. Www.ipcc.ch. https://www.ipcc.ch/report/ar6/syr/resources/spm-headline-statements/
[62] IPCC. (2023b, June 16). *Overarching Frequently Asked Questions and Answers-Sixth assessment report*. IPCC. https://www.ipcc.ch/report/ar6/wg2/downloads/faqs/IPCC_AR6_WGII_Overaching_OutreachFAQ4.pdf

[63] REN21. (2022). *RENEWABLES 2022 GLOBAL STATUS REPORT*. Www.ren21.net. https://www.ren21.net/gsr-2022/pages/keymessages/keymessages/
[64] IEA. (2021, November 10). *Greenhouse Gas Emissions from Energy Data Explorer – Data Tools*. IEA. https://www.iea.org/data-and-statistics/data-tools/greenhouse-gas-emissions-from-energy-data-explorer
[65] NASA. (2023). *Climate change: Vital signs of the planet*. Climate Change: Vital Signs of the Planet; NASA. https://climate.nasa.gov/
[66] Lu, Z. (2023). Analysis of the Impacts of the EU Carbon Border Adjustment Mechanism on Steel and Cement Export Trade. *CITIC Construction Investment Securities*.
[67] National Business Daily. (2023, July 12). *Expert: It is neither possible nor reasonable for China's carbon price to reach the level of developed countries.* Www.nbd.com.cn. http://www.nbd.com.cn/rss/xingye_zhengquan/articles/2913328.html
[68] Ministry of Ecology and Environment of the People's Republic of China, D. of C. C. (2023, March 16). *Notice from the Ministry of Ecology and Environment of the People's Republic of China on the Allocation of National Carbon Emission Trading Quotas for the Years 2021 and 2022"*. Www.mee.gov.cn. https://www.mee.gov.cn/zcwj/zcjd/202303/t20230316_1019718.shtml
[69] Ministry of Ecology and Environment of the People's Republic of China . (2022). *Officials from the Ministry of Ecology and Environment Discuss the Revision of Technical Guidelines for Corporate Greenhouse Gas Emission Accounting and Verification*.

Appendices

Table 17. Embedded Carbon Emissions for each Sector and Country

Country	Sector	To EU
CHN	a1	14.813
CHN	a2	12.104
CHN	a3	2.931
CHN	a4	9.839
CHN	a5	3.017
CHN	a6	1.197
CHN	a7	12.400
CHN	a8	12.155
CHN	Coal	4.861
CHN	Oil	0.225
CHN	Gas	3.577
CHN	Oil_pcts	15.673
CHN	Electricity	45.339
USA	a1	0.418
USA	a2	0.172
USA	a3	0.100
USA	a4	0.457
USA	a5	0.368
USA	a6	0.077
USA	a7	5.754
USA	a8	1.186
USA	Coal	0.022
USA	Oil	0.153
USA	Gas	2.883
USA	Oil_pcts	13.717
USA	Electricity	4.113
RUS	a1	0.661
RUS	a2	0.490
RUS	a3	0.040
RUS	a4	6.573
RUS	a5	0.145
RUS	a6	0.274
RUS	a7	2.508
RUS	a8	0.408
RUS	Coal	0.394
RUS	Oil	0.355
RUS	Gas	4.690
RUS	Oil_pcts	9.367

RUS	Electricity	14.509
IND	a1	2.376
IND	a2	2.047
IND	a3	0.347
IND	a4	6.663
IND	a5	0.200
IND	a6	0.109
IND	a7	2.479
IND	a8	0.928
IND	Coal	0.183
IND	Oil	0.006
IND	Gas	0.072
IND	Oil_pcts	7.659
IND	Electricity	11.199
KOR	a1	0.343
KOR	a2	0.443
KOR	a3	0.040
KOR	a4	0.274
KOR	a5	0.194
KOR	a6	0.023
KOR	a7	1.103
KOR	a8	0.343
KOR	Coal	0.032
KOR	Oil	0.000
KOR	Gas	0.090
KOR	Oil_pcts	1.139
KOR	Electricity	3.149
EU	a1	0.231
EU	a2	0.145
EU	a3	0.039
EU	a4	0.172
EU	a5	0.037
EU	a6	0.023
EU	a7	1.235
EU	a8	0.253
EU	Coal	0.052
EU	Oil	0.005
EU	Gas	0.354
EU	Oil_pcts	0.960
EU	Electricity	0.950
TUR	a1	0.578
TUR	a2	0.246
TUR	a3	0.068

TUR	a4	0.266
TUR	a5	0.140
TUR	a6	0.078
TUR	a7	1.235
TUR	a8	0.639
TUR	Coal	0.229
TUR	Oil	0.000
TUR	Gas	0.223
TUR	Oil_pcts	1.057
TUR	Electricity	2.000
UKR	a1	0.140
UKR	a2	0.280
UKR	a3	0.022
UKR	a4	0.013
UKR	a5	0.033
UKR	a6	0.008
UKR	a7	0.509
UKR	a8	0.366
UKR	Coal	0.024
UKR	Oil	0.004
UKR	Gas	0.372
UKR	Oil_pcts	0.233
UKR	Electricity	2.030
BRA	a1	0.413
BRA	a2	0.161
BRA	a3	0.066
BRA	a4	0.109
BRA	a5	0.007
BRA	a6	0.012
BRA	a7	0.966
BRA	a8	0.335
BRA	Coal	0.000
BRA	Oil	0.052
BRA	Gas	0.047
BRA	Oil_pcts	0.535
BRA	Electricity	0.471
SAU	a1	0.062
SAU	a2	0.028
SAU	a3	0.051
SAU	a4	2.641
SAU	a5	0.045
SAU	a6	0.043
SAU	a7	0.751

SAU	a8	0.071
SAU	Coal	0.000
SAU	Oil	0.114
SAU	Gas	0.147
SAU	Oil_pcts	3.438
SAU	Electricity	1.401
ROW	a1	5.932
ROW	a2	2.474
ROW	a3	1.486
ROW	a4	7.915
ROW	a5	2.835
ROW	a6	1.320
ROW	a7	27.371
ROW	a8	9.744
ROW	Coal	0.636
ROW	Oil	1.384
ROW	Gas	25.494
ROW	Oil_pcts	32.496
ROW	Electricity	36.763

Table 18. Carbon Tariffs for each Sector and Country
(EU import / Carbon- Intensive industries only)

Country	Sector	Tariff by EU
CHN	a1	19.502%
CHN	a2	9.597%
CHN	a3	0.515%
CHN	a4	4.813%
USA	a1	1.534%
USA	a2	2.482%
USA	a3	0.285%
USA	a4	0.388%
RUS	a1	1.328%
RUS	a2	0.703%
RUS	a3	0.047%
RUS	a4	1.305%
IND	a1	4.625%
IND	a2	2.076%
IND	a3	0.527%
IND	a4	1.269%
KOR	a1	14.385%
KOR	a2	2.177%

KOR	a3	0.215%
KOR	a4	0.455%
EU	a1	0.047%
EU	a2	0.017%
EU	a3	0.003%
EU	a4	0.012%
TUR	a1	2.766%
TUR	a2	0.676%
TUR	a3	0.104%
TUR	a4	0.832%
UKR	a1	0.890%
UKR	a2	1.178%
UKR	a3	0.936%
UKR	a4	0.384%
BRA	a1	0.639%
BRA	a2	1.476%
BRA	a3	1.575%
BRA	a4	1.362%
SAU	a1	8.168%
SAU	a2	9.266%
SAU	a3	1.032%
SAU	a4	2.162%
ROW	a1	1.905%
ROW	a2	1.341%
ROW	a3	0.220%
ROW	a4	1.034%

Table 19. Total Output of Final Goods

Country	Sector	CHN	USA	RUS	IND	KOR	EU	TUR	UKR	BRA	SAU	ROW
CHN	a1	1590	39109	4342	3329	2746	15894	1661	187	1650	1849	63396
CHN	a2	2150	38185	4119	3510	2679	15731	1507	176	1612	2117	63848
CHN	a3	3313	50530	6034	6352	4006	22520	2048	242	2205	3430	87180
CHN	a4	2012	49156	5539	4295	3836	21257	1931	191	2714	2430	79377
CHN	a5	3642	205283	21702	15721	14362	83927	8078	955	8986	7285	334749
CHN	a6	1635	39427	3273	2489	1965	14271	1203	131	1267	1867	47673
CHN	a7	1908	54645	6628	6027	5455	25858	1925	297	2726	2737	96402
CHN	a8	14298	505387	59929	67525	49221	195848	16290	2815	17604	21764	811871
CHN	Coal	222	4483	503	508	362	1960	169	24	194	220	8688
CHN	Oil	159	2211	243	336	189	1153	82	15	105	109	6659
CHN	Gas	27	232	35	22	21	216	14	2	10	12	481
CHN	Oil_pcts	713	9859	1085	1509	847	5146	367	68	469	488	29968

CHN	Electricity	437	10356	1172	1118	840	4340	383	51	434	511	17678
USA	a1	555	751	193	111	142	1027	74	6	92	158	4501
USA	a2	419	478	135	92	101	659	45	4	56	132	3099
USA	a3	1239	1167	386	356	317	2000	131	13	182	467	9540
USA	a4	611	1642	385	204	351	3841	186	11	741	400	12284
USA	a5	12956	3289	3978	1674	3167	18146	1172	100	1527	3240	90443
USA	a6	968	813	314	188	257	1840	112	11	173	275	8076
USA	a7	4429	2680	1724	1994	2103	10327	395	96	1522	1167	38661
USA	a8	19468	9332	6688	6923	6515	45982	2218	438	3786	4422	154706
USA	Coal	82	177	42	30	23	210	23	3	19	23	675
USA	Oil	358	705	136	161	113	1679	82	11	136	83	7050
USA	Gas	105	223	59	35	40	523	37	3	23	28	1040
USA	Oil_pcts	935	1743	357	419	297	4478	216	24	363	218	19155
USA	Electricity	317	239	114	103	106	765	38	6	77	86	2901
RUS	a1	171	558	83	94	45	779	124	41	34	60	1568
RUS	a2	245	778	120	94	56	698	77	26	44	117	1948
RUS	a3	321	1005	129	264	86	1187	193	31	78	279	2607
RUS	a4	419	3769	344	214	199	9546	523	163	1099	246	7703
RUS	a5	663	1470	92	365	168	3039	210	191	92	80	7115
RUS	a6	144	547	59	44	36	852	68	25	31	34	1417
RUS	a7	911	2989	281	458	395	5539	428	274	586	347	9809
RUS	a8	1733	4244	280	829	546	6955	1163	627	360	427	15155
RUS	Coal	160	515	70	50	36	511	47	15	44	35	870
RUS	Oil	794	4672	484	334	262	7786	661	234	664	263	9211
RUS	Gas	237	1075	137	103	163	3502	222	345	154	87	2566
RUS	Oil_pcts	666	4802	398	272	247	10505	803	283	816	256	9233
RUS	Electricity	267	1155	119	129	87	2289	184	79	180	110	2923
IND	a1	239	1536	116	49	57	890	148	6	54	191	3330
IND	a2	463	1996	180	98	94	947	126	8	72	494	4682
IND	a3	784	2901	240	149	187	1651	181	12	137	499	7506
IND	a4	1159	19539	1339	316	695	14505	1480	35	2138	2661	31535
IND	a5	1918	13292	629	84	342	7378	994	29	374	878	38916
IND	a6	159	1484	95	26	47	968	111	4	92	171	2604
IND	a7	1607	8126	722	162	627	5622	604	34	723	1046	18849
IND	a8	3500	21911	1998	266	1138	14800	1085	136	1182	2064	42079
IND	Coal	72	526	40	13	22	335	41	2	37	77	1057
IND	Oil	44	447	22	10	17	237	99	1	29	39	1096
IND	Gas	10	101	7	2	4	70	8	0	9	13	182
IND	Oil_pcts	713	7261	358	166	270	3845	1609	19	475	631	17827
IND	Electricity	356	2814	214	60	122	1879	200	9	216	380	5465
KOR	a1	962	1865	277	118	17	710	82	4	77	150	2987
KOR	a2	2135	4625	643	405	83	1817	201	12	187	491	7806
KOR	a3	2381	4474	636	541	60	1793	215	11	209	450	7810

KOR	a4	1855	6275	816	452	165	3283	571	15	352	535	12308
KOR	a5	16020	32208	4988	1726	145	12144	1362	67	1260	2653	50488
KOR	a6	1392	3468	417	206	43	1340	171	8	143	283	4748
KOR	a7	4419	6235	870	637	85	2959	299	22	413	520	12716
KOR	a8	42441	34931	3993	5372	576	15415	1663	143	2530	2571	71661
KOR	Coal	2	3	0	0	0	1	0	0	0	0	6
KOR	Oil	4	7	1	1	0	3	0	0	0	1	20
KOR	Gas	2	3	0	0	0	1	0	0	0	0	5
KOR	Oil_pcts	1421	2888	330	307	70	1327	167	9	142	203	7827
KOR	Electricity	974	1369	179	142	21	590	72	4	76	115	2539
EU	a1	2535	8070	2012	654	565	842	1128	96	399	675	15973
EU	a2	2542	6930	1700	528	555	767	891	82	355	587	14683
EU	a3	5340	14885	3840	1283	1188	1419	2048	183	851	1509	32377
EU	a4	1641	13612	3309	530	585	1327	1391	88	947	992	21903
EU	a5	56758	138924	36703	8286	12161	4245	20982	1635	6927	7690	290709
EU	a6	3063	10391	2501	711	703	908	1408	130	579	805	21145
EU	a7	20941	45850	13783	7395	6211	3682	4057	741	8743	5224	141779
EU	a8	70103	261820	72042	31044	17145	13966	21976	5791	16244	20584	598253
EU	Coal	69	239	61	23	17	21	25	4	17	19	565
EU	Oil	56	209	45	20	16	30	22	8	20	16	512
EU	Gas	81	297	81	27	22	43	38	9	20	23	673
EU	Oil_pcts	1399	5134	1139	491	400	544	579	205	515	397	13634
EU	Electricity	1430	4887	1266	471	351	375	499	81	338	381	11637
TUR	a1	91	540	213	31	26	901	17	10	23	67	1415
TUR	a2	162	652	186	49	36	829	29	7	26	108	1741
TUR	a3	154	622	231	58	36	1145	30	10	28	129	2113
TUR	a4	60	397	251	21	20	1006	13	7	27	105	1563
TUR	a5	380	2300	2024	113	119	9753	50	67	134	306	11565
TUR	a6	91	423	177	25	23	1147	17	9	24	76	1387
TUR	a7	1036	1775	1244	224	448	3667	45	53	307	486	7875
TUR	a8	1142	4497	2954	366	351	11416	84	393	235	1112	19087
TUR	Coal	3	12	6	1	1	25	0	0	1	2	42
TUR	Oil	4	14	5	1	1	31	0	0	1	2	79
TUR	Gas	0	1	0	0	0	2	0	0	0	0	2
TUR	Oil_pcts	62	211	76	22	22	455	7	5	18	33	1171
TUR	Electricity	51	224	100	16	14	462	7	7	11	38	746
UKR	a1	43	161	254	34	13	212	52	1	8	21	408
UKR	a2	60	180	178	29	13	150	17	2	8	40	458
UKR	a3	15	40	147	21	4	77	9	0	3	10	155
UKR	a4	5	31	95	6	2	81	20	0	3	3	83
UKR	a5	112	113	1687	86	13	434	23	1	6	20	922
UKR	a6	14	38	81	15	4	139	19	0	3	6	143
UKR	a7	144	322	406	157	83	576	40	2	84	83	1427

UKR	a8	556	1121	2276	1544	218	3287	393	5	82	534	6317
UKR	Coal	14	41	56	18	5	67	9	0	3	9	142
UKR	Oil	3	8	9	3	1	10	1	0	1	2	25
UKR	Gas	3	7	13	4	1	14	2	0	1	2	27
UKR	Oil_pcts	26	75	91	30	9	105	12	1	8	17	246
UKR	Electricity	74	188	364	127	26	412	50	1	16	55	811
BRA	a1	340	1889	165	125	95	964	135	7	46	138	3574
BRA	a2	168	732	61	53	26	292	22	2	9	40	1689
BRA	a3	230	821	78	107	37	369	25	3	11	50	1952
BRA	a4	337	1249	133	85	57	662	36	5	12	74	2431
BRA	a5	659	5592	206	183	77	1642	104	8	17	153	12872
BRA	a6	282	1208	102	72	41	525	30	4	9	75	2219
BRA	a7	1292	2611	474	365	297	2050	97	20	33	266	7767
BRA	a8	13585	18516	4987	2969	1672	15862	745	180	170	2391	52065
BRA	Coal	1	3	0	0	0	2	0	0	0	0	7
BRA	Oil	163	666	65	58	38	343	31	6	17	39	1256
BRA	Gas	27	77	10	8	5	44	3	0	1	6	171
BRA	Oil_pcts	198	726	75	59	39	338	21	3	8	43	1404
BRA	Electricity	202	446	76	52	30	289	19	3	6	41	1088
SAU	a1	23	107	11	20	7	80	11	1	5	6	387
SAU	a2	24	89	10	29	11	68	12	1	4	5	330
SAU	a3	61	205	23	121	45	164	42	1	11	13	690
SAU	a4	434	2483	341	311	244	3199	798	12	208	122	10156
SAU	a5	85	343	47	52	25	386	51	5	17	14	2219
SAU	a6	16	67	7	7	4	86	10	1	3	3	263
SAU	a7	91	184	70	39	35	253	11	3	45	5	1164
SAU	a8	191	674	95	232	50	559	66	5	33	18	7100
SAU	Coal	0	0	0	0	0	0	0	0	0	0	0
SAU	Oil	1256	5207	518	741	334	3660	511	80	318	301	12681
SAU	Gas	80	353	58	85	37	616	81	3	26	17	1540
SAU	Oil_pcts	376	1491	172	540	159	1940	236	9	106	67	7373
SAU	Electricity	30	131	20	26	14	158	32	1	11	6	671
ROW	a1	6373	30479	2387	1943	1465	11747	955	92	939	1714	11125
ROW	a2	4970	20710	1410	1550	943	7200	607	51	588	1797	5845
ROW	a3	9673	35402	2574	7332	1999	15584	1750	97	1201	4626	12124
ROW	a4	4086	39296	2464	1576	2211	24981	1378	75	2525	2040	10937
ROW	a5	74149	342124	17289	9908	12789	98995	5958	484	7978	11827	16011
ROW	a6	4935	30593	1631	1216	1150	11293	674	61	824	1351	4966
ROW	a7	37670	103130	11388	11340	10787	63111	2757	560	9058	7539	23379
ROW	a8	######	545754	47094	56353	35811	286613	12908	2757	17622	24963	73561
ROW	Coal	881	2981	277	447	184	1578	153	22	139	207	3276
ROW	Oil	3505	16889	1649	1781	1032	9697	1259	374	989	949	26826
ROW	Gas	1763	8091	849	629	3723	14824	4135	115	409	524	6546

ROW	Oil_pcts	4305	20338	1479	2180	1098	11790	914	592	921	852	5347
ROW	Electricity	3334	15268	1032	1167	760	7877	380	55	495	755	2991

Table 20: Carbon Emission intensity C_i for each Sector and Country

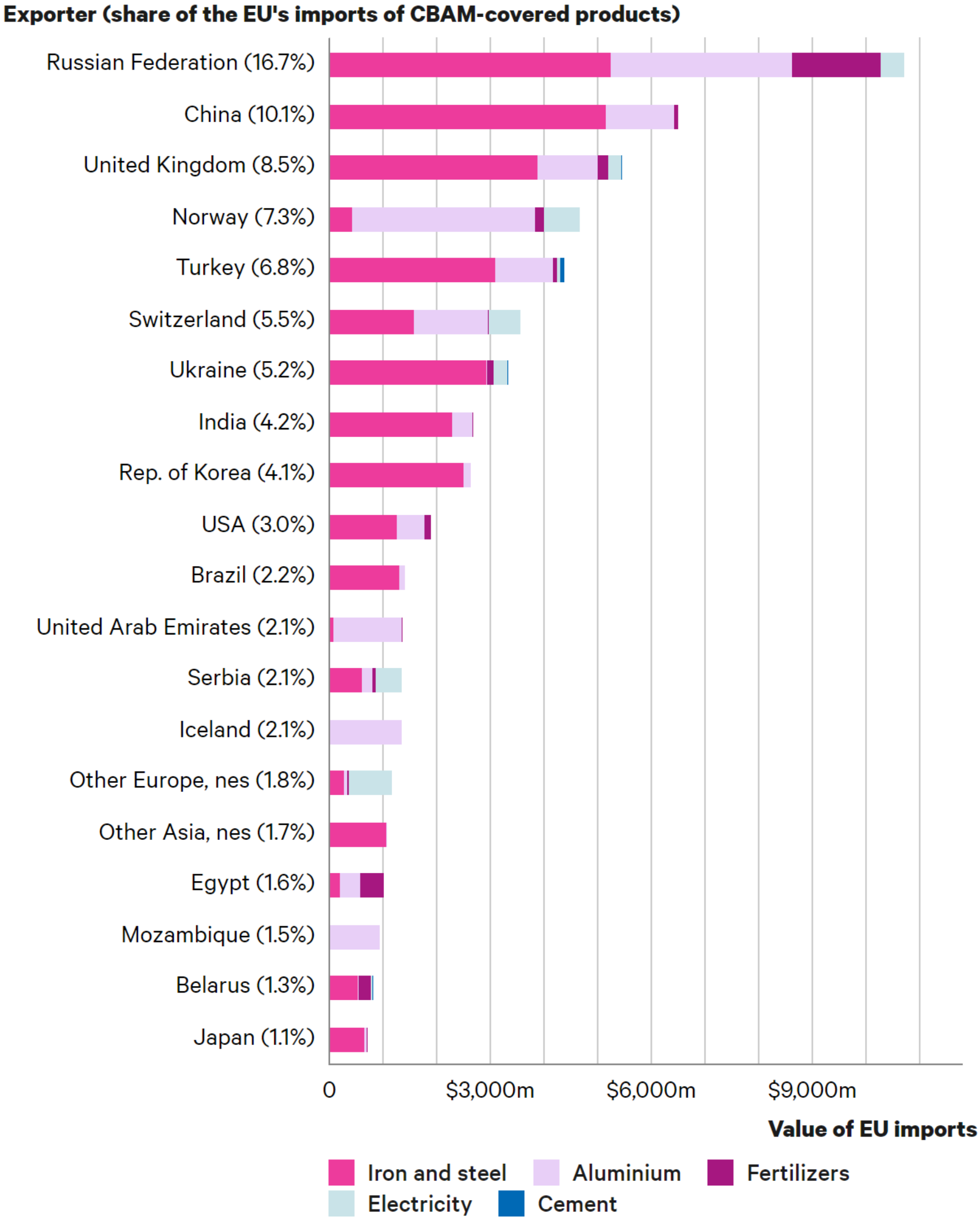
Country	Sector	Carbon Emission (MT/GTAP)	Output （GTAP）	Carbon Emission factor(C)
CHN	a1	866	929370	0.000932
CHN	a2	715	929250	0.000769
CHN	a3	175	1343843	0.000130
CHN	a4	486	1048887	0.000463
CHN	a5	170	4740699	0.000036
CHN	a6	58	688075	0.000084
CHN	a7	978	2039039	0.000480
CHN	a8	897	14450908	0.000062
CHN	Coal	360	145108	0.002480
CHN	Oil	17	85799	0.000195
CHN	Gas	188	11349	0.016562
CHN	Oil_pcts	1173	385003	0.003046
CHN	Electricity	3604	345012	0.010446
USA	a1	72	176210	0.000407
USA	a2	34	129424	0.000260
USA	a3	21	416976	0.000050
USA	a4	39	325578	0.000119
USA	a5	84	4134301	0.000020
USA	a6	23	553963	0.000042
USA	a7	1900	3410337	0.000557
USA	a8	461	17861910	0.000026
USA	Coal	5	52649	0.000103
USA	Oil	18	195034	0.000091
USA	Gas	473	85784	0.005519
USA	Oil_pcts	1609	525389	0.003063
USA	Electricity	1943	361396	0.005377
RUS	a1	38	44146	0.000849
RUS	a2	35	50220	0.000701
RUS	a3	2	53326	0.000034
RUS	a4	58	83619	0.000689
RUS	a5	16	333088	0.000048
RUS	a6	11	33999	0.000322
RUS	a7	214	473355	0.000453
RUS	a8	61	1040029	0.000059
RUS	Coal	19	24269	0.000771

RUS	Oil	8	184968	0.000046
RUS	Gas	115	86131	0.001339
RUS	Oil_pcts	153	171944	0.000892
RUS	Electricity	780	122977	0.006339
IND	a1	160	59840	0.002669
IND	a2	195	90349	0.002162
IND	a3	29	135722	0.000210
IND	a4	123	266695	0.000459
IND	a5	20	751378	0.000027
IND	a6	7	65077	0.000112
IND	a7	406	920007	0.000441
IND	a8	159	2530021	0.000063
IND	Coal	15	28156	0.000547
IND	Oil	0	14016	0.000026
IND	Gas	5	4478	0.001018
IND	Oil_pcts	454	227965	0.001992
IND	Electricity	1102	184917	0.005959
KOR	a1	16	32672	0.000483
KOR	a2	23	92362	0.000244
KOR	a3	2	90438	0.000022
KOR	a4	10	114777	0.000083
KOR	a5	7	467321	0.000016
KOR	a6	1	58532	0.000017
KOR	a7	114	306944	0.000373
KOR	a8	33	1487566	0.000022
KOR	Coal	4	156	0.026750
KOR	Oil	0	222	0.000068
KOR	Gas	23	284	0.080965
KOR	Oil_pcts	74	85939	0.000858
KOR	Electricity	251	46962	0.005340
EU	a1	67	242992	0.000274
EU	a2	40	211674	0.000189
EU	a3	14	508445	0.000027
EU	a4	40	310327	0.000130
EU	a5	30	3438433	0.000009
EU	a6	9	358778	0.000025
EU	a7	1178	3512488	0.000335
EU	a8	262	14451760	0.000018
EU	Coal	41	16127	0.002522
EU	Oil	2	12513	0.000158
EU	Gas	186	22442	0.008307
EU	Oil_pcts	557	315856	0.001764
EU	Electricity	823	325099	0.002532

TUR	a1	16	25620	0.000641
TUR	a2	8	27423	0.000297
TUR	a3	2	32700	0.000060
TUR	a4	6	22354	0.000264
TUR	a5	2	167644	0.000014
TUR	a6	2	25430	0.000068
TUR	a7	104	308118	0.000337
TUR	a8	48	860002	0.000056
TUR	Coal	15	1652	0.009180
TUR	Oil	0	1353	0.000001
TUR	Gas	26	252	0.102298
TUR	Oil_pcts	46	19900	0.002323
TUR	Electricity	106	24457	0.004326
UKR	a1	4	6426	0.000660
UKR	a2	13	7218	0.001866
UKR	a3	1	2821	0.000286
UKR	a4	0	1080	0.000157
UKR	a5	1	12388	0.000077
UKR	a6	0	2064	0.000059
UKR	a7	27	30213	0.000884
UKR	a8	10	85848	0.000111
UKR	Coal	1	3033	0.000361
UKR	Oil	0	480	0.000431
UKR	Gas	24	897	0.026836
UKR	Oil_pcts	10	4593	0.002209
UKR	Electricity	85	17327	0.004929
BRA	a1	27	64029	0.000429
BRA	a2	23	40920	0.000553
BRA	a3	9	52463	0.000178
BRA	a4	13	77624	0.000165
BRA	a5	1	292196	0.000004
BRA	a6	2	65698	0.000024
BRA	a7	170	360249	0.000471
BRA	a8	38	1806068	0.000021
BRA	Coal	0	227	0.000031
BRA	Oil	8	50819	0.000152
BRA	Gas	7	6554	0.001052
BRA	Oil_pcts	102	64484	0.001582
BRA	Electricity	77	47056	0.001632
SAU	a1	18	22819	0.000771
SAU	a2	7	16866	0.000406
SAU	a3	5	15910	0.000310
SAU	a4	55	66089	0.000826

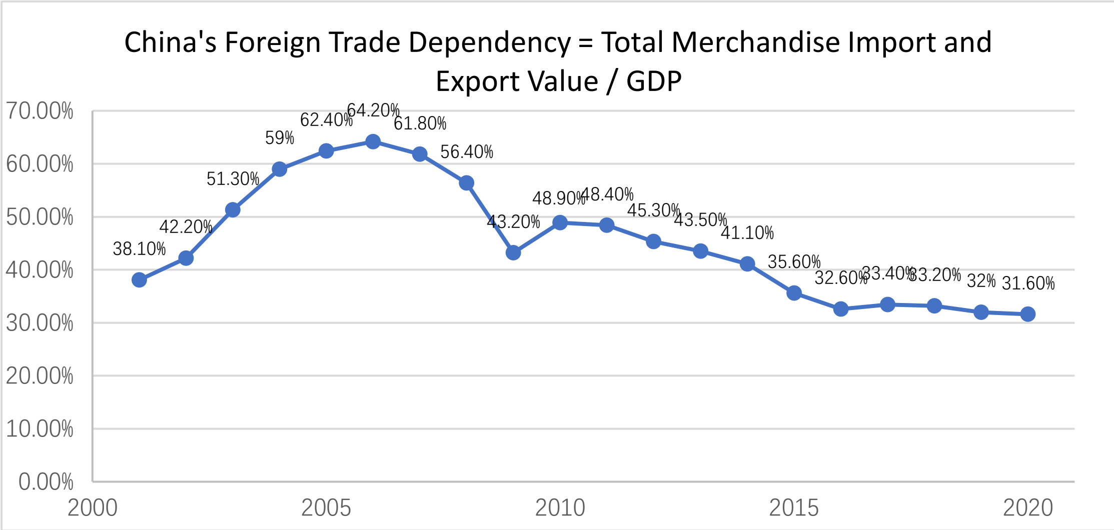
SAU	a5	18	149391	0.000118
SAU	a6	4	8712	0.000503
SAU	a7	103	34747	0.002974
SAU	a8	33	255969	0.000128
SAU	Coal	0	0.012	0.000000
SAU	Oil	8	244047	0.000031
SAU	Gas	5	20475	0.000239
SAU	Oil_pcts	123	69540	0.001772
SAU	Electricity	246	27740	0.008879
ROW	a1	335	663455	0.000505
ROW	a2	156	454489	0.000344
ROW	a3	81	846594	0.000095
ROW	a4	212	669448	0.000317
ROW	a5	157	5475793	0.000029
ROW	a6	70	595677	0.000117
ROW	a7	2619	6038786	0.000434
ROW	a8	810	23824718	0.000034
ROW	Coal	47	117790	0.000403
ROW	Oil	111	780582	0.000143
ROW	Gas	593	344755	0.001720
ROW	Oil_pcts	2027	735579	0.002756
ROW	Electricity	3052	653901	0.004667

Figure 6. Exporters (Share of the EU's Importers of CBAM-coved Products) [57]



Resource: https://resourcetrade.earth/publications/which-countries-are-most-exposed-to-the-eus-proposed-carbon-tariffs.

Figure 7: China's Foreign Trade Dependency = Total Merchandise Import and Export Value / GDP



Resource: China General Administration of Customs (2023), China Statistical Yearbook

Figure 8. Changes in the Output of Different Sectors (China only)

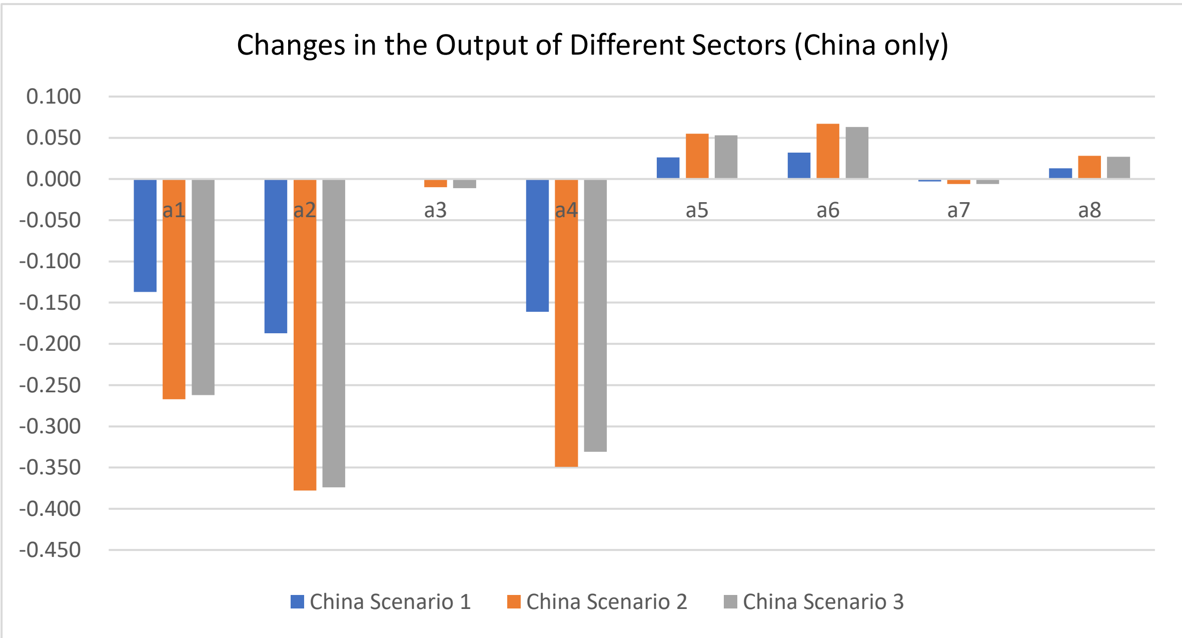


Figure 9. Changes in the Export of Different Sectors (China only)

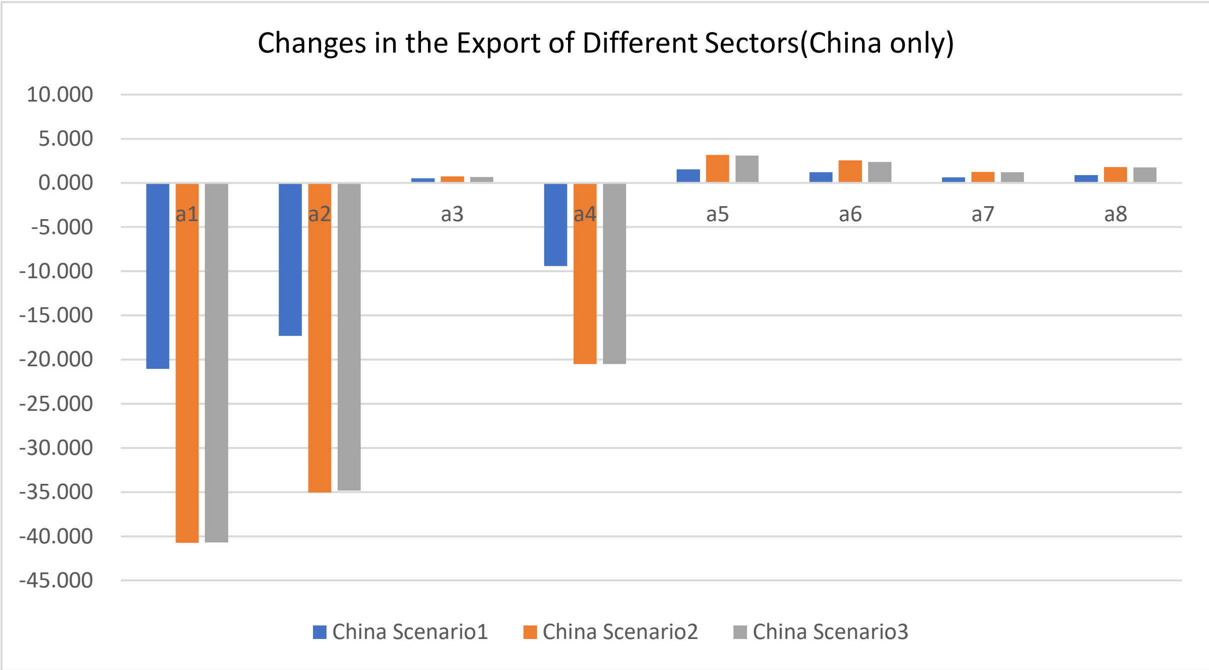


Figure 10: Changes in the GDP

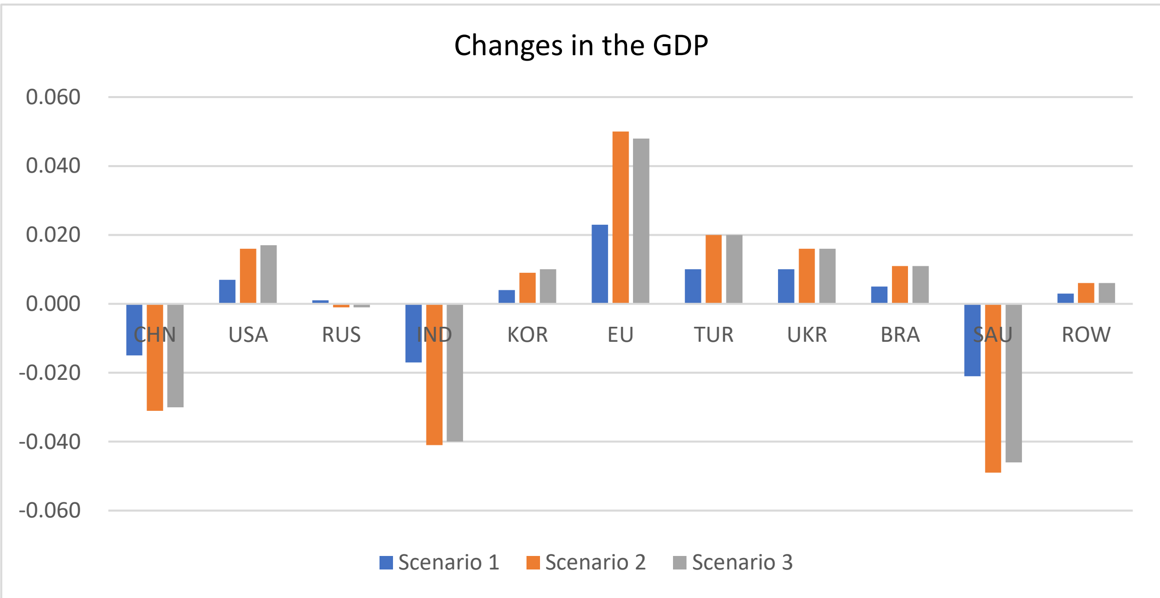


Figure 11: Changes in the Social Welfare

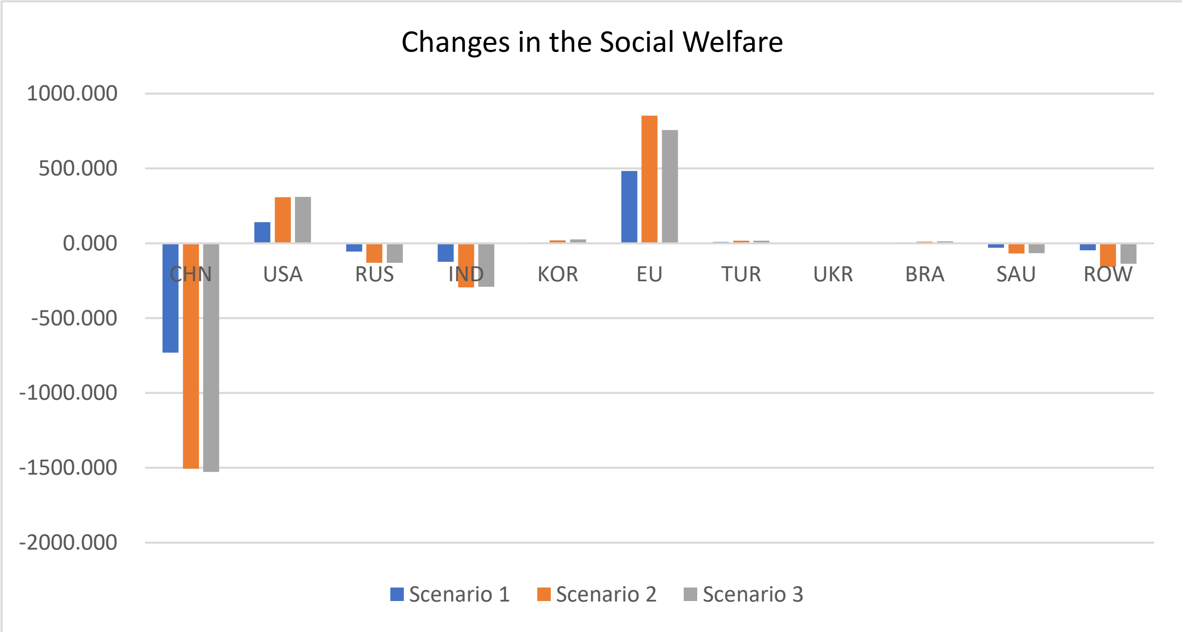


Figure 12: Changes in the Export by Countries

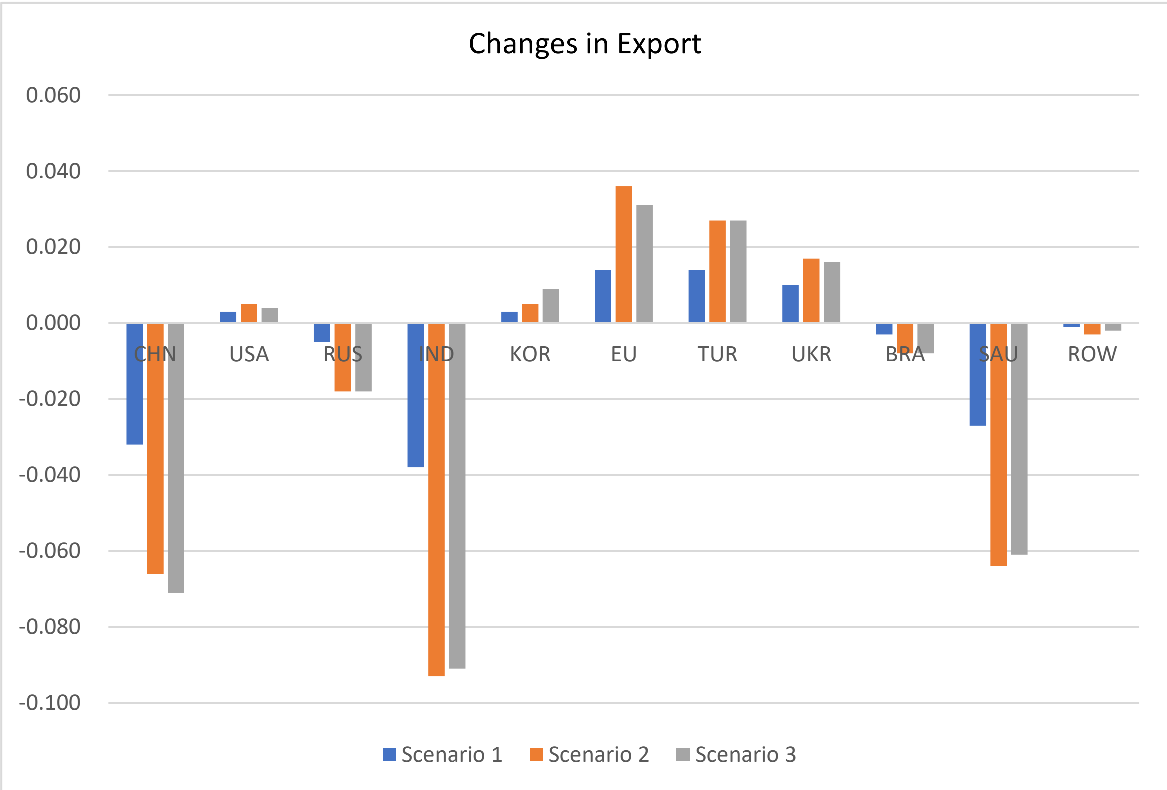


Figure 13: Changes in the Carbon Emission

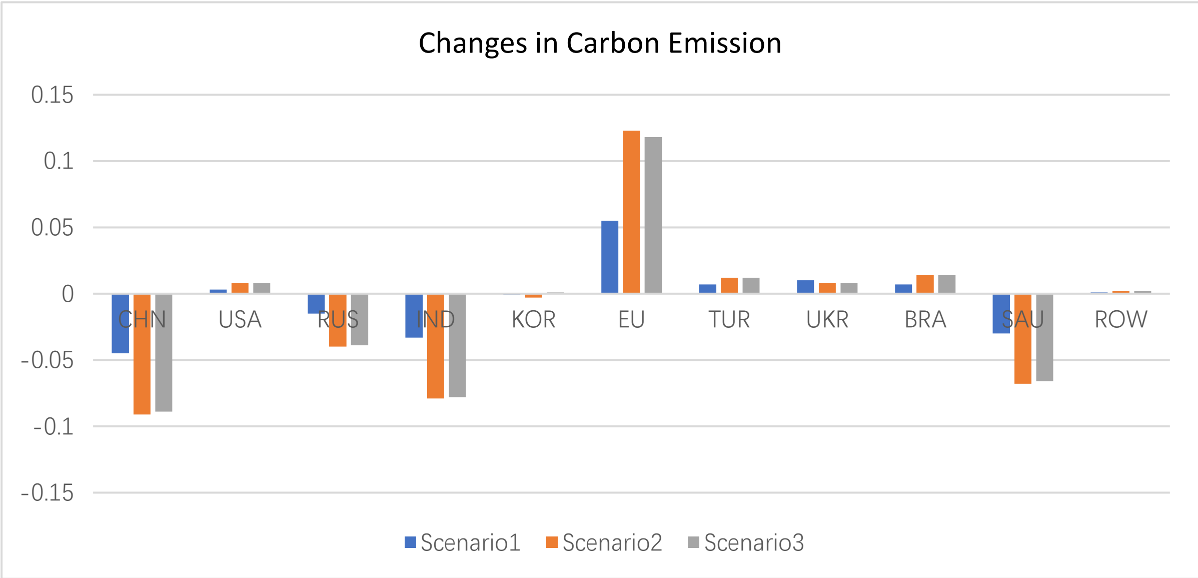


Figure 14: Price and Coverage across ETSs and Carbon Taxes [17]