UNIVERSITAT ROVIRA I VIRGILI

Essays on Climate Change and its Distributional Impacts: CO_2 Emissions Transmission in an Integrated Global Economic System

SRISHTI GOYAL

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TESI DOCTORAL – TESIS DOCTORAL- DOCTORAL THESIS
2025

Srishti Goyal

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DOCTORAL THESIS

Supervised by
Prof. Maria Llop Llop

Department of Economics
UNIVERSITAT ROVIRA i VIRGILI

Reus
2025

UNIVERSITAT ROVIRA i VIRGILI
Departament d'Economia

Universitat Rovira i Virgili
Facultat d'Economia i Empresa
Av. de la Universitat, 1 - 43204 Reus
Tel. 977 75 98 11 – 977 75 98 12

FAIG CONSTAR que aquest treball, titulat "**Essays on Climate Change and its Distributional Impacts: CO_2 Emissions Transmission in an Integrated Global Economic System**", que presenta **Srishti Goyal** per a l'obtenció del títol de Doctor, ha estat realitzat sota la meva direcció al **Departament d'Economia** d'aquesta universitat, i compleix tots els requisits per rebre la Distinció de Doctorat Europea/Internacional.

HAGO CONSTAR que el presente trabajo, titulado "**Essays on Climate Change and its Distributional Impacts: CO_2 Emissions Transmission in an Integrated Global Economic System**", que presenta **Srishti Goyal** para la obtención del título de Doctor, ha sido realizado bajo mi dirección en el **Departamento de Economía** de esta universidad, y cumple con todos los requisitos para recibir la Distinción de Doctorado Europeo/Internacional.

I STATE that the present study, entitled "**Essays on Climate Change and its Distributional Impacts: CO_2 Emissions Transmission in an Integrated Global Economic System**", presented by **Srishti Goyal** for the award of the degree of Doctor, has been carried out under my supervision at the **Department of Economics** of this university, and it fulfils all the requirements to receive the European/International Doctorate Distinction.

Reus, 28 de novembre de 2024/ Reus, 28 de noviembre de 2024/ Reus, 28th November 2024

El director de la tesi doctoral
El director de la tesis doctoral
Doctoral Thesis Supervisor

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Date: 2024.11.28 18:26:40 +01'00'

Maria Llop i Llop

Acknowledgments

"What seems to us as bitter trials are often blessings in disguise."

— Oscar Wilde

Every journey presents its own set of challenges, and my academic voyage from Delhi to Reus to pursue a PhD was no exception. This path, though arduous, was rich with learning and marked by many firsts—living independently, managing daily chores, and learning to cook Indian vegetarian food due to the difficulty of finding suitable vegetarian meals in a predominantly non-vegetarian landscape. The myriad of paperwork and adjustments to a new culture were significant, but these challenges only deepened my resolve and enhanced my learning.

I am incredibly grateful to my supervisor, Maria Llop Llop, for her unwavering faith and support. Her mentorship allowed me to explore a range of ideas and channel my energy effectively, guiding me thoughtfully while allowing me to find my own direction. Maria created a safe space where I could make mistakes, learn from them, and make the necessary corrections, which helped me grow both academically and personally. Her support extended well beyond the professional realm. She played a crucial role during a challenging period of illness in early 2022, assisted me in finding my first accommodation in Spain, and consistently provided guidance and support in numerous other personal aspects throughout my time here. Her influence in my life over these years has been tremendously impactful.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 945413 and from the Universitat Rovira i Virgili (URV). The MFP COFUND fellowship was pivotal in enabling my journey to Spain, and for that, I am sincerely thankful. I am also grateful to the evaluation committee and interview panel members who believed in my potential.

Throughout my dissertation, I gained significant insights into general equilibrium perspectives and modelling. While I am not yet an expert, the resources made available through the COFUND fellowship and the tutelage under Maria have greatly enhanced my skills in these areas. The Department of Economics at URV and my time at the University of Sussex have profoundly influenced my growth.

Following the submission of my thesis for external review, I had the privilege of receiving feedback from my thesis evaluators, Isabela Anamaria Butnar and Tobias Heinrich Kronenberg. Their thoughtful comments and constructive suggestions helped me address key aspects of my work and refine the final version of this dissertation. I am deeply grateful for their time, effort, and invaluable input.

I owe much of my academic growth to the supportive environment fostered by the Department of Economics at URV. Carolina Manzano Tovar was the first professor I met after Maria. Her welcoming demeanour and support were instrumental in easing my transition into the department. Josep-Maria Arauzo-Carod introduced me to teaching, which boosted my confidence and enabled me to present my work more effectively in various academic settings, including seminars, workshops, and conferences. Ricardo Flores-Fillol opened a new world to me by introducing LaTeX in his course, which was my first exposure to the tools used for professional academic presentations. Later, an ICE course on presentation skills, taught by Susana Iranzo Sancho, showed me how to create LaTeX-style presentations using Microsoft

PowerPoint, which I found to be a more accessible alternative to coding presentations directly in LaTeX. These experiences are just a few examples of the amazing professors at the department and how they have contributed to my academic development. While I can sometimes be a bit reserved in initiating interactions with senior colleagues, I often exchanged greetings with other professors in the corridors, always appreciating their kindness.

I must acknowledge the support from COFUND managers Oana Moldovan and Paloma Pontón Merino, and the administrative assistance from Magda Lleixà Solà, Lourdes Rofin Hortoneda, and Eulàlia Torner Lasalle, which was crucial in managing the maze of documentation and administrative procedures.

During my semester at the University of Sussex, I am particularly indebted to Richard Tol for his guidance. His advice to build on existing models rather than reinventing the wheel saved me time and directed my research efficiently. I also met and befriended brilliant fellow PhD students like Norah Al Mousa, Yuahan Cai, Taufik Hidayat, Tomoto Masuda, Walter Kiptoo Kiplagat, Juan Jose Francisco Cueto Alava, and Safwan Alsulami, whose friendship and intellectual camaraderie were highlights of my semester abroad. My host in Hove, Karen Roberts, and my housemates, Simran Budhwar and Lauren Woolley, made my stay both enjoyable and memorable.

The PhD scholars of the Department of Economics, URV, have been a tremendous source of support throughout my journey. I am especially grateful to Carles Méndez-Ortega, Carlos Cercós Pérez, and Françeska Tomori for their guidance and assistance in navigating both academic and administrative landscapes. My fellow PhD colleagues—whether they have already defended or are still pursuing their degrees—Mona Masoumi Dinan, Mimi Zhang, Foroogh Salekpay, Barbara Zelu, Charalampos Papadakis, Noemí Ramírez Hernández, Josep Tomàs-Porres, Ali Barakat, Laura Fernàndez Herrero, Cristina Valentina Heghes, Keli de Araujo Rocha, Yanik Nimtz, and Eric Barberà Mas—have also been integral to this enriching experience. Special thanks to Génesis María Guarimata Salinas, a fellow COFUND recipient from the Department of Business, who was instrumental in addressing HR inquiries that we didn't get addressed by the HR in a timely manner.

I am deeply thankful to the Indian community in Tarragona, including Satyam Shukla, Deepika Ahlawat, Naga Adithya Chandra Pandurangi, Deepak Parajuli, and Deepa Upadhayay. Their support was invaluable as I adjusted to life in a foreign country.

Finally, I express my profound gratitude to my family—my parents, Renu Goyal and Ashok Kumar Goyal, and my dear siblings, Kritika Singla and Vinayak Goyal. Their unwavering support and love have been the cornerstone of my resilience and success. I am equally grateful to my brother-in-law, Sachin Singla, and my sister-in-law, Chitranshi Goyal, for their encouragement and support. On days when I felt particularly low, my nieces, Myra Singla and Selvi Singla, were my joy and solace. Their cheerful conversations and playful interactions during our video calls were just what I needed to lift my spirits and keep pushing forward. Without this incredible emotional support system, I would not have been able to navigate through this journey.

A warm hug to my friends from India—Tushar Mehta, Mayank Choudhary, Arpita Chhikara, Shivani Gupta, Vasudha Chopra, Tanvi Khurana, and Surbhi Chetwani, Ojesvi Bhardwaj, Kritika Vashist—who, despite the distance and regardless of where they now reside, provided unwavering encouragement throughout this journey.

To everyone else who contributed to this chapter of my life, in ways big or small, your presence and support have been truly appreciated.

Lastly, I am thankful to the universe and God for the blessings and strength that have sustained me through this significant phase of my life.

ईशावास्यम् इदं सर्वं यत् किञ्च जगत्यां जगत्
तेन त्यक्तेन भुञ्जीथा मा गृधः कस्य स्विद् धनम्

Transliteration Īśāvāsyam idaṃ sarvaṃ yat kiñca jagatyāṃ jagat
Tena tyaktena bhuñjīthā mā gṛdhaḥ kasya svid dhanam

Translation Everything animate or inanimate that is within the universe is controlled and owned by the Lord. Therefore, one should only take what is necessary, which is set aside as his quota, and not covet the possessions of others, knowing well to whom they belong.

Explanation This is the first verse in the *Isha Upanishad*, a revered text that forms part of the *Shukla Yajurveda*, one of the principal Vedic scriptures in Hinduism. It teaches a principle of mindful and minimal consumption that resonates with contemporary environmental values. This ancient text emphasizes the importance of ethical resource use, advocating that our consumption should not impair the capacity of future generations to sustain themselves. It champions living within our ecological means and respecting the environmental limits imposed by nature. By stressing these principles, the *Isha Upanishad* aligns with modern discussions about sustainability and climate change, advocating for a balance between consumption and conservation. This philosophical stance is crucial in the pursuit of policies that aim to mitigate the environmental and societal impacts of climate change.

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Summary

This dissertation explores the intricate relationship between global economic activities and CO_2 emissions, focusing on international trade and key sectors such as air transport, shipping. By employing advanced input-output methodologies, including Structural Decomposition Analysis (SDA), the Hypothetical Extraction Method (HEM), and Input-Output Impact Analysis (IOIA), it provides a nuanced understanding of the drivers of emissions and their implications for sustainable development. The research aligns with the urgency of addressing climate change while balancing economic and environmental goals, particularly in the context of globalization and interconnected global value chains.

Climate change is not just an environmental crisis but also an economic challenge, demanding targeted policies that address its distributional impacts across countries, sectors, and populations. The increasing acknowledgment of environmental challenges posed by economic growth has led to global agreements like the Paris Agreement and Sustainable Development Goals (SDGs), which emphasize the interconnectedness of economic growth, environmental sustainability, and social equity. However, the complexities of international trade, resource-intensive production systems, and cross-border emissions require careful analysis and equitable solutions.

Using CO_2 as a primary focus, this research examines emissions generation, distribution, and mitigation through a systematic framework. With data from the OECD Inter-Country Input-Output database, the study provides insights into emissions trends and the interplay between economic growth and sustainability. The findings offer actionable recommendations for policymakers to pursue low-carbon development pathways without compromising economic progress.

The research highlights how developed countries have decoupled economic growth from emissions through decarbonization and energy efficiency. In contrast, emerging economies such as China and India exhibit rising emissions due to population growth and increasing income per capita, underscoring the global inequality in emissions responsibility. This calls for targeted policies, including international cooperation for technology transfer and renewable energy adoption, to ensure equitable emissions reductions.

The introduction of Emission Balance of Trade as a metric provides a novel approach to evaluating the balance between emissions and goods in international trade. It reveals that net exporters like China and India sustain global trade while shouldering the environmental burden of production. Additionally, the service sector, often seen as less emission-intensive, demonstrates significant emissions intensity in global trade. The research underscores the need to internalize environmental costs within trade frameworks and harmonize environmental standards to ensure fair accountability across global value chains.

Air transport, as analysed through the HEM, contributes significantly to emissions due to its integration into global supply chains. This sector's overall emissions are 19% higher than commonly reported direct emissions. Addressing these emissions requires targeted investments in sustainable aviation fuels and energy-efficient technologies.

The extension of the European Union Emissions Trading System (EU ETS) to the shipping industry demonstrates the potential of market-based mechanisms to reduce emissions. However, the policy increases costs for producers and consumers. While reducing emissions

by raising production costs, this policy introduces short-term trade-offs between economic and environmental goals. A phased implementation of ETS policies and reinvestment into decarbonization initiatives, such as zero-emission vessels and port electrification, are recommended to address these challenges.

The findings emphasize the need for systemic, sectoral, and international approaches to emissions reduction. Emerging economies must receive technological and financial support to transition to low-carbon pathways without compromising development. Tools like EBT can guide policymakers in integrating environmental costs into global trade agreements, promoting sustainable practices across value chains. Sector-specific strategies for air transport and shipping, coupled with measures to mitigate economic disruptions, are critical for achieving decarbonization while ensuring equity.

While the research provides significant contributions, its reliance on static input-output models introduces limitations. These models assume fixed production technologies and cannot capture dynamic adjustments or the heterogeneity of economic agents. Future research should explore dynamic Computable General Equilibrium models and agent-based models to represent diverse behaviours and enhance policy analysis. Expanding the temporal analysis of the EBT metric and broadening the scope to include other environmental impacts, such as greenhouse gas emissions, biodiversity loss and water usage, would provide a more comprehensive understanding of sustainability challenges and opportunities.

This thesis underscores the importance of coordinated global action to address climate change and economic development. By analysing emissions embedded in international trade and critical sectors, it highlights the complexities of balancing economic and environmental goals. The findings provide a foundation for policies that integrate environmental sustainability and social equity considerations, aligning with the broader shift toward "beyond GDP" frameworks. This research affirms the need for equitable and inclusive solutions to climate change, ensuring that the benefits of sustainability are shared across nations and generations, fostering a more resilient and harmonious global community.

Chapter 1

Introduction

> "*The future is not ceteris paribus. It's ceteris imparibus.*
> *Change happens, pretty much all the time*."
> — *Tol (2014)*

This observation encapsulates the fundamental reality of climate change: the world is in constant flux, with the dynamics of our environment, economies, and societies deeply interwoven. Instead of holding other factors constant, it is crucial to study how small changes within an economic system—whether in a country or a sector—affect the integrated global economic system. This highlights the dynamic nature of climate change, where interconnected systems constantly evolve, necessitating just and equitable policies.

Through his work, Tol emphasizes that climate change is fundamentally an economic issue rather than an existential threat. While its impacts are significant, particularly for global economies, they primarily alter resource availability, productivity, and trade patterns rather than jeopardize humanity's survival. Consequently, policymakers must design strategies that account for the distributional impacts of these changes on society and ensure equitable outcomes for all.

1.1 Context

Over the past few decades, the global community has increasingly recognized the environmental challenges posed by economic growth and development. The debate on the limits to growth (Meadows et al., 1972) has gained renewed attention as economists and environmentalists argue that continued economic expansion cannot be sustained within the planet's finite resources (Gardner, 2004; Herrington, 2021; Schröder, 2023). The traditional focus on gross domestic product (GDP) as a measure of progress is being challenged by calls for "beyond GDP" indicators that account for environmental degradation, resource depletion, and social well-being (Costanza et al., 2009, 2013; van den Bergh, 2022).

In 2015, over 190 economies across the globe came together under the banner of the United Nations to adopt the 17 Sustainable Development Goals (SDGs) and ratify the Paris Agreement, a landmark treaty aimed at limiting global warming to well below 2 °C preferably 1.5 °C, compared to pre-industrial levels. These actions reflect the global recognition of the urgency of the climate crisis and the need for a holistic development strategy.

The SDGs underscore the interconnectedness of economic growth, social equity, and environmental sustainability, advocating for a comprehensive approach to tackling pressing global challenges such as poverty, inequality, and climate change (Zhenmin, 2018). However, achieving these ambitious targets remains challenging as economic growth continues to be strongly linked to environmental degradation. Global efforts, while critical, often face barriers due to the intricate linkages between production and consumption patterns across borders, particularly in a highly interconnected global economy.

Climate change, driven by unsustainable production and consumption, is one of the most significant consequences of these global dynamics (UNEP, 2024). Rising greenhouse gas (GHG) emissions, primarily fueled by industrial activities, deforestation, and reliance on fossil fuels, have exacerbated global warming, threatening ecosystems, economies, and livelihoods worldwide (UN, 2024). Climate change is inherently a transboundary phenomenon, as GHG emissions originating in one country contribute to global warming, with far-reaching effects on ecosystems, economies, and communities worldwide.

Globalization, through international trade, has added another layer of complexity to the climate crisis. Interconnected global value chains amplify emissions across borders, making it increasingly difficult to assign accountability for mitigation. For example, carbon-intensive production in one country often supports consumption in another, creating a mismatch between the location of emissions and the beneficiaries of the associated economic activity. These dynamics underscore the importance of understanding the distributional impacts of climate change across sectors, countries, and value chains.

While globalization has fostered economic integration and innovation, it has also accelerated resource extraction and energy consumption, heightening environmental pressures (Wiedmann & Lenzen, 2018; WTO, 2023; Yoon, 2016). These shared pressures and their transboundary nature underscore the need for coordinated strategies that take into account the uneven distribution of climate change’s causes and impacts. Frameworks like the SDGs provide a broad foundation for collective action, but targeted research is needed to assess their implications and identify gaps.

Among the SDGs, Goal 13 emphasizes climate action, highlighting the importance of reducing GHG emissions and building resilience to climate impacts. However, these frameworks alone cannot address the complexities of emissions distribution and risk exposure. Policies and strategies must account for the unequal generation of emissions and their disproportionate impacts on vulnerable populations.

This highlights the importance of analysing the distributional impacts of climate change—both in terms of emissions generation and the consequences of climate policies. By examining how emissions are generated and transmitted across sectors, countries, and value chains, and by understanding who bears the costs and benefits of mitigation efforts, it becomes possible to design policies that are not only effective but also equitable. Without such an approach, global efforts risk exacerbating existing inequalities and failing to achieve the transformative change needed to address the climate crisis.

As climate change and globalization continue to reshape the global economic system, targeted research is critical to inform evidence-based policies. Understanding these distributional dynamics is essential to ensure that strategies are not only sustainable but also just, balancing the need for economic growth with environmental and social equity.

1.2 Scope and Analytical Framework

In a complex, interconnected system, even the smallest cog plays a critical role in ensuring the smooth functioning of the whole machine. When one cog is adjusted, replaced, or removed, its impact is often felt throughout the entire system. Similarly, within the global economy, changes—whether due to policies, shifts in trade, or climate impacts—propagate through a web of relationships, influencing production, consumption, and emissions on a global scale. This interconnectedness necessitates an analytical framework that can capture these systemic effects, especially when addressing challenges as pervasive and transboundary as climate change.

To analyse these systemic interactions, this thesis employs a general equilibrium perspective through the Multi-regional Input-Output (MRIO) modelling framework. Input-Output models provide a robust method for examining the interdependencies within the global economy, capturing the cascading effects and feedback loops that occur when economic agents and markets interact (Miller & Blair, 2022). The methodologies employed—Structural Decomposition Analysis (SDA), Hypothetical Extraction Method (HEM), and Input-Output Impact Analysis (IOIA)—allow for a nuanced understanding of emissions drivers, the environmental impacts of international trade, and the role of key sectors such as air transport and shipping. These transport sectors, which facilitate global trade, are not only pivotal to economic integration (Hummels, 2007) but also significant contributors to environmental challenges associated with economic growth (EEA, 2018). As global trade expands, assessing the environmental impacts of these industries and exploring pathways for their decarbonization is critical for meeting international climate commitments.

While climate change results from multiple GHGs, this thesis narrows its focus to CO_2 emissions. CO_2 is the most significant contributor to global warming, accounting for approximately 74% of all GHG emissions (Ge et al., 2020). Its dominance in the emissions profile makes it the primary focus of global mitigation strategies. Furthermore, the availability and reliability of CO_2 data enable a detailed and consistent analysis. This thesis utilizes the 2018 OECD Inter-Country Input-Output (ICIO) database, which provides a comprehensive representation of global trade and production interlinkages, and the OECD TeCO2 database, which aligns with the ICIO framework and ensures accurate information on CO_2 emissions. By focusing on CO_2, this research delivers precise insights into the primary driver of climate change while acknowledging the broader context of GHGs.

The thesis investigates key aspects of emissions generation, distribution, and policy impacts by examining both the impact *on* climate change and the impact *of* climate change, using CO_2 emissions as a proxy for climate change. The overarching objective of this thesis is to assess how global trade and sectoral activities shape the emissions landscape and to provide insights into pursuing low-carbon development paths without compromising economic growth. Specifically, this thesis addresses the following objectives:

i. To examine how the level of development influences the intensity of key factors driving changes in CO_2 emissions over time.
ii. To analyse whether international trade predominantly facilitates exchange of goods or also amplifies emissions (bads) as a byproduct.
iii. To quantify the role of the air transport sector in generating CO_2 emissions and analyse how these emissions are distributed across the global economy.
iv. To evaluate the distributional and economic impacts of a climate policy, i.e. extending the European Union Emissions Trading System (EU ETS) to the shipping industry.

By addressing these objectives, this thesis contributes to the broader understanding of how CO_2 emissions are generated, transmitted, and mitigated within global systems. These findings not only advance academic understanding of global CO_2 emissions but also provide practical recommendations for policymakers seeking to design effective and equitable climate policies.

1.3 Thesis Structure

The remainder of this thesis is organized as follows.

Chapter 2 explores the relationship between countries' development levels, as measured by the Human Development Index (HDI), and their contributions to global direct CO_2 emissions from 1995 to 2018. This chapter addresses Objective (i) by employing Structural Decomposition Analysis (SDA) using augmented Kaya identity factors. With the availability of input-output (IO) tables, it was possible to differentiate between output and value added, leading to an expansion of the Kaya factors to include carbonization, energy intensity, productivity, income per capita, and population. Additionally, the change in population is decomposed into natural population growth and migration. Countries are categorized based on their improvement in HDI over the time period into three groups: limited improvement in HDI (LIH), moderate improvement in HDI (MDI), and substantial improvement in HDI (SIH). Notably, most of the developed world falls under LIH, while emerging economies belong to SIH. This approach provides a nuanced understanding of how different development trajectories influence emissions. The findings reveal that countries in the LIH group have successfully reduced direct CO_2 emissions through decarbonization and energy efficiency. In contrast, countries in the SIH group, such as China and India, face rising direct emissions due to natural population growth and increasing income per capita, highlighting the complex interplay between development and sustainability. These results underscore the need for targeted policies to address these challenges and promote low-carbon development pathways.

Chapter 3 introduces the Emission Balance of Trade (EBT), a novel metric designed to assess the environmental sustainability of international trade. This chapter addresses Objective (ii) and provides a comprehensive framework to quantify how emissions ("bads") are traded alongside goods, offering insights into the sustainability of trade practices. Unlike traditional metrics that focus solely on emissions or economic outputs, the EBT compares the openness of bads to that of goods within specific sectors and countries, facilitating a nuanced understanding of their proportional relationship. The analysis reveals that despite the lower global integration of the service sector, it exhibits unexpectedly high emission intensity. The service sector also demonstrates heterogeneity, with transport sectors being more integrated into the global economy in terms of both goods and bads, while quaternary sectors are emission-intensive in international trade despite being less globally integrated. Additionally, trade activities in India and China are found to be less emission-intensive compared to the developed world. These findings suggest that policy measures should focus on regulating emissions in the service sector and supporting small developing countries, such as Lao PDR, in maintaining low emission intensities through capacity building and knowledge transfer.

Chapter 4 provides a comprehensive understanding of the air transport sector's environmental impact. This chapter addresses Objective (iii) by employing the Hypothetical Extraction Method (HEM) to assess the implications of removing the air transport sector from the global economy. The results indicate that while direct emissions from air transport operations are significant, the indirect emissions—stemming from the broader supply chain and associated infrastructure—also play a critical role in the sector's overall environmental impact. The analysis reveals that the air transport sector's contribution to global CO_2 emissions is 19% higher than commonly reported direct emissions, highlighting the importance of addressing indirect emissions in decarbonization strategies.

Chapter 5 analyses the immediate impact of extending the European Union Emissions Trading System (EU ETS) to the shipping industry, focusing on economic agents in EU countries and the EU's top 10 trading partners. This chapter addresses Objective (iv) by employing an environmentally-extended input-output (EEIO) model and the Leontief price model to simulate the effects on production prices, consumption prices, consumer welfare, output, and total revenue generated for the European Commission through this policy measure. The results indicate that introducing the EU ETS for the shipping industry will lead to increased production and consumption prices, resulting in reduced output and consumer welfare in the short term. Notably, producers in EU countries are likely to bear a greater burden compared to their counterparts in non-EU countries. These findings highlight a short-term trade-off between environmental and economic objectives, suggesting that while the policy aims to reduce CO_2 emissions, it may impose economic losses on key stakeholders. The analysis emphasizes the need for a phased implementation to mitigate adverse effects.

Finally, Chapter 6 provides the main conclusions of the thesis, outlines corresponding policy implications, and suggests directions for future research.

By examining key sectors and employing diverse methodologies within the general equilibrium framework, this thesis offers a comprehensive understanding of the role international trade plays in shaping the global emissions landscape. The insights gained contribute to broader discussions on sustainable development, offering actionable recommendations for balancing economic growth with environmental limits and transitioning to a “beyond GDP” framework. These findings provide valuable guidance for policymakers seeking to align economic prosperity with environmental sustainability, especially in the context of decarbonizing critical industries that facilitate global trade.

Chapter 2

Main Drivers of Carbon Emissions across the World: Does the Level of Development Matter?[1]

2.1 Introduction

For several decades, the scientific community has recognized the need to control global warming. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations and World Meteorological Organization to assess and provide scientific evidence of global warming and its potential impacts. In the same year, the World Conference on the Changing Atmosphere was held in Toronto, Canada, which brought together scientists and policymakers to discuss the issue of climate change. Since then, numerous international agreements and initiatives have been created to address global warming, including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Conference of the Parties (COP) in 1995 (which led to the Paris Agreement in 2015). These agreements and initiatives reflect the global consensus that climate change poses a significant threat to human society and the planet, and that urgent action is needed to mitigate its impacts.

As the need to address the issue of climate change has spanned over three decades now, it is important to explore how the world is directing its efforts to mitigating global warming and what factors have been contributing to the increase in CO_2 emissions, especially given the diverse development trajectories experienced by different countries.

Previous research has often linked economic growth with CO_2 emissions, observing that higher economic activity generally leads to higher emissions (Choudhury et al., 2023; Mitić et al., 2023; Onofrei et al., 2022). However, the relationship between development, as measured by the Human Development Index (HDI), and emissions is less explored. Theoretically, one might expect that advancements in HDI, which indicate better education, higher incomes, and improved health, would contribute to sustainable practices and lower emissions. Contrary to this expectation, empirical studies indicate that, generally, improvements in HDI are often accompanied by an increase in CO_2 emissions (Fakhri et al., 2024; Balsamo et al., 2023; Costa et al., 2011).

Identifying the key drivers of CO_2 emissions, based on the countries' efforts towards development, is crucial for developing effective strategies and policies to mitigate climate change. By understanding the main sources and causes of CO_2 emissions, policymakers can develop targeted interventions that address these drivers and reduce the overall level of emissions. Broadly speaking, there are two methods to identify key factors governing the temporal changes in emissions: (i) Index Decomposition Analysis (IDA), and (ii) Structural Decomposition Analysis (SDA). While both methods have their advantages, SDA is recognized as a comprehensive approach as it is based on input-output (IO) model and takes economic systems into account (Su & Ang, 2012; Wang et al., 2017b). (Wang et al., 2017)

Several studies have shown the effectiveness of SDA to identify key drivers of CO_2 emissions for individual countries (Butnar & Llop, 2011; Cansino et al., 2016; Chang et al., 2008; De

[1] This chapter is co-authored with Maria Llop Llop.

Haan, 2001; Wood, 2009; Yamakawa & Peters, 2011), as well as for regions (Baiocchi & Minx, 2010; Cellura et al., 2012; Feng et al., 2012; Zhu et al., 2012). A few studies have taken a global approach and investigated both global and individual countries' main drivers of CO_2 emissions (Arto & Dietzenbacher, 2014; Jiang et al., 2021; Wang et al., 2017; Xu & Dietzenbacher, 2014), with Wang et al. (2017a) comparing emerging and advanced economies based on individual countries' analyses.

Given this paradox, where advancements in HDI are associated with increased CO_2 emissions despite theoretical expectations of environmental improvements, it becomes imperative to dissect and understand the underlying factors driving this trend. This study, therefore, seeks to study the main drivers of the carbon emissions for economies based on the improvement in HDI between 1995 to 2018, to learn from the experiences of the countries which shows substantial increase in HDI. This chapter uses OECD ICIO tables for the year 1995 and 2018 and divides the 66 countries into three categories based on the level of improvement according to their HDI. This chapter aims to use SDA technique to decompose the carbon emissions for all the three sets of countries and draw valuable insights that helps steer the countries to a more sustainable and low-carbon development path. Specifically, the study focuses on understanding the influences of net migration, natural population growth, and income per capita on carbon emissions, which have received limited attention in previous research. By examining these factors, the chapter aims to provide a comprehensive understanding of the drivers of carbon emissions and contribute to the formulation of effective policies for a greener future.

The chapter is organized as follows. Section 2.2 provides information on the method and modelling technique utilized for this analysis. In section 2.3, detailed information is presented regarding the data utilized in this chapter, including its sources and relevant considerations. Section 2.4 presents the results obtained from the SDA analysis, and section 2.5 discusses them Finally, section 2.5 concludes the chapter.

2.2 Methodology

This section outlines the methodology used to categorize countries based on the improvement in their HDI between 1995 and 2018, as described in Section 2.2.1. Section 2.2.2 explains how CO_2 emissions are decomposed using the augmented Kaya identity.

2.2.1 Categorization of countries

To categorize countries, the HDI values for 1995 and 2018 were recorded. The HDI is a composite measure based on life expectancy, education, and per capita income indicators, used to assess a country's level of development. The HDI ranges from 0.000 (lowest development) to 1.000 (highest development). HDI classifications are determined using fixed cut-off points as follows: less than 0.550 for low human development, 0.550–0.699 for medium human development, 0.700–0.799 for high human development, and 0.800 or greater for very high human development (UNDP, 2021). Countries classified under very high human development are considered developed (UNDP, 2024).

In this analysis, the improvement in HDI was calculated by subtracting the 1995 HDI value from the 2018 HDI value. This improvement ranged from 0.044 (limited improvement) to 0.234 (substantial improvement). Based on this, the 66 countries were divided into three categories of 22 countries each, according to the criteria outlined in Table 2.1.

Table 2.1: Classification Criteria Based on HDI Value Improvement

Category	**Improvement in HDI value (x)**
Limited improvement (LIH)	$x < 0.1$
Moderate improvement (MIH)	$0.1 \leq x < 0.14$
Substantial improvement (SIH)	$x \geq 0.14$

2.2.2 Decomposition using augmented Kaya Identity

The general approach adopted to study the factors affecting environment is the IPAT identity or the Kaya identity. The IPAT identity studies the impact of population, affluence and technology on the environmental factor, on the other hand, Kaya identity adds energy intensity to the mix (IPCC, 2000). The Kaya identity as shown in equation (1) illustrates the relationship between population growth, per capita value added, energy intensity, and CO_2 emissions per unit of energy. It links these factors on one side of the equation with changes in CO_2 emissions on the other (Nakicenovic, 1997).

$$c = \frac{c}{e} \times \frac{e}{g} \times \frac{g}{p} \times p \qquad (1)$$

In this formula, e represents energy consumption, g refers to gross domestic product (GDP) or value added, and p stands for population. This framework helps explain how changes in CO_2 emissions (c) are driven by variations in these four factors.

Note that GDP and value added are used synonymously in equation (1). However, since we have access to input-output tables that distinguish between output and value added, this study employs the augmented Kaya identity to perform SDA on CO_2 emissions. In equation (2), value added is used instead of GDP for per capita income.

$$c = \frac{c}{e} \times \frac{e}{g} \times \frac{g}{v} \times \frac{v}{p} \times p \qquad (2)$$

This equation shows that CO_2 emissions can be decomposed into five factors: carbonization (C, CO_2 emissions per unit of energy consumption), energy intensity (X, energy consumption per unit of GDP), productivity[2] (R, GDP per unit of value added), income per capita (I, value added per population), and population (P).

Equation 2 can also be written as:

$$c = CXRIP \qquad (3)$$

Additionally, as several studies point out that only the size of the population is not of interest but its growth and flow also informs about population dynamics (Bilsborrow, 1992; Morris, 2021), thereby informing how they contribute to changes in the total CO_2 emissions. Therefore,

[2] To account for productivity (R), output is divided by total value added that shows how efficiently value added is transformed into final output (Cobbold, 2003).

change in population is further subdivided into natural population growth (M) and net migration (N).

$$\Delta P = M + N \tag{3.1}$$

Dietzenbacher & Los (1998) pointed out that there are $m!$ possible decompositions, m being the number of factors under consideration. This chapter uses the average of the two polar decompositions as suggested by Miller & Blair (2022). Based on that, using both (3) and (3.1), the final additive decomposition statement can be expressed as[3]:

$$\Delta c = \Delta CXRIP + C\Delta XRIP + CX\Delta RIP + CXR\Delta IP + CXRI(N) + CXRI(M) \tag{4}$$

In this approach, for each component (such as $\Delta CXRIP$), the change in the factor is calculated by subtracting its value in 1995 from its value in 2018 (in this case, C). For the other factors in that component, the values from 1995 and 2018 are added together (in this case, $XRIP$). Afterward, the average of these combined values is taken for the entire component. By summing the changes across all the six components, the overall change in CO_2 emissions over time can be determined. This additive method allows us to break down how each factor contributes to the total change in emissions.

2.3 Data

This chapter uses the OECD Inter-Country Input-Output (ICIO) Tables for the year 1995 and 2018. ICIO tables comprise of 66 countries and rest of the world (RoW) along with 45 sectors. Additionally, to account for inflation, the ICIO table for 1995 was converted to 2018 prices by using GDP deflator as the price index. Furthermore, to balance the 1995 table after accounting for inflation, Generalized RAS (GRAS) technique was employed (Department of Economic and Social Affairs - Statistics Division, 2018; Temurshoev et al., 2013).

Furthermore, the direct CO_2 emissions data based on production for each of the 66 economies for the 45 sectors is obtained from the OECD TeCO2 Database. The UNDP is the source for the HDI based classification of the countries. For detailed classification of the countries based on HDI and their categorization, see Table 2.A1 in the Appendix.

For the purpose of decomposition, data on energy consumption is collected from EXIOBASE in terajoules (TJ). ICIO tables give information on output, consumption and value added in 2018 prices. Data for population, natural population growth, and net migration is collected from UNDP. For more information on the data sources see Table 2.A2 in the Appendix.

2.4 Results

Based on the country categorization explained in Section 2.2.1, three groups were formed: LIH, MIH, and SIH. Notably, most of the countries in the LIH group are developed nations that were already classified as developed in 1995. Since these countries already had an HDI value of 0.8 or higher, their potential for significant HDI improvement is naturally limited. The only two

[3] The symbol Δ accompanying a variable denotes the difference between the value in 2018 and the corresponding the value in 1995.

exceptions in this group are the Philippines and South Africa, which remain developing countries.

In contrast, the SIH group primarily consists of countries that were developing in 1995, but by 2018, about a dozen of them had transitioned to developed status. It is important to note that a significant portion of the increase in global CO_2 emissions is attributed to China and India (Table 2.3), both of which remain developing nations.

As for the MIH group, all but three countries (Singapore, Iceland, and Israel) were developing in 1995. By 2018, however, the majority had attained developed status, with the exceptions of Tunisia, Peru, Colombia, Brazil, and Mexico, which are still classified as developing countries.

Figure 2.1 presents a scatter plot showing the change in CO2 emissions from 1995 to 2018 against the corresponding increase in HDI values for each country. A linear trend line is also plotted as a red dashed line, indicating a positive slope. This upward slope suggests that increases in development, as measured by HDI, are often associated with higher environmental costs in the form of increased CO_2 emissions.

Interestingly, at around a 0.10 increase in HDI value—representing the threshold that separates LIH from MIH—the trend line crosses the 0 mark for the change in CO_2 emissions. This implies that countries experiencing an HDI increase of less than 0.10, which are predominantly developed countries, tend to reduce their CO_2 emissions, while those with an HDI increase beyond this point tend to contribute more to CO_2 emissions. This finding highlights a potential tipping point in the relationship between human development and environmental impact.

Figure 2.1: Relationship Between Changes in CO_2 Emissions and HDI Improvement (1995-2018)

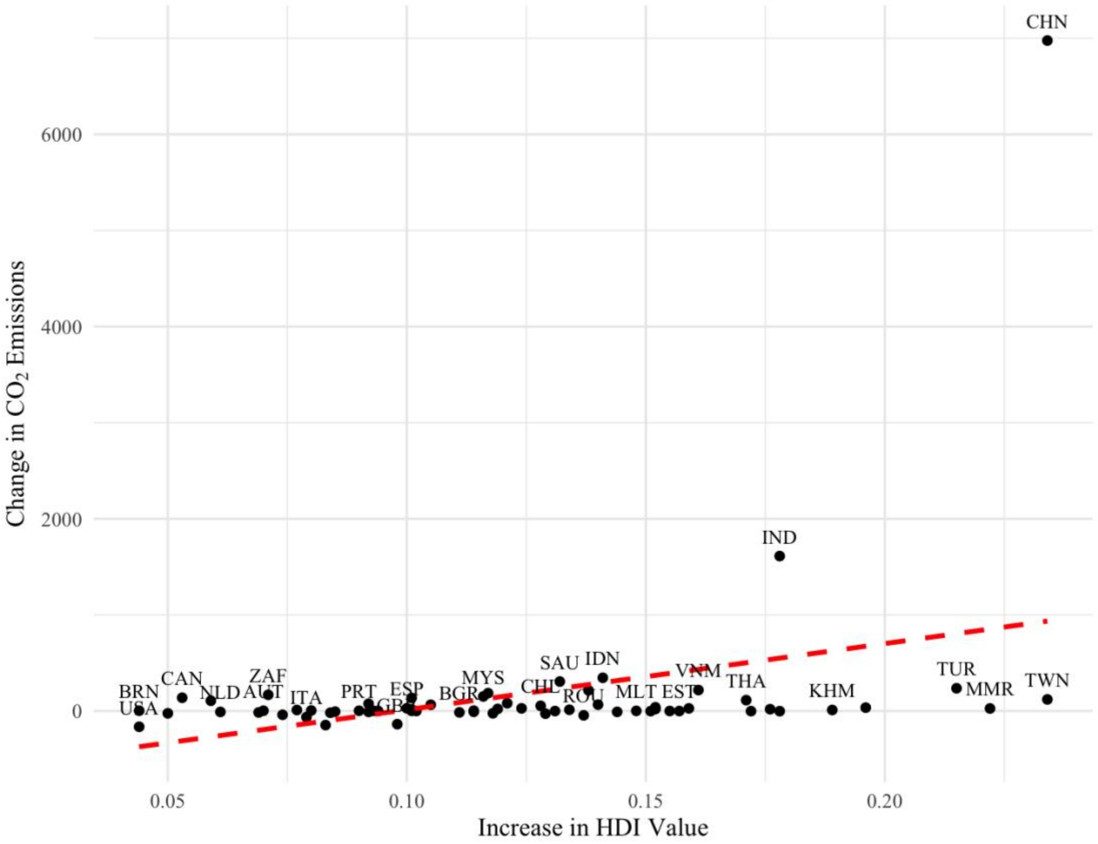


Table 2.2: Change in CO_2 emissions (in million tons) by HDI Improvement category (1995-2018)

World	LIH	MIH	SIH
11387.23	-28.89	1018.03	9346.21

Figure 2.2 illustrates the increase in CO_2 emissions from 1995 to 2018, totaling approximately 11.4 billion tons. The LIH group, which primarily consists of countries that have remained developed throughout this period, emitted more CO_2 than the MIH group. Notably, MIH countries have emitted the least CO_2 compared to the other two groups during this period, although they experienced an increase in emissions of 1.02 billion tons (as shown in Table 2.2). In contrast, the LIH group managed to reduce its emissions by approximately 29 million tons. The SIH group, which includes countries that were developing in 1995 and some that transitioned to developed status by 2018, contributed the most to the global increase in CO_2 emissions, accounting for 9.3 billion tons.

Table 2.3 presents the change in CO_2 emissions by country in descending order. Notably, countries such as China, India, Saudi Arabia, Indonesia, and Turkey are the top five contributors to the increase in global CO_2 emissions, with China contributing 60% to these increase in CO_2 emissions. Additionally, developed countries like Canada and Australia, which have shown limited increase in development, have also contributed to the rise in global emissions. Conversely, the majority of countries that have offset the global increase in CO_2 emissions are developed nations, such as the USA, UK, and Germany, which have shown limited development since 1995, as they were already highly developed at the outset.

Figure 2.2: Direct CO_2 Emissions (1995-2018)

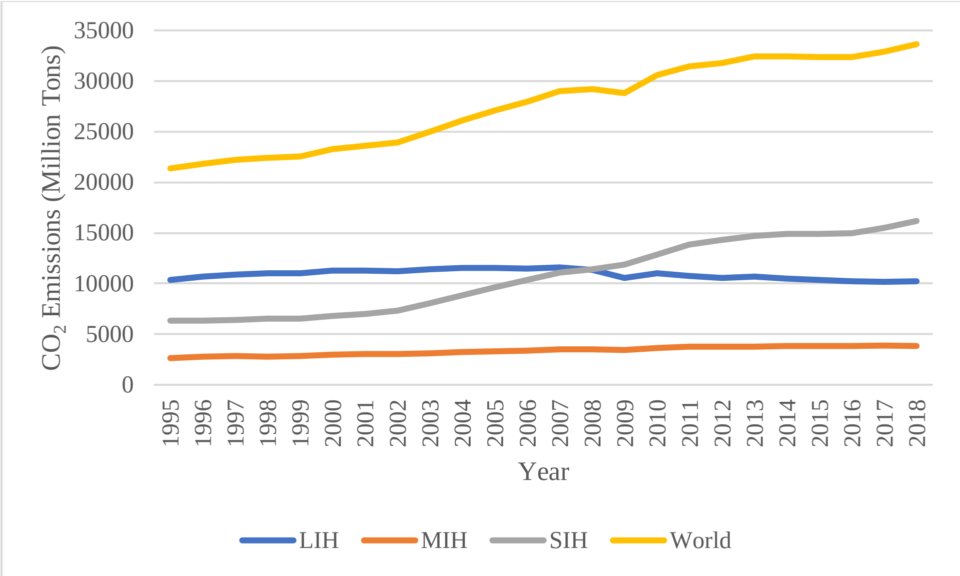


Table 2.3: Change in direct CO_2 emissions (1995-2018) by country (in million tons)

Country Code	**Country**	**HDI Category**	**Change in CO_2 emissions**
CHN	China (People's Republic of)	SIH	6800.17
IND	India	SIH	1523.43
SAU	Saudi Arabia	MIH	305.79
IDN	Indonesia	SIH	294.85
TUR	Turkey	SIH	220.78
VNM	Viet Nam	SIH	212.25
KOR	Korea	MIH	199.42
ZAF	South Africa	LIH	151.72
BRA	Brazil	MIH	145.84
MYS	Malaysia	MIH	134.47
MEX	Mexico	MIH	117.94
TWN	Chinese Taipei	SIH	115.55
CAN	Canada	LIH	115.44
AUS	Australia	LIH	101.93
THA	Thailand	SIH	100.20
SGP	Singapore	MIH	79.76
PHL	Philippines	LIH	65.12
ARG	Argentina	MIH	53.14
CHL	Chile	MIH	45.40
MMR	Myanmar	SIH	26.04
HKG	Hong Kong, China	SIH	25.66
MAR	Morocco	SIH	25.09
COL	Colombia	MIH	21.55
PER	Peru	MIH	20.99
LAO	Lao People's Democratic Republic	SIH	17.33

IRL	Ireland	SIH	16.95
ESP	Spain	MIH	15.47
ISR	Israel	MIH	11.86
KAZ	Kazakhstan	SIH	9.52
TUN	Tunisia	MIH	9.07
KHM	Cambodia	SIH	7.98
NZL	New Zealand	LIH	6.70
NOR	Norway	LIH	6.69
AUT	Austria	LIH	2.87
CHE	Switzerland	LIH	2.75
BRN	Brunei Darussalam	LIH	2.65
ISL	Iceland	MIH	1.27
CRI	Costa Rica	MIH	1.20
MLT	Malta	SIH	0.85
LUX	Luxembourg	LIH	0.57
PRT	Portugal	LIH	0.20
SVN	Slovenia	SIH	-0.24
EST	Estonia	SIH	-1.27
CYP	Cyprus	MIH	-1.78
GRC	Greece	MIH	-2.26
LVA	Latvia	SIH	-2.36
NLD	Netherlands	LIH	-3.16
DNK	Denmark	LIH	-3.47
HRV	Croatia	SIH	-3.60
LTU	Lithuania	SIH	-3.63
FIN	Finland	LIH	-3.79
JPN	Japan	LIH	-6.03
HUN	Hungary	MIH	-9.46
SWE	Sweden	LIH	-9.53
BEL	Belgium	LIH	-10.41
SVK	Slovak Republic	SIH	-11.99
BGR	Bulgaria	MIH	-15.14
CZE	Czech Republic - Czechia	MIH	-24.69
RUS	Russian Federation	SIH	-29.10
POL	Poland	MIH	-37.44
FRA	France	LIH	-39.95
ROU	Romania	MIH	-54.32
ITA	Italy	LIH	-59.87
DEU	Germany	LIH	-89.92
GBR	United Kingdom	LIH	-124.60
USA	United States	LIH	-134.87

Tables 2.4 and 2.5 present the decomposition of CO_2 emissions into the augmented Kaya identity factors for groups of countries and individual countries, respectively. As outlined in equation (3.1), the change in population is broken down into natural population growth and net migration, and the corresponding column provides this information. Additionally, by summing the first two decomposed factors, carbonization and energy intensity, the tables also provide insights into carbon intensity[4].

Table 2.4 presents that carbonization offsets the increase in CO_2 emissions, meaning CO_2 emissions per unit of energy have decreased for all three groups. In contrast, energy intensity contributes to increased CO_2 emissions. This suggests that while decarbonization have occurred, they are accompanied by a rise in energy inefficiency. Interestingly, carbon intensity (CO_2 emissions per unit of output) reduces CO_2 emissions for LIH, whereas it contributes to emissions for MIH and SIH. This is because the carbonization effect—lower CO_2 emissions per unit of energy—is more dominant for LIH, effectively reducing emissions. In contrast, for MIH and SIH, energy intensity becomes the dominant factor, meaning that any reductions from improved carbonization are overshadowed by increased energy use, resulting in higher overall CO_2 emissions.

Table 2.5 shows that for LIH countries, carbon intensity generally offsets CO_2 emissions, with the exceptions of Brunei Darussalam, the Philippines, and South Africa. In the case of MIH countries, Argentina is the main contributor to CO_2 emissions, while for LIH countries, Turkey and Russia are the primary contributors. Notably, CO_2 intensity offsets CO_2 emissions for China, driven by improvements in both carbonization and energy efficiency.

Furthermore, productivity offsets CO_2 emissions for MIH countries, particularly due to contributions from Argentina, Brazil, and Romania. However, productivity leads to higher CO_2 emissions for both LIH and SIH countries, with the increase being more substantial for LIH in absolute terms. Table 2.5 shows that this contribution from LIH primarily comes from Japan, the USA, the UK, and Germany. On the other hand, within the SIH group, some countries—such as Turkey and India—see productivity contributing to increased CO_2 emissions, while others, like China and Russia, experience a reduction in emissions due to productivity gains.

Income per capita helps reduce emissions for LIH and MIH countries, but it contributes to emissions for SIH countries, primarily driven by China, likely due to income-driven production. Table 2.5 shows that, for LIH countries, income per capita offsets CO_2 emissions in countries such as Japan, the UK, and South Africa, whereas countries like Canada and the Australia are contributing to CO_2 emissions, suggesting consumption patterns that are less sustainable despite higher incomes. In the case of MIH countries, the major contributors where income per capita offsets CO_2 emissions include Bulgaria, Argentina, Romania, and Mexico. For SIH countries, income per capita offsets CO_2 emissions in countries like Turkey, Russia, Indonesia, and India. However, China's income per capita contributes to CO_2 emissions. In fact, income per capita is the main factor driving CO_2 emissions for China.

While population factors contribute to rising CO_2 emissions across all groups, 49.8% of this contribution comes from net migration for LIH, 20.3% for MIH, and only 1.2% for SIH. In absolute terms, however, the total population-related contribution is higher for SIH compared to the other two groups. This suggests that natural population growth from SIH is a significant

[4] In equations (1) or (2), if e (energy consumption) is canceled out, what remains is carbon intensity, represented as $\frac{c}{g}$, where c is CO_2 emissions and g is output.

driver of global CO_2 emissions. Table 2.5 shows that while natural population growth is offsetting emissions in Germany, Italy, and Japan, the contribution from net migration outweighs these effects, resulting in population changes contributing to CO_2 emissions overall. For MIH countries, Romania, Bulgaria, and Greece offset emissions due to both net migration and natural population growth, whereas Saudi Arabia and South Africa are the main contributors to CO_2 emissions due to population factors. In the case of SIH countries, China and India unsurprisingly lead as the main contributors to CO_2 emissions, while Russia offsets emissions due to a reduction in natural population growth.

Table 2.4: Contribution of decomposed factors to CO_2 emissions (in million tons) for group of countries based on HDI categorization

Country categorization	Carbonization	Energy Intensity	Carbon Intensity	Productivity	Income per capita	Net Migration	Natural Population Growth	Population	Change in CO_2 emissions
	(1)	(2)	(1+2)*	(3)	(4)	(5)	(6)	(5+6)*	(1+2+3+4+5+6)
LIH	-39,319.37	36,398.84	-2,920.53	1,862.85	-348.40	685.78	691.41	1,377.19	-28.89
MIH	-815.68	3,115.96	2,300.28	-686.41	-1,194.76	121.73	477.18	598.91	1,018.03
SIH	-1,710.57	6,210.30	4,499.73	925.78	2,335.23	22.73	1,562.74	1,585.47	9,346.21
World	-41,545.97	46,385.67	4,839.70	2,147.65	-184.28	762.27	3,821.87	4,584.15	11,387.23

Note: Columns marked with an asterisk (*) are not part of the decomposed factors listed in equation (4) and, as such, are not included in the total (final column).

Table 2.5: Contribution of decomposed factors to CO_2 emissions (in million tons) for each country

Country	HDI Category	Carbonization	Energy Intensity	Carbon Intensity	Productivity	Income per capita	Net Migration	Natural Population Growth	Population	Change in CO_2 emissions
		(1)	(2)	(1+2)*	(3)	(4)	(5)	(6)	(5+6)*	(1+2+3+4 +5+6)
Australia	LIH	-60.04	-71.57	-131.61	105.21	30.48	53.64	44.21	97.85	101.93
Austria	LIH	-16.42	-2.41	-18.83	23.43	-6.47	4.50	0.24	4.74	2.87
Belgium	LIH	-7.98	-15.86	-23.85	32.90	-29.52	7.65	2.41	10.05	-10.41
Canada	LIH	-19.79	-146.86	-166.65	26.17	157.35	64.55	34.02	98.56	115.44
Denmark	LIH	-3.75	-20.17	-23.92	18.31	-3.29	3.76	1.67	5.43	-3.47
Finland	LIH	-13.09	-6.08	-19.17	13.51	-1.55	2.09	1.34	3.43	-3.79
France	LIH	-48.19	-63.34	-111.54	42.54	2.52	7.29	19.24	26.53	-39.95
Germany	LIH	-138.68	-178.15	-316.83	212.73	1.01	36.87	-23.69	13.18	-89.92

Italy	LIH	-79.00	-52.58	-131.58	129.84	-71.59	19.24	-5.78	13.46	-59.87
Japan	LIH	123.14	-285.80	-162.67	489.05	-336.17	23.04	-19.28	3.76	-6.03
Luxembourg	LIH	-37,028.20	37,026.01	-2.19	2.13	-1.52	1.78	0.45	2.23	0.65
Netherlands	LIH	18.20	-54.46	-36.26	35.13	-17.99	6.79	9.17	15.97	-3.16
New Zealand	LIH	8.58	-13.28	-4.70	2.16	2.49	2.86	3.88	6.74	6.70
Norway	LIH	1.00	3.50	4.50	8.67	-15.82	5.72	3.62	9.33	6.69
Portugal	LIH	-0.90	-16.15	-17.05	6.74	9.65	1.30	-0.43	0.87	0.20
Sweden	LIH	-2.48	-13.15	-15.63	5.57	-5.69	4.99	1.24	6.23	-9.53
Switzerland	LIH	9.42	-30.83	-21.41	13.92	4.00	4.73	1.50	6.24	2.75
United Kingdom	LIH	-71.27	-188.17	-259.44	136.65	-47.99	27.60	18.58	46.18	-124.60
United States	LIH	-622.07	-1,232.87	-1,854.95	482.22	351.48	407.79	478.58	886.37	-134.87
Brunei Darussalam	LIH	-5.18	5.93	0.75	-2.06	1.64	0.26	2.06	2.32	2.65
Philippines	LIH	3.74	20.71	24.46	4.40	0.18	-2.61	38.68	36.08	65.12
South Africa	LIH	-1,366.38	1,734.42	368.04	73.63	-371.61	1.95	79.71	81.66	151.72
Chile	MIH	4.43	15.29	19.73	-8.04	19.99	3.04	10.68	13.71	45.40
Colombia	MIH	5.15	22.47	27.62	-3.04	-19.31	0.23	16.05	16.28	21.55
Costa Rica	MIH	-1.50	5.19	3.69	-0.62	-3.29	0.18	1.24	1.42	1.20
Czech Republic - Czechia	MIH	-28.34	-49.33	-77.66	36.14	14.65	3.20	-1.02	2.18	-24.69
Greece	MIH	-10.74	-38.01	-48.75	44.67	2.94	-0.17	-0.90	-1.07	-2.21
Hungary	MIH	-17.43	29.95	12.52	-1.73	-18.13	1.24	-3.38	-2.13	-9.46
Iceland	MIH	-2.89	2.75	-0.14	1.22	-0.81	0.39	0.61	1.00	1.27
Israel	MIH	-29.55	15.77	-13.78	9.79	-4.27	2.80	17.33	20.12	11.86
Korea	MIH	-487.84	297.34	-190.51	256.72	71.28	10.06	51.87	61.92	199.42

Mexico	MIH	-213.63	461.45	247.82	5.68	-223.32	-12.75	100.61	87.86	118.04
Poland	MIH	-39.02	-82.16	-121.18	30.25	52.27	-0.93	1.67	0.74	-37.91
Spain	MIH	-42.30	-13.98	-56.28	88.68	-47.71	26.04	4.74	30.78	15.47
Argentina	MIH	11.01	1,209.95	1,220.96	-848.95	-341.85	-0.60	23.59	22.98	53.14
Brazil	MIH	-8.46	424.50	416.04	-140.55	-186.57	0.11	56.95	57.05	145.98
Bulgaria	MIH	-15.99	302.40	286.41	46.70	-340.74	-1.38	-6.13	-7.51	-15.14
Cyprus	MIH	-5.02	1.94	-3.08	2.64	-3.27	1.33	0.76	2.09	-1.61
Malaysia	MIH	5.07	53.73	58.80	-7.67	19.83	18.44	45.07	63.51	134.47
Peru	MIH	-25.74	33.08	7.34	-3.53	9.93	-1.97	9.21	7.24	20.99
Romania	MIH	-27.21	461.93	434.71	-196.12	-281.83	-7.29	-3.83	-11.12	-54.35
Saudi Arabia	MIH	148.58	-50.80	97.78	-75.49	107.36	43.19	132.95	176.14	305.79
Singapore	MIH	-25.64	-8.82	-34.46	59.37	2.96	37.31	14.57	51.88	79.76
Tunisia	MIH	-8.62	21.30	12.67	17.45	-24.89	-0.72	4.56	3.84	9.07
Estonia	SIH	-3.37	-7.36	-10.73	-9.98	20.72	-0.52	-0.75	-1.28	-1.27
Ireland	SIH	-12.18	-1.75	-13.93	7.65	13.43	3.85	5.95	9.80	16.95
Latvia	SIH	-6.52	-1.95	-8.46	1.93	6.17	-1.17	-0.82	-1.99	-2.36
Lithuania	SIH	-1.78	-10.85	-12.63	-0.10	11.41	-1.67	-0.64	-2.31	-3.63
Slovak Republic	SIH	-7.41	-30.56	-37.97	5.64	19.79	0.08	0.47	0.54	-11.99
Slovenia	SIH	-6.15	7.92	1.77	-2.17	-0.41	0.45	0.12	0.57	-0.24
Turkey	SIH	-731.59	6162.20	5430.62	2743.63	-8025.67	2.85	71.07	73.92	222.50
Cambodia	SIH	-6.38	9.98	3.61	1.01	1.80	-0.17	1.73	1.56	7.98
China (People's Republic of)	SIH	-533.23	-7,679.01	-8,212.23	-908.52	15,058.80	-36.66	898.78	862.12	6,800.17
Croatia	SIH	-8.63	3.87	-4.76	-0.30	3.35	-1.21	-0.66	-1.87	-3.60
India	SIH	39.31	466.40	505.71	808.52	-235.07	-8.12	452.38	444.27	1,523.43

Indonesia	SIH	-333.63	1119.75	786.12	-332.56	-252.53	-1.85	95.67	93.82	294.85
Hong Kong, China	SIH	-49.10	48.61	-0.49	36.56	-20.21	5.34	4.46	9.80	25.66
Kazakhstan	SIH	1.88	235.86	237.74	-188.74	-62.80	-14.86	38.20	23.33	9.53
Lao People's Democratic Republic	SIH	5.65	19.79	25.44	-3.39	-7.44	-0.76	3.49	2.73	17.33
Malta	SIH	0.31	-0.45	-0.14	-1.65	1.93	0.55	0.16	0.71	0.85
Morocco	SIH	-15.13	8.32	-6.82	5.71	16.28	-1.95	11.87	9.93	25.09
Myanmar	SIH	-0.02	39.57	39.55	6.37	-23.40	-0.97	4.49	3.52	26.04
Russian Federation	SIH	-8.19	5,731.45	5,723.26	-1,378.36	-4,348.85	74.34	-99.48	-25.15	-29.10
Chinese Taipei	SIH	24.19	-52.64	-28.45	73.60	50.23	1.49	18.68	20.17	115.55
Thailand	SIH	-61.85	48.68	-13.17	34.05	47.82	5.39	26.12	31.50	100.20
Viet Nam	SIH	3.23	92.47	95.70	26.89	59.87	-1.69	31.47	29.79	212.25

Note: Columns marked with an asterisk (*) are not part of the decomposed factors listed in equation (4) and, as such, are not included in the total (final column).

2.5 Discussion

This study explores the relationship between countries' development levels, as measured by HDI improvements, and their contributions to global CO_2 emissions. By analyzing emissions through the augmented Kaya identity, we have uncovered significant patterns across limited (LIH), moderate (LIH), and substantial (SIH) HDI improvement groups, each with distinct economic and environmental trajectories. The analysis reveals how development levels shape energy use, carbon efficiency, and population dynamics, underscoring the complexity of achieving both growth and sustainability.

2.5.1 Decoupling Development from CO2 Emissions in Developed Countries

In developed countries, particularly those categorized as LIH, the decoupling of economic development from carbon emissions is apparent. Countries such as the USA, UK, and Germany have managed to reduce their CO_2 emissions despite already high levels of development. These countries have benefited from advancements in clean technology and stringent environmental regulations. However, what we observe for these countries could be influenced by the focus of this research on direct CO_2 emissions. Once we account for indirect emissions, the picture could change. Some LIH countries, like Canada and the Australia, continue to contribute to global emissions. These findings align with the work of Freire-González et al. (2024), which confirmed the existence of decoupling for the wealthiest nations during the period 2004–2018, emphasizing the need to interpret these trends within a broader context that includes indirect emission dynamics.

The findings suggest that in LIH countries, decarbonization and energy efficiency improvements are leading to a reduction in CO_2 emissions in 2018 from the levels observed in 1995. These countries show that economic growth can be sustained while reducing environmental impacts through advancements in clean technology and better energy practices. Decarbonization is indeed occurring, but to fully understand the scope of these reductions, it is important to study total CO_2 emissions, which will provide a broader picture of both direct and indirect emissions. While LIH countries continue to make strides toward lowering their carbon footprint, further progress may require continued focus on shifting consumption patterns toward more sustainable practices and maintaining stringent regulations on energy use across sectors.

2.5.2 Challenges of Energy Intensity in Developing Countries

China has made notable strides in decarbonizing its economy, as reflected in reductions in carbon emissions per unit of energy due to the increased adoption of clean energy technologies (Liu et al., 2023). Despite these efforts, the overall increase in China's emissions can be attributed primarily to rising income levels and population growth. Research by Guan et al. (2008) similarly identified per capita GDP growth as the dominant driver behind China's CO_2 emissions, with efficiency improvements only partially offsetting this rise.

In contrast, India has struggled to achieve significant progress in decarbonization or energy efficiency. Its heavy reliance on carbon-intensive energy sources, such as coal, oil, and solid biomass, continues to drive increasing emissions. Reports from the International Energy Agency (IEA, 2021) indicate that India's energy consumption has doubled since 2000, with approximately 80% of this demand still being met by these high-carbon sources. The differing timelines for achieving net-zero emissions—2060 for China and 2070 for India—highlight the significant progress India still needs to make in transitioning to a low-carbon economy.

Meanwhile, countries like Russia, Indonesia, Turkey, and Brazil have managed to reduce their carbon intensity to some extent, demonstrating progress in decarbonization. However, these nations still face significant challenges due to their inefficient energy use, which keeps their economic development closely tied to rising CO_2 emissions.

The findings suggest that developing countries, particularly those in the SIH group, must prioritize energy efficiency improvements alongside decarbonization efforts. While these countries have made strides in decarbonization, energy intensity continues to be a dominant factor driving emissions. To address this, policymakers should focus on promoting cleaner energy technologies, tightening energy use regulations, and ensuring that economic growth is decoupled from energy consumption. International cooperation will be crucial, with a particular focus on technology transfer, financing for renewable energy projects, and supporting the transition to low-carbon growth pathways in these developing economies.

2.5.3 Role of Income, Productivity, and Consumption Patterns

Income per capita plays a dual role in influencing emissions across different levels of development. For LIH and MIH countries, rising incomes have contributed to reducing emissions, as these countries have adopted more energy-efficient technologies. For example, income per capita in countries like Japan, Romania, and Argentina has contributed to offsetting emissions, suggesting that higher incomes, when coupled with technological advancements, can support environmental goals. However, it is important to note that these findings pertain specifically to direct CO_2 emissions. As highlighted by Wiedmann et al. (2020), achieving sustainability requires more than just technological progress, it also demands transformative changes in lifestyles and consumption patterns. Yet, the current structure of societies, economies, and cultures fosters increasing consumption, while the competitive nature of market economies creates a systemic reliance on growth, often obstructing the societal shifts needed for a sustainable future.

However, in SIH countries, particularly China, rising income per capita is a significant driver of CO_2 emissions through its impact on production, even though the country has made notable progress in decarbonizing its production processes and adopting energy-efficient technologies. The challenge remains that despite improvements in energy efficiency, the scale of production driven by increased income and demand still leads to higher emissions. This suggests that income-driven production growth continues to outpace the benefits of decarbonization, these findings are similar to Guan et al. (2008). While China's efforts in energy efficiency are commendable, further policies are needed to ensure that production growth aligns with sustainable practices, such as stricter emissions caps, and enhancing circular economy practices to minimize carbon footprints.

Productivity also plays a crucial role in shaping emissions patterns. For MIH countries, productivity improvements have helped offset emissions, particularly in countries like Brazil and Romania. In contrast, for LIH and SIH countries, productivity contributes to increased emissions. This is particularly pronounced in developed countries like Japan and Germany. The challenge for these countries lies in improving productivity without increasing energy consumption, which may require deeper structural changes in their economies, such as a shift toward green industries.

2.5.4 Population Growth and Migration: A Diverging Trend

Population dynamics play a critical role in shaping emissions, with varying implications across different levels of development. Our findings reveal that in LIH countries, net migration emerges as the primary driver of population-related emissions increases, while natural population growth offsets emissions in countries such as Germany, Italy, and Japan. Shen et al. (2024) and Morris (2021) provide evidence that aligns with and supports our findings. Shen et al. demonstrate that in high-income economies, an increase in the international migrant population correlates with higher CO_2 emissions, as migrants drive economic activities and urbanization, leading to increased energy consumption. Similarly, Morris highlights that per capita CO_2 emissions are nearly three times higher in countries with net immigration compared to those with net emigration. These studies reinforce our findings and underscore the need for LIH countries to incorporate the demographic impacts of migration into their climate strategies, particularly through sustainable urban planning and the development of energy-efficient infrastructure to address the additional energy demands migration brings.

In contrast, for SIH countries, natural population growth is the main driver of emissions, particularly in populous countries like China and India. The rapid increase in population in these countries creates significant challenges in terms of providing energy, housing, and transportation, all of which contribute to higher emissions. The evidence suggests that addressing population-related emissions in developing countries will require not only investment in clean energy but also efforts to reduce the carbon intensity of infrastructure and services in rapidly growing urban areas.

2.6 Conclusion

This chapter provides a comprehensive examination of the changes in global CO_2 emissions from 1995 to 2018, exploring the primary drivers through the lens of the augmented Kaya identity. The analysis offers insights into the contributions of countries with different levels of Human Development Index (HDI) improvements—categorized as having limited (LIH), moderate (MIH), or substantial (SIH) development. By focusing on key factors such as carbonization, energy intensity, productivity, income per capita, and population, this chapter illustrates how countries with varied development trajectories influence global emissions.

The findings highlight that while carbonization efforts have led to reductions in CO_2 emissions in many countries, particularly those in the LIH group, these gains are often negated by increases in energy intensity. The analysis reveals that in LIH countries, advancements in decarbonization and energy efficiency have successfully led to a reduction in CO_2 emissions between 1995 and 2018. However, examining direct emissions alone may provide an incomplete picture. Future analysis of total CO_2emissions, including both direct and indirect emissions, could reveal a broader understanding of global emissions trends.

In contrast, developing countries in the SIH group, such as China, have made progress in decarbonizing their energy systems but face challenges from rising emissions due to population growth and increasing income per capita. India, meanwhile, has struggled to decarbonize and improve energy efficiency, underscoring the diverse challenges faced by rapidly developing economies. Other countries like Russia, Brazil, and Indonesia have successfully decarbonized, but high energy inefficiency remains a key issue.

To address these challenges, policymakers in LIH countries should focus on ensuring that efficiency gains do not lead to higher consumption. Promoting sustainable consumption patterns and maintaining stringent regulations on energy use are essential to maintaining the decarbonization trajectory. Meanwhile, SIH countries must prioritize energy efficiency improvements while continuing efforts to decarbonize. International cooperation will be key, particularly in terms of technology transfer and financial support for renewable energy infrastructure.

The focus of this chapter on direct CO_2 emissions limits the scope of understanding how global emissions are shaped by indirect factors such as trade and global supply chains. Future research should extend the decomposition analysis to include total emissions across production and consumption activities. This would provide a more comprehensive view of the global emissions landscape and offer deeper insights into how technology, consumption patterns, and structural changes in economies influence CO_2 emissions.

Appendix A2

Table A2.1: Classification of countries based on their income level and consequential categorization of their development status and trajectory

S.no.	Country Code	Country	HDI Values		Increase in HDI Value	HDI Improvement Category
			1995	2018		
1	AUS	Australia	0.882	0.941	0.234	LIH
2	AUT	Austria	0.847	0.917	0.234	LIH
3	BEL	Belgium	0.864	0.933	0.222	LIH
4	CAN	Canada	0.877	0.93	0.215	LIH
5	CHL	Chile	0.728	0.856	0.196	MIH
6	COL	Colombia	0.647	0.766	0.189	MIH
7	CRI	Costa Rica	0.69	0.804	0.178	MIH
8	CZE	Czech Republic - Czechia	0.775	0.893	0.178	MIH
9	DNK	Denmark	0.857	0.942	0.176	LIH
10	EST	Estonia	0.733	0.89	0.172	SIH
11	FIN	Finland	0.844	0.936	0.171	LIH
12	FRA	France	0.829	0.903	0.161	LIH
13	DEU	Germany	0.863	0.946	0.159	LIH
14	GRC	Greece	0.784	0.886	0.157	MIH
15	HUN	Hungary	0.736	0.85	0.155	MIH
16	ISL	Iceland	0.857	0.958	0.152	MIH
17	IRL	Ireland	0.786	0.938	0.152	SIH
18	ISR	Israel1	0.807	0.908	0.151	MIH
19	ITA	Italy	0.815	0.894	0.148	LIH
20	JPN	Japan	0.867	0.917	0.144	LIH
21	KOR	Korea	0.78	0.918	0.141	MIH

22	LVA	Latvia	0.696	0.868	0.14	SIH
23	LTU	Lithuania	0.704	0.882	0.138	SIH
24	LUX	Luxembourg	0.828	0.921	0.137	LIH
25	MEX	Mexico	0.678	0.779	0.134	MIH
26	NLD	Netherlands	0.878	0.939	0.132	LIH
27	NZL	New Zealand	0.859	0.936	0.131	LIH
28	NOR	Norway	0.88	0.96	0.129	LIH
29	POL	Poland	0.747	0.876	0.128	MIH
30	PRT	Portugal	0.768	0.858	0.124	LIH
31	SVK	Slovak Republic	0.716	0.86	0.121	SIH
32	SVN	Slovenia	0.761	0.916	0.119	SIH
33	ESP	Spain	0.799	0.899	0.118	MIH
34	SWE	Sweden	0.859	0.943	0.117	LIH
35	CHE	Switzerland	0.863	0.957	0.116	LIH
36	TUR	Turkey	0.623	0.838	0.114	SIH
37	GBR	United Kingdom	0.83	0.928	0.114	LIH
38	USA	United States	0.886	0.93	0.111	LIH
39	ARG	Argentina	0.747	0.852	0.105	MIH
40	BRA	Brazil	0.645	0.762	0.102	MIH
41	BRN	Brunei Darussalam	0.782	0.826	0.101	LIH
42	BGR	Bulgaria	0.7	0.811	0.101	MIH
43	KHM	Cambodia	0.399	0.588	0.101	SIH
44	CHN	China (People's Republic of)	0.532	0.766	0.1	SIH
45	HRV	Croatia	0.709	0.86	0.098	SIH
46	CYP	Cyprus2	0.765	0.896	0.094	MIH
47	IND	India	0.458	0.636	0.093	SIH
48	IDN	Indonesia	0.571	0.712	0.092	SIH

49	HKG	Hong Kong, China	0.79	0.949	0.092	SIH
50	KAZ	Kazakhstan	0.652	0.804	0.09	SIH
51	LAO	Lao People's Democratic Republic	0.437	0.613	0.085	SIH
52	MYS	Malaysia	0.686	0.802	0.084	MIH
53	MLT	Malta	0.755	0.903	0.083	SIH
54	MAR	Morocco	0.481	0.677	0.08	SIH
55	MMR	Myanmar	0.373	0.595	0.079	SIH
56	PER	Peru	0.646	0.77	0.077	MIH
57	PHL	Philippines	0.614	0.706	0.074	LIH
58	ROU	Romania	0.692	0.829	0.071	MIH
59	RUS	Russian Federation	0.696	0.836	0.07	SIH
60	SAU	Saudi Arabia	0.724	0.856	0.069	MIH
61	SGP	Singapore	0.821	0.942	0.061	MIH
62	ZAF	South Africa	0.66	0.731	0.059	LIH
63	TWN	Chinese Taipei	0.532	0.766	0.053	SIH
64	THA	Thailand	0.625	0.796	0.05	SIH
65	TUN	Tunisia	0.603	0.737	0.044	MIH
66	VNM	Viet Nam	0.55	0.711	0.044	SIH

Note: A separate HDI value is not recorded for Chinese Taipei (Taiwan), so China's values were used instead.

Table A2.2: Description of all the variables

Variable	Unit	Description	Source
Direct Emissions	Million Tonnes	CO_2 emissions based on production.	OECD Trade in embodied CO2 (TeCO2) Database
Energy Consumption	Terajoules (TJ)	Energy Carrier Use.	EXIOBASE
Output	USD (2018 prices)	Total output produced by the country. Converted to 2018 prices using GDP deflator.	Estimated using OECD ICIO Tables.

Value Added	USD (2018 prices)	Value added includes compensation for labour (or employees) and capital (i.e., gross operating surplus). It also includes taxes less subsidies on intermediate products. It is converted to 2018 prices using GDP deflator.	Calculated using OECD ICIO Tables.
Productivity	Ratio	Ratio of output and value added.	Calculated using OECD ICIO Tables.
Natural Population Growth	persons	Difference between crude birth and crude death.	United Nations - Population Division
Population	persons	De facto population in a country, area or region as of 1 July of the year indicated.	United Nations - Population Division
Net migration	persons	Net migration is the total number of immigrants (people moving into a given country) minus the number of emigrants (people moving out of the country).	United Nations - Population Division
GDP Deflator	Index	It shows change in GDP due to change in price level. The information is available for countries with different base year.	The World Bank, NASDAQ (Taiwan)
Note: To estimate GDP deflator and CPI for the Rest of the World, the data for the two indicators was collected from the World Bank for the countries that are not included in the 66 countries considered in this chapter and for whom the data was available for both the indicators. This comprised of 87 countries. As the base year was not the same for GDP deflator, the series for all the countries were rescaled to make 2010 as the base year. The CPI series already had 2010 as the base year. Additionally, data was extrapolated for GDP deflator information of Canada for the years 1995 and 1996.			

Chapter 3

Goods and Bads in International Trade: A New Approach[1]

3.1. Introduction

The dichotomy of 'goods' and 'bads' is underscored in the environmental economics textbook by Kolstad (2010), where goods tend to increase the welfare of individuals or society and bads tend to decrease it. While two agents engage in trade of goods, the unintended production of bads also occurs. We traced one of the early mentions of bads to Daly (1968), who introduced the concept in the context of ecological economics, describing bads as ecological commodities with negative value, such as pollution and waste. These bads have detrimental impacts on human welfare by degrading the environment, which in turn affects health, reduces the quality of life, and imposes economic costs through damage to natural resources and increased healthcare expenses. Today, the reference to pollution and similar externalities as 'bads', 'public bads', 'collective bads', or 'social bads' has permeated various branches of economics, including public economics (Musgrave, 1974; Oakland, 1987; Musgrave & Musgrave, 1989), health economics (Kaul, 2004; Folland, 2008; Roberto & Kawachi, 2014), behavioural economic (Nagatsu, 2015; Abatayo & Li, 2024), development economics (Harris et al., 2009; Corbacho et al., 2013; Graaf & Wiertz, 2019), urban economics (Izraeli, 1987; Kahn, 2010), regional economics (Shaw & Newby, 1998; de Haan, 2004; Harstad, 2012), and international economics (Markusen, 1975; Braden & Bromley, 1981; Førsund 2009; Bogmans, 2015). International economics, generally, uses theoretical models or econometric analysis to study bads in international trade context. More recently, quantification and distribution of bads in international trade is done from general equilibrium perspective using frameworks like input-output models.

Input-Output based emission multipliers provide a powerful framework for understanding how CO_2 emissions are distributed across sectors and the economy. By accounting for both direct and indirect emissions, these models offer a comprehensive view of the carbon intensity of production and consumption (Miller & Blair, 2022). Global Value Chain analysis extends this by mapping how emissions are generated at different stages of production across multiple countries, offering insights into the carbon footprint of internationally fragmented production processes. Emissions Embodied in Trade complements this by tracking how emissions are transferred across borders through traded goods and services, highlighting the responsibility of consuming countries for emissions produced abroad. Sato (2014) underscored the critical flows of carbon emissions associated with international trade and their implications for environmental and economic policies. Similarly, Peters & Hertwich (2008) emphasized the impact of emissions embodied in trade on global climate policies, advocating for the inclusion of traded goods' carbon footprints in crafting effective environmental strategies. Sánchez-

[1] This chapter is co-authored with Maria Llop Llop.

Chóliz and Duarte (2004) further highlighted the significant role of sectors like transport materials, mining, and energy as major exporters of CO_2 emissions in international trade. Further analysis by Yang et al. (2022) through multi-region input-output analysis quantifies the transfer of environmental costs in international trade and its regional impacts. The use of input-output (IO) models, especially multi-regional ones as explored by Zhao et al. (2014) and Valodka & Snieška (2020), has proven instrumental in revealing the substantial carbon footprints linked to global trade dynamics, particularly in sectors like textiles and clothing.

The interaction between trade openness and environmental outcomes has attracted significant scholarly attention. Research by Ragoubi & Mighri (2021) delves into the nuanced effects of trade openness on CO_2 emissions, demonstrating both positive and negative impacts. For instance, trade openness can foster technological advancements and efficiency improvements that reduce emissions, yet it may also intensify production and consumption patterns that exacerbate them. The latter point is also highlighted by Tu et al. (2019) using a theoretical framework indicating that the globalization of food trade is unsustainable. This complexity is further illustrated by Wang & Zhang (2021), who noted varying impacts of trade openness on CO_2 emissions across different income groups, highlighting the disparate environmental consequences of trade liberalization. Building on this discourse, Doganay et al. (2014) and Honma (2015) have explored the concept of environmental efficiency from a partial equilibrium perspective, investigating its influence on trade dynamics. Doganay et al. (2014) constructed an environmental efficiency index to determine whether it acts as a trade inducer or hindrance, while Honma (2015) applied a data envelopment analysis (DEA) model to measure how international trade impacts environmental efficiency regarding air pollutants. These studies contribute significantly to understanding how environmental efficiency correlates with trade activities.

During international trade, countries and sectors inadvertently exchange not only the goods they pay for but also the bads they produce. These unintentional exchanges of bads alongside goods highlight the need for a metric to determine which of the two—goods or bads—predominates in trade interactions. In this chapter, we broaden the traditional scope of trade analysis by focusing not only on trade openness with regards to goods and services (the 'goods') but also incorporating the trade openness of CO_2 emissions (the 'bads'). By employing the Hypothetical Extraction Method (HEM) for each sector, the intertwined roles of both conventional trade and emissions are methodically dissected. This approach enables a holistic examination of each sector by taking the global supply chain into account, revealing not just the economic interdependencies and trade dynamics but also the associated environmental impacts. Using the measure of trade openness for both the good and the bad, a novel metric is constructed that quantifies the emission balance of trade (EBT). This metric aims to fill the gap left by traditional analyses which, though comprehensive, fall short of quantifying the balance between the economic and environmental considerations.

While the sectoral trade openness ratio (STOR) indicates how much a country engages in trade with respect to its domestic production and the emission trade openness ratio (ETOR) indicates how much emissions are embodied in trade with respect to the domestically produced emissions, the EBT informs about the emission intensity of trade. In other words, EBT helps identify the sectors and countries that trade more in the bad than the good , as well as those that trade more in the good than the bad. A value of EBT closer to 0 indicates clean trade, a value less than 1 indicates that emissions in trade are less than the goods traded (bad < good), a value equal to 1 indicates that emissions are balanced to trade in goods (bad = good), and a value greater than 1 indicates emissions in trade is more than the goods traded (bad > good). This metric provides crucial insights into how sectors balance economic and environmental considerations.

The remainder of the chapter is structured as follows. Section 3.2 provides a detailed explanation of how the EBT is constructed using the HEM and the trade openness ratio (TOR). Section 3.3 presents the data used in the analysis. Section 3.4 outlines the results, followed by a discussion and conclusion in Section 3.5.

3.2. Methodology

The methodology adopted in this chapter utilizes a general equilibrium perspective through an IO modelling framework, which is instrumental in including both direct and indirect emissions[2]. This comprehensive approach allows for a fuller understanding of the entire emissions footprint of sectors, capturing not just the emissions they produce directly but also those they cause indirectly through their economic activities and intermediate consumption of goods and services. Central to IO models is their ability to trace the flow of goods and services from production to final consumption. This capability is crucial for mapping how emissions are embedded in products that are consumed both domestically and internationally, providing a detailed view of the emissions' lifecycle (Miller & Blair, 2022; Wei et al., 2011).

Building on this, the chapter employs an Environmentally Extended Input-Output (EEIO) framework, which extends the traditional IO analysis by integrating environmental data, i.e. carbon emissions in this case. By doing so, it allows for a nuanced examination of how emissions are not only produced but also transferred through international trade. The EEIO framework effectively traces these emissions from the production phase to final consumption, shedding light on the global movement of embodied carbon through trade networks.

To explore the sector-specific contributions to bads (emissions) and goods (economic outputs), the chapter applies the HEM. This method simulates the removal of specific sector from the economic model to assess its impact. It involves comparing actual data with scenarios where a particular sector is absent, quantifying the bads and goods attributable to that sector (Miller & Blair, 2022). According to Guerra & Sancho (2010), HEM is a measure of the sector's 'keyness'—its economic relevance and implicit weight within the network. By altering production of one sector, ripple effects occur throughout the economy impacting sectors with linkages to the eliminated sector. Analysing the differences between benchmark values and those generated under hypothetical scenarios, HEM provides insights into each sector's

[2] Indirect emissions refer to those emissions that are not produced directly by a sector but occur as a consequence of the activities within that sector. For instance, a sector may directly emit CO_2 during production processes, but it also causes emissions indirectly through its intermediate consumption of energy, which might be generated from fossil fuels.

significance to global emissions and the broader economic landscape[3]. It helps in identifying sectors for decarbonization.

Mathematically, the multi-country IO equation is given by:

$$x = Ax + y \tag{1}$$

Here, x is the vector of total outputs for each sector i in country n. A is the matrix of technical coefficients, indicating the amount of input from sector i in country n is required per unit of output in sector j of country m[4], and y is the matrix of final demand for each sector i in country n.

Now, rearranging the equation to solve for the output vector x:

$$x = (I - A)^{-1}y \tag{2}$$

Here, I is the identity matrix, and $(I - A)^{-1}$ is known as the Leontief inverse, which represents the total direct and indirect inputs required to satisfy both intermediate and final demands.

From EEIO model, the emissions are equal to:

$$e = B(I - A)^{-1}y \tag{3}$$

Here, e is the vector of total environmental impacts (i.e., CO_2 emissions) associated with each sector, and B is the diagonal matrix of emission coefficients, indicating the emissions produced per unit of output by each sector of each country.

For HEM in EEIO, say that all the entries corresponding to sector k are set to zero, in other words, it is extracted out of A and y to arrive at modified A' and y'. So, the modified output and environmental impact can be estimated as:

$$x' = (I - A')^{-1}y' \tag{2.1}$$

$$e' = B(I - A')^{-1}y' \tag{3.1}$$

Now, the changes in outputs and environmental impacts due to the extraction of sector k is given by:

$$\Delta x = x' - x \tag{2.2}$$

[3] Unlike Dietzenbacher et al. (2019), this chapter does not introduce a substitute for the output of the eliminated sector during HEM, as the objective is to ascertain the ‘keyness’ of the eliminated sector.
[4] When $n = m$, the trade is taking place domestically.

$$\Delta e = e' - e \tag{3.2}$$

The changes estimated in equation 2.2 and 3.2 are summed over sectors for each country to estimate total changes in goods and bads in each country due to extraction of sector k. The final matrix is an $n \times n$ matrix that is used to estimate how much of goods and bads associated with sector k were exported, imported and produced within the country[5].

Fig 3.1: Country-level matrix representation of change in goods or bads (Δx or Δe) when sector k is extracted

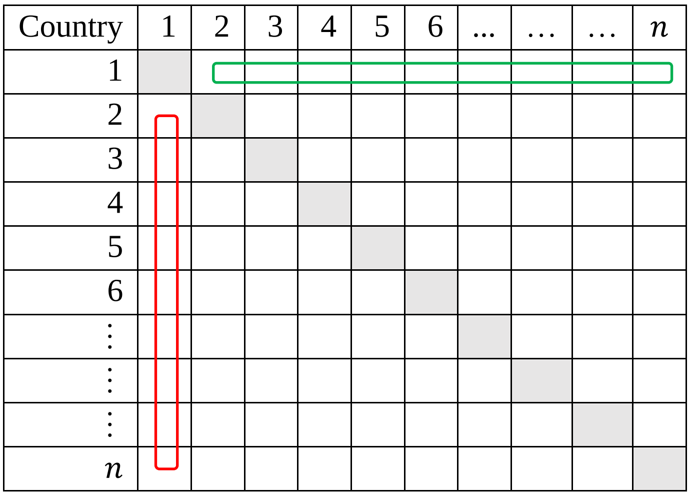


Figure 3.1 shows the matrix of Δx (or Δe) for $n \times n$ countries. Here, the diagonally shaded blocks informs about the change in trade taking place domestically[6]. Like in an IO table, the columns for a country depicts the inputs used in production and the rows depicts the output distribution. Therefore, the sum of columns gives the change in total domestic production of each country due to extraction of sector k, the sum of column without the shaded block gives the change in imports for the country (i.e. the sum of red block countries for country 1) , and the sum of row without the shaded block gives the change in exports from the country (i.e. the sum of green block countries for country 1). This change in exports, imports and domestic production due to extraction of sector k is basically the export (ΔEX_k), import (ΔIM_k) and domestic production (ΔGDP_k) associated with sector k. We then use this information to estimate trade openness ratio.

[5] The goods and bads produced, exported, and imported by a sector will differ from those associated with the elimination of the sector. This is because when a sector is eliminated, it also affects the production of other sectors across countries, and these indirect effects are accounted for in the latter case.

[6] Each block of countries contains 45 sectors. Therefore, the elimination of one sector from the world economy will not only affect international trade but also lead to changes within the domestic economy, as trade occurs between sectors within the same country. This change in domestic trade is represented by the shaded diagonal blocks in Figure 3.1.

The trade openness ratio[7] (TOR) is utilized to gauge the significance of international transactions relative to domestic ones (OECD, 2011). This ratio is calculated by taking the simple average (the mean) of total trade, which is the sum of exports (EX) and imports (IM) of goods and services, relative to the Gross Domestic Product (GDP). Exports and imports together provide an indication of the total trade activity. It is expressed as:

$$Trade\ Openness\ Ratio = \frac{EX + IM}{GDP} \tag{4}$$

To estimate the sectoral dependency on the foreign market for intermediate goods consumption and final sale, we can calculate sector-specific trade openness ratio:

$$Sectoral\ Trade\ Openness\ Ratio_{kn} = \frac{\Delta EX_{kn} + \Delta IM_{kn}}{\Delta GDP_{kn}} \tag{5}$$

Here, ΔEX_{kn} is change in exports of sector k in country n, ΔIM_{kn} is change in imports of sector k in country n, and ΔGDP_{kn} is change in domestic production of sector k in country n, when sector k is hypothetically extracted.

Similarly, to assess the extent to which the environmental impacts associated with that sector are linked to international trade, we can calculate emissions trade openness ratio:

$$Emissions\ Trade\ Openness\ Ratio_{kn} = \frac{\Delta EXe_{kn} + \Delta IMe_{kn}}{\Delta e_{kn}} \tag{6}$$

Here, ΔEXe_{kn} is change in exported emissions of sector k in country n, ΔIMe_{kn} is change in imported emissions of sector k in country n, and Δe_{kn} is change in total domestically produced emissions of sector k in country n, when sector k is hypothetically extracted.

Table 3.1: Interpretation of TOR values

Value	**Interpretation**
0.0-0.5	Relatively closed economy
0.5-1.0	Balanced international integration
>1.0	Highly open economy

Table 3.1 presents the interpretations of the values of TOR: values between 0-0.5 indicate a relatively closed economy with limited dependency on international trade. Values between 0.5-1 suggest a balanced engagement with international trade, reflecting a blend of domestic economic activities and global market integration. However, when the ratio exceeds 1, it

[7] Although often termed 'openness,' this descriptor can be misleading as a low ratio does not necessarily indicate high barriers (tariff or non-tariff) to foreign trade. Instead, it may reflect factors such as the size of the economy or geographic remoteness from potential trading partners (OECD, 2011). However, the objective of this chapter is to analyse how much CO_2 emissions a country is trading in relation to its domestic production, and to determine whether its openness to trading a bad—in this case, CO_2 emissions—surpasses its trade in goods.

denotes a highly open economy that is highly integrated with the global economy or heavily reliant on international trade. In case when emissions trade openness ratio exceeds 1, it implies that the total emissions associated with imported and exported goods surpass the emissions produced domestically. This suggests that the sector's international trade activities contribute more significantly to global emissions than to local production processes, highlighting a potential environmental burden being shifted beyond national borders.

Now, if we divide equation (6) by (5), we will get emission intensity of trade, we will refer to it as emission balance of trade (EBT):

$$Emission\ Balance\ of\ Trade_{kn} = \frac{Emissions\ Trade\ Openness\ Ratio_{kn}}{Sectoral\ Trade\ Openness\ Ratio_{kn}} \quad (7)$$

The unitless EBT metric assesses the environmental intensity of a sector's international trade activities relative to its overall trade volume. This metric offers a nuanced perspective on how sectors balance economic output with environmental impacts. Values less than 1 indicate higher economic efficiency compared to emissions, suggesting environmentally sustainable trading practices. Conversely, values greater than 1 highlight a disproportionate emissions burden relative to economic gains, signalling areas where environmental efficiency could be improved.

While it is important to acknowledge the limitation of the trade openness ratio, which can be skewed with high values for countries with small geographical areas (Fujii, 2017), it is relevant to note that the EBT metric provides a more balanced perspective. The EBT metric assesses whether the trade that a sector of a country engages in is environmentally efficient by considering the international integration of its associated bads in relation to the international integration of its associated goods.

As both the numerator (emissions from trade) and the denominator (sectoral trade activity) account for the domestic share, the metric effectively scales the trade's environmental impact to domestic production. This means that even if a country has a high GDP, resulting in significant domestic emissions production, the EBT metric balances this by incorporating the proportionate share of emissions from trade.

In this way, the EBT metric can mitigate the skewed effects observed in the traditional trade openness ratio. By focusing on the emission balance of trade, it offers a more nuanced and equitable assessment of a country's trade practices, taking into account both economic and environmental dimensions. This approach ensures that the metric remains relevant and comparable across countries with different geographical sizes and economic structures.

It is important to note that the HEM is applied to eliminate one sector across all the countries at a time to determine the significance of that sector. Consequently, the total exports and total imports attributed to the sector worldwide remain balanced, at the global level, imports for one country are simply exports for another. In other words, when considering the world as a whole, trade is a closed system—exports and imports are always balanced because goods do not leave or enter from outside the planet. For exports and imports to be different from each other, it would imply that we are trading with entities outside the global economy, which is not the case. Therefore, the sum of exports across all countries must equal the sum of imports for each sector at global level[8]. To avoid double-counting trade for a given sector globally, when calculating the trade openness ratio, trade for a sector is measured as the sum of exports across countries (since the sum of exports equals the sum of imports). With this approach, equations (5), (6), and (7) can be used to compute the STOR, ETOR, and EBT for each sector and country, as outlined in the formulas below.

For each sector:

$$STOR_k = \frac{\sum_{n=1}^{67} \Delta EX_{kn}}{\sum_{n=1}^{67} GDP_{kn}} \tag{5.1}$$

$$ETOR_k = \frac{\sum_{n=1}^{67} \Delta EXe_{kn}}{\sum_{n=1}^{67} \Delta e_{kn}} \tag{6.1}$$

$$EBT_k = \frac{ETOR_k}{STOR_k} \tag{7.1}$$

For each country we calculate the total values by adding the respective sectors for each country:

$$STOR_n = \frac{\sum_{k=1}^{45}(\Delta EX_{kn} + \Delta IM_{kn})}{\sum_{k=1}^{45} \Delta GDP_{kn}} \tag{5.2}$$

$$ETOR_n = \frac{\sum_{k=1}^{45}(\Delta EXe_{kn} + \Delta IMe_{kn})}{\sum_{k=1}^{45} \Delta e_{kn}} \tag{6.2}$$

$$EBT_n = \frac{ETOR_n}{STOR_n} \tag{7.2}$$

In this manner STOR[9], ETOR and EBT can be estimated for all the countries and sectors. This will help us understand which sectors and countries are more integrated in the global economy

[8] Note that this principle does not apply to countries in this analysis because the totals for countries are computed by summing the sector-specific values associated with each country when the respective sector is eliminated globally, one sector at a time. If we were to eliminate a country from the analysis instead, the double counting principle would apply to the countries rather than the sectors.
[9] Note that $STOR_n \neq TOR_n$, as $STOR_n$ takes backward and forward linkages into account. In other words, $STOR_n$ takes indirect effects into account while TOR_n does not (See footnote 5).

via trade of a good, which engage more in trade of a bad and which trade more in bad compared to the good.

3.3. Data

In this chapter, the 2018 OECD Inter-Country Input-Output Database is employed, encompassing data from 45 sectors[10] and 66 countries, along with the Rest of the World (RoW), totalling 67 regions. The RoW is an aggregated account comprising information from over 130 countries, designed to simulate a closed economy model (OECD, 2021a; OECD Directorate for Science Technology and Innovation, 2021; Guilhoto, 2021). This database adheres to the benchmark standards set by the National Accounts and Balance of Payments of the involved countries. Additionally, direct CO_2 emissions[11] data for the year 2018, measured in Million Tons (MTs) and based on production, are extracted from the Trade in embodied CO_2 (TeCO2) database (OECD, 2021b). These comprehensive datasets provide a robust foundation for analysing the global economic and environmental interactions across sectors and nations.

3.4. Results

The elimination of a sector results in the reduction of both the goods and bads produced directly by that sector, as well as those produced indirectly through its linkages with other sectors. Table 3.2 presents the results in absolute terms, highlighting the significance of each sector in terms of goods and bads production. Among primary sectors, *Agriculture, hunting, and forestry* (X1) contributes the most to both goods and bads, followed by *Mining and quarrying, energy producing products* (X3). In the secondary sectors, *Construction* (X25) is the largest contributor to goods, followed by *Food products, beverages and tobacco* (X6). However, in terms of bads, the *Electricity, gas, steam and air conditioning supply sector* (X23) contributes the most, followed by *Construction* (X25). In the tertiary sectors, *Wholesale and retail trade; repair of motor vehicles* (X26) is the largest contributor to goods, while in terms of bads, X26 is followed by *Land transport and transport via pipelines* (X27).

Table 3.2: Contribution of each sector towards Goods and Bads

Sector Code[12]	Sector Name	Contribution to	
		Bads (in MTs)	Goods (in USD)
X23	Electricity, gas, steam and air conditioning supply	13,511.17	6,891,316.26
X25	Construction	5,763.21	26,279,397.68
X15	Basic metals	5,124.25	7,716,155.95
X26	Wholesale and retail trade; repair of motor vehicles	2,510.62	24,649,560.32
X14	Other non-metallic mineral products	2,240.29	4,302,921.44

[10] Output from sector 45, i.e. 'Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use', is not traded, therefore, it is not displayed in the results section. However, the value forms part of the denominator in equation (5.1) and (6.1).
[11] The data for CO_2 emissions is utilized for the 45 sectors across the countries/regions under consideration.
[12] The sectors X1-X5 can be identified as primary sectors, X6-X25 as secondary sectors, and X26-X45 as tertiary sectors.

X27	Land transport and transport via pipelines	2,233.19	7,507,854.29
X10	Coke and refined petroleum products	2,086.63	7,467,123.80
X11	Chemical and chemical products	2,012.35	727,0701.51
X6	Food products, beverages and tobacco	1,936.76	1,476,7588.68
X1	Agriculture, hunting, forestry	1,671.98	9,693,415.36
X3	Mining and quarrying, energy producing products	1,578.00	5,267,773.20
X16	Fabricated metal products	1,533.06	5,682,108.57
X19	Machinery and equipment, nec	1,510.59	7,571,846.10
X20	Motor vehicles, trailers and semi-trailers	1,454.40	9,256,243.69
X40	Public administration and defence; compulsory social security	1,332.59	13,376,426.65
X29	Air transport	1,317.60	2,030,806.26
X13	Rubber and plastics products	1,264.90	4,177,358.90
X18	Electrical equipment	1,182.79	4,851,644.85
X37	Real estate activities	1,120.05	14,440,640.66
X22	Manufacturing nec; repair and installation of machinery and equipment	1,071.29	4,271,167.20
X28	Water transport	1,059.80	1,532,464.68
X17	Computer, electronic and optical equipment	1,031.51	7,027,840.64
X32	Accommodation and food service activities	887.87	8,360,370.12
X38	Professional, scientific and technical activities	858.82	11,277,804.78
X42	Human health and social work activities	846.61	11,414,730.69
X39	Administrative and support services	836.26	8,489,544.02
X7	Textiles, textile products, leather and footwear	748.20	5,145,186.42
X4	Mining and quarrying, non-energy producing products	720.86	2,073,428.26
X41	Education	656.45	6,862,242.58
X36	Financial and insurance activities	618.84	11,636,312.63
X9	Paper products and printing	596.22	3,110,666.19
X30	Warehousing and support activities for transportation	528.39	3,359,225.85
X12	Pharmaceuticals, medicinal chemical and botanical products	479.59	2,802,612.28
X34	Telecommunications	444.28	4,030,750.06
X21	Other transport equipment	397.61	2,604,283.94
X44	Other service activities	378.29	3,452,977.08
X24	Water supply; sewerage, waste management and remediation activities	335.74	1,940,565.24
X35	IT and other information services	289.80	4,730,894.16
X8	Wood and products of wood and cork	240.59	1,545,121.85
X33	Publishing, audiovisual and broadcasting activities	212.87	3,041,450.96
X43	Arts, entertainment and recreation	197.33	2,240,228.10
X31	Postal and courier activities	164.58	1,009,652.82
X2	Fishing and aquaculture	161.45	977,619.82

X5	Mining support service activities	118.53	631,955.76

With respect to the production and export of bads, China is the largest contributor across all sectors. Conversely, the USA is the largest importer of bads, except in sectors X1, X2, X25, X28, and X29, where China is the leading importer.

Now to understand, how the sectors across all the countries fare on the three metrics, viz. Sectoral Trade Openness Ratio (STOR), Emissions Trade Openness Ratio (ETOR), and Emission Balance of Trade (EBT), Figures 3.2 & 3.3 presents world maps and heatmaps. The values closer to 0 are represented in white, transitioning to blue for values near 1. For values greater than 1 but less than or equal to 2, the colour shifts from yellow to dark yellow. Values above 2 are depicted in increasingly darker shades of red, indicating a higher intensity the further the value deviates from 2. In the case of STOR and ETOR, a value greater than 2 indicates that trade in goods and bads, respectively, is very highly integrated into the global economy, so much so that trade is more than double the domestic production of goods and bads, respectively. In the case of EBT, a value higher than 2 indicates that trade in bads is more than double the trade in goods, which reflects unintended trade outcomes. In other words, in such cases, the sector and/or country are engaged in trading goods but end up trading a significant volume of bads.

3.4.1 Sectoral Trade Openness Ratio (STOR)

Figure 3.3(a) illustrates that the integration of primary (X1-X5) and secondary sectors (X6-X25) within the global economy is significantly higher compared to the tertiary sector (X26-X44). Notably, the secondary sectors of *Electricity, gas, steam, and air conditioning supply* (X23), *Water supply; sewerage, waste management, and remediation activities* (X24), and *Construction* (X25) demonstrate lower engagement in international trade relative to domestic production. This domestic focus is largely attributed to the substantial infrastructure requirements and stringent regulatory constraints that restrict their international trade activities.

Additionally, quaternary sectors (X40-X44) within the tertiary sector, which involve the handling and processing of information and knowledge, and *Real estate activities* (X37) also exhibit limited openness to international trade. Conversely, the transport sectors (X27-X29) within the tertiary sector and the mining and quarrying sectors (X3-X4) within the primary sectors are highly integrated with the global economy, reflecting their significant participation in international trade activities.

Furthermore, figures 3.2(a) & 3.3(a) shows that Luxembourg (2.67), Ireland (2.00), Malta (1.83), and Singapore (1.85) are small economies with high integration into the global economy. This high integration is largely attributable to the fact that these smaller economies are unable to produce all the required goods and services domestically and must therefore engage in trade with other economies to meet the needs of their populations. On the other hand, large economies like Argentina, Brazil, China, India, Japan, and the United States are integrated into the global economy, but their trade volume is less than their GDP. Additionally, there are sets of countries that exhibit similar trade profiles and engage in trade activities in specific sectors. For example, Cambodia and Vietnam are heavily involved in textiles, Kazakhstan and Saudi Arabia focus on energy products, and Canada and Russia, both with vast geographical areas rich in resources such as oil, gas, and minerals, have trade activities significantly driven by the export of these commodities.

3.4.2 Emissions Trade Openness Ratio (ETOR)

Figure 3.3(b) illustrates that metals, electronics, and machinery Sectors (X15-X22) engage more in embodied emissions in trade compared to domestic production, with *Computer, electronic and optical equipment* (X17) contributing significantly to such emissions. Among the primary sectors, the mining and quarrying sectors (X3-X4) contribute more emissions to trade than domestically produced. In tertiary sector, Water and Air transport (X28, X29) emit more emissions internationally, while quaternary sectors (X40-X44), *Real estate activities* (X37) and X23-X25, embody fewer emissions in trade relative to domestic production.

Furthermore, figures 3.2(b) & 3.3(b) shows that geographically small countries like Singapore (2.26), Lao PDR (1.82), Ireland (1.63), Iceland (1.57) contribute more emissions to trade than are domestically produced. In fact, most of the other European Union countries (1.03-1.50) exchange more emissions than domestically produced. On the other hand, among the large economies Canada (1.14) contribute more to emissions in trade than domestically produced, while other large economies like Argentina, China, India, Japan, and the United States contribute less emissions to trade compared to their domestic production.

3.4.3 Emission Balance of Trade (EBT)

Figure 3.3(c) illustrates that trade in tertiary sector (X26-X44) is highly emission intensive, especially in quaternary sectors (X40-X44). Trade by transport sectors (X27-X29) on the other hand is environmentally efficient. Among the secondary sectors (X6-X25), trade by *Construction* (X25) sector is highly emission intensive. While among the primary sectors (X1-X5), trade by *Agriculture, hunting, forestry* (X1) and *Fishing and aquaculture* (X2) are more emission intensive compared to the mining sectors (X3-X5).

Furthermore, figures 3.2(c) & 3.3(c) shows that among the geographically small economies, the trade activities of Lao PDR (2.19), Iceland (1.56), Denmark (1.51), and Singapore (1.22) are emission intensive, while the trade activities of other small geographies like Luxembourg, Malta, Cyprus, Ireland are more environmentally efficient. Among the larger economies, the trade activities of Brazil (1.60), Colombia (1.52), Canada (1.44), United States of America (1.33) are emission intensive. In fact, most of the European and American countries' trade activities are emission intensive. On the other hand, trade activities of India and China are environmentally efficient.

Fig. 3.2: World Map for STOR, ETOR, and EBT

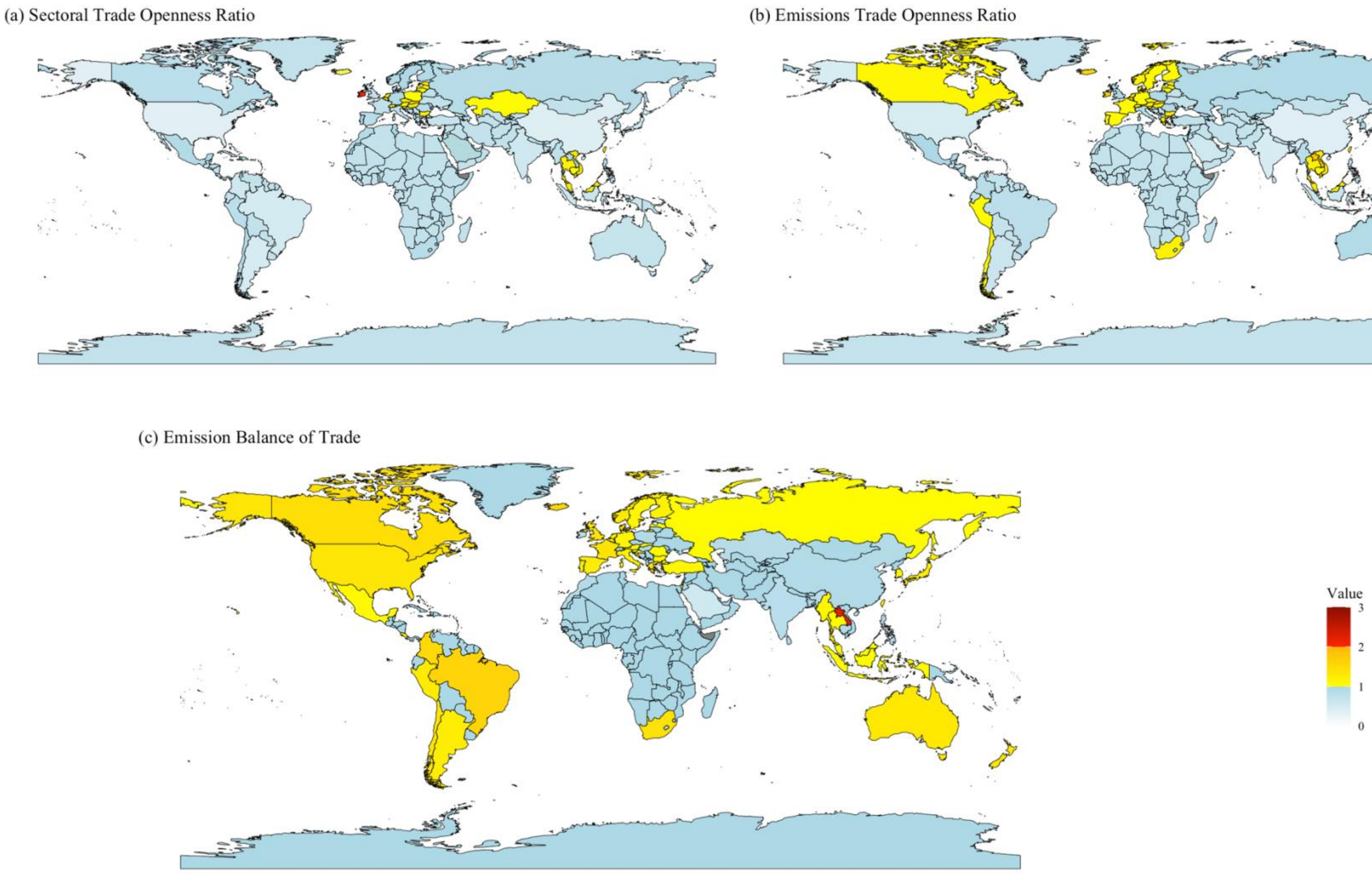


Fig. 3.3(a): STOR by Sector and Country

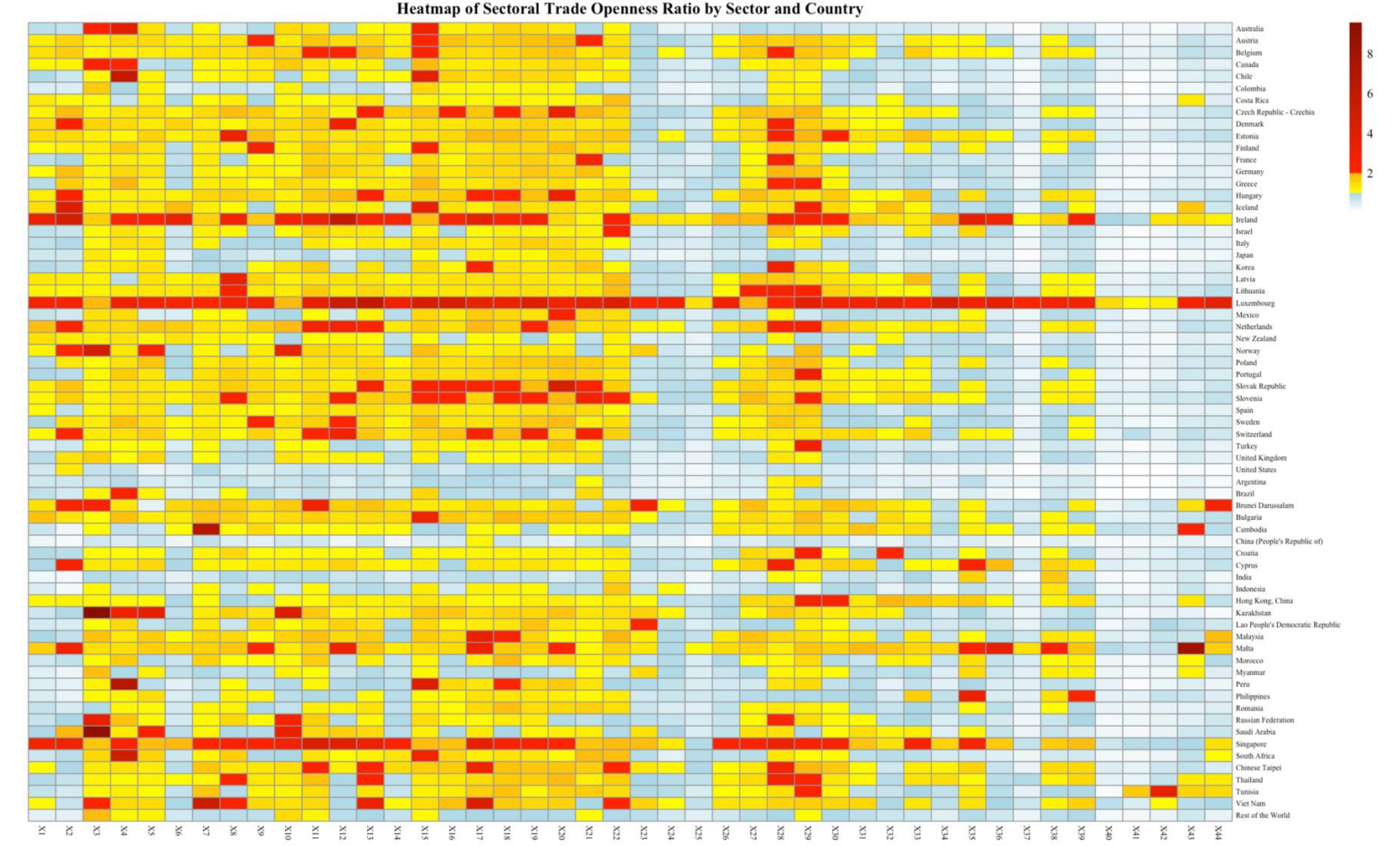


Fig. 3.3(b): ETOR by Sector and Country

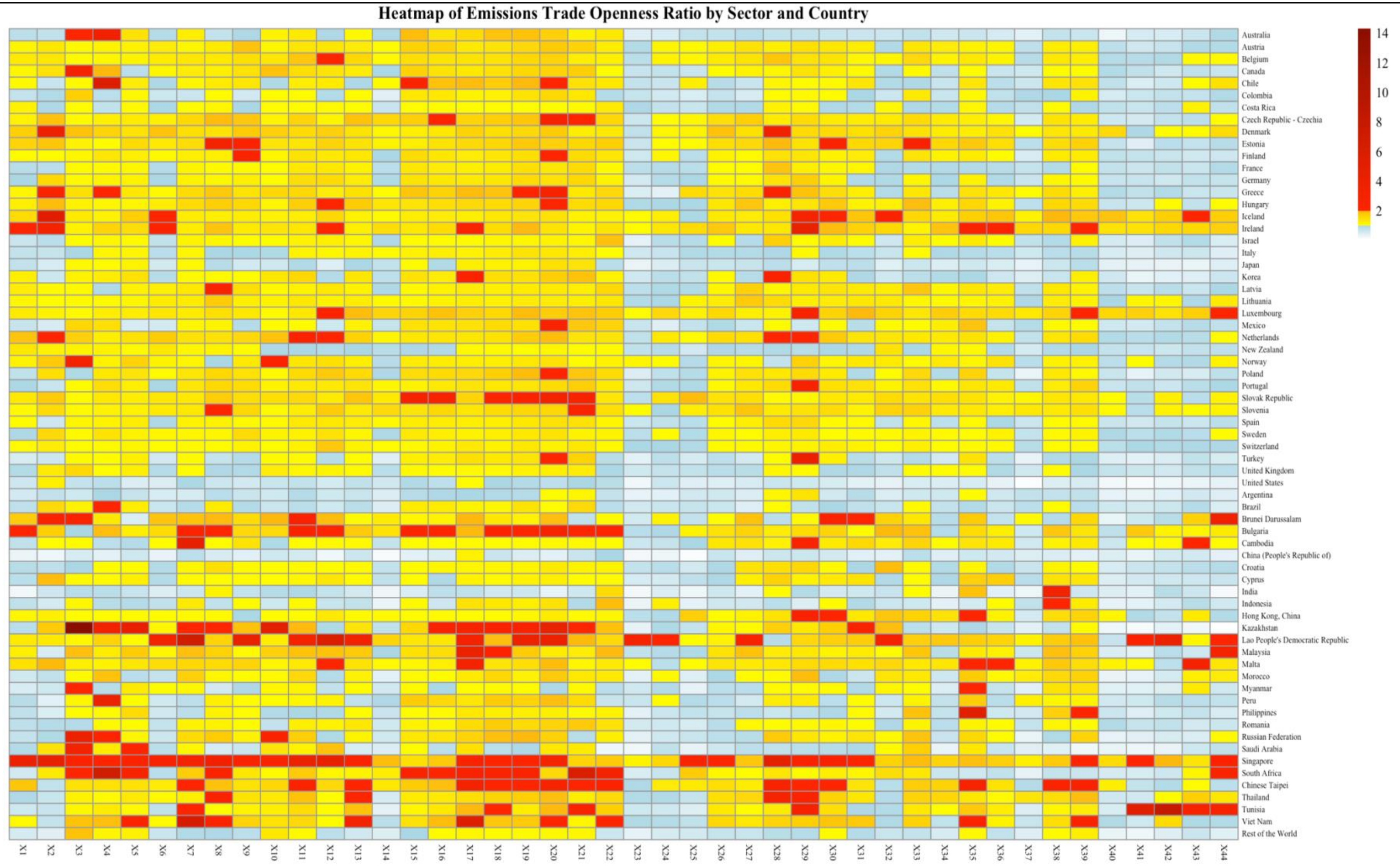
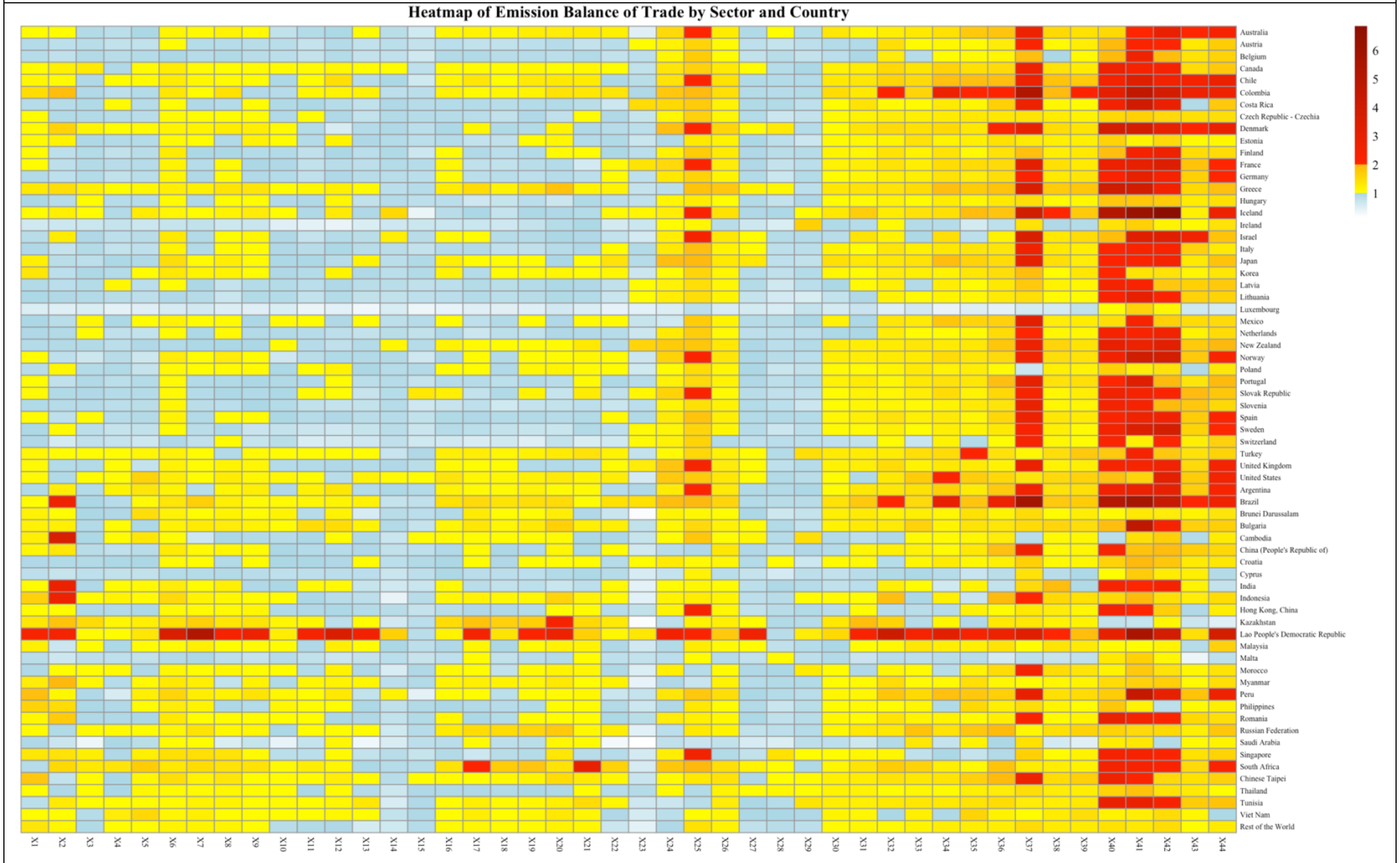


Fig. 3.3(c): EBT by Sector and Country



3.5. Discussion

This chapter introduces EBT that utilizes the HEM to compare the openness of bads to the openness of goods within the same sectors and countries, thus providing a nuanced view of trade's environmental efficiency.

In this process, we constructed three unitless metrics to measure the sustainability of trade: STOR, ETOR, and EBT. STOR assesses whether the trade in goods exceeds domestic production, ETOR evaluates if trade in bads surpasses domestic production of bads, and EBT examines whether trade openness in bads exceeds trade openness in goods, indicating a scenario where sectors or countries trade more in an externality than the economic output intended for the trade.

3.5.1 Sectoral Trade: Goods versus Bads

The analysis reveals that primary and secondary sectors display high emissions in trade due to their extensive integration into the global economy. Conversely, despite previous studies suggesting lower emission intensity in the service sector (Huo et al., 2014; Dombi, 2019; Taşdemir, 2021), our findings indicate high emission intensity in trade activities within this sector. Importantly, studies by Roberts et al. (2021), Zhang et al. (2015), and Rosenblum et al. (2000) reveals that when accounting for all inputs and goods associated with the production in the service sector—essentially when considering total rather than just direct emissions—the emissions attributed to the service sector are far from negligible, small, or insignificant. This insight aligns with narrowing of the perceived emission gap between services and manufacturing when considering indirect emissions via the global value chain (Marin & Zoboli, 2017). Furthermore, a study by Yassin and Aralas (2020) support the idea that trade openness intensifies carbon emissions within the service sector, corroborating our findings of significant emission intensity in these activities.

Even within the service sector, quaternary services tend to be more emission-intensive. While at first glance, transport sectors appear to emit more, with land transport generating notably high emissions (see Table 3.2), air and water transports are more integrated into the world economy, thus contributing a substantial amount of emissions in trade compared to domestic production (see Fig. 3.3(b)). However, among the service sectors, it is only these three transport sectors that demonstrate emission efficiency in trade—where the openness in trade of goods exceeds the openness in trade of bads (see Fig. 3.3(c)).

Conversely, while quaternary sectors are less integrated into the global economy, the emission intensity of their trade activities is substantially high due to significant upstream emissions (Zhang et al., 2015). This finding suggests that expectations for a 'cleaner' economy through a shift from manufacturing to services may need to be reconsidered. Such a re-evaluation is crucial as it challenges the prevailing assumption that a service-oriented economy inherently leads to reduced environmental impacts (Ström, 2020). These observations underscore the importance of incorporating comprehensive emissions accounting within all sectors to inform more effective environmental policy-making.

3.5.2 EBT Overcoming TOR Limitations

Transitioning from sector-specific trade dynamics to broader economic indicators, it is important to address the limitations associated with the trade openness ratio, notably its tendency to display disproportionately high values for geographically smaller countries (Fujii, 2017). The EBT metric offers a more nuanced perspective, inherently adjusting for the scale of a country's GDP and its domestic emissions. This makes EBT a robust measure that compensates for potential skewness in traditional trade openness ratios by accounting for the proportional share of emissions related to trade activities. Such an adjustment ensures that the EBT metric remains relevant and comparable across countries with diverse geographical sizes, economic structures, and time[13]. For example, countries like Luxembourg, Ireland, and Malta exhibit high levels of openness in terms of both goods and emissions yet manage to maintain environmental efficiency. On the other hand, smaller economies like Lao PDR, Iceland, Denmark, and Singapore, which show significant emission intensity in their trade patterns, underscore the effectiveness of the EBT metric in capturing these critical nuances.

Singapore's trade-related emissions are due to its strategic location, extensive ports and advanced logistics, exemplified by Changi Airport's transformation into a major food cargo hub. It has been established as a key player in global food and petroleum product trading. This status is bolstered by its refining capacities and role as an energy hub in Southeast Asia, enhancing its trade openness (Lin, 2019; García & Palazuelos, 2014). In contrast, Lao PDR, as a developing country with significant reliance on exporting natural resources and agricultural products, exhibits higher emissions per unit of trade due to less efficient production processes.

3.5.3 Performance of Large Economics: Goods versus Bads

The analysis shows that larger, developed economies such as those in Europe and America are typically associated with emission-intensive trade. In contrast, trade activities in India and China are surprisingly less emission-intensive. This disparity could be explained by the fact that developed regions like the EU, USA, and Japan exhibit high emission intensity as net importers of CO_2 emissions (Steen-Olsen et al., 2012; Bastianoni et al., 2014; Weber et al., 2017; Xue & Liu, 2022). Conversely, while countries like India and China are major exporters of emissions in absolute terms (Meng et al., 2018; Wang et al., 2018; Xue & Liu, 2022), their proportion of bads relative to goods traded is smaller, rendering their trade activities comparatively more environmentally efficient. Therefore, the sectoral composition significantly influences the emission efficiency of trade activities.

3.5.4 Economic – Environmental Trade-off

EBT provides unique insights into the trade-offs between economic benefits and environmental burdens. By quantifying the extent to which sectors and countries prioritize the trade of goods over bads, or vice versa, EBT serves as a crucial tool for policymakers and businesses to guide sustainable trade practices. Unlike existing methodologies that focus primarily on the volume of emissions, EBT assesses the proportionality of emissions relative to economic activities in trade. This approach not only highlights sectors where environmental impact mitigation is most urgent but also underscores the importance of balancing economic and environmental goals.

3.6. Conclusion

This chapter introduces the EBT, a novel metric developed using the HEM. Unlike traditional metrics that primarily focus on the volume of emissions or economic outputs, EBT is a unitless metric that compares the openness of bads to the openness of goods within the same sector and/or country. This approach provides a comprehensive measure of how bads are traded in relation to goods, offering a detailed view of their proportional relationship.

[13] This chapter does not analyse EBT over time; however, the metric is designed to support future longitudinal assessments of trade impacts.

EBT's unique ability to quantify the relative scale of goods and bads exchanged provides crucial insights into the balance between economic benefits and environmental burdens. This is essential for policymakers, researchers, and businesses as they navigate the complexities of sustainable trade practices. By identifying sectors and countries where the trade of bads outweighs the goods, EBT serves as a critical tool in guiding global efforts towards reducing environmental impacts and enhancing trade sustainability.

Our findings indicate that while the service sector, particularly the quaternary sectors, is less integrated in the global economy, it exhibits high emission intensity in trade. This challenges the common perception that service-oriented sectors inherently contribute to a cleaner economy. Contrary to traditional TOR, which shows disproportionately high values for smaller economies, EBT offers comparability across different geographies and time frames. Notably, trade activities in China and India were found to be less emission-intensive compared to those in more developed economies, reflecting a structural composition where both the countries are trading more in less emission-efficient goods and services.

To further promote sustainability in global trade, targeted regulatory measures and international cooperation are essential. In the service sector, stringent environmental regulations should ensure the use of inputs—both goods and services—that are produced using clean technologies. This strategy will not only incentivize the adoption of cleaner goods and services but also promote their production further up the supply chain. Developing countries like Lao PDR require support to enhance production efficiency and reduce emissions, highlighting the importance of technology transfer and capacity building. Additionally, harmonizing environmental standards and implementing effective monitoring mechanisms will ensure compliance and enhance the efficacy of sustainability policies across nations. Such comprehensive strategies are crucial for aligning global trade practices with environmental objectives and contributing to the achievement of sustainable development goals.

While this chapter does not perform a temporal analysis of EBT, the design inherently supports longitudinal studies. Future research could utilize this metric to assess changes over time, determining whether a sector's or country's trade in goods versus bads is increasing, decreasing, or remaining stable. Such studies would enhance our understanding of the temporal dynamics of trade-related environmental impacts.

Furthermore, the future research could extend this framework to develop metrics that evaluate the efficiency of trade in terms of other environmental impacts, such as greenhouse gas emissions or water usage. By building on the concepts of STOR, ETOR, and EBT, researchers could explore how trade influences global resource consumption and environmental degradation beyond carbon emissions, thereby providing a more comprehensive perspective on the sustainability of global trade.

Appendix A3

Table A3.1: List of 44 sectors along with the values for STOR, ETOR, and EBT

Sector Code	Name	STOR	ETOR	EBT
X1	Agriculture, hunting, forestry	0.28	0.26	1.07
X2	Fishing and aquaculture	0.28	0.24	1.17
X3	Mining and quarrying, energy producing products	0.53	0.57	0.93
X4	Mining and quarrying, non-energy producing products	0.43	0.49	0.88
X5	Mining support service activities	0.45	0.41	1.08
X6	Food products, beverages and tobacco	0.31	0.27	1.15
X7	Textiles, textile products, leather and footwear	0.50	0.46	1.07
X8	Wood and products of wood and cork	0.43	0.39	1.11
X9	Paper products and printing	0.37	0.37	0.99
X10	Coke and refined petroleum products	0.49	0.50	0.99
X11	Chemical and chemical products	0.46	0.51	0.91
X12	Pharmaceuticals, medicinal chemical and botanical products	0.31	0.40	0.77
X13	Rubber and plastics products	0.42	0.49	0.86
X14	Other non-metallic mineral products	0.20	0.27	0.76
X15	Basic metals	0.38	0.48	0.79
X16	Fabricated metal products	0.43	0.43	1.00
X17	Computer, electronic and optical equipment	0.64	0.63	1.02
X18	Electrical equipment	0.48	0.52	0.94
X19	Machinery and equipment, nec	0.43	0.48	0.90
X20	Motor vehicles, trailers and semi-trailers	0.42	0.46	0.92
X21	Other transport equipment	0.50	0.54	0.93
X22	Manufacturing nec; repair and installation of machinery and equipment	0.50	0.49	1.01
X23	Electricity, gas, steam and air conditioning supply	0.17	0.28	0.60
X24	Water supply; sewerage, waste management and remediation activities	0.27	0.25	1.06
X25	Construction	0.18	0.16	1.15
X26	Wholesale and retail trade; repair of motor vehicles	0.39	0.32	1.22
X27	Land transport and transport via pipelines	0.34	0.37	0.92
X28	Water transport	0.52	0.59	0.88
X29	Air transport	0.49	0.53	0.93
X30	Warehousing and support activities for transportation	0.44	0.43	1.01
X31	Postal and courier activities	0.33	0.33	1.01
X32	Accommodation and food service activities	0.30	0.24	1.25
X33	Publishing, audiovisual and broadcasting activities	0.44	0.33	1.33
X34	Telecommunications	0.28	0.23	1.21

X35	IT and other information services	0.45	0.34	1.33
X36	Financial and insurance activities	0.31	0.23	1.35
X37	Real estate activities	0.17	0.10	1.67
X38	Professional, scientific and technical activities	0.37	0.30	1.24
X39	Administrative and support services	0.35	0.30	1.17
X40	Public administration and defence; compulsory social security	0.20	0.11	1.87
X41	Education	0.17	0.10	1.75
X42	Human health and social work activities	0.24	0.10	2.33
X43	Arts, entertainment and recreation	0.29	0.20	1.44
X44	Other service activities	0.23	0.15	1.54
X45	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.00	0.00	0.00

Table A3.2: List of Countries with the values for STOR, ETOR, and EBT

Country Name	STOR	ETOR	EBT
Australia	0.69	0.90	1.31
Austria	1.10	1.21	1.11
Belgium	1.18	1.25	1.06
Canada	0.79	1.14	1.44
Chile	0.87	1.18	1.36
Colombia	0.56	0.85	1.52
Costa Rica	0.81	0.98	1.21
Czech Republic - Czechia	1.23	1.17	0.95
Denmark	0.99	1.50	1.51
Estonia	1.24	1.15	0.93
Finland	0.90	1.06	1.18
France	0.76	1.05	1.38
Germany	0.92	1.03	1.13
Greece	0.86	1.21	1.40
Hungary	1.31	1.28	0.98
Iceland	1.00	1.57	1.56
Ireland	2.00	1.63	0.81
Israel	0.73	0.83	1.14
Italy	0.78	0.92	1.18
Japan	0.54	0.67	1.24
Korea	0.89	0.99	1.12
Latvia	1.05	1.11	1.05
Lithuania	1.18	1.18	1.00
Luxembourg	2.67	1.48	0.56
Mexico	0.90	0.97	1.09
Netherlands	1.17	1.35	1.15

New Zealand	0.72	0.94	1.31
Norway	0.92	1.19	1.28
Poland	1.04	0.95	0.91
Portugal	0.96	1.10	1.15
Slovak Republic	1.33	1.49	1.12
Slovenia	1.29	1.30	1.01
Spain	0.82	1.03	1.25
Sweden	0.96	1.09	1.14
Switzerland	1.10	1.08	0.99
Turkey	0.68	0.76	1.11
United Kingdom	0.70	0.93	1.33
United States	0.36	0.49	1.35
Argentina	0.50	0.61	1.23
Brazil	0.51	0.81	1.60
Brunei Darussalam	1.24	1.12	0.90
Bulgaria	1.20	1.35	1.12
Cambodia	1.11	1.01	0.91
China (People's Republic of)	0.41	0.37	0.92
Croatia	0.89	0.94	1.06
Cyprus	1.13	0.90	0.80
India	0.56	0.47	0.84
Indonesia	0.62	0.64	1.03
Hong Kong, China	1.05	1.08	1.03
Kazakhstan	1.02	0.88	0.86
Lao People's Democratic Republic	0.83	1.82	2.19
Malaysia	1.21	1.24	1.03
Malta	1.83	1.34	0.73
Morocco	0.88	0.78	0.89
Myanmar	0.74	0.82	1.10
Peru	0.80	1.01	1.26
Philippines	0.80	0.77	0.96
Romania	0.84	0.89	1.06
Russian Federation	0.87	0.90	1.03
Saudi Arabia	1.00	0.58	0.58
Singapore	1.85	2.26	1.22
South Africa	0.85	1.20	1.41
Chinese Taipei	1.32	1.56	1.19
Thailand	1.17	1.19	1.02
Tunisia	0.96	0.94	0.98
Viet Nam	1.31	1.26	0.96
Rest of the World	0.73	0.71	0.98

Table A3.3: Sectoral Trade Openness Ratio (STOR) across countries and sectors

Country	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	X19	X20	X21	X22
Australia	0.80	0.73	2.16	3.89	1.40	0.78	1.14	0.62	0.89	1.48	1.37	0.99	1.01	1.12	2.97	1.20	1.28	1.61	1.48	1.30	0.94	1.08
Austria	1.23	1.58	1.23	1.48	1.51	1.26	1.27	1.40	2.04	1.28	1.81	1.46	1.59	1.23	2.08	1.83	1.61	1.73	1.84	1.93	2.05	1.39
Belgium	1.43	1.64	1.15	1.26	1.25	1.28	1.48	1.38	1.64	1.58	2.31	2.25	2.00	1.34	2.30	1.48	1.44	1.57	1.72	1.86	1.31	1.52
Canada	1.11	1.16	2.23	2.08	0.79	0.89	1.14	1.16	1.31	1.72	1.36	1.21	1.23	0.96	1.97	1.26	1.23	1.32	1.39	1.52	1.50	1.01
Chile	0.95	0.65	1.10	5.53	1.17	0.76	1.03	1.17	1.31	0.97	1.19	0.87	1.09	1.04	3.65	1.62	1.44	1.63	1.52	1.55	1.10	1.32
Colombia	0.50	0.48	1.73	0.99	1.17	0.48	0.65	0.72	0.61	1.16	0.94	0.79	0.85	0.50	1.56	1.10	1.09	1.08	1.16	1.10	0.97	0.65
Costa Rica	1.29	1.07	1.07	0.71	1.19	0.94	1.06	1.20	0.99	1.09	1.04	1.20	1.32	0.72	1.13	1.12	1.13	1.17	1.14	1.11	1.23	1.89
Czech Republic - Czechia	1.17	1.94	1.17	1.35	1.45	1.13	1.51	1.89	1.71	1.24	1.59	1.19	2.38	1.65	1.85	2.22	1.81	2.10	1.88	3.10	2.00	1.60
Denmark	1.53	2.36	1.60	1.51	1.27	1.59	1.23	1.12	1.40	1.51	1.66	2.79	1.49	1.14	1.43	1.34	1.43	1.51	1.62	1.49	1.29	1.43
Estonia	1.48	1.51	1.22	1.12	1.62	1.18	1.38	2.99	1.90	1.35	1.45	1.36	1.41	1.24	1.42	1.54	1.95	1.92	1.71	1.43	1.67	1.75
Finland	1.04	1.23	1.21	1.69	1.37	0.87	1.22	1.22	2.62	1.18	1.72	1.30	1.53	1.04	2.22	1.30	1.31	1.56	1.54	1.86	1.47	1.36
France	0.84	1.00	1.15	1.25	1.24	0.80	1.27	0.98	1.08	1.07	1.67	1.48	1.41	0.91	1.50	1.11	1.50	1.57	1.64	1.46	2.47	0.97
Germany	1.06	1.88	1.19	1.51	1.35	0.87	1.21	1.06	1.26	1.12	1.80	1.55	1.41	1.08	1.62	1.27	1.52	1.52	1.78	1.58	1.84	1.13
Greece	0.86	1.66	1.17	2.00	1.20	0.89	1.24	1.28	1.01	1.49	1.39	1.03	1.29	1.21	1.98	1.28	1.28	1.52	1.41	1.48	1.11	1.30
Hungary	1.24	2.15	1.16	1.26	1.25	1.16	1.56	1.63	1.54	1.19	1.74	1.92	2.16	1.49	1.61	1.70	2.30	2.03	1.83	3.11	1.55	1.76
Iceland	1.45	4.25	1.22	1.27	1.33	1.92	1.21	1.03	1.00	1.16	1.26	1.20	1.21	0.72	3.31	1.41	1.21	1.75	1.39	1.45	1.27	1.11
Ireland	3.13	4.71	1.66	2.10	2.12	3.12	1.59	2.71	1.77	2.77	3.07	5.62	2.22	2.21	1.86	2.12	3.57	2.24	2.52	1.51	1.17	2.27
Israel	0.76	0.67	1.08	1.36	1.20	0.61	1.22	1.10	0.94	1.03	1.57	1.33	1.31	0.80	1.16	0.96	1.03	1.23	1.20	1.19	1.19	2.36
Italy	0.78	0.94	1.07	1.43	1.39	0.72	1.17	0.93	0.93	0.98	1.31	1.12	1.29	1.20	1.52	1.35	1.24	1.51	1.70	1.49	1.27	1.01
Japan	0.62	0.60	1.30	1.03	1.21	0.40	1.00	0.71	0.53	0.64	0.95	0.51	0.85	0.90	1.07	0.77	1.21	1.10	1.10	1.44	1.34	0.60
Korea	0.90	0.77	1.21	1.33	1.40	0.67	0.93	0.94	1.03	1.38	1.69	0.79	1.38	0.94	1.50	1.08	2.44	1.39	1.29	1.46	1.75	1.07
Latvia	1.33	1.27	1.17	0.82	1.38	1.17	1.32	3.42	1.56	1.15	1.37	1.36	1.35	1.12	1.32	1.41	1.37	1.40	1.36	1.29	1.23	1.87
Lithuania	1.15	1.10	1.15	1.24	1.32	1.30	1.40	2.40	1.31	1.27	1.70	1.27	1.54	1.32	1.29	1.33	1.30	1.40	1.40	1.31	1.33	1.87
Luxembourg	2.40	2.36	1.98	2.80	2.54	2.28	2.02	2.77	2.68	1.98	3.55	5.21	5.96	2.83	4.44	4.49	3.40	3.23	3.93	2.74	3.43	4.00
Mexico	0.71	0.59	1.40	1.48	0.51	0.49	1.06	1.09	0.91	0.98	1.01	0.64	1.18	0.85	1.55	1.32	1.71	1.57	1.38	2.40	1.63	1.47
Netherlands	1.89	2.23	1.55	1.52	1.79	1.69	1.42	1.28	1.63	1.96	2.70	2.54	2.09	1.30	1.66	1.41	1.95	1.65	2.11	1.96	1.42	1.51
New Zealand	1.43	1.28	1.24	1.37	1.13	1.40	1.15	1.18	1.06	0.95	1.10	1.12	1.07	0.77	1.08	0.80	1.02	1.07	0.99	1.07	0.78	1.19

Norway	1.15	2.11	4.69	1.34	2.38	0.93	1.13	0.80	1.27	3.43	1.53	1.50	1.30	0.93	1.88	1.28	1.20	1.29	1.32	1.32	0.95	1.15
Poland	0.88	1.30	1.03	1.37	1.81	0.98	1.30	1.45	1.31	1.12	1.41	1.47	1.51	1.08	1.56	1.42	1.53	1.72	1.71	1.86	1.68	1.45
Portugal	0.97	0.85	1.10	1.70	1.34	0.91	1.43	1.62	1.49	1.22	1.38	1.23	1.60	1.25	1.55	1.43	1.52	1.56	1.44	1.72	1.58	1.31
Slovak Republic	1.22	1.82	1.14	1.41	1.34	1.22	1.44	1.73	1.53	1.47	1.43	1.28	2.40	1.46	2.18	2.28	2.04	2.12	1.93	4.41	2.14	1.65
Slovenia	1.12	1.67	1.17	1.40	1.37	1.16	1.50	2.44	1.56	1.17	1.57	2.24	1.66	1.67	2.06	2.05	1.61	2.26	2.06	1.98	2.75	2.04
Spain	1.00	0.77	1.10	1.33	1.33	0.83	1.23	1.17	1.09	1.10	1.42	1.34	1.44	1.23	1.56	1.30	1.27	1.34	1.38	1.55	1.49	1.02
Sweden	0.99	1.44	1.25	1.84	1.46	1.07	1.27	1.18	2.09	1.48	1.65	2.12	1.54	1.11	1.83	1.34	1.38	1.57	1.77	1.94	1.23	1.43
Switzerland	1.09	2.06	1.28	1.42	1.63	1.08	1.34	1.02	1.59	1.22	2.10	2.92	1.78	1.24	1.62	1.82	2.33	1.89	2.68	1.54	2.33	1.63
Turkey	0.47	0.63	1.06	1.04	1.08	0.49	1.02	0.76	0.82	1.04	1.05	0.88	0.98	0.61	1.26	1.03	1.17	1.18	1.16	1.70	1.15	0.73
United Kingdom	0.85	1.39	1.66	1.04	1.56	0.78	1.02	0.84	0.84	1.37	1.22	1.19	1.17	0.88	1.22	0.97	1.06	1.08	1.27	1.28	1.40	0.95
United States	0.58	1.26	0.73	0.80	0.31	0.38	0.94	0.51	0.51	0.62	0.74	0.63	0.65	0.55	0.90	0.59	0.88	0.91	0.77	0.63	0.86	0.70
Argentina	0.59	0.61	0.67	0.87	0.54	0.46	0.62	0.77	0.55	0.65	0.77	0.46	0.74	0.50	0.92	0.83	0.91	0.85	0.75	0.95	1.06	0.83
Brazil	0.79	0.57	1.19	2.33	1.15	0.50	0.53	1.04	0.87	0.60	0.74	0.55	0.70	0.64	1.57	0.89	0.76	0.82	0.96	0.70	1.50	0.60
Brunei Darussalam	1.42	2.28	2.45	1.36	0.34	1.52	1.76	1.70	1.47	1.74	2.87	1.66	1.85	1.44	1.29	1.26	1.57	1.34	1.17	1.52	0.81	1.49
Bulgaria	1.83	1.37	1.05	1.84	1.23	1.28	1.82	1.64	1.31	1.50	1.65	1.42	1.52	1.48	2.91	1.78	1.48	1.97	1.73	1.70	1.67	1.67
Cambodia	0.65	0.28	1.06	0.79	0.66	1.01	6.67	1.04	1.48	1.04	1.05	1.09	1.14	1.04	0.99	0.96	1.01	1.02	0.99	1.03	1.10	1.04
China (People's Republic of)	0.27	0.19	0.58	0.47	0.69	0.26	0.75	0.46	0.40	0.61	0.60	0.28	0.66	0.23	0.46	0.52	1.12	0.69	0.50	0.35	0.69	0.98
Croatia	0.91	0.84	1.05	1.05	1.04	0.85	1.13	1.53	1.05	1.06	1.10	1.03	1.07	0.89	1.11	1.12	1.12	1.17	1.11	1.21	1.15	1.27
Cyprus	0.97	2.58	1.30	1.36	1.54	0.97	1.19	1.10	1.23	1.27	1.34	1.58	1.25	1.07	1.24	0.99	1.35	1.29	1.40	1.27	1.03	1.18
India	0.25	0.22	0.90	0.81	0.65	0.37	0.62	0.95	0.75	0.90	0.89	0.68	0.77	0.45	0.70	0.76	0.90	0.74	0.77	0.48	0.74	1.37
Indonesia	0.47	0.20	1.11	0.73	0.84	0.51	1.09	0.68	1.01	0.60	1.09	0.79	0.88	0.76	1.23	0.56	1.17	1.17	1.09	0.87	0.77	1.79
Hong Kong, China	1.14	1.18	1.12	1.13	1.09	0.97	1.00	0.99	0.88	1.10	1.10	1.32	1.15	1.22	1.35	1.24	1.10	1.08	1.21	1.25	1.08	1.24
Kazakhstan	0.63	0.93	9.55	3.00	3.54	0.80	1.29	1.60	1.35	4.26	1.75	1.14	1.30	1.25	1.78	1.76	1.44	1.58	1.56	1.82	1.33	1.44
Lao People's Democratic Republic	0.55	0.52	1.01	1.52	0.76	0.86	1.32	0.65	1.56	1.01	1.32	1.60	1.41	0.97	1.55	1.15	1.25	1.37	1.85	1.36	1.17	1.36

Malaysia	0.98	0.75	1.86	1.30	1.70	1.01	1.56	1.54	1.02	1.59	1.90	1.51	1.69	1.00	1.70	1.51	3.28	2.23	1.57	1.07	1.07	2.00
Malta	1.63	2.90	1.44	1.43	1.67	1.56	1.60	1.78	2.11	1.26	1.63	3.03	1.80	1.27	1.49	1.48	3.08	1.72	1.67	2.10	1.10	1.58
Morocco	0.61	0.77	1.06	1.70	0.89	0.65	1.61	1.01	1.02	1.08	1.68	0.76	1.23	0.73	1.12	0.94	1.23	1.98	1.13	1.48	1.15	1.33
Myanmar	0.42	0.31	1.91	0.95	1.19	0.78	0.95	0.74	0.82	1.17	1.04	0.64	0.92	0.70	1.13	0.85	0.88	0.95	0.93	0.74	1.03	0.72
Peru	0.46	0.37	1.18	6.62	0.83	0.39	0.67	1.04	0.74	0.94	1.11	0.90	0.99	0.82	3.91	1.49	1.35	2.02	1.56	1.75	1.35	1.00
Philippines	0.49	0.33	1.07	1.15	1.46	0.49	0.71	1.20	1.13	0.84	0.95	0.91	1.04	0.86	1.08	1.08	1.40	1.36	1.28	1.22	1.06	1.25
Romania	0.73	0.51	0.92	1.12	1.06	0.57	1.14	1.16	0.98	0.74	1.22	1.18	1.38	0.78	1.24	1.03	1.50	1.88	1.45	1.56	1.64	1.42
Russian Federation	0.69	1.00	3.46	1.83	1.09	0.56	1.09	1.55	1.07	2.52	1.64	0.92	1.12	0.93	1.47	1.07	1.06	1.25	1.25	0.93	0.78	0.97
Saudi Arabia	0.96	1.99	9.15	1.28	2.34	0.80	1.12	0.97	0.89	3.30	1.52	1.63	1.50	0.85	1.20	0.94	1.30	1.00	1.11	1.19	1.21	0.92
Singapore	2.77	2.97	1.80	2.23	1.90	1.98	2.03	2.37	2.16	2.91	4.32	3.86	3.07	2.19	1.94	1.86	3.56	2.34	2.36	2.07	1.79	1.92
South Africa	0.63	0.85	1.55	5.05	1.59	0.64	1.15	1.69	0.96	0.99	1.40	1.00	1.19	1.37	2.75	1.54	1.21	1.38	1.35	1.09	1.94	1.89
Chinese Taipei	1.02	0.96	1.30	1.41	1.25	0.85	1.81	1.36	1.32	1.45	2.31	1.21	2.04	1.48	1.66	1.71	2.89	1.85	1.78	1.81	1.70	2.02
Thailand	0.90	0.72	1.16	1.10	1.17	1.02	1.13	2.01	1.33	1.28	1.83	0.96	2.29	0.81	1.31	1.36	1.50	1.71	1.67	1.93	1.21	1.67
Tunisia	0.72	0.55	1.08	1.21	1.05	0.72	1.78	0.90	1.11	1.10	1.45	0.90	1.38	0.69	1.18	1.24	1.64	1.83	1.14	1.62	1.70	1.47
Viet Nam	1.07	0.70	2.02	1.50	1.50	0.97	5.25	2.25	1.51	1.38	1.52	0.94	3.10	1.06	1.46	1.85	4.38	1.72	1.54	1.59	0.99	2.09
Rest of the World	0.40	0.38	1.94	1.11	1.15	0.56	0.81	0.83	0.79	1.49	1.14	0.85	0.99	0.71	1.10	0.94	0.99	0.97	0.98	0.91	1.00	0.94

Country	**X23**	**X24**	**X25**	**X26**	**X27**	**X28**	**X29**	**X30**	**X31**	**X32**	**X33**	**X34**	**X35**	**X36**	**X37**	**X38**	**X39**	**X40**	**X41**	**X42**	**X43**	**X44**
Australia	0.93	0.34	0.36	0.58	0.89	0.74	0.82	0.52	0.60	0.53	0.58	0.42	0.38	0.30	0.14	0.47	0.47	0.19	0.26	0.18	0.33	0.39
Austria	0.87	0.96	0.67	1.12	1.70	1.60	1.70	1.45	1.31	0.64	1.26	1.14	1.11	0.92	0.37	1.13	0.98	0.41	0.28	0.34	0.72	0.53
Belgium	0.99	1.05	0.65	1.22	1.73	2.04	1.81	1.59	1.14	0.90	1.68	1.14	1.24	1.02	0.47	1.32	1.16	0.45	0.33	0.49	0.78	0.66
Canada	0.89	0.57	0.41	0.77	1.14	1.24	1.39	1.01	0.87	0.60	0.78	0.49	0.71	0.45	0.23	0.74	0.82	0.33	0.32	0.25	0.52	0.39
Chile	0.84	0.48	0.55	0.61	0.72	1.25	1.14	0.83	1.00	0.57	0.63	0.37	0.70	0.44	0.23	0.74	0.81	0.33	0.15	0.23	0.41	0.50
Colombia	0.74	0.33	0.26	0.50	0.57	1.18	1.17	0.71	0.76	0.31	0.82	0.25	0.52	0.37	0.18	0.51	0.53	0.17	0.15	0.20	0.27	0.34
Costa Rica	0.65	0.49	0.40	0.79	0.98	1.24	1.33	0.93	0.66	1.02	0.89	0.71	0.98	0.54	0.28	0.92	0.89	0.30	0.17	0.29	1.28	0.44
Czech Republic - Czechia	0.87	0.93	0.70	1.31	1.80	1.83	1.97	1.20	1.07	1.03	1.24	1.01	0.94	0.84	0.41	1.08	1.07	0.40	0.35	0.47	0.57	0.72
Denmark	0.93	0.59	0.53	1.17	1.42	2.61	1.67	1.45	1.04	1.04	0.97	0.82	0.92	0.64	0.35	0.89	0.93	0.40	0.25	0.34	0.49	0.52
Estonia	0.94	1.07	0.79	1.23	1.54	2.38	2.00	2.18	1.41	1.38	1.86	1.32	1.43	1.02	0.65	1.20	1.35	0.46	0.38	0.56	0.67	0.78

Finland	0.71	0.95	0.49	0.91	1.10	1.62	1.48	1.02	1.11	0.65	1.17	0.84	1.17	0.72	0.28	1.02	0.96	0.41	0.30	0.25	0.40	0.42
France	0.60	0.58	0.38	0.82	1.03	2.36	1.42	0.94	0.89	0.70	0.74	0.64	0.61	0.58	0.23	0.63	0.83	0.27	0.23	0.23	0.38	0.44
Germany	0.68	0.69	0.60	0.93	1.16	2.00	1.79	1.10	0.83	0.78	0.93	0.70	0.94	0.64	0.30	0.84	0.78	0.31	0.23	0.26	0.46	0.34
Greece	0.63	0.44	0.80	0.79	1.28	2.12	2.21	1.11	0.87	0.65	0.88	0.44	0.82	0.72	0.27	0.85	0.69	0.23	0.20	0.36	0.44	0.37
Hungary	1.16	0.88	0.78	1.28	1.88	1.59	1.39	1.71	1.10	1.01	1.77	0.97	1.41	0.89	0.55	1.43	1.35	0.40	0.36	0.60	0.59	0.71
Iceland	0.95	0.99	0.44	0.90	1.30	1.44	2.65	1.53	1.06	1.83	1.11	0.88	0.85	0.98	0.30	0.99	1.01	0.35	0.23	0.24	1.77	0.61
Ireland	1.47	1.32	1.31	1.98	1.96	2.44	2.60	2.04	1.78	1.43	1.28	2.00	3.65	2.71	1.12	1.60	2.34	1.00	0.84	1.33	1.44	1.16
Israel	0.61	0.70	0.37	0.79	0.87	1.86	1.11	1.39	0.74	0.55	1.25	0.69	1.53	0.88	0.21	0.70	0.80	0.29	0.14	0.24	0.36	0.28
Italy	0.63	0.54	0.49	0.78	0.90	1.15	1.29	0.80	0.81	0.50	0.84	0.73	0.66	0.62	0.23	0.65	0.70	0.25	0.20	0.27	0.40	0.34
Japan	0.34	0.26	0.34	0.52	0.54	1.00	0.66	0.56	0.63	0.31	0.46	0.25	0.38	0.34	0.12	0.45	0.67	0.19	0.15	0.14	0.24	0.25
Korea	0.88	0.80	0.50	0.95	0.96	3.23	1.54	1.17	0.94	0.48	0.68	0.79	0.74	0.43	0.24	0.70	0.91	0.30	0.24	0.29	0.39	0.47
Latvia	0.81	0.80	0.64	1.01	1.75	1.77	1.49	1.37	1.19	1.03	1.90	0.90	1.28	0.95	0.44	1.10	1.08	0.34	0.30	0.48	0.41	0.57
Lithuania	0.86	0.80	0.79	1.09	2.28	2.50	2.13	1.59	1.38	1.09	1.03	0.96	1.01	0.93	0.67	1.15	1.08	0.45	0.38	0.53	0.60	0.80
Luxembourg	2.30	2.89	1.42	2.80	1.99	2.10	3.70	2.61	2.73	3.22	2.18	4.37	2.98	3.46	2.20	2.69	2.59	1.49	1.01	1.22	2.57	3.61
Mexico	0.92	0.68	0.43	0.83	0.74	1.19	0.60	0.86	0.88	0.77	0.77	0.69	1.14	0.44	0.28	0.87	0.82	0.43	0.24	0.44	0.58	0.50
Netherlands	1.13	1.01	0.61	1.36	1.69	2.42	2.62	1.76	1.38	1.09	1.30	1.23	1.30	0.78	0.38	1.22	1.33	0.38	0.37	0.36	0.72	0.70
New Zealand	0.49	0.50	0.33	0.73	0.89	1.11	0.92	0.79	0.77	1.10	0.73	0.87	0.82	0.50	0.20	0.57	0.72	0.25	0.26	0.20	0.43	0.40
Norway	1.64	0.63	0.41	0.83	1.12	0.82	1.89	0.95	1.06	1.00	0.79	0.86	0.85	0.91	0.32	0.80	0.86	0.33	0.26	0.24	0.53	0.52
Poland	0.74	0.78	0.61	1.04	1.41	1.85	1.88	1.17	0.86	0.89	1.18	0.77	1.29	0.67	0.47	1.08	0.89	0.41	0.29	0.42	0.56	0.59
Portugal	0.70	0.79	0.63	0.93	1.38	1.76	2.99	1.20	1.11	1.04	1.06	0.75	1.00	0.68	0.25	0.89	1.10	0.33	0.24	0.32	0.62	0.50
Slovak Republic	0.74	0.88	0.85	1.31	1.64	1.35	1.40	1.29	1.09	1.32	1.12	0.97	1.17	0.77	0.48	1.20	1.07	0.39	0.37	0.57	0.43	0.66
Slovenia	1.21	0.89	0.86	1.22	1.93	1.55	2.02	1.48	1.05	1.39	1.48	1.11	1.02	0.89	0.46	1.15	1.25	0.44	0.36	0.60	0.59	0.74
Spain	0.70	0.61	0.46	0.82	1.27	1.59	1.66	0.95	0.90	0.56	0.94	0.63	0.96	0.63	0.24	0.78	0.84	0.32	0.22	0.28	0.38	0.39
Sweden	0.78	0.89	0.58	1.02	1.17	1.75	1.55	0.95	0.98	0.89	1.13	0.91	0.91	0.89	0.33	0.89	1.08	0.40	0.24	0.25	0.53	0.52
Switzerland	0.92	0.85	0.58	1.12	1.32	1.31	1.38	1.51	1.47	1.02	1.69	0.90	1.17	1.09	0.38	0.91	1.06	0.38	0.81	0.46	0.79	0.60
Turkey	0.51	0.76	0.35	0.70	0.55	1.12	2.82	0.95	0.68	0.51	0.62	0.37	0.66	0.60	0.29	0.64	0.57	0.25	0.16	0.27	0.54	0.33
United Kingdom	0.49	0.41	0.33	0.67	0.85	1.34	1.18	0.82	0.79	0.54	0.89	0.76	0.82	0.81	0.21	0.91	0.83	0.31	0.28	0.23	0.50	0.34
United States	0.40	0.36	0.25	0.34	0.51	0.70	0.70	0.52	0.41	0.26	0.30	0.24	0.31	0.22	0.09	0.31	0.32	0.12	0.11	0.09	0.17	0.14
Argentina	0.37	0.32	0.28	0.47	0.49	1.19	1.40	0.58	0.66	0.37	0.43	0.36	0.82	0.35	0.29	0.53	0.53	0.14	0.11	0.14	0.35	0.19

Brazil	0.42	0.36	0.36	0.42	0.46	1.18	0.87	0.72	0.45	0.34	0.72	0.26	0.50	0.24	0.14	0.59	0.50	0.12	0.10	0.15	0.43	0.18
Brunei Darussalam	2.62	1.03	0.68	1.01	1.87	1.24	1.43	1.83	1.70	1.36	1.11	0.78	1.20	0.65	0.74	0.88	1.25	0.30	0.46	0.69	1.41	2.42
Bulgaria	1.06	0.87	0.78	1.18	1.52	1.33	1.90	1.36	0.81	1.51	1.15	0.78	1.08	0.91	0.42	1.13	0.93	0.41	0.37	0.50	0.69	0.77
Cambodia	0.86	0.70	0.55	1.31	1.28	1.32	1.62	1.38	1.86	1.31	1.45	0.95	1.20	1.02	0.66	1.11	1.16	0.76	0.71	0.64	2.19	0.82
China (People's Republic of)	0.34	0.31	0.15	0.51	0.45	0.76	0.67	0.63	0.37	0.31	0.70	0.40	0.47	0.30	0.17	0.44	0.33	0.20	0.17	0.29	0.34	0.24
Croatia	0.72	0.67	0.54	0.86	1.51	1.40	2.35	1.02	0.92	2.13	0.94	0.73	1.02	0.78	0.41	1.09	0.94	0.32	0.33	0.41	0.64	0.68
Cyprus	0.89	0.73	0.67	1.10	1.60	2.68	1.41	1.62	1.55	0.99	1.05	1.06	2.24	1.92	0.61	1.58	1.37	0.43	0.33	0.48	0.52	0.73
India	0.49	0.47	0.24	0.61	0.45	1.09	1.01	0.70	0.71	0.58	1.00	0.49	1.60	0.52	0.19	1.74	0.66	0.20	0.18	0.37	0.56	0.25
Indonesia	0.68	1.03	0.29	0.54	0.70	0.95	0.46	0.94	0.93	0.34	0.63	0.31	0.76	0.51	0.39	1.35	0.89	0.24	0.19	0.38	0.69	0.40
Hong Kong, China	1.04	0.81	0.72	0.90	1.47	1.56	2.75	2.29	1.31	1.99	1.84	1.56	1.74	1.13	0.42	1.17	1.41	0.48	0.46	0.45	1.31	0.74
Kazakhstan	1.61	1.13	0.64	0.94	1.06	1.73	1.46	1.25	1.29	1.18	0.93	0.56	0.98	0.52	0.29	0.63	0.87	0.34	0.23	0.33	0.36	0.20
Lao People's Democratic Republic	2.06	0.86	0.48	0.68	0.96	0.99	1.23	1.06	0.75	0.71	0.67	0.56	0.71	0.59	0.35	0.83	0.96	0.23	0.40	0.97	0.77	0.58
Malaysia	1.20	0.94	0.75	1.28	1.82	1.54	1.46	1.16	1.21	0.94	1.32	0.69	1.04	0.87	0.62	1.36	1.25	0.46	0.38	0.72	0.66	1.94
Malta	1.33	0.95	1.01	1.51	1.61	1.24	1.78	1.61	1.95	1.76	1.57	1.54	2.40	3.48	1.41	2.35	1.81	0.90	0.66	0.72	8.02	1.63
Morocco	0.70	0.89	0.50	0.93	1.05	1.08	1.51	0.94	0.69	1.19	1.23	0.71	1.44	0.71	0.50	1.00	1.19	0.29	0.20	0.40	1.10	0.90
Myanmar	1.49	0.95	0.49	0.70	0.94	1.14	1.15	1.03	0.87	0.76	0.94	0.45	1.47	0.63	0.40	1.24	1.21	0.28	0.26	0.28	1.17	0.42
Peru	0.91	0.76	0.51	0.59	0.58	1.37	1.49	0.75	0.91	0.36	0.76	0.40	0.96	0.50	0.40	0.78	0.76	0.34	0.14	0.29	0.45	0.28
Philippines	0.58	0.69	0.58	0.69	0.88	0.92	0.93	0.95	1.00	0.54	1.65	0.76	3.23	0.51	0.40	1.42	2.07	0.37	0.38	0.73	0.69	0.42
Romania	0.66	0.50	0.44	0.78	1.10	1.29	1.22	1.00	0.94	0.70	0.99	0.73	1.08	0.84	0.33	1.04	0.89	0.33	0.29	0.37	0.37	0.44
Russian Federation	0.81	0.71	0.53	0.70	1.07	2.06	1.47	1.06	1.04	0.82	0.99	0.50	0.87	0.53	0.28	0.65	0.99	0.22	0.28	0.34	0.40	0.60
Saudi Arabia	1.40	0.97	0.48	0.76	1.39	1.40	0.97	1.05	1.45	1.14	1.23	0.44	1.11	0.69	0.30	0.70	0.51	0.26	0.21	0.34	0.58	0.65
Singapore	1.93	1.27	0.91	2.28	2.22	3.22	2.40	2.45	1.82	1.41	2.34	1.60	2.48	1.73	0.73	1.72	1.90	0.64	0.86	0.93	0.97	1.44
South Africa	0.87	0.39	0.86	0.76	0.86	1.34	1.03	1.07	0.81	0.86	0.82	0.54	0.56	0.42	0.27	0.58	0.56	0.22	0.22	0.28	0.75	1.05
Chinese Taipei	1.31	1.14	0.96	1.05	1.28	2.70	1.99	1.77	1.07	0.60	1.26	1.16	1.61	0.70	0.33	1.50	1.52	0.45	0.34	0.60	0.75	0.49
Thailand	1.00	0.87	0.76	1.21	1.49	2.55	2.12	1.36	1.12	0.86	1.39	1.47	1.09	0.86	0.93	1.17	1.53	0.37	0.31	0.73	1.27	1.27

Tunisia	0.94	0.86	0.53	1.05	1.07	1.42	2.17	1.18	0.79	0.70	1.00	0.77	1.26	0.84	0.38	0.93	0.95	0.18	1.73	3.36	1.59	1.50
Viet Nam	1.58	1.05	0.75	1.37	1.35	1.59	1.69	1.57	1.55	0.95	1.34	0.78	1.39	0.99	0.65	1.14	1.62	0.81	0.50	1.00	0.84	0.95
Rest of the World	0.82	0.56	0.41	0.61	0.86	0.98	1.05	0.95	0.81	0.65	0.64	0.42	0.88	0.61	0.30	0.81	0.94	0.23	0.21	0.30	0.62	0.33

Table A3.4: Emission Trade Openness Ratio (ETOR) across countries and sectors

Country	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**	**X14**	**X15**	**X16**	**X17**	**X18**	**X19**	**X20**	**X21**	**X22**
Australia	0.83	0.76	2.02	3.33	1.40	0.88	1.22	0.74	0.96	1.18	1.28	0.97	1.07	0.97	1.92	1.36	1.51	1.82	1.84	1.63	1.20	1.32
Austria	1.12	1.31	1.09	1.19	1.19	1.26	1.15	1.26	1.82	1.12	1.35	1.34	1.25	1.05	1.61	1.58	1.30	1.37	1.54	1.73	1.59	1.24
Belgium	1.28	1.33	1.08	1.11	1.16	1.27	1.34	1.31	1.44	1.35	1.78	2.09	1.53	1.09	1.45	1.39	1.37	1.39	1.55	1.60	1.24	1.23
Canada	1.12	1.41	2.90	2.00	0.84	1.13	1.25	1.22	1.41	1.85	1.45	1.37	1.26	0.98	1.61	1.37	1.30	1.41	1.55	1.59	1.67	1.05
Chile	1.06	0.69	1.07	5.74	1.25	0.96	1.13	1.27	1.34	0.95	1.24	1.27	0.97	1.03	2.37	1.84	1.93	1.70	1.98	2.04	1.41	1.31
Colombia	0.73	0.93	1.66	0.83	1.09	0.64	0.67	1.02	0.58	1.05	1.04	0.93	1.01	0.42	1.33	1.32	1.15	1.20	1.38	1.53	1.31	0.89
Costa Rica	1.17	0.97	1.02	0.77	1.07	0.98	1.02	1.11	1.00	1.04	1.02	1.07	1.06	0.70	1.01	1.03	1.04	1.04	1.04	1.04	1.07	1.29
Czech Republic - Czechia	1.19	1.83	1.10	1.23	1.28	1.21	1.55	1.93	1.77	1.19	1.59	1.16	1.87	1.56	1.67	2.01	1.59	1.68	1.81	2.54	2.04	1.56
Denmark	1.67	3.85	1.83	1.57	1.39	1.87	1.44	1.41	1.73	1.64	1.51	1.63	1.38	1.11	1.22	1.33	1.61	1.44	1.52	1.72	1.24	1.30
Estonia	1.59	1.79	1.19	1.05	1.49	1.29	1.46	2.86	2.27	1.37	1.35	1.58	1.38	1.15	1.20	1.39	1.53	1.56	1.75	1.63	1.55	1.66
Finland	1.04	1.02	1.11	1.35	1.22	1.10	1.22	1.21	2.41	1.11	1.39	1.30	1.32	0.99	1.51	1.34	1.26	1.35	1.44	2.03	1.49	1.36
France	0.87	0.85	1.07	1.10	1.12	0.92	1.15	1.07	1.07	1.03	1.31	1.31	1.18	0.85	1.34	1.25	1.21	1.26	1.44	1.36	1.48	1.07
Germany	0.99	1.55	1.09	1.19	1.18	0.98	1.17	1.12	1.21	1.03	1.46	1.49	1.26	0.95	1.39	1.32	1.29	1.33	1.51	1.42	1.56	1.17
Greece	1.13	2.44	1.44	2.11	1.33	1.10	1.51	1.75	1.38	1.57	1.55	1.26	1.42	1.04	1.80	1.61	1.93	1.82	2.03	2.76	1.31	1.54
Hungary	1.23	1.92	1.16	1.12	1.14	1.24	1.51	1.67	1.56	1.14	1.68	2.19	1.71	1.36	1.36	1.46	1.53	1.51	1.58	2.16	1.47	1.53
Iceland	1.49	5.15	1.28	1.20	1.68	2.18	1.24	1.21	1.24	1.19	1.23	1.56	1.18	1.10	1.24	1.25	1.21	1.32	1.36	1.40	1.18	1.20
Ireland	2.02	3.14	1.17	1.60	1.47	2.30	1.27	1.82	1.27	1.37	1.34	2.18	1.23	1.46	1.30	1.49	2.50	1.48	1.95	1.38	1.15	1.38
Israel	0.68	0.85	1.04	1.14	1.07	0.79	1.15	1.13	1.05	1.01	1.20	1.22	1.14	0.96	1.03	1.03	1.07	1.11	1.11	1.19	1.14	1.85
Italy	0.76	0.72	1.00	1.12	1.14	0.85	1.11	1.00	0.98	0.95	1.16	1.11	1.15	1.05	1.18	1.23	1.16	1.24	1.38	1.33	1.23	1.06
Japan	0.75	0.52	1.10	1.01	1.16	0.58	1.08	0.88	0.56	0.63	0.94	0.45	0.98	0.77	1.02	0.94	1.21	1.15	1.15	1.43	1.36	0.84
Korea	1.22	0.64	1.18	1.23	1.40	0.88	1.07	1.10	1.04	1.34	1.55	0.91	1.34	0.81	1.40	1.25	2.24	1.45	1.41	1.66	1.83	1.18
Latvia	1.25	1.09	1.08	0.93	1.19	1.20	1.31	2.58	1.44	1.06	1.18	1.32	1.18	0.98	1.07	1.17	1.25	1.22	1.26	1.28	1.20	1.53

Lithuania	1.13	1.06	1.07	1.09	1.11	1.26	1.27	1.71	1.22	1.18	1.33	1.18	1.23	1.06	1.06	1.15	1.21	1.19	1.25	1.25	1.23	1.34
Luxembourg	1.28	1.18	1.09	1.24	1.24	1.33	1.26	1.43	1.30	1.09	1.32	2.41	1.93	1.59	1.61	1.83	1.64	1.53	1.92	1.70	1.82	1.70
Mexico	0.71	0.51	1.57	1.46	0.52	0.57	1.12	1.16	0.90	1.05	1.02	0.62	1.20	0.72	1.40	1.38	1.41	1.48	1.42	2.32	1.77	1.57
Netherlands	1.82	2.11	1.63	1.23	1.40	1.71	1.39	1.40	1.54	1.85	2.41	2.12	1.61	1.13	1.34	1.35	1.34	1.38	1.69	1.92	1.36	1.37
New Zealand	1.33	1.20	1.16	1.17	1.09	1.32	1.13	1.18	1.05	0.96	0.98	0.92	1.00	0.86	0.98	0.94	1.08	1.09	1.03	1.14	1.02	1.07
Norway	1.19	1.73	3.14	1.18	1.60	1.16	1.15	1.00	1.29	2.28	1.34	1.43	1.21	0.88	1.25	1.24	1.21	1.21	1.33	1.41	1.05	1.17
Poland	0.78	1.46	0.95	1.31	1.37	1.04	1.35	1.55	1.40	1.10	1.48	1.74	1.51	0.97	1.46	1.48	1.54	1.65	1.93	2.14	1.79	1.48
Portugal	0.98	0.69	1.05	1.46	1.23	1.00	1.35	1.55	1.48	1.16	1.29	1.29	1.36	1.13	1.19	1.30	1.37	1.32	1.35	1.51	1.68	1.29
Slovak Republic	1.32	1.74	1.10	1.31	1.24	1.33	1.33	1.70	1.47	1.44	1.52	1.30	1.79	1.32	2.89	2.75	1.60	2.03	2.23	3.27	2.71	1.35
Slovenia	1.07	1.51	1.06	1.20	1.19	1.27	1.31	2.11	1.56	1.07	1.24	1.70	1.30	1.52	1.36	1.53	1.33	1.48	1.56	1.55	2.33	1.44
Spain	1.03	0.63	1.14	1.19	1.24	0.97	1.17	1.19	1.10	1.10	1.29	1.31	1.26	1.10	1.24	1.24	1.23	1.23	1.31	1.40	1.40	1.10
Sweden	0.97	1.54	1.07	1.38	1.17	1.10	1.11	1.12	1.51	1.15	1.16	1.40	1.14	0.97	1.29	1.21	1.17	1.21	1.31	1.37	1.17	1.19
Switzerland	1.06	1.25	1.04	1.07	1.11	1.05	1.09	1.04	1.17	1.06	1.18	1.77	1.18	1.01	1.07	1.15	1.30	1.19	1.33	1.18	1.33	1.07
Turkey	0.54	0.65	1.08	1.06	1.23	0.59	1.08	0.72	0.90	1.10	1.08	0.88	1.02	0.45	1.22	1.26	1.44	1.31	1.37	2.18	1.61	0.86
United Kingdom	0.91	1.29	1.56	1.06	1.21	0.90	1.04	0.97	0.94	1.26	1.14	1.15	1.08	0.85	1.07	1.02	1.09	1.08	1.20	1.20	1.26	0.98
United States	0.63	1.21	0.74	0.83	0.49	0.48	0.98	0.65	0.56	0.68	0.77	0.55	0.78	0.60	0.93	0.80	1.00	1.00	0.92	0.81	0.99	0.86
Argentina	0.56	0.76	0.63	0.99	0.72	0.53	0.54	0.85	0.68	0.63	0.90	0.61	0.68	0.50	0.87	0.97	0.99	0.93	0.90	1.00	1.12	0.76
Brazil	0.80	1.52	1.19	2.08	1.24	0.67	0.89	1.26	0.92	0.66	0.84	0.63	0.84	0.48	1.27	1.27	1.16	1.12	1.39	1.05	1.53	0.84
Brunei Darussalam	1.69	2.28	2.43	1.32	0.50	1.82	1.83	1.95	1.49	2.00	2.60	1.94	1.08	1.29	1.11	1.19	2.00	1.34	1.19	1.89	0.79	1.07
Bulgaria	2.20	1.65	0.99	1.90	1.21	1.48	2.33	2.04	1.54	1.52	2.43	2.09	1.74	1.39	2.18	2.00	1.98	2.22	2.20	2.80	2.03	2.02
Cambodia	0.79	1.01	1.04	0.81	0.89	1.02	4.46	1.04	1.38	0.95	1.03	1.09	1.09	0.74	1.01	1.01	1.07	1.03	1.04	1.10	1.10	1.04
China (People's Republic of)	0.31	0.26	0.52	0.38	0.61	0.34	0.81	0.51	0.41	0.61	0.55	0.25	0.64	0.18	0.38	0.50	1.18	0.68	0.48	0.39	0.68	1.00
Croatia	0.88	0.80	0.99	1.04	1.04	0.92	1.14	1.44	1.07	1.05	1.09	1.01	1.08	0.74	1.05	1.12	1.14	1.13	1.14	1.28	1.16	1.15
Cyprus	0.82	1.92	1.07	1.09	1.22	0.90	1.10	1.03	1.09	1.05	1.12	1.35	1.08	0.77	1.04	0.97	1.18	1.10	1.19	1.20	1.02	1.08
India	0.25	0.63	0.87	0.84	0.71	0.47	0.64	1.15	0.73	0.89	0.97	0.74	0.57	0.28	0.50	0.81	0.79	0.59	0.64	0.34	0.63	1.50
Indonesia	0.77	0.55	1.13	0.86	0.90	0.78	1.29	0.76	1.03	0.63	1.08	0.69	0.74	0.31	1.09	0.63	1.41	1.30	1.22	1.39	0.92	1.92

Hong Kong, China	1.14	1.21	1.06	1.06	1.07	1.05	1.07	1.07	0.98	1.05	1.06	1.29	1.07	1.09	1.03	1.08	1.06	1.04	1.11	1.27	1.08	1.12
Kazakhstan	0.85	1.72	###	3.40	4.34	1.13	2.16	2.13	1.86	4.82	1.95	0.95	1.36	0.78	1.53	2.60	2.68	2.58	2.61	4.27	2.07	1.86
Lao People's Democratic Republic	1.28	1.30	1.11	1.60	1.02	3.14	6.96	1.58	4.27	1.25	3.19	5.74	3.53	1.59	1.35	1.34	3.09	1.89	3.96	3.78	1.96	1.52
Malaysia	1.20	0.52	1.88	1.27	1.71	1.11	1.88	1.61	1.10	1.63	1.85	1.86	1.74	0.99	1.42	1.47	3.72	2.22	1.73	1.27	1.25	1.95
Malta	1.43	1.96	1.21	1.18	1.34	1.47	1.57	1.50	1.60	1.13	1.29	2.08	1.38	1.10	1.11	1.22	3.11	1.37	1.46	1.92	1.11	1.30
Morocco	0.59	0.78	1.06	1.86	0.85	0.73	1.63	1.13	1.05	1.08	1.54	0.89	1.20	0.41	1.09	1.02	1.29	1.56	1.20	1.73	1.31	1.30
Myanmar	0.52	0.62	2.11	0.86	1.28	1.01	1.14	0.58	0.97	1.11	1.15	0.75	1.03	0.59	1.07	0.98	1.06	1.10	1.05	0.97	1.08	0.85
Peru	0.88	0.41	1.14	3.86	1.01	0.63	0.83	1.22	1.03	1.06	1.14	1.19	0.77	0.97	1.71	1.52	1.35	1.72	1.58	1.88	1.50	0.71
Philippines	0.79	0.49	1.05	1.10	1.51	0.61	0.83	1.17	1.05	0.94	1.00	0.95	1.02	0.70	1.03	1.07	1.32	1.22	1.22	1.23	1.09	1.17
Romania	0.80	0.89	0.89	1.08	1.06	0.74	1.17	1.17	1.02	0.74	1.23	1.16	1.32	0.61	1.17	1.15	1.48	1.73	1.51	1.58	1.73	1.39
Russian Federation	0.74	0.95	3.73	2.00	1.13	0.64	1.51	1.71	1.19	2.49	1.68	0.95	1.15	0.60	1.32	1.37	1.57	1.88	1.98	1.63	0.86	1.20
Saudi Arabia	0.92	1.40	3.22	1.27	2.04	0.83	1.12	0.53	0.66	1.37	1.16	1.86	0.51	0.47	1.01	0.83	1.42	0.84	0.96	1.32	1.29	0.26
Singapore	3.75	4.19	2.22	2.16	2.29	2.84	2.95	3.34	2.33	2.49	3.70	4.23	2.41	1.93	1.44	1.74	2.38	2.07	2.18	2.78	1.58	1.74
South Africa	0.57	1.30	2.04	6.89	2.70	0.85	1.69	2.38	1.33	1.09	1.73	1.14	1.17	1.24	2.50	2.14	2.55	2.37	2.46	1.52	5.72	3.05
Chinese Taipei	1.81	0.75	1.41	1.39	1.41	1.25	2.18	1.86	1.39	1.57	2.51	1.52	2.17	1.31	1.70	1.87	2.98	2.04	2.05	2.71	2.19	2.30
Thailand	0.96	0.69	1.17	1.09	1.29	1.10	1.23	2.24	1.37	1.30	1.83	1.03	2.08	0.55	1.27	1.30	1.46	1.61	1.67	1.87	1.24	1.53
Tunisia	0.61	0.71	1.11	1.27	1.09	0.77	2.10	1.04	1.17	1.21	1.49	1.01	1.84	0.39	1.13	1.31	1.98	2.01	1.27	1.96	2.53	1.65
Viet Nam	1.09	0.73	1.83	1.88	2.35	1.09	6.34	2.38	1.58	1.39	1.52	1.04	3.25	0.83	1.41	1.92	5.40	1.78	1.74	2.10	1.13	2.02
Rest of the World	0.54	0.42	1.84	1.13	1.19	0.65	0.93	0.96	0.83	1.32	1.07	0.82	0.59	0.47	1.00	1.03	1.11	1.06	1.07	1.08	1.11	0.65

Country	**X23**	**X24**	**X25**	**X26**	**X27**	**X28**	**X29**	**X30**	**X31**	**X32**	**X33**	**X34**	**X35**	**X36**	**X37**	**X38**	**X39**	**X40**	**X41**	**X42**	**X43**	**X44**
Australia	0.44	0.52	0.75	0.74	0.84	0.74	0.74	0.70	0.67	0.65	0.77	0.60	0.66	0.55	0.39	0.73	0.67	0.29	0.55	0.52	0.65	0.93
Austria	0.92	1.14	1.07	1.21	1.39	1.21	1.42	1.33	1.24	0.94	1.34	1.26	1.18	1.14	0.80	1.24	1.21	0.81	0.61	0.71	0.95	0.92
Belgium	0.84	1.18	1.10	1.28	1.37	1.81	1.40	1.38	1.14	1.12	1.53	1.18	1.32	1.16	0.88	1.32	1.24	0.90	0.87	0.93	1.09	1.07
Canada	0.71	0.77	0.68	1.02	1.16	1.12	1.39	1.22	1.10	0.94	1.08	0.80	1.02	0.69	0.61	1.05	1.06	0.91	0.77	0.60	0.78	0.69
Chile	0.73	0.68	1.22	0.87	0.68	1.14	1.06	1.09	1.35	0.93	0.96	0.69	1.35	0.83	0.65	1.36	1.41	0.79	0.50	0.60	1.01	1.42
Colombia	0.72	0.59	0.51	0.73	0.52	1.06	1.09	1.05	1.00	0.65	1.30	0.70	1.07	0.77	0.97	0.99	1.15	0.54	0.67	0.75	0.74	0.93
Costa Rica	0.97	0.76	0.69	0.94	0.93	1.17	1.10	0.96	0.92	1.10	0.96	0.92	1.11	0.91	0.77	1.01	0.96	0.77	0.69	0.82	1.20	0.77

Czech Republic - Czechia	0.64	1.05	1.14	1.46	1.67	1.26	1.51	1.29	1.26	1.28	1.52	1.29	1.25	1.12	0.57	1.37	1.26	0.62	0.57	0.73	0.82	1.05
Denmark	0.79	1.13	1.15	1.86	1.42	3.37	1.51	1.51	1.43	1.58	1.39	1.26	1.24	1.40	1.03	1.35	1.29	1.52	0.97	1.01	1.03	1.49
Estonia	0.68	1.02	1.04	1.45	1.53	1.98	1.37	2.33	1.55	1.58	2.61	1.56	1.74	1.45	0.84	1.47	1.62	0.74	0.45	0.86	0.73	0.87
Finland	0.62	1.12	0.85	1.16	1.06	1.42	1.35	1.18	1.25	0.91	1.37	1.17	1.27	1.02	0.52	1.26	1.26	0.78	0.73	0.68	0.59	0.63
France	0.83	0.90	0.84	1.02	1.01	1.82	1.22	1.12	1.11	0.97	0.92	0.94	0.92	0.88	0.74	0.91	1.06	0.75	0.68	0.79	0.69	0.92
Germany	0.56	0.91	0.98	1.06	1.08	1.40	1.67	1.16	0.95	0.95	1.13	0.99	1.18	0.94	0.68	1.10	1.06	0.70	0.71	0.63	0.77	0.72
Greece	0.49	0.38	1.49	1.41	1.48	2.42	1.84	1.47	1.23	0.91	1.34	0.84	1.41	1.33	1.01	1.48	1.23	0.93	0.77	0.92	0.68	0.69
Hungary	0.95	0.98	0.99	1.34	1.78	1.23	1.35	1.73	1.18	1.20	1.89	1.22	1.56	1.17	0.80	1.55	1.51	0.70	0.64	1.04	0.76	1.01
Iceland	1.05	1.23	0.98	1.28	1.26	1.42	2.77	2.02	1.80	2.31	1.57	1.26	1.64	1.79	1.18	1.99	1.76	1.82	1.41	1.65	2.14	1.67
Ireland	1.03	1.36	1.49	1.76	1.33	1.33	4.29	1.94	1.62	1.55	1.17	1.82	2.24	2.24	1.56	1.56	2.16	1.40	1.40	1.54	1.56	1.63
Israel	0.37	0.86	0.88	1.05	0.89	1.69	1.01	1.23	1.02	0.63	1.23	1.00	1.27	1.03	0.77	0.92	1.20	0.55	0.47	0.78	0.92	0.51
Italy	0.60	0.70	0.93	0.92	0.91	0.97	1.10	0.95	0.84	0.68	1.02	0.97	0.90	0.85	0.62	0.85	0.87	0.52	0.46	0.60	0.65	0.44
Japan	0.31	0.49	0.68	0.67	0.71	0.83	0.53	0.80	0.83	0.42	0.64	0.49	0.61	0.51	0.35	0.65	0.84	0.39	0.34	0.33	0.32	0.45
Korea	0.61	0.84	0.78	1.07	0.88	2.63	1.42	1.28	0.97	0.60	0.83	0.93	0.99	0.63	0.46	0.70	1.21	0.61	0.32	0.41	0.45	0.64
Latvia	0.81	0.95	0.94	1.14	1.62	1.13	1.28	1.37	1.30	1.24	1.78	1.11	1.34	1.25	0.77	1.30	1.19	0.80	0.68	0.85	0.68	0.99
Lithuania	0.91	0.99	1.16	1.25	1.73	1.50	1.23	1.25	1.33	1.29	1.12	1.10	1.14	1.19	0.97	1.26	1.18	1.00	1.13	1.14	0.98	1.29
Luxembourg	1.05	1.54	1.20	1.55	1.22	1.18	2.81	1.61	1.98	1.60	1.35	1.70	1.51	1.51	1.30	1.58	2.08	1.55	1.63	1.39	1.67	2.14
Mexico	0.69	0.45	0.74	0.95	0.67	1.05	0.59	1.02	0.86	1.04	1.01	1.24	1.82	0.72	0.89	1.09	1.03	0.63	0.56	0.73	0.87	0.77
Netherlands	0.77	1.28	1.03	1.48	1.43	2.05	2.21	1.73	1.37	1.35	1.32	1.30	1.39	1.18	0.76	1.35	1.47	0.92	0.84	0.93	0.86	1.05
New Zealand	0.77	0.87	0.59	0.97	0.87	0.94	0.86	0.98	0.96	1.38	0.99	1.12	1.10	0.89	0.56	0.91	1.00	0.73	0.71	0.64	0.75	0.79
Norway	1.12	1.01	0.89	1.12	1.11	0.73	1.62	1.14	1.31	1.27	1.02	1.29	1.13	1.38	0.85	1.18	1.20	0.83	1.03	0.90	0.93	1.18
Poland	0.48	0.80	0.91	1.17	1.40	1.33	1.49	1.27	0.94	1.02	1.52	0.92	1.58	0.72	0.32	1.32	1.07	0.68	0.36	0.59	0.52	0.80
Portugal	0.63	0.94	0.95	1.09	1.33	1.47	2.68	1.43	1.41	1.16	1.40	1.06	1.34	1.28	0.78	1.26	1.59	0.68	0.77	0.64	0.84	0.99
Slovak Republic	0.81	1.41	1.93	1.41	1.44	1.10	1.14	1.32	1.28	1.50	1.39	1.44	1.38	1.20	1.11	1.33	1.33	1.01	0.86	1.21	0.85	1.18
Slovenia	1.04	0.99	1.23	1.42	1.80	1.29	1.41	1.50	1.16	1.59	1.62	1.29	1.30	1.22	1.32	1.29	1.43	1.07	0.85	1.17	1.06	1.15
Spain	0.67	0.78	0.85	1.01	1.21	1.50	1.53	1.07	1.10	0.78	1.14	0.81	1.09	0.98	0.66	1.04	1.08	0.68	0.59	0.71	0.65	0.83
Sweden	0.83	1.01	0.93	1.14	1.05	1.22	1.29	1.02	1.07	1.07	1.16	1.09	1.05	1.17	0.74	1.09	1.15	0.97	0.84	0.94	0.85	1.05
Switzerland	0.99	1.00	0.94	1.06	1.09	1.13	1.16	1.23	1.19	1.06	1.23	1.06	1.08	1.10	0.88	1.01	1.08	0.82	0.99	0.94	0.97	0.97

Turkey	0.39	0.81	0.54	0.81	0.56	1.03	4.08	1.22	0.86	0.65	0.90	0.56	1.40	0.84	0.33	0.93	0.99	0.45	0.37	0.47	0.77	0.54
United Kingdom	0.62	0.74	0.76	0.84	0.86	1.12	1.07	0.97	0.96	0.80	1.04	1.01	1.05	0.95	0.60	1.06	1.00	0.74	0.64	0.59	0.77	0.83
United States	0.24	0.64	0.43	0.45	0.53	0.67	0.61	0.54	0.39	0.34	0.51	0.50	0.53	0.35	0.13	0.47	0.52	0.22	0.17	0.27	0.30	0.34
Argentina	0.36	0.41	0.59	0.61	0.47	1.12	1.38	0.59	0.88	0.50	0.61	0.60	1.05	0.61	0.76	0.74	0.77	0.35	0.31	0.41	0.59	0.44
Brazil	0.59	0.69	0.72	0.67	0.43	1.04	0.77	1.00	0.79	0.69	1.10	0.75	0.92	0.67	0.84	1.04	0.84	0.62	0.57	0.65	0.89	0.49
Brunei Darussalam	0.58	1.20	0.75	1.05	1.86	0.83	1.09	2.22	2.17	1.60	1.34	0.88	1.72	0.74	1.10	0.90	1.55	0.32	0.62	0.86	1.63	3.31
Bulgaria	0.85	0.97	1.19	1.41	1.58	1.25	1.48	1.60	1.03	1.96	1.87	0.90	1.48	1.23	0.63	1.78	1.37	0.79	1.75	1.17	1.13	1.29
Cambodia	0.64	0.72	1.00	1.34	1.41	1.20	2.35	1.29	1.55	1.26	1.60	1.03	1.37	1.28	0.59	1.20	1.28	0.65	1.03	1.08	2.02	1.03
China (People's Republic of)	0.21	0.28	0.15	0.68	0.43	0.64	0.65	0.58	0.41	0.38	0.84	0.43	0.62	0.56	0.46	0.48	0.38	0.46	0.32	0.55	0.56	0.37
Croatia	0.73	0.86	0.58	0.96	1.40	1.43	1.57	1.09	1.00	1.92	1.07	0.93	1.13	0.94	0.68	1.16	1.03	0.53	0.66	0.74	0.82	0.90
Cyprus	0.52	0.56	0.80	0.96	1.21	1.61	1.19	1.30	1.37	0.94	1.03	0.97	1.63	1.68	0.85	1.39	1.35	0.46	0.58	0.61	0.63	0.68
India	0.22	0.48	0.27	0.63	0.38	1.04	0.92	0.57	0.62	0.71	1.04	0.31	1.85	0.41	0.29	3.39	0.63	0.46	0.38	0.86	0.65	0.19
Indonesia	0.32	1.21	0.36	0.61	0.59	0.84	0.46	1.01	0.93	0.65	0.62	0.38	0.56	1.01	0.78	2.10	1.27	0.36	0.37	0.55	0.86	0.59
Hong Kong, China	0.82	0.94	1.69	1.02	1.18	1.38	2.59	2.03	1.33	1.77	1.61	1.40	2.04	1.17	0.55	1.47	1.58	1.14	0.94	0.76	1.28	0.91
Kazakhstan	0.35	0.95	0.74	1.14	1.07	1.64	1.32	1.65	2.48	1.89	0.84	0.61	0.96	0.69	0.39	0.75	1.00	0.27	0.17	0.37	0.25	0.09
Lao People's Democratic Republic	2.76	2.18	1.04	1.20	2.54	0.87	1.54	1.64	1.70	2.98	1.63	1.76	1.67	1.58	1.18	1.69	1.84	0.70	2.22	3.73	1.12	2.20
Malaysia	0.76	0.89	0.95	1.40	1.85	1.26	1.32	1.16	1.27	1.04	1.79	0.86	1.28	1.20	0.64	1.88	1.62	0.49	0.40	0.85	0.60	3.18
Malta	1.04	0.82	1.02	1.37	1.29	1.32	1.50	1.50	1.42	1.54	1.32	1.36	2.13	2.12	1.17	1.75	1.47	1.18	1.09	0.81	2.91	1.35
Morocco	0.37	1.07	0.45	0.99	1.01	1.07	1.93	0.97	0.66	1.36	1.32	0.63	1.71	1.08	1.25	1.52	1.62	0.33	0.36	0.56	1.22	1.25
Myanmar	0.61	0.91	0.35	0.83	0.85	1.06	1.08	1.08	0.94	1.14	1.04	0.49	2.14	0.72	0.41	1.38	1.40	0.42	0.42	0.47	1.28	0.61
Peru	0.70	1.03	0.90	0.86	0.57	1.26	1.30	0.85	1.02	0.65	1.18	0.76	1.70	0.84	1.20	1.13	1.16	0.59	0.63	0.87	0.83	0.76
Philippines	0.40	0.67	0.77	0.72	0.83	0.66	0.81	0.96	1.09	0.57	1.85	0.73	4.94	0.62	0.59	1.64	2.16	0.66	0.45	0.62	0.74	0.52
Romania	0.57	0.62	0.53	0.86	1.08	1.05	1.08	1.11	1.02	0.97	1.16	0.85	1.16	1.03	0.73	1.12	1.03	0.94	0.72	0.79	0.58	0.64
Russian Federation	0.37	0.61	0.70	0.81	0.86	1.74	1.34	1.18	1.37	1.09	1.83	0.70	1.55	1.05	0.32	0.94	1.58	0.36	0.43	0.53	0.49	1.08

Saudi Arabia	0.24	0.79	0.35	0.61	0.80	0.75	0.82	0.88	0.97	1.07	1.65	0.33	1.30	0.69	0.43	0.42	0.24	0.33	0.28	0.31	0.63	0.77
Singapore	1.16	1.57	2.39	2.15	1.78	4.58	2.50	2.53	2.01	1.61	1.92	1.60	1.87	1.63	1.20	1.74	2.21	1.50	2.06	2.00	1.37	2.31
South Africa	0.50	0.70	1.72	1.10	1.01	1.35	1.00	1.22	1.12	1.46	1.34	0.66	0.61	0.76	0.34	0.72	0.66	0.54	0.53	0.63	1.13	2.34
Chinese Taipei	0.96	1.25	1.28	1.46	1.24	2.71	2.13	2.14	1.37	0.84	1.69	1.60	2.65	1.38	0.90	2.23	2.56	1.21	0.73	0.92	1.05	0.81
Thailand	0.93	0.93	0.72	1.43	1.54	2.82	2.22	1.60	1.34	0.90	1.58	1.57	1.34	1.08	1.36	1.47	1.90	0.60	0.59	1.02	1.65	1.33
Tunisia	0.62	0.60	0.46	1.30	1.06	1.29	2.99	1.45	0.96	0.92	1.33	1.00	1.73	1.24	0.48	1.15	1.25	0.51	4.93	7.94	2.73	2.75
Viet Nam	0.93	0.90	0.77	1.57	1.33	1.58	1.64	1.81	1.74	0.94	1.61	0.76	2.25	1.15	0.68	1.45	2.36	0.94	0.62	1.50	0.95	0.93
Rest of the World	0.36	0.54	0.58	0.72	0.69	0.86	0.89	1.02	0.90	0.70	0.73	0.52	1.09	0.75	0.45	1.03	1.21	0.32	0.27	0.44	0.65	0.42

Table A3.5: Emission Balance of Trade (EBT) across countries and sectors

Country	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**	**X14**	**X15**	**X16**	**X17**	**X18**	**X19**	**X20**	**X21**	**X22**
Australia	1.03	1.05	0.93	0.86	1.00	1.13	1.07	1.19	1.08	0.80	0.93	0.98	1.05	0.87	0.65	1.13	1.18	1.13	1.24	1.26	1.28	1.22
Austria	0.92	0.83	0.89	0.80	0.79	1.00	0.90	0.90	0.89	0.88	0.75	0.92	0.79	0.85	0.78	0.87	0.81	0.79	0.83	0.90	0.78	0.89
Belgium	0.90	0.81	0.94	0.88	0.92	0.99	0.91	0.95	0.88	0.86	0.77	0.93	0.77	0.81	0.63	0.94	0.95	0.89	0.90	0.86	0.95	0.81
Canada	1.01	1.21	1.30	0.96	1.06	1.27	1.10	1.05	1.07	1.07	1.06	1.13	1.03	1.02	0.82	1.09	1.06	1.07	1.11	1.05	1.11	1.04
Chile	1.12	1.06	0.97	1.04	1.07	1.27	1.10	1.09	1.02	0.98	1.04	1.45	0.89	0.99	0.65	1.14	1.34	1.04	1.30	1.31	1.28	0.99
Colombia	1.47	1.93	0.96	0.84	0.93	1.34	1.02	1.42	0.96	0.90	1.11	1.17	1.19	0.85	0.85	1.20	1.06	1.11	1.19	1.39	1.34	1.36
Costa Rica	0.91	0.90	0.95	1.08	0.90	1.05	0.97	0.92	1.01	0.95	0.98	0.89	0.80	0.97	0.90	0.92	0.93	0.89	0.92	0.94	0.87	0.68
Czech Republic - Czechia	1.02	0.94	0.94	0.91	0.88	1.07	1.03	1.02	1.04	0.96	1.00	0.97	0.78	0.94	0.91	0.90	0.88	0.80	0.96	0.82	1.02	0.97
Denmark	1.09	1.63	1.15	1.04	1.09	1.17	1.17	1.27	1.23	1.08	0.92	0.59	0.92	0.97	0.85	0.99	1.13	0.95	0.94	1.15	0.96	0.91
Estonia	1.07	1.18	0.98	0.94	0.92	1.09	1.06	0.96	1.19	1.02	0.93	1.16	0.98	0.93	0.85	0.90	0.78	0.81	1.02	1.14	0.92	0.95
Finland	1.00	0.83	0.91	0.80	0.89	1.27	1.00	0.99	0.92	0.94	0.81	1.00	0.86	0.95	0.68	1.03	0.96	0.87	0.94	1.09	1.01	1.00
France	1.04	0.85	0.94	0.88	0.90	1.15	0.91	1.10	1.00	0.96	0.79	0.89	0.84	0.93	0.90	1.12	0.81	0.80	0.88	0.93	0.60	1.10
Germany	0.94	0.83	0.92	0.79	0.88	1.14	0.97	1.06	0.96	0.93	0.81	0.97	0.89	0.88	0.86	1.04	0.85	0.88	0.85	0.90	0.85	1.03
Greece	1.31	1.47	1.23	1.06	1.11	1.24	1.21	1.37	1.36	1.05	1.12	1.21	1.10	0.86	0.91	1.27	1.51	1.20	1.43	1.87	1.18	1.19
Hungary	0.99	0.89	1.00	0.90	0.91	1.06	0.97	1.02	1.01	0.96	0.97	1.14	0.79	0.91	0.85	0.85	0.66	0.74	0.86	0.69	0.95	0.87
Iceland	1.03	1.21	1.05	0.95	1.26	1.13	1.03	1.17	1.25	1.02	0.98	1.30	0.97	1.53	0.38	0.88	1.00	0.75	0.98	0.97	0.93	1.08
Ireland	0.64	0.67	0.70	0.76	0.69	0.74	0.80	0.67	0.72	0.49	0.44	0.39	0.55	0.66	0.70	0.70	0.70	0.66	0.77	0.91	0.99	0.61

Israel	0.89	1.26	0.96	0.83	0.89	1.31	0.95	1.02	1.12	0.98	0.76	0.91	0.87	1.20	0.89	1.07	1.04	0.90	0.93	1.00	0.96	0.78
Italy	0.97	0.76	0.93	0.78	0.82	1.18	0.95	1.08	1.05	0.97	0.88	0.99	0.89	0.88	0.77	0.91	0.94	0.82	0.81	0.89	0.97	1.05
Japan	1.21	0.87	0.85	0.98	0.95	1.46	1.08	1.24	1.07	0.98	0.98	0.89	1.16	0.86	0.95	1.21	1.00	1.04	1.05	0.99	1.02	1.41
Korea	1.35	0.83	0.98	0.93	1.00	1.32	1.15	1.16	1.01	0.97	0.92	1.15	0.98	0.86	0.93	1.16	0.92	1.04	1.10	1.14	1.04	1.11
Latvia	0.94	0.86	0.92	1.14	0.86	1.03	1.00	0.75	0.92	0.93	0.86	0.97	0.87	0.87	0.81	0.83	0.92	0.87	0.93	0.99	0.98	0.82
Lithuania	0.98	0.96	0.93	0.88	0.85	0.97	0.91	0.71	0.94	0.93	0.78	0.93	0.80	0.81	0.82	0.87	0.93	0.85	0.89	0.95	0.92	0.71
Luxembourg	0.53	0.50	0.55	0.44	0.49	0.58	0.63	0.52	0.49	0.55	0.37	0.46	0.32	0.56	0.36	0.41	0.48	0.47	0.49	0.62	0.53	0.43
Mexico	1.00	0.88	1.12	0.98	1.03	1.17	1.06	1.07	1.00	1.06	1.01	0.97	1.02	0.84	0.91	1.04	0.82	0.94	1.03	0.97	1.08	1.07
Netherlands	0.96	0.95	1.06	0.81	0.78	1.01	0.98	1.10	0.94	0.95	0.89	0.84	0.77	0.87	0.81	0.96	0.68	0.83	0.80	0.98	0.96	0.90
New Zealand	0.93	0.94	0.94	0.85	0.96	0.94	0.98	1.00	1.00	1.01	0.90	0.82	0.93	1.11	0.91	1.18	1.06	1.02	1.04	1.07	1.31	0.90
Norway	1.04	0.82	0.67	0.88	0.67	1.25	1.02	1.25	1.02	0.66	0.88	0.95	0.94	0.94	0.66	0.97	1.01	0.94	1.01	1.07	1.11	1.02
Poland	0.88	1.13	0.93	0.95	0.75	1.06	1.04	1.07	1.07	0.99	1.05	1.19	1.00	0.91	0.94	1.04	1.01	0.96	1.13	1.15	1.06	1.02
Portugal	1.02	0.81	0.96	0.86	0.92	1.10	0.94	0.95	0.99	0.95	0.94	1.05	0.85	0.91	0.77	0.91	0.90	0.85	0.94	0.88	1.06	0.98
Slovak Republic	1.08	0.95	0.96	0.93	0.92	1.09	0.92	0.98	0.96	0.98	1.06	1.01	0.75	0.90	1.33	1.20	0.78	0.95	1.15	0.74	1.27	0.82
Slovenia	0.95	0.90	0.91	0.86	0.87	1.10	0.87	0.87	1.00	0.92	0.79	0.76	0.78	0.91	0.66	0.75	0.83	0.65	0.76	0.78	0.85	0.71
Spain	1.03	0.82	1.03	0.89	0.93	1.17	0.95	1.02	1.01	1.00	0.91	0.98	0.87	0.90	0.79	0.95	0.97	0.91	0.95	0.91	0.94	1.08
Sweden	0.98	1.07	0.86	0.75	0.80	1.03	0.88	0.95	0.72	0.78	0.71	0.66	0.74	0.88	0.70	0.91	0.85	0.77	0.74	0.71	0.95	0.83
Switzerland	0.97	0.61	0.82	0.75	0.68	0.98	0.81	1.02	0.74	0.87	0.56	0.61	0.66	0.81	0.66	0.63	0.56	0.63	0.50	0.77	0.57	0.66
Turkey	1.14	1.02	1.02	1.02	1.14	1.20	1.06	0.95	1.09	1.05	1.03	1.00	1.04	0.73	0.97	1.22	1.23	1.12	1.18	1.28	1.40	1.18
United Kingdom	1.08	0.93	0.94	1.02	0.77	1.16	1.02	1.15	1.13	0.92	0.94	0.97	0.93	0.97	0.87	1.06	1.03	1.00	0.95	0.94	0.90	1.03
United States	1.09	0.95	1.02	1.05	1.61	1.24	1.05	1.27	1.11	1.11	1.04	0.88	1.20	1.09	1.03	1.37	1.14	1.10	1.19	1.30	1.15	1.23
Argentina	0.95	1.24	0.93	1.15	1.35	1.16	0.87	1.10	1.23	0.97	1.17	1.33	0.92	0.99	0.95	1.17	1.09	1.09	1.19	1.06	1.06	0.91
Brazil	1.02	2.67	1.00	0.90	1.08	1.35	1.66	1.21	1.06	1.09	1.13	1.15	1.20	0.75	0.81	1.42	1.52	1.37	1.44	1.50	1.02	1.42
Brunei Darussalam	1.19	1.00	0.99	0.97	1.47	1.20	1.04	1.15	1.02	1.15	0.91	1.17	0.58	0.89	0.86	0.94	1.28	1.00	1.02	1.24	0.98	0.72
Bulgaria	1.20	1.20	0.95	1.03	0.98	1.16	1.28	1.25	1.17	1.02	1.47	1.47	1.15	0.94	0.75	1.12	1.34	1.13	1.28	1.65	1.22	1.21
Cambodia	1.21	3.65	0.98	1.02	1.34	1.01	0.67	1.00	0.93	0.91	0.98	1.00	0.95	0.71	1.02	1.06	1.05	1.01	1.05	1.07	1.00	1.00
China (People's Republic of)	1.13	1.35	0.89	0.81	0.88	1.27	1.08	1.12	1.03	0.99	0.92	0.91	0.97	0.79	0.82	0.96	1.05	0.99	0.96	1.13	0.98	1.02

Croatia	0.97	0.95	0.95	0.99	1.00	1.09	1.01	0.94	1.02	0.99	0.99	0.97	1.00	0.83	0.95	1.00	1.01	0.97	1.03	1.05	1.01	0.91
Cyprus	0.84	0.74	0.82	0.80	0.79	0.92	0.93	0.94	0.88	0.82	0.83	0.85	0.86	0.72	0.84	0.98	0.88	0.86	0.85	0.95	0.99	0.91
India	1.00	2.83	0.97	1.04	1.10	1.26	1.03	1.21	0.97	0.99	1.09	1.08	0.74	0.63	0.71	1.06	0.88	0.80	0.83	0.72	0.85	1.10
Indonesia	1.63	2.72	1.02	1.18	1.07	1.52	1.19	1.11	1.02	1.05	1.00	0.88	0.84	0.40	0.88	1.13	1.20	1.12	1.12	1.60	1.19	1.08
Hong Kong, China	1.00	1.02	0.95	0.93	0.98	1.09	1.07	1.08	1.11	0.95	0.96	0.98	0.93	0.89	0.76	0.87	0.96	0.97	0.92	1.02	1.00	0.90
Kazakhstan	1.34	1.85	1.50	1.14	1.23	1.42	1.67	1.33	1.38	1.13	1.11	0.84	1.05	0.62	0.86	1.48	1.86	1.63	1.67	2.34	1.55	1.30
Lao People's Democratic Republic	2.30	2.47	1.10	1.05	1.34	3.67	5.27	2.42	2.73	1.23	2.40	3.59	2.51	1.65	0.87	1.16	2.47	1.38	2.15	2.79	1.67	1.12
Malaysia	1.23	0.69	1.01	0.98	1.01	1.10	1.21	1.05	1.08	1.03	0.97	1.24	1.03	0.99	0.83	0.97	1.14	0.99	1.10	1.19	1.17	0.98
Malta	0.88	0.68	0.84	0.83	0.80	0.94	0.98	0.84	0.76	0.89	0.79	0.69	0.77	0.87	0.75	0.82	1.01	0.80	0.87	0.92	1.01	0.82
Morocco	0.98	1.01	1.00	1.10	0.96	1.13	1.01	1.12	1.03	1.01	0.92	1.17	0.97	0.56	0.97	1.08	1.05	0.79	1.06	1.17	1.14	0.97
Myanmar	1.25	1.99	1.10	0.91	1.07	1.30	1.21	0.78	1.18	0.95	1.10	1.17	1.12	0.84	0.95	1.15	1.21	1.16	1.13	1.32	1.05	1.18
Peru	1.90	1.10	0.96	0.58	1.23	1.59	1.23	1.17	1.38	1.12	1.03	1.32	0.78	1.18	0.44	1.02	1.00	0.85	1.01	1.07	1.11	0.71
Philippines	1.63	1.50	0.98	0.96	1.03	1.24	1.15	0.98	0.93	1.12	1.05	1.04	0.98	0.81	0.95	0.99	0.95	0.90	0.95	1.00	1.02	0.94
Romania	1.11	1.74	0.96	0.96	1.00	1.30	1.03	1.01	1.04	1.01	1.01	0.99	0.96	0.79	0.94	1.11	0.99	0.92	1.04	1.02	1.06	0.98
Russian Federation	1.06	0.95	1.08	1.09	1.03	1.14	1.38	1.11	1.12	0.99	1.02	1.04	1.02	0.65	0.90	1.28	1.48	1.50	1.58	1.75	1.11	1.24
Saudi Arabia	0.96	0.71	0.35	0.99	0.87	1.03	1.00	0.55	0.74	0.41	0.77	1.14	0.34	0.56	0.85	0.87	1.10	0.84	0.87	1.10	1.06	0.28
Singapore	1.35	1.41	1.23	0.97	1.21	1.44	1.45	1.41	1.08	0.86	0.86	1.10	0.78	0.88	0.74	0.94	0.67	0.89	0.92	1.34	0.88	0.90
South Africa	0.90	1.53	1.32	1.36	1.70	1.32	1.47	1.41	1.39	1.10	1.24	1.14	0.98	0.91	0.91	1.39	2.10	1.72	1.82	1.39	2.94	1.62
Chinese Taipei	1.78	0.78	1.08	0.99	1.13	1.47	1.20	1.37	1.05	1.08	1.09	1.26	1.07	0.89	1.02	1.09	1.03	1.10	1.15	1.50	1.29	1.14
Thailand	1.06	0.96	1.01	0.99	1.11	1.08	1.09	1.12	1.03	1.02	1.00	1.08	0.91	0.67	0.97	0.95	0.97	0.94	1.00	0.97	1.03	0.91
Tunisia	0.85	1.29	1.03	1.05	1.04	1.07	1.18	1.15	1.06	1.10	1.03	1.12	1.33	0.57	0.96	1.06	1.21	1.10	1.11	1.21	1.49	1.12
Viet Nam	1.03	1.05	0.90	1.25	1.57	1.13	1.21	1.05	1.05	1.00	1.00	1.11	1.05	0.79	0.97	1.04	1.23	1.03	1.13	1.31	1.14	0.96
Rest of the World	1.37	1.12	0.95	1.01	1.04	1.17	1.15	1.15	1.05	0.88	0.94	0.97	0.60	0.65	0.91	1.10	1.12	1.09	1.10	1.18	1.11	0.69
Country	**X23**	**X24**	**X25**	**X26**	**X27**	**X28**	**X29**	**X30**	**X31**	**X32**	**X33**	**X34**	**X35**	**X36**	**X37**	**X38**	**X39**	**X40**	**X41**	**X42**	**X43**	**X44**
Australia	0.48	1.53	2.07	1.26	0.95	1.01	0.90	1.35	1.11	1.23	1.31	1.42	1.75	1.82	2.74	1.55	1.42	1.53	2.08	2.87	2.01	2.41
Austria	1.05	1.19	1.59	1.08	0.82	0.76	0.84	0.92	0.94	1.45	1.06	1.11	1.06	1.25	2.18	1.09	1.24	1.98	2.20	2.07	1.31	1.71
Belgium	0.85	1.12	1.70	1.04	0.80	0.89	0.77	0.87	1.00	1.24	0.91	1.04	1.07	1.14	1.89	1.00	1.07	1.97	2.66	1.92	1.39	1.62

Canada	0.80	1.36	1.64	1.32	1.02	0.91	1.00	1.20	1.26	1.57	1.38	1.62	1.44	1.52	2.71	1.41	1.29	2.78	2.40	2.37	1.51	1.75
Chile	0.87	1.40	2.20	1.42	0.95	0.92	0.93	1.31	1.35	1.61	1.53	1.88	1.91	1.89	2.79	1.85	1.74	2.43	3.37	2.56	2.48	2.82
Colombia	0.98	1.77	1.95	1.45	0.92	0.89	0.93	1.47	1.31	2.13	1.58	2.78	2.06	2.09	5.26	1.95	2.16	3.10	4.59	3.84	2.78	2.72
Costa Rica	1.50	1.53	1.74	1.19	0.96	0.94	0.83	1.04	1.40	1.08	1.09	1.30	1.14	1.67	2.78	1.10	1.08	2.60	3.99	2.86	0.94	1.76
Czech Republic - Czechia	0.74	1.14	1.63	1.12	0.93	0.69	0.77	1.08	1.18	1.25	1.22	1.27	1.32	1.34	1.38	1.27	1.18	1.57	1.65	1.54	1.43	1.47
Denmark	0.85	1.91	2.16	1.59	1.00	1.29	0.91	1.04	1.38	1.52	1.44	1.53	1.34	2.19	2.97	1.51	1.39	3.80	3.84	3.01	2.11	2.88
Estonia	0.72	0.95	1.31	1.18	0.99	0.84	0.69	1.07	1.10	1.15	1.41	1.18	1.22	1.42	1.29	1.22	1.20	1.62	1.18	1.52	1.09	1.11
Finland	0.87	1.18	1.72	1.28	0.97	0.88	0.91	1.15	1.13	1.39	1.17	1.40	1.08	1.41	1.87	1.24	1.32	1.91	2.43	2.73	1.48	1.51
France	1.38	1.54	2.19	1.24	0.97	0.77	0.85	1.20	1.24	1.39	1.24	1.48	1.50	1.52	3.16	1.44	1.27	2.82	3.01	3.43	1.83	2.07
Germany	0.82	1.31	1.63	1.15	0.94	0.70	0.93	1.06	1.14	1.22	1.21	1.40	1.25	1.46	2.23	1.31	1.37	2.24	3.04	2.40	1.65	2.08
Greece	0.77	0.85	1.87	1.78	1.15	1.14	0.83	1.33	1.41	1.40	1.51	1.90	1.72	1.85	3.67	1.73	1.79	4.02	3.93	2.52	1.55	1.87
Hungary	0.81	1.12	1.26	1.04	0.95	0.77	0.98	1.01	1.07	1.19	1.07	1.26	1.11	1.31	1.46	1.08	1.11	1.78	1.81	1.72	1.27	1.44
Iceland	1.10	1.24	2.24	1.42	0.97	0.99	1.05	1.32	1.70	1.26	1.41	1.44	1.94	1.83	3.96	2.01	1.75	5.14	6.23	6.86	1.21	2.74
Ireland	0.70	1.03	1.14	0.89	0.68	0.55	1.65	0.95	0.91	1.08	0.92	0.91	0.61	0.83	1.39	0.97	0.93	1.41	1.67	1.16	1.08	1.40
Israel	0.60	1.24	2.37	1.33	1.03	0.91	0.91	0.89	1.38	1.15	0.98	1.45	0.83	1.17	3.62	1.31	1.49	1.92	3.32	3.23	2.59	1.84
Italy	0.95	1.30	1.89	1.18	1.01	0.85	0.85	1.18	1.03	1.37	1.21	1.34	1.37	1.37	2.64	1.30	1.24	2.04	2.27	2.26	1.63	1.30
Japan	0.91	1.91	1.98	1.30	1.32	0.83	0.80	1.44	1.31	1.33	1.39	1.94	1.62	1.51	3.01	1.46	1.25	2.11	2.21	2.38	1.33	1.83
Korea	0.69	1.05	1.57	1.13	0.91	0.82	0.92	1.10	1.03	1.25	1.21	1.17	1.34	1.46	1.92	1.01	1.33	2.02	1.37	1.40	1.14	1.35
Latvia	1.00	1.19	1.45	1.13	0.92	0.64	0.86	1.00	1.09	1.21	0.94	1.24	1.05	1.31	1.75	1.18	1.11	2.40	2.25	1.77	1.65	1.74
Lithuania	1.06	1.23	1.46	1.14	0.76	0.60	0.58	0.78	0.97	1.18	1.09	1.15	1.12	1.29	1.45	1.09	1.09	2.22	2.96	2.17	1.62	1.61
Luxembourg	0.46	0.53	0.85	0.56	0.61	0.56	0.76	0.62	0.72	0.50	0.62	0.39	0.51	0.44	0.59	0.59	0.80	1.04	1.62	1.14	0.65	0.59
Mexico	0.74	0.65	1.72	1.15	0.91	0.89	0.99	1.19	0.98	1.35	1.30	1.80	1.59	1.64	3.21	1.25	1.26	1.45	2.32	1.67	1.49	1.53
Netherlands	0.68	1.27	1.70	1.09	0.84	0.85	0.84	0.98	0.99	1.24	1.01	1.06	1.07	1.50	2.01	1.11	1.11	2.40	2.28	2.60	1.18	1.50
New Zealand	1.58	1.73	1.80	1.33	0.98	0.85	0.93	1.24	1.24	1.26	1.35	1.28	1.33	1.80	2.74	1.60	1.38	2.95	2.74	3.16	1.73	1.99
Norway	0.69	1.60	2.17	1.35	0.99	0.88	0.86	1.21	1.23	1.28	1.28	1.51	1.33	1.52	2.62	1.47	1.39	2.54	3.96	3.77	1.75	2.25
Poland	0.65	1.02	1.48	1.13	1.00	0.72	0.79	1.09	1.09	1.15	1.29	1.19	1.23	1.07	0.69	1.22	1.19	1.65	1.24	1.41	0.93	1.34
Portugal	0.90	1.19	1.52	1.18	0.96	0.84	0.90	1.19	1.27	1.11	1.32	1.41	1.34	1.89	3.08	1.41	1.45	2.08	3.26	1.98	1.36	1.97
Slovak Republic	1.10	1.61	2.29	1.07	0.88	0.81	0.81	1.02	1.17	1.14	1.24	1.48	1.18	1.56	2.31	1.11	1.24	2.57	2.34	2.13	1.96	1.79

Slovenia	0.86	1.11	1.43	1.16	0.93	0.83	0.69	1.01	1.11	1.14	1.10	1.17	1.28	1.37	2.90	1.11	1.14	2.44	2.36	1.96	1.78	1.56
Spain	0.95	1.29	1.84	1.23	0.95	0.94	0.92	1.12	1.22	1.40	1.22	1.29	1.13	1.56	2.73	1.33	1.28	2.15	2.64	2.52	1.71	2.12
Sweden	1.08	1.14	1.59	1.11	0.90	0.69	0.83	1.07	1.09	1.20	1.03	1.20	1.15	1.31	2.21	1.22	1.06	2.43	3.43	3.74	1.61	2.01
Switzerland	1.08	1.18	1.61	0.95	0.83	0.86	0.84	0.82	0.81	1.04	0.73	1.17	0.92	1.00	2.33	1.11	1.01	2.13	1.23	2.06	1.24	1.64
Turkey	0.77	1.06	1.56	1.16	1.02	0.92	1.45	1.28	1.27	1.27	1.46	1.51	2.12	1.40	1.14	1.46	1.75	1.77	2.37	1.78	1.41	1.61
United Kingdom	1.25	1.82	2.32	1.25	1.01	0.83	0.91	1.19	1.22	1.49	1.17	1.32	1.28	1.17	2.82	1.17	1.21	2.33	2.30	2.57	1.52	2.47
United States	0.60	1.76	1.74	1.33	1.03	0.95	0.88	1.03	0.95	1.31	1.70	2.11	1.69	1.56	1.37	1.52	1.62	1.87	1.59	3.09	1.71	2.46
Argentina	0.98	1.28	2.10	1.29	0.95	0.94	0.98	1.02	1.32	1.34	1.43	1.65	1.28	1.75	2.63	1.40	1.44	2.53	2.80	2.97	1.69	2.28
Brazil	1.42	1.92	2.00	1.58	0.93	0.89	0.89	1.39	1.75	2.01	1.52	2.94	1.82	2.78	5.80	1.76	1.70	5.08	5.68	4.37	2.06	2.65
Brunei Darussalam	0.22	1.16	1.11	1.04	0.99	0.67	0.76	1.21	1.27	1.18	1.20	1.13	1.43	1.15	1.49	1.03	1.24	1.07	1.33	1.25	1.15	1.36
Bulgaria	0.80	1.11	1.52	1.19	1.04	0.95	0.78	1.17	1.27	1.30	1.63	1.15	1.37	1.34	1.49	1.57	1.46	1.93	4.70	2.34	1.63	1.67
Cambodia	0.74	1.04	1.80	1.03	1.10	0.91	1.44	0.93	0.83	0.96	1.10	1.09	1.14	1.26	0.89	1.08	1.11	0.85	1.45	1.68	0.92	1.26
China (People's Republic of)	0.63	0.89	0.98	1.33	0.97	0.84	0.96	0.93	1.12	1.22	1.19	1.08	1.33	1.89	2.65	1.09	1.13	2.34	1.87	1.93	1.67	1.53
Croatia	1.01	1.28	1.08	1.12	0.93	1.02	0.67	1.07	1.08	0.90	1.14	1.28	1.10	1.21	1.65	1.07	1.10	1.62	1.98	1.79	1.28	1.33
Cyprus	0.58	0.76	1.19	0.87	0.76	0.60	0.84	0.80	0.89	0.95	0.99	0.91	0.73	0.87	1.41	0.88	0.98	1.06	1.72	1.27	1.21	0.93
India	0.44	1.01	1.11	1.04	0.83	0.96	0.91	0.82	0.86	1.22	1.04	0.63	1.15	0.78	1.52	1.94	0.95	2.31	2.05	2.34	1.17	0.78
Indonesia	0.46	1.17	1.27	1.15	0.85	0.88	1.02	1.08	1.01	1.89	0.99	1.22	0.73	1.97	2.02	1.56	1.43	1.53	1.97	1.44	1.25	1.47
Hong Kong, China	0.79	1.15	2.35	1.13	0.80	0.89	0.94	0.89	1.02	0.89	0.88	0.90	1.17	1.03	1.30	1.26	1.12	2.39	2.04	1.68	0.98	1.24
Kazakhstan	0.22	0.85	1.16	1.22	1.01	0.95	0.90	1.32	1.92	1.60	0.90	1.11	0.98	1.32	1.33	1.18	1.16	0.80	0.75	1.11	0.70	0.48
Lao People's Democratic Republic	1.34	2.54	2.17	1.76	2.63	0.88	1.25	1.55	2.27	4.20	2.45	3.16	2.36	2.68	3.34	2.03	1.92	3.04	5.56	3.85	1.45	3.78
Malaysia	0.64	0.94	1.27	1.10	1.01	0.82	0.90	0.99	1.05	1.11	1.35	1.24	1.23	1.39	1.03	1.38	1.29	1.07	1.04	1.17	0.91	1.64
Malta	0.78	0.86	1.01	0.91	0.80	1.07	0.84	0.93	0.73	0.87	0.84	0.88	0.89	0.61	0.83	0.75	0.81	1.31	1.66	1.12	0.36	0.83
Morocco	0.53	1.20	0.90	1.06	0.96	0.99	1.28	1.03	0.96	1.14	1.08	0.89	1.19	1.51	2.47	1.51	1.36	1.17	1.76	1.41	1.12	1.39
Myanmar	0.41	0.96	0.73	1.20	0.91	0.94	0.95	1.05	1.08	1.50	1.10	1.09	1.45	1.13	1.01	1.11	1.16	1.51	1.63	1.68	1.09	1.45
Peru	0.77	1.35	1.78	1.46	1.00	0.91	0.87	1.13	1.12	1.80	1.55	1.88	1.77	1.68	3.00	1.44	1.51	1.72	4.43	3.00	1.83	2.69

Philippines	0.68	0.96	1.32	1.04	0.94	0.71	0.87	1.02	1.09	1.05	1.12	0.95	1.53	1.21	1.47	1.15	1.04	1.80	1.20	0.85	1.07	1.23
Romania	0.87	1.24	1.21	1.11	0.98	0.82	0.89	1.10	1.09	1.37	1.17	1.17	1.07	1.23	2.22	1.07	1.16	2.89	2.45	2.15	1.56	1.47
Russian Federation	0.46	0.86	1.31	1.15	0.81	0.84	0.91	1.11	1.32	1.34	1.84	1.41	1.77	1.97	1.14	1.44	1.60	1.62	1.54	1.55	1.22	1.80
Saudi Arabia	0.17	0.81	0.73	0.80	0.58	0.54	0.84	0.84	0.67	0.94	1.35	0.76	1.17	1.00	1.42	0.60	0.48	1.27	1.33	0.92	1.08	1.17
Singapore	0.60	1.24	2.63	0.94	0.80	1.42	1.04	1.03	1.10	1.14	0.82	1.00	0.76	0.94	1.65	1.01	1.16	2.34	2.41	2.16	1.42	1.61
South Africa	0.58	1.79	1.99	1.45	1.18	1.00	0.98	1.14	1.38	1.71	1.63	1.22	1.09	1.84	1.26	1.24	1.18	2.48	2.41	2.24	1.52	2.23
Chinese Taipei	0.73	1.10	1.32	1.39	0.97	1.00	1.07	1.21	1.27	1.39	1.34	1.39	1.64	1.97	2.74	1.49	1.68	2.67	2.18	1.54	1.42	1.63
Thailand	0.93	1.08	0.95	1.18	1.03	1.11	1.05	1.18	1.20	1.05	1.14	1.07	1.22	1.25	1.46	1.26	1.24	1.63	1.87	1.40	1.30	1.05
Tunisia	0.66	0.69	0.88	1.24	0.99	0.91	1.38	1.23	1.22	1.31	1.33	1.31	1.37	1.48	1.26	1.23	1.32	2.86	2.84	2.37	1.72	1.83
Viet Nam	0.59	0.86	1.02	1.14	0.98	1.00	0.98	1.15	1.12	0.99	1.21	0.97	1.61	1.16	1.05	1.27	1.46	1.16	1.24	1.50	1.14	0.98
Rest of the World	0.43	0.96	1.43	1.18	0.81	0.88	0.84	1.08	1.11	1.08	1.15	1.24	1.24	1.23	1.51	1.27	1.29	1.42	1.33	1.47	1.05	1.28

Chapter 4

How Much does Air Transport Contribute to Global CO_2 Emissions?[1]

4.1. Introduction

The air transport industry is a key component of the global economy owing to its role as a trade facilitator for global value chains and the increasing demand for transport services in the tourism industry. On one hand, this industry facilitates economic growth via the international movements of goods and services and, on the other, it enables tourism companies to sell their services worldwide. The industry includes key actors, such as airline companies (e.g., Delta Air Lines is the leading company thanks to its 95,000 employees and, according to Forbes Global 2000 (2023), $54 billion in sales in 2023, while United Airlines -$48 billion in sales- and American Airlines -$53 billion in sales- also occupy prominent positions) and aircraft manufacturers (e.g., Boeing with $70 billion in sales and Airbus with $61 billion in sales). The industry also plays a leading role in technology generation thanks to huge R&D investments that generate important knowledge spillovers into many other economic activities.

The air transport industry is set to face numerous challenges in the next few years. These challenges include sustainability targets, technological changes, increased demand and a stronger competition scenario. Sustainability targets are currently shaping strategies in the aviation industry, since it is facing increasing pressure to reduce its environmental impact. Specifically, the strategies currently being explored by airlines include more fuel-efficient aircrafts and alternative fuels (e.g., hydrogen and biofuels), though these are at a very initial stage and, with the technology currently available, have higher operational costs than standard (carbon) fuels. Technological changes have been a key dimension of firms' competitiveness in this industry. Such changes involve a continuous investment process to develop new products that are either strictly related to the transport service provided by airlines or to the quality, efficiency and comfort provided to their users. Increases in demand are a standard trend in this industry, with periods of strict lockdown during the COVID-19 pandemic being the sole exception. These increases are explained by GDP growth, population growth, leisure expenditure, and the growing market share of low-cost carriers. Stronger competition is also a distinctive feature of this industry, especially after the entry of low-cost carriers that employ a different business model. The recent emergence of ultra-low-cost carriers, and government regulations in some Western European countries that ban short-distance trips in favour of high-speed trains. Efforts to mitigate air transport emissions also include implementing operational measures such as optimized flight routes and shorter taxiing times to reduce operational costs.

[1] This chapter is co-authored with Maria Llop Llop and Josep-Maria Arauzo-Carod.

The above figures notwithstanding, the climate emergency has put significant pressure on the air transport industry, and environmental issues have become one of the most urgent challenges it will face in the next few decades. . In 2021, the International Air Transport Association (IATA)[2] approved the Fly Net Zero resolution, committing the industry to achieving Net Zero carbon emissions by 2050.[3] This plan is accompanied by a consistent methodology, which includes instruments for monitoring process towards the 2050 Net Zero goal. This Association emphasizes that data availability, collection, and validation are crucial for tracking the process, building trust and consumer confidence in the industry's progress. Consequently, data ownership remains within the industry, and the IATA plays a leading role in monitoring the transition towards the Net Zero target. Since the aviation industry is considered the natural unit to control this process, the impacts beyond direct activity are not taken into account in the IATA's calculations. Among other regulatory issues linked to environment, the EU's Emissions Trading Scheme (ETS) and the CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) also define emission reduction goals within the EU and internationally.

For a full understanding of the total impacts of the aviation industry, that is not limited to direct emissions but includes indirect impacts on their outward suppliers, in this chapter we determine the total CO_2 emissions of air transport worldwide.[4] Although the IATA and the aviation industry focus mainly on direct emissions from air transport operations (which are the most significant source of emissions), there are several reasons that support that looking at indirect impacts is equally important for a full assessment of the sector's total environmental footprint. Firstly, because ignoring indirect emissions could underestimate the industry's total environmental impact. Secondly, because air transport is deeply embedded on a complex supply chain from which it cannot be isolated. Thirdly, because air transport activities also involve other ground activities and infrastructures that contribute to total emissions.

Our method is based on an inter-country input-output (IO) model that fully represents the world production system (including its inter-sectoral and inter-country transactions and corresponding emissions) of which air transport is a component.

In the last few years, the IO model has been used extensively to study the air transport sector and aviation activities. Examples of input-output production-focused analyses include the studies by: Lee and Yoo (2016), who evaluated the economic impact of the transportation sectors (rail, road, water and air transport) on production in Korea; Dimitrios et al. (2017), who quantified the impact of air transport on jobs and income in Greece; Vukic et al. (2021), who quantified the economic impact of the transportation sector on output and value-added in the Croatian economy; and Zhao et al. (2022), who analyzed the industrial interactions of air

[2] This Association, made up by the most important airlines in the world, represents over 80% of total air traffic, comprising of 330 companies (IATA, 2024).
[3] This resolution is available at:
https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/iata-agm-resolution-on-net-zero-carbon-emissions.pdf.
[4] Carbon dioxide (CO_2) is the primary greenhouse gas emitted by aircraft engines; it is produced when aviation fuel (typically kerosene) undergoes combustion.

transport (linkages, production induction, ripple effects and supply shortages) in China. Examples of input-output emission-focused applications include: Lenzen et al. (2003), who used the input-output model to calculate indirect (off-site) impacts of the second Sydney airport on land disturbance, employment water use, greenhouse gas emissions and emissions of NOx and SOx; and Andrés et al. (2021), who developed a subsystem decomposition in the IO model based on the Ghosh (supply-driven) IO model to analyze air emissions from all transport modes in Spain.

Unlike existing IO analyses of aviation, in this chapter we use a global (worldwide) perspective of production that embraces all production sectors in the world. This is especially relevant when analyzing emissions because: i) the impacts of air transport encompass a wide range of activities (from passenger flights to cargo flights) and technologies (from the oldest aircraft to those of the latest generation), which all need to be taken into account; ii) the precise metrics of the emissions need to account not only for direct impacts but also for indirect ones generated and channeled throughout the global value chains; and iii) aviation activity is not limited to any of the national administrative borders of countries.

When Grewe et al. (2021) quantified emissions form the aviation sector by including feasible technical improvement scenarios, they concluded that the air transport sector is highly unlikely to meet the emission targets established by the Paris Agreement.[5] Although the above authors made an exhaustive evaluation of the future trends in aviation, their analysis was limited to direct (i.e., observed on-site) impacts. However, methods based on an (individual) industry-focused accounting perspective may lead to imprecise (incomplete) interpretations of the real impact of air transport activity on world pollution. Sacchi et al. (2023), on the other hand, used life-cycle analysis to quantify the efforts needed to mitigate global warming from European aviation, by including the indirect impacts of air transport (i.e., those not observed off-site) in their analysis. Similarly, our approach in this chapter is not limited to direct emissions from air transportation but embraces total emissions, i.e., it includes environmental loads (especially CO_2 emissions) channelled throughout the intermediate inputs required by the air transport sector.

We contribute to current literature by providing a complementary perspective that goes beyond what sectoral statistics strictly reflect in order to quantify the total CO_2 emissions caused by air transportation. Thus extension provides a broader picture of the environmental effects caused by air transport activities.

The rest of the chapter is organized as follows. Section 4.2 describes our conceptual framework, which includes the global value chain of sectors and industries and their related emissions. Section 4.3 details our database and results. Finally, Section 4.4 presents our conclusions.

[5] See a comprehensive description of this agreement at: https://unfccc.int/process-and-meetings/the-paris-agreement.

4.2. Methodological Framework

To provide a precise view of the environmental impacts of air transportation, we evaluated the amount of CO_2 emissions that must be attributed to this activity at both the country and world levels. To do so, we defined a world input-output model, which we extended to account for CO_2 emissions. We then applied the 'Hypothetical Extraction Method' (HEM)[6] to quantify the importance of air transportation in the global carbon emissions landscape. HEM simulates hypothetical situations in which some elements of the IO model are cancelled out, and in our analysis that element is the air transport sector. By comparing the real (benchmark) values for emissions with those corresponding to a simulated situation in which air transportation is eliminated from the model, this method provides a measurement of the emissions that must be attributed to this activity. The difference between the benchmark values of the emissions and the hypothetical ones if this transport mode were to disappear, is a measurement of how much the removed element contributes to CO_2 emissions.[7]

The environmental impact of air transportation, which is analysed by assuming an extreme situation in which this activity completely disappears from the global economic input-output system, enables us to calculate the (fictitious) total amount of world CO_2 emissions when air transport is set to zero. Comparing this figure with the actual (benchmark) emissions figure, we obtain a proxy measure for CO_2 emissions attributed to the air transport mode. This helps understand the relevance of the air transportation in global CO_2 emissions.

Let us consider M countries, each of which has N different sectors that produce goods for both the domestic and the external markets. Production can be assigned either to final demand or used as intermediate inputs. Each country can trade with every other country. The equation describing the world input-output structure of production is as follows:[8]

$$\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_M \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{1M} \\ A_{21} & A_{22} & \cdots & A_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ A_{M1} & A_{M2} & \cdots & A_{MM} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_M \end{pmatrix} + \begin{pmatrix} Y_{11} & Y_{12} & \cdots & Y_{1M} \\ Y_{21} & Y_{22} & \cdots & Y_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{M1} & Y_{M2} & \cdots & Y_{MM} \end{pmatrix} \begin{pmatrix} I \\ I \\ \vdots \\ I \end{pmatrix}. \quad (1)$$

In this equation, the elements are blocks: X_M contain the $N \times 1$ sectoral production in each country, so the dimension of the resulting vector is $MN \times 1$; A_{MM} is an $N \times N$ block of input-output inter-country coefficients calculated by dividing the corresponding intermediate transactions by the sectoral production with dimension $MN \times MN$; Y_{MM} are the $N \times 1$ elements of the final demand in each country, resulting in an $MN \times M$ matrix of exogenous demand. Finally, the right-hand side in equation (1) contains an $M \times 1$ vector, where I are unitary elements.

[6] This method was originally proposed by Paelink et al. (1965), Strassert (1968) and Schultz (1977).
[7] Dietzenbacher et al. (2019) adapted HEM when using it for a single country as part of a multiregional input-output model. These authors defined an alternative origin for the inputs provided by the extracted sector to other sectors and countries in the system. Unlike the situation proposed by Dietzenbacher et al. (2019), in this chapter we extracted the air transport sector completely from the world input-output structure, to assume that no other sector or country continues to use its inputs.
[8] See Miller and Blair (2022) for a thorough description of the inter-regional input-output model.

From equation (1), sectoral production can also be obtained as:

$$\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_M \end{pmatrix} = \begin{pmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1M} \\ -A_{21} & I - A_{22} & \cdots & -A_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{M1} & -A_{M2} & \cdots & I - A_{MM} \end{pmatrix}^{-1} \begin{pmatrix} Y_{11} & Y_{12} & \cdots & Y_{1M} \\ Y_{21} & Y_{22} & \cdots & Y_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{M1} & Y_{M2} & \cdots & Y_{MM} \end{pmatrix} \begin{pmatrix} I \\ I \\ \vdots \\ I \end{pmatrix}, \quad (2)$$

where the dimension of the inverse matrix is $MN \times MN$.

To transform the production model into an environmental structure, the total emissions in each country (E_M) are derived from the following calculation:

$$\begin{pmatrix} E_1 \\ E_2 \\ \vdots \\ E_M \end{pmatrix} = \begin{pmatrix} \widehat{e_1} & 0 & \cdots & 0 \\ 0 & \widehat{e_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \widehat{e_M} \end{pmatrix} \begin{pmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1M} \\ -A_{21} & I - A_{22} & \cdots & -A_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{M1} & -A_{M2} & \cdots & I - A_{MM} \end{pmatrix}^{-1} \begin{pmatrix} Y_{11} & Y_{12} & \cdots & Y_{1M} \\ Y_{21} & Y_{22} & \cdots & Y_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{M1} & Y_{M2} & \cdots & Y_{MM} \end{pmatrix} \begin{pmatrix} I \\ I \\ \vdots \\ I \end{pmatrix}, \quad (3)$$

where $\widehat{e_M}$ are $N \times N$ diagonal matrices containing the ratios of carbon emissions to gross output in each sector in the main diagonal and zeros elsewhere for the M countries, thus configuring an $MN \times MN$ matrix of direct emission coefficients.

In view of the emission model's structure in equation (3), the hypothetical extraction method can be used to individually cancel out any component of the model. Let an asterisk (*) represent the model's elements with the air transport's rows and columns set to zero. The difference in CO_2 emissions (or $\overline{E_M}$) is equal to:

$$\begin{pmatrix} \overline{E_1} \\ \overline{E_2} \\ \vdots \\ \overline{E_M} \end{pmatrix} = \begin{pmatrix} \widehat{e_1} & 0 & \cdots & 0 \\ 0 & \widehat{e_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \widehat{e_M} \end{pmatrix} \begin{pmatrix} I - A_{11} & -A_{12} & \cdots & -A_{1M} \\ -A_{21} & I - A_{22} & \cdots & -A_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ -A_{M1} & -A_{M2} & \cdots & I - A_{MM} \end{pmatrix}^{-1} \begin{pmatrix} Y_{11} & Y_{12} & \cdots & Y_{1M} \\ Y_{21} & Y_{22} & \cdots & Y_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ Y_{M1} & Y_{M2} & \cdots & Y_{MM} \end{pmatrix} \begin{pmatrix} I \\ I \\ \vdots \\ I \end{pmatrix}$$
$$- \begin{pmatrix} \widehat{e*_1} & 0 & \cdots & 0 \\ 0 & \widehat{e*_2} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \widehat{e*_M} \end{pmatrix} \begin{pmatrix} I - A^*_{11} & -A^*_{12} & \cdots & -A^*_{1M} \\ -A^*_{21} & I - A^*_{22} & \cdots & -A^*_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ -A^*_{M1} & -A^*_{M2} & \cdots & I - A^*_{MM} \end{pmatrix}^{-1} \begin{pmatrix} Y^*_{11} & Y^*_{12} & \cdots & Y^*_{1M} \\ Y^*_{21} & Y^*_{22} & \cdots & Y^*_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ Y^*_{M1} & Y^*_{M2} & \cdots & Y^*_{MM} \end{pmatrix} \begin{pmatrix} I \\ I \\ \vdots \\ I \end{pmatrix} \quad (4)$$

The difference between the emissions in the benchmark and the hypothetical emissions if air transportation is completely removed from the system quantifies the Environmental Impact of Air Transportation in each country ($\overline{E_M} = \sum_1^N \overline{E_{MN}}$) and globally ($\bar{E} = \sum_1^M \overline{E_M}$). Since the aim is to quantify the reduction in carbon emissions if air transportation did not exist, the extraction is based on eliminating every economic transaction (both intermediate and final) by this sector in every country.

Note that the environmental impact of air transportation in expression (4) yields a maximum value comprising a complete elimination of this transport mode from the production system worldwide, thus assuming that it is no longer operational. In the medium-to-long term, technological transformation processes may emerge that allow today's aircraft to be substituted by alternative (carbon-free) aircraft. However, such changes cannot be reflected in the static framework described above.9 The quantification provided here may therefore be considered an upper value for the pollution generated by air transport activity.

4.3. Empirical Application

4.3.1. Database

In this study we use the OECD Inter-Country Input-Output Database for 2018, which encompasses data across 45 sectors and 66 countries, while the remaining nations constitute an aggregated Rest of the World (RoW) account (OECD, 2021a). This database is benchmarked to the National Accounts and Balance of Payments of the respective countries. The RoW component is determined from data from over 130 countries to simulate a closed economy model (OECD Directorate for Science, Technology and Innovation, 2021; Guilhoto, 2021). The data for direct CO_2 emissions, measured in million tons (MTs) of CO_2 and based on production in 2018, are drawn from Trade in embodied CO_2 (TeCO2) database10 (OECD, 2021b)).[11]

The resulting Input-Output table, which was used for our analysis, is a 3015×3015 symmetric matrix that represents the production system for the world economy. The rows provide information about the distribution of the outputs from sector N of country M, while the columns show the inputs used to produce the output by sector N of country M.

Table 4.1 shows the direct CO_2 emissions of countries extracted from the database used. This table distinguishes between total values (left-hand column in Table 4.1 and Map 4.1) and the emissions generated by air transport services (middle column in Table 4.1). The right-hand column in Table 4.1 and Map 4.2 shows the relative importance of air transport emissions in relation to the total emissions in each country.

Table 4.1: Ranking of Direct CO_2 Emissions (in MTs) for 2018

All Sectors of Production		Air Transport Sector		Percentage of Air Transport (%)	
China	9,424.17	United States	239.97	Iceland	59.34
United States	3,912.25	Rest of the World	149.90	Ireland	43.56
Rest of the World	2,688.72	China	122.16	Luxembourg	35.01
India	2,151.12	United Kingdom	45.96	Hong Kong	22.39

[9] Our analysis does not focus on transport adaptation or transformation processes towards a carbon-free scenario, but on the (accounting) emission impacts of the air transport sector based on the final carbon-free (target) situation.
[10] The CO_2 emissions data corresponding to each of the 45 sectors across all countries was sourced from this database.
[11] The CO_2 emissions data corresponding to each of the 45 sectors across all countries was sourced from this database.

Russian Federation	1,372.39	Canada	37.97	Switzerland	18.00
Japan	997.82	Russian	34.39	United Kingdom	17.28
Korea	586.36	Germany	33.53	New Zealand	17.21
Germany	554.92	Korea	30.20	Chile	13.09
Indonesia	482.30	Japan	28.70	Malta	13.05
Canada	477.89	France	23.99	Portugal	12.29
Saudi Arabia	467.51	Turkey	23.20	Singapore	11.83
South Africa	391.99	India	22.81	Hungary	11.67
Australia	351.12	Australia	21.67	Norway	11.42
Turkey	349.55	Ireland	18.09	France	11.16
Mexico	341.46	Singapore	18.02	Netherlands	9.33
Brazil	310.39	Spain	17.93	Spain	9.09
United Kingdom	265.99	Indonesia	16.28	Latvia	8.25
Chinese Taipei	265.92	Thailand	15.87	Finland	8.19
Poland	246.93	Hong Kong	15.52	Sweden	7.95
Viet Nam	237.93	Saudi Arabia	15.48	Canada	7.94
Italy	237.00	Brazil	14.81	Colombia	7.52
Thailand	234.08	Netherlands	13.16	Austria	7.25
France	215.08	Chinese Taipei	13.08	Thailand	6.78
Malaysia	213.45	Malaysia	10.45	Turkey	6.64
Spain	197.31	Chile	10.12	Cambodia	6.50
Kazakhstan	177.98	Italy	8.48	Brunei Darussalam	6.38
Singapore	152.36	Philippines	7.20	Australia	6.17
Netherlands	141.00	Mexico	6.76	United States	6.13
Argentina	125.74	South Africa	6.61	Israel	6.11
Philippines	117.91	Viet Nam	6.24	Philippines	6.11
Czech Republic	85.38	Switzerland	6.12	Germany	6.04
Chile	77.33	Norway	5.76	Morocco	5.60
Belgium	73.27	Portugal	5.09	Rest of the World	5.58
Greece	69.56	New Zealand	4.77	Korea	5.15
Hong Kong	69.31	Colombia	4.75	Denmark	4.92
Colombia	63.23	Hungary	4.04	Chinese Taipei	4.92
Romania	54.40	Argentina	3.58	Malaysia	4.90
Denmark	53.93	Finland	3.56	Brazil	4.77
Israel	52.49	Belgium	3.46	Belgium	4.72
Norway	50.43	Austria	3.29	Tunisia	4.58
Morocco	47.18	Israel	3.21	Costa Rica	4.12
Austria	45.33	Sweden	2.84	Peru	4.01

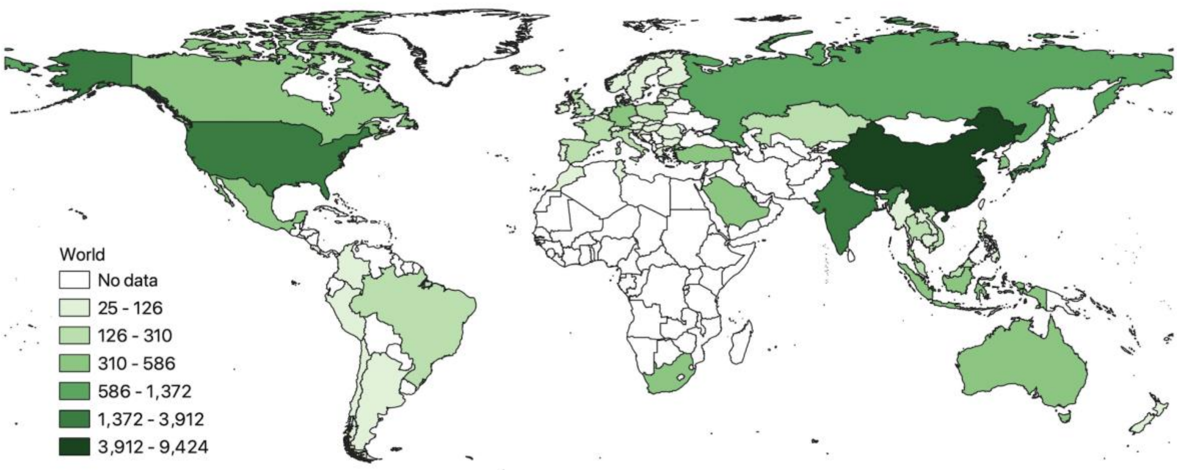
Finland	43.42	Denmark	2.66	Cyprus	3.82
Ireland	41.53	Morocco	2.64	Italy	3.58
Portugal	41.43	Iceland	2.48	Indonesia	3.37
Peru	37.72	Poland	2.23	Saudi Arabia	3.31
Bulgaria	35.78	Luxembourg	2.02	Japan	2.88
Sweden	35.68	Greece	1.93	Argentina	2.85
Hungary	34.66	Peru	1.51	Greece	2.77
Switzerland	33.98	Kazakhstan	1.44	Viet Nam	2.62
Myanmar	31.56	Romania	1.18	Russian Federation	2.51
New Zealand	27.69	Czech Republic	1.16	Romania	2.17
Slovak Republic	24.51	Tunisia	0.94	Slovenia	2.01
Tunisia	20.47	Myanmar	0.61	Croatia	2.00
Laos	17.59	Cambodia	0.58	Mexico	1.98
Estonia	14.38	Brunei	0.50	Myanmar	1.92
Croatia	11.41	Latvia	0.49	South Africa	1.69
Slovenia	9.67	Malta	0.42	Czech Republic	1.36
Cambodia	8.78	Bulgaria	0.34	China	1.30
Brunei Darussalam	7.77	Croatia	0.23	Lithuania	1.16
Lithuania	7.01	Costa Rica	0.20	India	1.06
Latvia	5.97	Cyprus	0.20	Bulgaria	0.96
Luxembourg	5.78	Slovenia	0.19	Poland	0.90
Cyprus	5.10	Laos	0.11	Kazakhstan	0.81
Costa Rica	4.83	Lithuania	0.08	Laos	0.65
Iceland	4.17	Slovak Republic	0.06	Estonia	0.26
Malta	3.18	Estonia	0.04	Slovak Republic	0.24
Total CO_2 Emissions	28,944.53	CO_2 Emissions of Air transport sector	1,103.24	Air Transport/Total	3.81

Unsurprisingly, the countries that generate the highest percentages of world production are among the greatest polluters. Specifically, the top emitter is China (9,424.17 MTs), followed at a great distance by the United States (3,912.25 MTs), the Rest of the World (2,688.72MTs), India (2,151.12 MTs) and Russia (1,372.39 MTs)[12], whilst small countries such as Costa Rica (4.83 MTs), Iceland (4.17MTs) and Malta (3.18 MTs) have the lowest impacts[13]. In total, direct emissions worldwide are quantified at 28,944.53 MTs.

[12] Note, however, that no direct relationship exists between the size of economic activity and emissions since institutional commitment to environmental protection differs across large producers, which explains why China's emissions are much higher than its predominance in economic terms.
[13] In any case, the category Rest of World includes all (smaller) countries not listed here.

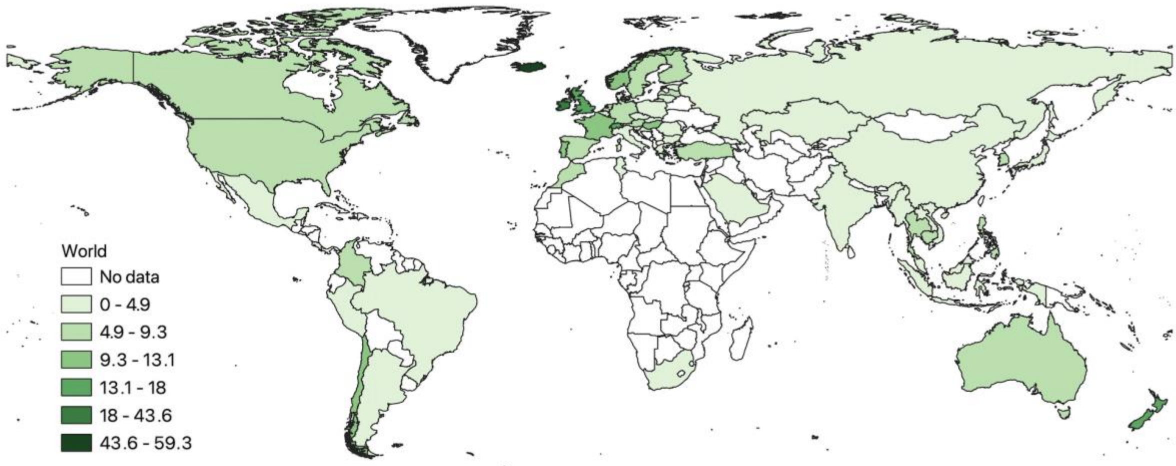
If we focus on direct emissions from the air transport sector, again the United States (239.97 MTs), the Rest of the World (149.90 MTs) and China (122.16 MTs), in that order, exert the greatest pressure on CO_2 emissions. From the last row in Table 4.1, we see that air transportation is responsible for 1,103.2 MTs, which represents 3.81% of total (direct) emissions.

Map 4.1: Total Direct CO_2 Emissions (in MTs) for 2018



The right-hand column in Table 4.1 (see also Map 4.2) shows that the relative importance of aviation at the country level is highly asymmetrical, which can be easily explained according to asymmetries of geography, trade connections and availability of transport infrastructures: in Iceland (59.34%), Ireland (43.56%) and Luxembourg (35.01%) this mode of transport explains more than a third of CO_2 emissions in those countries,[14] while in Bulgaria (0.96%), Poland (0.90%), Kazakhstan (0.81%), Laos (0.65%), Estonia (0.26%) and Slovakia (0.24%) it represents less than 1%.

Map 4.2: Contribution of Air Transport CO_2 Emissions to Total Emissions - Direct Effects (%) for 2018



[14] These results are largely explained by the small size of these countries and/or their geographical isolation (Ireland and Iceland, for example, are islands that depend strongly on air connections).

4.3.2. Quantifying the Environmental Impact of Air Transport

Table 4.2 and Maps 4.3 and 4.4 summarize the results of the model and provide a view of the (quantitative) environmental pressure exerted by air transport in total terms. Specifically, Table 4.2 shows the total CO_2 emissions from each country, which are derived from expression (3) in section 4.2, and it also shows the Environmental Impact of Air Transportation, or the CO_2 emissions attributed to the air transport sector, calculated from expression (4). The right-hand column in Table 4.2 shows the environmental impact of air transportation as percentage of total emissions in each country. In all three columns, countries are listed in order of decreasing importance.

Table 4.2: Ranking of Total CO_2 Emissions (in MTs) for 2018

All Sectors of Production		Air Transport Sector Transport		Percentage of Air Transport	
Country	Total Emissions	Country	E_M	Country	%
China	8,544.01	United States	255.08	Iceland	28.54
United States	4,658.21	China	202.29	Malta	18.71
Rest of the World	2,803.17	Rest of the World	177.9	New Zealand	15.48
India	2,043.61	India	53.4	United Kingdom	13.08
Japan	1,155.71	United Kingdom	50.51	Ireland	12.40
Russian Federation	1,027.16	Germany	45.84	Singapore	12.39
Germany	679.98	Saudi Arabia	43.22	Cyprus	12.20
Korea	529.87	Japan	40.86	Switzerland	11.90
Indonesia	505.29	Russian Federation	38.3	Luxembourg	11.89
Saudi Arabia	493.28	Canada	29.44	Hungary	11.33
Canada	424.35	Indonesia	28.5	Denmark	10.56
United Kingdom	386.24	Australia	28.5	Sweden	9.61
Australia	363.89	France	28.46	Norway	9.34
Mexico	348.96	Brazil	23.4	Latvia	9.18
Turkey	340.72	Korea	22.84	Saudi Arabia	8.76
Brazil	327.17	Italy	22.55	France	8.73
France	326.09	Spain	15.36	Chile	8.49
Italy	317.01	Mexico	13.92	Finland	7.87
South Africa	269.56	Singapore	11	Australia	7.83
Poland	226.34	Chinese Taipei	10.56	Belgium	7.80
Spain	219.94	Malaysia	9.45	Costa Rica	7.57
Thailand	198.29	Switzerland	9.26	Colombia	7.17
Viet Nam	185.12	Netherlands	8.9	Brazil	7.15
Chinese Taipei	188.43	Thailand	8.68	Italy	7.11
Malaysia	167.72	Philippines	8.37	Austria	7.11
Philippines	157.53	Belgium	7.68	Spain	6.98
Kazakhstan	149.11	Hong Kong	7.47	Canada	6.94

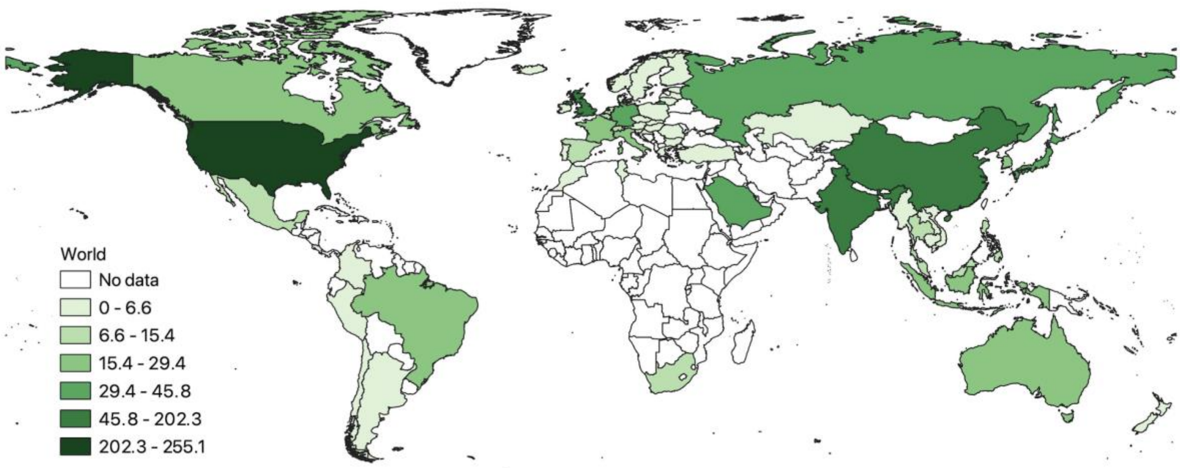
Argentina	138.74	South Africa	7.22	Portugal	6.75
Hong Kong	138.23	Chile	6.62	Germany	6.74
Netherlands	136.1	Turkey	6.57	Netherlands	6.54
Belgium	98.49	Norway	6.41	Brunei Darussalam	6.40
Singapore	88.74	Sweden	6.24	Rest of the World	6.35
Czech Republic	77.04	New Zealand	6.06	Israel	6.04
Israel	76.31	Argentina	5.5	Indonesia	5.64
Chile	77.96	Colombia	5.21	Malaysia	5.63
Switzerland	77.81	Denmark	5.13	Chinese Taipei	5.60
Colombia	72.61	Viet Nam	4.86	United States	5.48
Norway	68.64	Ireland	4.8	Hong Kong	5.40
Austria	66.83	Austria	4.75	Philippines	5.31
Romania	63.08	Israel	4.61	Lithuania	4.92
Sweden	64.97	Hungary	4.12	Greece	4.74
Greece	60.82	Finland	4.1	Morocco	4.44
Morocco	55.16	Poland	4.07	Thailand	4.38
Finland	52.09	Portugal	3.01	Slovenia	4.32
Peru	49.16	Greece	2.88	Korea	4.31
Denmark	48.59	Kazakhstan	2.74	Slovak Republic	4.01
Portugal	44.56	Romania	2.51	Peru	4.00
Myanmar	35.88	Morocco	2.45	Mexico	3.99
Ireland	38.73	Peru	1.97	Romania	3.98
New Zealand	39.13	Czech Republic	1.93	Argentina	3.97
Hungary	36.4	Slovak Republic	1.1	Russian Federation	3.73
Bulgaria	27.96	Iceland	1.1	Japan	3.54
Slovak Republic	27.5	Luxembourg	0.98	Bulgaria	3.45
Tunisia	19.6	Myanmar	0.98	Croatia	3.32
Croatia	14.82	Bulgaria	0.97	Laos	3.21
Cambodia	13.2	Cyprus	0.9	Estonia	2.99
Estonia	12.94	Latvia	0.8	Cambodia	2.90
Lithuania	12.93	Costa Rica	0.8	Myanmar	2.73
Laos	10.91	Malta	0.73	South Africa	2.68
Slovenia	10.89	Lithuania	0.64	Viet Nam	2.63
Costa Rica	10.61	Brunei Darussalam	0.52	India	2.61
Latvia	8.77	Croatia	0.49	Czech Republic	2.51
Brunei Darussalam	8.14	Tunisia	0.48	Tunisia	2.44
Luxembourg	8.28	Slovenia	0.47	China	2.37
Cyprus	7.36	Estonia	0.39	Turkey	1.93
Malta	3.9	Cambodia	0.38	Kazakhstan	1.84
Iceland	3.86	Laos	0.35	Poland	1.80

Total CO_2 Emissions	28,945	Air Transport CO_2 Emissions	1,318	Air Transport / Total	4.55

The total CO_2 emissions for the world, obtained from the input-output model, mirror the values of direct emissions for the world as shown in Table 4.1. These values are in line with those already contained in world statistics. The model estimates total emissions based on direct emissions, thus ensuring that the calculated values for world emissions remain consistent. This uniformity is rooted in the inherent equivalence of total emissions at the global level. At the national level, however, variations emerge in emissions estimates due to the intricate dynamics of international trade. Countries display diverse emissions profiles shaped by their trade activities, thus introducing nuances that underscore the importance of accounting for trade-induced variations in emission patterns when assessing and comparing national environmental impacts.

As expected, the highly populated countries that generate the lion's share of the world's economic activity exert the greatest pressure on the environment, whilst the countries with the lowest CO_2 emissions are relatively small and sparsely populated and make low contributions to global production. The emissions of countries in the intermediate range vary widely. The main conclusion to be drawn from any international comparison of pollution, therefore, is that the high heterogeneity between countries introduces complexity in the definition and implementation of global environmental policies. In summary, these diverging figures illustrate huge disparities in the individual pollution impacts of countries and provide a complementary view to available statistics.

Map 4.3: Total CO_2 Emissions of Air Transport by Country (in Mts) for 2018



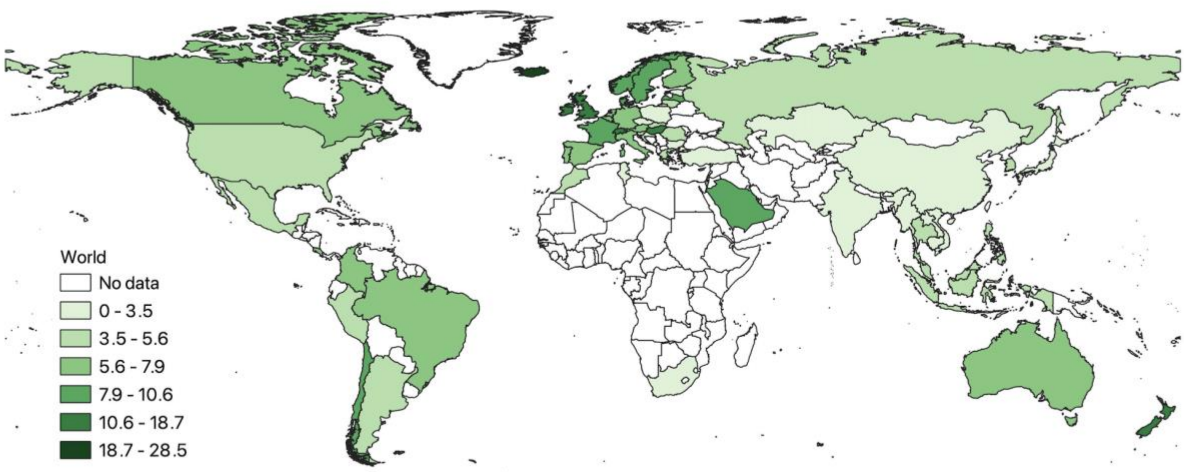
The Environmental Impact of Air Transportation ($\overline{\boldsymbol{E_M}}$), or the emissions attributed to this transport sector (middle column in Table 4.2 and Map 4.3), largely reproduces the ranking of countries that was obtained for total emissions (left-hand column in Table 4.2). Among the top air transport emitters are the United States (255.08 MTs), China (202.29 MTs) and the (aggregated) Rest of the World (177.90 MTs). The impacts from these two countries and the

RoW represent 48% of the impacts worldwide caused by this transport activity. The United States and China are countries with outstanding aviation activity, with airports that operate as important hubs for international flights and international connections. Among the lowest CO_2 emitters are Estonia (0.39 MTs), Cambodia (0.38 MTs), and Laos (0.35 MTs). The last row in Table 4.2 shows that the total Environmental Impact of Air Transportation amounts to 1,318 MTs, which corresponds to CO_2 emissions due to air transport globally.

To clarify the importance of the above results, the right-hand column in Table 4.2 shows the percentage of air transport emissions (middle column) in relation to total emissions (left-hand column) in each country. Not surprisingly, Iceland and Malta, which show low emissions from aviation, are among the highest in relative values (28.54% and 18.71%, respectively), surely because their geographical disconnection with main markets, which makes air transport a strategic option to bridge this disconnection. For these two countries, air transportation is a main source of carbon emissions, whereas other sectors contribute very little to their national CO_2 pollution mainly thanks to a lack of heavy industry (Iceland) and public commitment to renewables (Iceland and Malta). The lowest percentage values are held by Kazakhstan (1.84%) and Poland (1.80%), whose CO_2 emissions from air transportation are marginal. At the world (total) level, the last row in Table 4.2 shows that aviation is responsible for 4.55% of the world's CO_2 emissions.

An important finding from these results is the total change in a county's ranking when total or relative CO_2 emissions are analysed. This shows that a large (insignificant) amount of a country's CO_2 emissions corresponds to an insignificant (large) relative importance of its air pollution. This is observed from the results for Iceland and Malta on the one hand, and from those for China and India on the other (see Maps 4.3 and 4.4). Moreover, the asymmetrical effects observed for countries clearly reflect the complexity of environmental loads around the world, which mirror industry specialization at country level, trade relationships with the rest of the world, and the transport infrastructures available.

Map 4.4: Contribution of Air Transport CO_2 Emissions – Total Effects (%) for 2018



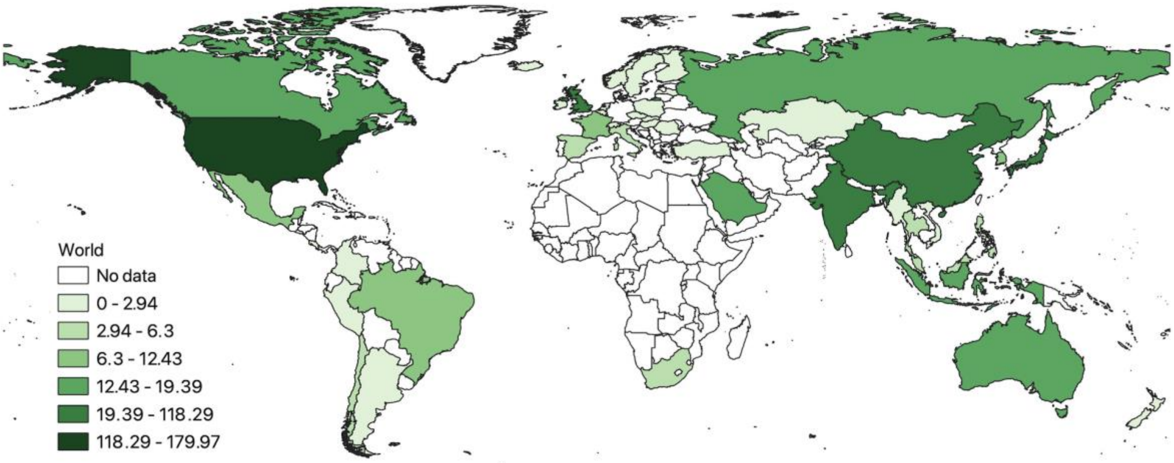
The overall impact of emissions from air transportation cannot ignore the indirect effects exerted on input suppliers throughout the global value chain of aviation. The broader analysis used here, which captures propagation mechanisms other than within-sector impacts, clarifies the role currently played by air transportation in the global CO_2 emissions landscape.

4.3.3. Domestic and Bilateral Environmental Impacts of Air Transportation

Complementary information is provided by CO_2 emissions from air transportation generated by countries' domestic interactions (i.e., excluding carbon emissions due to inter-country transactions). Map 4.5 displays this information, in decreasing order of importance by country. Although the figures in Table 4.3 are different (i.e., smaller) than those for the Environmental Impact of Air Transportation ($\overline{E_M}$) shown in Table 4.2, the ranking of countries is roughly reproduced for domestic impacts. Again, the asymmetry of the effects is huge given the clear disparity in the values shown in Table 4.3. In total terms, the CO_2 emissions produced by domestic air transport activities amounts to 671.27 MTs, which represents approximately 51% of the total CO_2 impact of air transportation (1,318 MTs). In other words, only half of the total CO_2 emissions due to air transportation is allocated to the country in which it originates, while the remaining 49% crosses the administrative borders of countries. This result supports the idea that air transport pollution is a global problem that must be globally treated and globally addressed.

From a geographic point of view, it is clear that although most of domestic CO_2 emissions of air transport are originated in North America and Asia, their effects are global and affect even African countries that only contribute marginally. This underscores the need for global solutions and the acceptance of multilateral governance frameworks to address the transboundary nature of these emissions.

Map 4.5: Domestic CO_2 Emissions of Air Transportation by Country (in MTs) for 2018



Another interesting and complementary aspect of environmental loads due to air transportation are the bilateral linkages between countries explained by country-to-country (city-to-city or airport-to-airport) commercial routes. Although these bilateral impacts are small components of total CO_2 pollution from air transport, information about these partial impacts will help to disentangle the carbon-emission channels. Logically, this detailed evidence is of the utmost interest for identifying impacts from air aviation and defining measures aimed at reducing air transport emissions, such as optimized flight routes and/or reduced flight taxiing times.

Table 4.3 and Map 4.6 show the highest carbon emissions generated by air transport bilaterally. The values in Table 4.4 should be read as follows. The highest world CO_2 emissions from country-to-country air transportation (14.41 MTs of CO_2) are caused by flights from the RoW to China. Among the most impacting countries (i.e., CO_2 emitters) are, apart from the RoW, the world's largest economies: Canada, United States, China, Hong Kong, Germany, India and United Kingdom. Among the most impacted countries (i.e., CO_2 receivers) are just five top economies: China, United States, Germany, Canada, and United Kingdom. It is important to note that these countries are highly engaged on both sides, as they are significant contributors to emissions as well as primary recipients of the associated environmental impacts. This highlights the interconnectedness of global air transportation and suggests that the largest economies are both drivers and victims of air transport-related emissions. This means that commercial air transportation routes generate the harmful impacts received by the largest economies in the world and that these impacts are caused by a high number of large-to-medium economies.

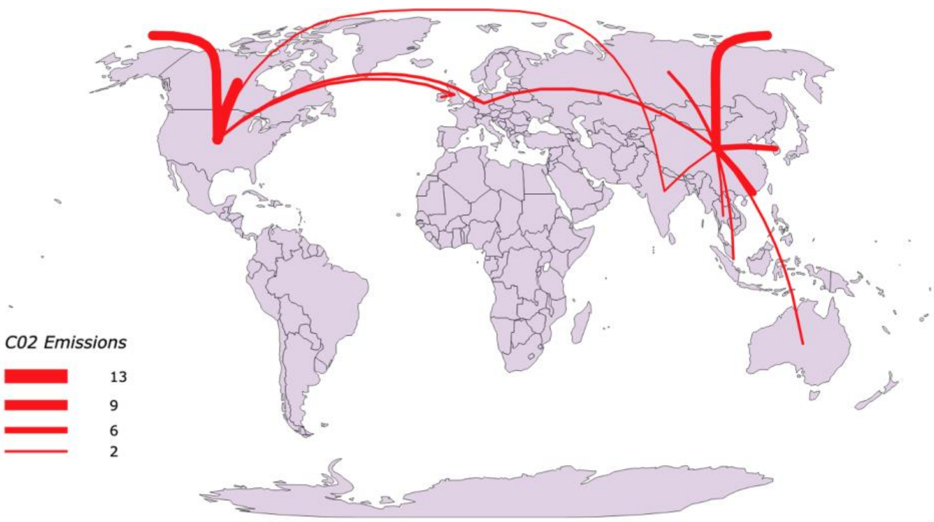
Table 4.3: Ranking of Country-to-Country Environmental Impact of Air Transportation of CO_2 (in MTs) for 2018

S.No.	From	To	CO_2 Emissions
1	Rest of the World	China	14.41
2	Canada	United States	13.04
3	United States	China	11.25
4	China	United States	7.94
5	Korea	China	6.94
6	United States	Germany	6.05
7	Hong Kong	China	5.84
8	United States	Canada	5.73
9	Russian Federation	China	3.98
10	Germany	United States	3.66
11	United Kingdom	United States	3.52
12	Germany	China	3.50
13	Ireland	United Kingdom	3.26
14	Australia	China	3.05
15	Singapore	China	2.99
16	Chinese Taipei	United States	2.79
17	Thailand	China	2.71
18	India	China	2.43
19	India	United States	2.42

20	Netherlands	Germany	2.38

Map 4.6 illustrates the main bilateral air transport emissions, which are highly concentrated in just a few countries: China, United States, Canada and the RoW. These spatially concentrated air transport emissions define a roadmap for achieving sustainability that is strongly dependent on just a few commercial routes, some of them of shorter distance for which, potentially, alternative (ground and/or maritime) transport connections could be explored (e.g., Canada – United States, Korea – China, Hong Kong – China), and some others of longer distance (e.g., United States – China, United States – Germany) for which alternatives would consist only of maritime transport.

Map 4.6: Bilateral (country-to-country) CO_2 Emissions of Air Transportation in of CO_2 (in MTs) for 2018



4.4. Conclusions

This chapter provides a novel framework for calculating total CO_2 emissions attributed to air transport worldwide. Our method considers all economic interdependencies throughout the global value chain and includes both the direct (observed) impacts as well as indirect impacts, generated and transmitted throughout the global value chain of air transport activity.

Several interesting aspects deserve special attention. First, this method shows that the contribution of air transportation to global CO_2 emissions is 19% higher than is commonly reported figures for direct emissions, as this study incorporated both direct and indirect emissions—emphasizing that these additional emissions therefore merit attention. Second, the outcomes we present provide new insights into national impacts, which display a huge disparity around the world. Third, this method offers opposite results when it comes to comparing quantitative air transport emissions and the percentage of carbon emissions with respect to total emissions by country. Fourth, it differentiates between the loads of air transport produced and received domestically and those produced outside the country of origin. Fifth, the method can be applied directly at the empirical level by using available global inter-country input-output statistics. Finally, it can improve decision-making in areas such as transport policy, environmental policy, trade policy and industrial policy.

To increase understanding of environmental loads around the world, it is crucial to know the underlying forces through which pollution is caused. With a tractable method, this article clarifies the complexity of the environmental impacts of air transport to provide results beyond what is strictly reflected by reported emissions data.

The advantages of this approach notwithstanding, it should also be acknowledged that there are some limitations, since the rigidity of the production functions in the input-output structure places the model's impacts at the upper limit of possible effects. Equally, the hypothetical method used in this chapter assumes total elimination of air activity around the world. However, this extreme situation, entailing complete disappearance of emissions from this transport mode, does not exactly correspond to the expected scenarios in the medium-term, although the recent COVID-19 pandemic and subsequent lockdowns led to a similar scenario as the one suggested by our estimations.

Appendix A4

Table A4.1: Ranking of Total Domestic CO_2 Emissions of Air Transportation (in MTs) for 2018

Country	Domestic CO_2 emissions	Country	Domestic CO_2 emissions
United States	179.97	Norway	1.30
China	118.29	Finland	1.28
Rest of the World	96.89	Ireland	1.28
Japan	27.27	Argentina	1.24
India	23.91	Kazakhstan	0.87
United Kingdom	22.59	Austria	0.78
Russian Federation	19.39	Poland	0.74
Indonesia	18.93	Romania	0.65
Australia	16.47	Sweden	0.65
Canada	16.29	Peru	0.62
Saudi Arabia	14.79	Belgium	0.52
Korea	12.43	Myanmar	0.47
Brazil	11.32	Czech Republic	0.35
France	9.53	Brunei Darussalam	0.31
Mexico	7.98	Iceland	0.28
Spain	6.30	Morocco	0.27
Malaysia	5.21	Portugal	0.27
Chile	5.14	Denmark	0.27
South Africa	4.87	Greece	0.20
Philippines	4.71	Latvia	0.16
Thailand	3.88	Luxembourg	0.14
Italy	3.75	Costa Rica	0.07
Hong Kong	3.49	Bulgaria	0.06
Germany	3.21	Malta	0.05
New Zealand	2.94	Cambodia	0.05
Colombia	2.63	Tunisia	0.05
Switzerland	2.49	Cyprus	0.03
Viet Nam	2.25	Slovenia	0.03
Turkey	2.21	Lao Republic	0.03
Chinese Taipei	2.15	Slovak Republic	0.03
Netherlands	1.99	Lithuania	0.02
Israel	1.75	Croatia	0.01
Singapore	1.72	Estonia	0.01
Hungary	1.45	Total Domestic CO_2 Emissions	671.27

Chapter 5

The shipping industry under the EU Green Deal: An Input-Output impact analysis[1]

5.1 Introduction

Industrialization has had an enormous impact on how the world sees the economy, economic activities, and welfare in society. It has brought greater productivity to all industries, including the shipping industry with the introduction of steam-powered engines to the merchant ships (Lehmacher, 2017; Durua, 2010). After the onset of industrialization, humankind moved away from living in an Empty World[2] towards living in a Full World, a transformation that has affected the Earth's carrying capacity and set us on the course towards climate change. This effect has been felt for decades now. In 2015 it led to the introduction of the Paris Climate Accord, or Paris Agreement (as it is famously called), which established the framework for limiting global warming to 2°C below pre-industrial levels while seeking to extend this limit to 1.5°C (European Commission, 2019). According to the Intergovernmental Panel on Climate Change (IPCC)'s sixth assessment report, the world is likely to exceed the 1.5°C mark in the next two decades, though it can reach the 1.5°C limit if some transformational measures are adopted (Levin et al., 2021).

With the goal of making Europe a climate-neutral continent by 2050, the European Commission has introduced a transformative measure in the form of the EU Green Deal. This incorporates the 'Fit for 55' package, a group of policies aimed at reducing greenhouse gas (GHG) emissions by at least 55% with respect to the levels of the 1990s by 2030. Carbon pricing, whether executed through a carbon tax or an emission trading system, is touted as a cost-effective measure for reducing emissions (Baranzini et al., 2017; Baumol & Oates, 1971). Following its introduction in 2005, the European Union Emissions Trading System (EU ETS)[3] was able to reduce emissions by 35% by 2019 (Directorate-General for Climate Action, 2020) and is now planning to expand its horizons by also including the shipping industry.

Over 90% of global trade is transported via ships (OECD, 2019). Although shipping is one of the most energy-efficient modes of transportation, it makes up 3.2% of global CO_2 emissions.[4] Thus far, no measures have been introduced to encourage the water transport industry to contribute towards the world's collective climate ambition (Directorate-General for Climate Action, 2021). Now, however, the 'Fit for 55' package is extending the EU ETS to cover CO_2 emissions by the shipping industry.

[1] This chapter is co-authors with Maria Llop Llop. It has already been published in *Transportation Research Part A: Policy and Practice, 182*.
[2] In the Empty World, natural capital is abundant and other capitals, such as human or financial capital, are scarce. In the Full World, on the other hand, natural capital is scarce while other capitals are relatively abundant (Daly & Farley, 2004).
[3] The EU ETS works on the 'cap and trade' system. A cap on the total amount of GHG emissions is set and reduced over time. Entities can buy and trade emission allowances within this cap.
[4] This number is based on the authors' calculations (see section 5.5).

The European Commission proposes that the EU ETS should be introduced in a phased manner whereby the shipping industry would cover 20% of its CO_2 emissions by 2023, 45% by 2024, 70% by 2025 and 100% by 2026 (Howard, 2022). MEP Peter Liese, on the other hand, has called for this phase-in period to be accelerated to 33.3% by 2023, to 66.6% by 2024 and to 100% by 2025 (EEB, 2022), while the European Parliament has adopted legislation to cover 100% of CO_2 emissions by 2024 without any phase-in period (European Parliament, 2022). Moreover, under the European Commission's proposal, 100% of emissions on intra-EU routes and 50% of emissions on extra-EU routes are to be covered by 2026, with this latter figure extended to 100% from 2027 onwards (Norton Rose Fulbright, 2021). The European Parliament further suggests that if the International Maritime Organization (IMO) fails to bring in similar legislation to hold the maritime transportation of non-EU countries to account, then 100% of extra-EU routes should be covered by the EU ETS (European Parliament, 2022). At the time of writing, only vessels with over 5,000 gross tonnage are covered under the EU ETS (Gerretsen, 2022), though coverage is expected to be extended to vessels with a gross tonnage of between 400 and 5000 (Ship Technology, 2022).

Incorporating one of the most emissions-intensive[5] industries into the EU ETS makes it imperative to analyse the consequences of this new policy on agents (consumers and producers) in the economies of the EU and its top 10 (non-EU) trading partners (henceforth, EU's Top 10 Trading Countries). Greater interdependence between countries often leads to the domestic policies of one country affecting the other countries (Owens, 1993). This phenomenon is often studied in a partial equilibrium framework using regression analysis, as was conducted by Gober & Burns (1997) and Crozet et al. (2016).

Unlike the usual approaches for analysing the inter-country influence of domestic measures, this chapter uses a general equilibrium perspective that includes every country in the world. Specifically, the analysis is based on a multi-national input-output model using the Leontief price model. The input-output model illuminates economic interdependencies within a single economy, showcasing how industries are linked through both input and output exchanges. Extending this concept, the multi-national input-output model broadens the perspective to illustrate global economic linkages among countries. The Leontief price model within input-output analysis examines the impact of cost shocks on the production prices, providing a comprehensive understanding of the cost and price interconnectedness between sectors and nations.

The macroeconomic model used for the analysis is based on the interdependence of different sectors across countries and is used to analyse the ripple effects of a shock in the economy. This linear model follows the principles[6] of homogeneity and proportionality, and assumes fixed technology (IMPLAN, 2021). The model does not take into account substitution effects among modes of transportation or products from different countries. It depicts immediate changes (i.e., short term impacts) in the economy (Government of British Columbia, 2019). Only impacts from shock to the economy in the first year are therefore analysed. However, given the model's linear nature, the impacts of 20%, 33.3% and 100% of CO_2 emission coverage will be proportional. Nevertheless, it is still interesting to put things into perspective and this chapter will therefore study the following three cases:

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[5] With respect to CO_2 emission intensity, *water transport* is second only following the *electricity, gas, steam and air conditioning supply*.

[6] According to the principle of homogeneity, each industry uses a unique set of inputs to produce its respective output. And according to the principle of proportionality, the inputs used are directly proportional to the output, and economies of scale are not taken into consideration.

- Case 1: The European Commission's proposal: to cover 20% of the shipping industry's CO_2 emissions under EU ETS in the first year.
- Case 2: MEP Peter Liese's proposal: to cover 33.3% of the shipping industry's CO_2 emissions under EU ETS in the first year.
- Case 3: the European Parliament's proposal: to cover 100% of the shipping industry's CO_2 emissions under EU ETS in the first year[7].

The rest of this chapter is organised as follows. Section 5.2 describes the models (i.e., the Leontief price model and the environmental input-output model) used for the analysis, and explains the methodology for estimating consumer welfare, the cost of living, changes in output and emissions, and revenue generated. Section 5.3 discusses the data and report limitations. Section 5.4 presents the empirical results from the simulation, and section 5.5 discusses those results. Finally, section 5.6 presents our conclusions.

5.2 Methodology

Input-output (IO) modelling, along with computable general equilibrium (CGE) models, provides unique insights into the wider economic impacts resulting from sectoral linkages (Lakshmanan, 2011; Rey, 2000). It recognizes the interdependencies between industries and describes the connections between transportation and other sectors, allowing for a comprehensive understanding of the impacts on the economy. IO models offer several advantages, including the ability to identify how aggregated impacts are distributed among different economic sectors, enabling sector-specific modelling (Allan, 2015). Additionally, IO models are more straightforward to construct compared to CGE models, which can be complex and challenging (Loveridge, 2004; Partridge & Rickman, 2010). The simplicity and widely recognized multiplier effect concept of IO modelling have led to its extensive application in both practical and academic contexts, making it a valuable tool for informed decision-making in policy formulation and economic analysis.

There are two main types of Leontief IO models: quantity models and price models. When studying the role of transportation in the economy, researchers have predominantly used quantity models in various papers. For example, Pompigna & Mauro (2020) developed a macro-level IO model to analyse freight demand in the Italian-Austrian cross-border stretch of the Brenner corridor. Alises & Vassallo (2016) explored the impact of economic restructuring on road freight transport demand in the UK and Spain, emphasizing the influence of non-economic factors on defining transport demand. Cascetta et al. (2013) created a multi-regional input-output (MRIO) model incorporating elastic trade coefficients to estimate freight demand in Europe. Jin et al. (2005) utilized a random-utility-based MRIO (RUMBRIO) model to study spatial trade patterns in Texas via highway and rail, assessing impacts of production technology change, transportation congestion, and demand fluctuations. Ali et al. (2021) quantified the macroeconomic impacts of a transportation strike in Pakistan using an inoperability input-output model. Lee & Yoo (2016) employed IO to examine transportation sectors' role in the Korean national economy. They also applied the price model to investigate a hypothetical scenario of a 10% increase in transport service rates. Additionally, Chang et al. (2014) utilized IO to assess the economic impact of port sectors on the South African economy, revealing high forward linkages indicating its significance as an input for other industries, but relatively weak

[7] To keep the estimation simple, this chapter takes 50% coverage of extra-EU routes into account for all the three cases.

backward linkages suggesting less reliance on other sectors for production. Furthermore, they used the price model to study hypothetical scenarios of port sectoral price increase.

This chapter uses the Leontief price model for its suitability to study the cost and price impacts of implementing the EU ETS in the shipping industry. This model also enables an in-depth evaluation of the economic consequences of the cost effects – namely, the impact on consumption price, welfare, output, emissions, and public revenue. The IO table is in the form of a symmetrical matrix that provides information about how output is distributed across different sectors in different countries. It also shows how much input is used from different sectors across different countries to produce the output.

The IO model is based on the Leontief production function, where a fixed amount of input (intermediate goods and value added) is used to produce a unit of output. Final demand is an exogenous element in the model. The model also ignores economies of scale and operates under constant returns to scale. However, although these assumptions potentially simplify the complexities of real-world economic systems, they align with the aim of studying the immediate impacts of the new policy.

To understand the impact of a shock (i.e., implementing the EU ETS in the shipping industry), the first step is to set the benchmark Leontief price model as follows (Miller & Blair, 2022):

$$p = (I - A')^{-1}v = L'v \tag{1}$$

Here, I is an $n \times n$ dimension identity matrix, where n is 1710, i.e., 45x38 or the total number of sectors across all the countries under consideration. A is an $n \times n$ dimension matrix of technical coefficients, where a_{rs} is the amount of output from sector r used to produce \$1 worth of output from sector s. The Leontief inverse (L') with transposed technical coefficient matrix (A') is post-multiplied with the cost of value added per unit of output (v).[8]

Once the price model gives a column vector p of 1s, the model is ready to introduce the shock. Since the shock is based on CO_2 emissions from 45 sectors and 38 countries, the next step is to use the Environment Input Output (EIO) model to estimate total emissions[9] per unit of output for each of the 45 sectors in the 38 countries:

$$m = e(I - A)^{-1} \tag{2}$$

Here, e is a diagonal matrix of direct carbon intensity, i.e., direct carbon emission produced by \$1 worth of output for a sector. Pre-multiplying e by Leontief inverse (L) gives total carbon intensity (m)[10]. This is multiplied by a scalar (ϕ), which represents carbon price, expressed in \$/ton of CO_2, to arrive at ε (Gemechu et al., 2013):

$$\varepsilon = \phi m \tag{3}$$

Note that ε is a vector that represents all sectors across all countries. However, the shock introduced in this chapter is only for the forward linkages of the shipping industry (i.e.,

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[8] Value added includes compensation for labour (or employees) and capital (i.e., gross operating surplus). It also includes taxes less subsidies on intermediate products (OECD, 2022).
[9] This includes both direct and indirect emissions.
[10] The matrix m is summed over column to arrive at total carbon intensity of each sector of the 38 regions.

wherever shipping industry is used as an input), which is 100% for EU countries and 50% for non-EU countries. This involves the construction of a shock matrix (E), where output from the shipping industry used as an input has the shock value ε_i for EU countries i and $\varepsilon_i/2$ for all non-EU countries i when trading with the EU. Input used from other sectors and trade between non-EU countries has a shock value of 0. The transposed version of the shock matrix (E') is depicted below:

$$E' = \begin{array}{c} \\ EU \\ \\ \\ Non-EU \\ \\ \\ So\ on\ldots \\ \end{array} \overset{\quad\quad EU \quad\quad\quad\quad\quad\quad Non-EU \quad\quad\quad\quad So\ on\ldots}{\begin{bmatrix} 0 & \cdots & \varepsilon_i & 0 & 0 & \cdots & \varepsilon_i/2 & 0 & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & \varepsilon_i & 0 & 0 & \cdots & \varepsilon_i/2 & 0 & \cdots & \cdots \\ 0 & \cdots & \varepsilon_i & 0 & 0 & \cdots & \varepsilon_i/2 & 0 & \cdots & \cdots \\ 0 & \cdots & \varepsilon_i/2 & 0 & 0 & \cdots & 0 & 0 & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & \cdots & \varepsilon_i/2 & 0 & 0 & \cdots & 0 & 0 & \cdots & \cdots \\ 0 & \cdots & \varepsilon_i/2 & 0 & 0 & \cdots & 0 & 0 & \cdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix}}$$

This matrix (E') was used to introduce shock into the Leontief price model as follows:

$$p^E = [(1 + E').(I - A')^{-1}]v \tag{4}$$

Here, p^E gives the production price due to the introduced shock. The matrix $(1 + E')$ is dot-multiplied (i.e., multiplied element-by-element) with the Leontief inverse (L') and then post-multiplied by v.

This change in price also affects the consumer price index (CPI). The CPI (p^c) is defined as follows (Llop & Pié, 2008):

$$p_i^c = \sum_{j=1}^{n} p_{ij}^E \alpha_{ij} \tag{5}$$

Here, p_i^c is the CPI for country i given by the sum of the product of the new price (p_{ij}^E) in country i for sector j[11] and share (α_{ij}) of sector j final good in the final private consumption of country i. It can also be referred to as the consumption price.

To ascertain the impact of the shock on private real income, the change in consumer welfare can be estimated as follows:

[11] Note that sector j is 45x38 sectors, i.e., the sectors of all countries are included.

$$\triangle W_i = W_i - W_i^E = \sum_{j=1}^{n} p_{ij}^{c} C_{ij} - \sum_{j=1}^{n} p_{ij}^{cE} C_{ij} \tag{6}$$

Welfare is estimated as expenditure on consumption by the final consumer.[12] Here, W_i and W_i^E are the welfare of country i before and after the introduction of EU ETS, respectively. C_{ij} is the consumption of final good from sector j in country i.

The change in production price can also be used to estimate new output (x^E) and CO_2 emissions (ϵ^E) (Gemechu et al., 2013):

$$x_{ij}^E = p_{ij} x_{ij} / p_{ij}^E \tag{7}$$

$$\epsilon_{ij}^E = e_{ij} x_{ij}^E \tag{8}$$

New CO_2 emissions (ϵ^E) can be used to estimate the total revenue (R^s) that the European Commission receive by introducing EU ETS for the shipping industry.

$$R^s = \sum_{i=1}^{38} \epsilon_i^S \, \phi \theta_i \rho_i \tag{9}$$

Here, ϵ_i^S is the new CO_2 emissions from the shipping industry, ϕ is the carbon emission price, and θ_i is the share of shipping industry trade of country i with the EU.[13] For EU countries, this share will always be 1 as they themselves will always be a party to the trade activity. Additionally, ρ_i is the share of emissions country i is held accountable for by the European Commission.[14] For EU countries, $\rho_i = 1$ (i.e., 100% of emissions), while for non-EU countries, $\rho_i = 0.5$ (i.e., 50% of emissions).

5.3 Data

This chapter uses the OECD Inter-Country Input-Output (ICIO)[15] Table for 2018 for 45 sectors, with the *water transport* sector taken as a proxy for the shipping industry[16]. OECD ICIO tables[17] comprise 66 countries and Rest of the World (RoW). Since the focus is on the EU and

[12] For the analysis, 'Household Final Consumption Expenditure' is taken as consumption by the final consumer.
[13] Since ϵ_i^S provides the total emissions of the shipping industry for country i but the revenue is generated only for emissions when trade is conducted with an EU country, it is essential to consider only the share of shipping industry trade that takes place with the EU, which is represented by θ_i.
[14] Based on the differential treatment of intra-EU routes and the extra-EU route.
[15] The OECD ICIO Database was selected for this study because, with a release date of November 2021, it provided the most recent data available at the time of analysis. Moreover, its credibility is underscored by the OECD's benchmarking to the National Accounts and Balance of Payments of the individual countries. In addition, it incorporates underlying data from over 130 countries to estimate the Rest of the World (RoW), thus ensuring a closed economy model (OECD Directorate for Science, Technology and Innovation, 2021; Guilhoto, 2021).
[16] The gross tonnage of the vessels has not been taken into consideration. The water transport sector of the OECD ICIO Tables includes both inland water transport and sea transport.
[17] These tables provide information about the flow of final and intermediate goods and services for all countries and all industries. It is assumed that each industry produces one good. The blocks of diagonal matrices provide information about the domestic flow of intermediate goods and services, while the blocks of off-diagonal matrices provide information about trade in intermediate goods and services between two countries.

its Top 10 Trading Countries, the chapter has used data for 37 countries (27 EU countries and the EU's Top 10 Trading Countries), while the remaining countries are collapsed with the RoW. The ICIO table for 2018 is also used to determine the EU's Top 10 Trading Countries (in goods and services), which are USA, UK, China, Switzerland, Russia, Japan, India, Turkey, Norway, and South Korea, in that order.[18]

The IO table used for the analysis is a 1710×1710 symmetric matrix representing the production side of the economy. The rows provide information about the distribution of the output from sector j of country i, while the columns provide information about the input used to produce the output by sector j of country i. Direct CO_2 emissions based on production for sector j of country i (OECD, 2021) are used to estimate the impact of the introduced shock. The carbon price is taken as $45 per ton.[19]

The ICIO Tables describe the economic structure by reflecting the inter-industry and inter-country transactions. The starting point for constructing any multi-regional input-output (MRIO) table are the individual country's input-output tables together with international trade data. This leads to uncertainties in relation to the data source, such as adjustment to common base currency, mismatch in import and export data between any two countries, dealings with the 'Rest of the World', and the assumption of proportionality. Also, since the tables are given *industry-by-industry*, this leads to uncertainties associated with the aggregated sector classification (Owen, 2013). For instance, the *Agriculture, hunting, forestry* sector in the OECD ICIO Tables includes both animal and plant farming but the difference between the CO_2 emissions for these two types of farming is not captured in the table.

5.4 Results

In this section, we present the results obtained by applying the methodology outlined in section 5.2 to the data from section 5.3. The analysis provides valuable insights into the changes in production prices, consumption prices, consumer welfare, output, CO2 emissions, and total revenue generated for each of the three cases studied.

Figure 5.1 illustrates the size of the contributions of the EU and the EU's Top 10 Trading Countries to emissions from their respective shipping industries in the year 2018. In terms of total CO_2 emissions from the shipping industry, China leads the way[20]. Amongst the EU countries, Denmark, Italy, and Greece are the main contributors to global CO_2 emissions from that industry.

Like any tax increase on goods and services, introducing EU ETS into the shipping industry leads to a corresponding increase in production prices in the shipping industry. This increase will have a snowball effect that will be felt by producers (of other industries) and consumers across the economy.

[18] Except for the order in which the countries appear, the list of the Top 10 Trading Countries of EU27 is the same as that recorded by the European Commission for 2020 (Directorate General for Trade, 2022).
[19] The European Commission's Impact Assessment Report uses €45 as the average carbon price for assessment between 2021 and 2025 (European Commission, 2021). Since the data in the OECD table are presented in $ and €45 is currently roughly equivalent to $46.02, to keep the calculations simple the carbon price is assumed to be $45.
[20] China is followed by USA, India, Russia, and Japan. No EU country features among the top five CO_2 emitters when all 45 sectors are taken into account.

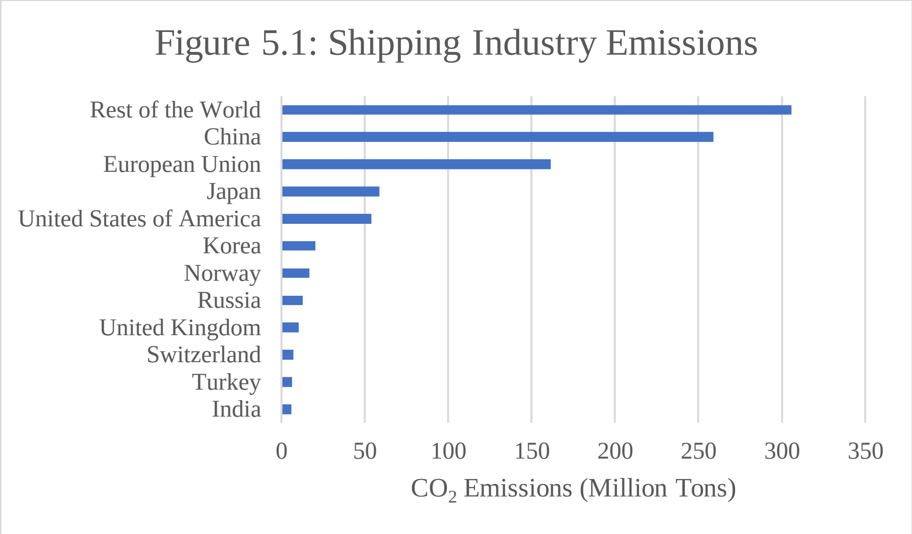
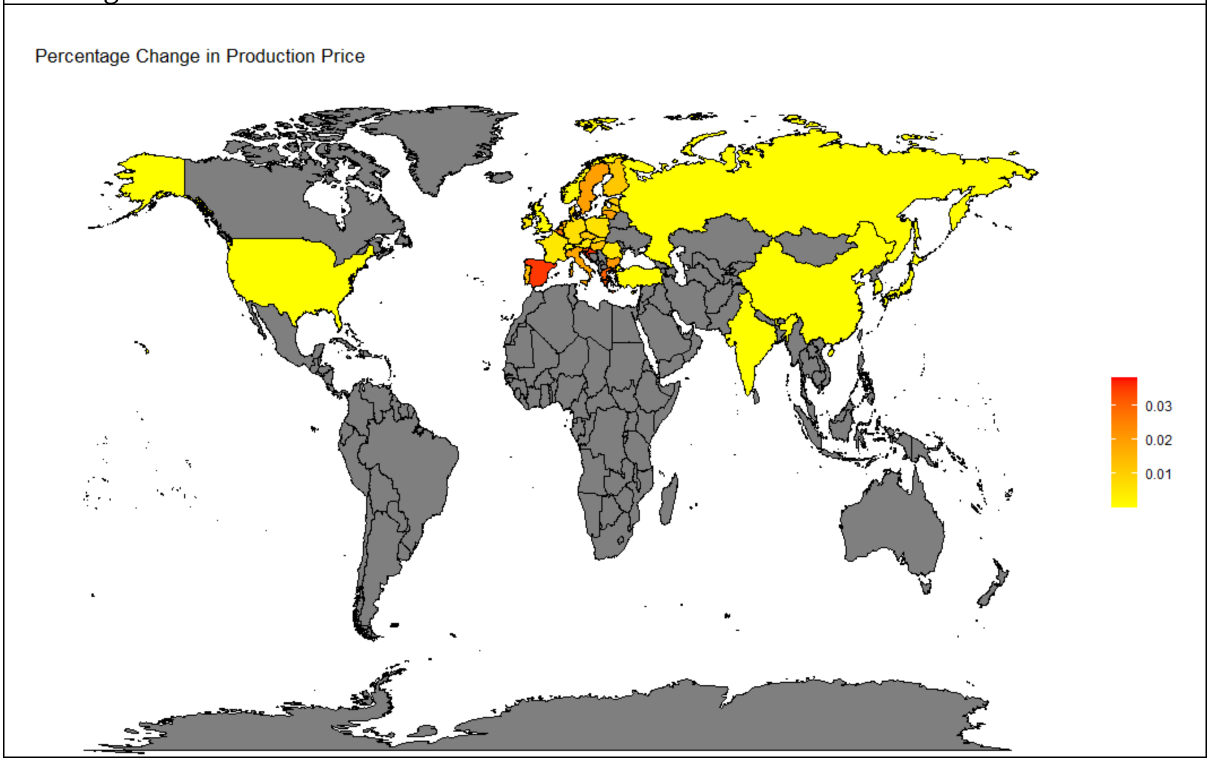


Table 5.1: Average Percentage Change in Production Prices (%)			
Region	**Case 1**	**Case 2**	**Case 3**
EU	0.0157	0.0262	0.0786
EU's Top 10 Trading Countries	0.0003	0.0006	0.0017
World	0.0113	0.0187	0.0563

Map 5.1: Percentage increase in production prices for EU countries and the EU's Top 10 Trading Countries.



Based on the average change in production price, the impact felt by the EU countries is roughly 0.02%, while in the EU's Top 10 Trading Countries it is 0.0003% when the shipping industry is held accountable for only 20% of its CO_2 emissions in the first year (Case 1). Due to the linear nature of IO, this average percentage change in production price will increase when the accountability for CO_2 emissions increases. For instance, in Case 3, when the European

Parliament's proposal is implemented, when the shipping industry is accountable for 100% of its CO_2 emissions in the first year (but only 50% accountability is held from the extra-EU routes), the average percentage increase in production prices in the EU is roughly 0.08%, while in the EU's Top 10 Trading Countries it is roughly 0.002%. On average, the world will experience a 0.06% increase in production prices in the first year if 100% of CO_2 emissions from the shipping industry are accounted for and a 0.01% increase if only 20% of CO_2 emissions are (Table 5.1). Map 5.1 (below) shows the comparative increase in production price across the EU countries and the EU's Top 10 Trading Countries. The highest increases are seen in Malta, Croatia, Spain, Slovenia, and Greece.

Except for the *water transport* sector, where the change in production price is highest (0.40%),[21] the top ten sectors are shown in Table 5.2 for the EU, the EU's Top 10 Trading Countries, and the World.

Table 5.2: Ranking of Sectors by Change in Production Price (Descending Order)

EU	**EU's Top 10 Trading Countries**	**World**
Fishing and aquaculture	Warehousing and support activities for transportation	Fishing and aquaculture
Land transport and transport via pipelines	Land transport and transport via pipelines	Warehousing and support activities for transportation
Warehousing and support activities for transportation	Fishing and aquaculture	Land transport and transport via pipelines
Air transport	Other non-metallic mineral products	Air transport
Basic metals	Coke and refined petroleum products	Basic metals
Mining and quarrying, energy producing products	Mining and quarrying, non-energy producing products	Mining and quarrying, energy producing products
Electrical equipment	Paper products and printing	Electrical equipment
Other non-metallic mineral products	Wood and products of wood and cork	Other non-metallic mineral products
Coke and refined petroleum products	Basic metals	Coke and refined petroleum products
Food products, beverages and tobacco	Rubber and plastics products	Food products, beverages and tobacco

Since the EU is affected the most by the implementation of the EU ETS in the shipping industry,[22] the top ten sectors for the World are the same as those for the EU except for the ranking of the first three sectors (due to the influence of the EU's Top 10 Trading Countries). Intuitively, the sectors related to the water transportation and supply chain are expected to be the most affected, as is illustrated by the *Fishing and aquaculture* and the warehousing and transportation sectors. This change in the average production price also affects the metallic and non-metallic mineral sectors. Notably, *Food products, beverages and tobacco* is also among the top sectors in the EU countries to be affected by this increase in average production price.

[21] This is the percentage change in production price across the world for the *water transport* sector. It is 0.57% for the EU and 0.003% for the EU's Top 10 Trading Countries.
[22] The weight of EU countries is also greater in the analysis than the EU's Top 10 Trading Countries and the RoW, i.e., 27 versus 11.

Table 5.3: Impact on Consumers			
Region	**Case 1**	**Case 2**	**Case 3**
Percentage Change in Consumer Price Index (%)			
EU	0.0039	0.0065	0.0194
EU's Top 10 Trading Countries	0.0008	0.0013	0.0040
World	0.0030	0.0050	0.0149
Percentage Change in Consumer Welfare (%)			
EU	-0.0017	-0.0028	-0.0083
EU's Top 10 Trading Countries	-0.0001	-0.0001	-0.0003
World	-0.0002	-0.0004	-0.0011
Absolute Change in Consumer Welfare (in million USD)			
EU	-0.10	-0.16	-0.49
EU's Top 10 Trading Countries	-1.09	-1.82	-5.46
World	-7.13	-11.88	-35.67

Table 5.3 shows the changes in the consumer price index (CPI) and consumer welfare (in both percentage and absolute terms). The CPI provides information about cost of living in an economy. An increase in the cost of living reduces consumers' purchasing power, thus leading to a reduction in their economic welfare.[23]

Both these parameters, which help to determine the impact on consumers, show that, in percentage terms, consumers in EU countries are impacted more than those in the EU's Top 10 Trading Countries. However, in terms of absolute change, the EU's Top 10 Trading Countries face greater reductions in consumer welfare than EU countries.

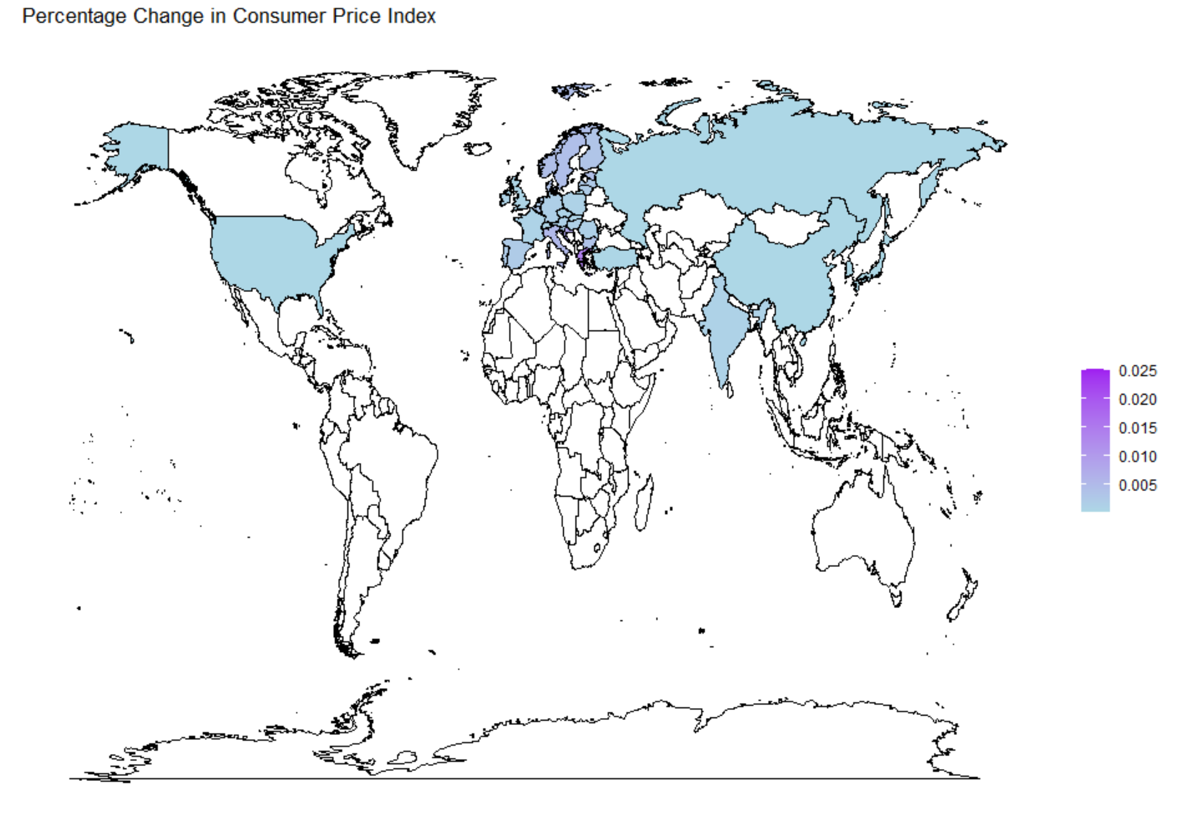
In EU countries, the highest percentage increases in the cost of living are observed in Malta, Greece, Croatia, Italy, and Sweden. However, the highest absolute decreases in consumer welfare are observed in Italy, Germany, Greece, Spain, and France. Italy and Greece have not only the highest cost of living but also the largest decrease in private real income. These decreases in the welfare of Italy and Greece are due to the large amount of initial final consumption.

Among the EU's Top 10 Trading Countries, the largest increase in the cost of living is observed in Norway, India, Switzerland, the UK and Turkey. However, the greatest decrease in consumer welfare (in absolute terms) is observed in China, USA, Russia, Norway, and the UK. The UK and Norway saw an increase in the cost of living as well as the greatest decrease in consumer welfare. This implies that final consumption in those countries is highly dependent on foreign goods and services.

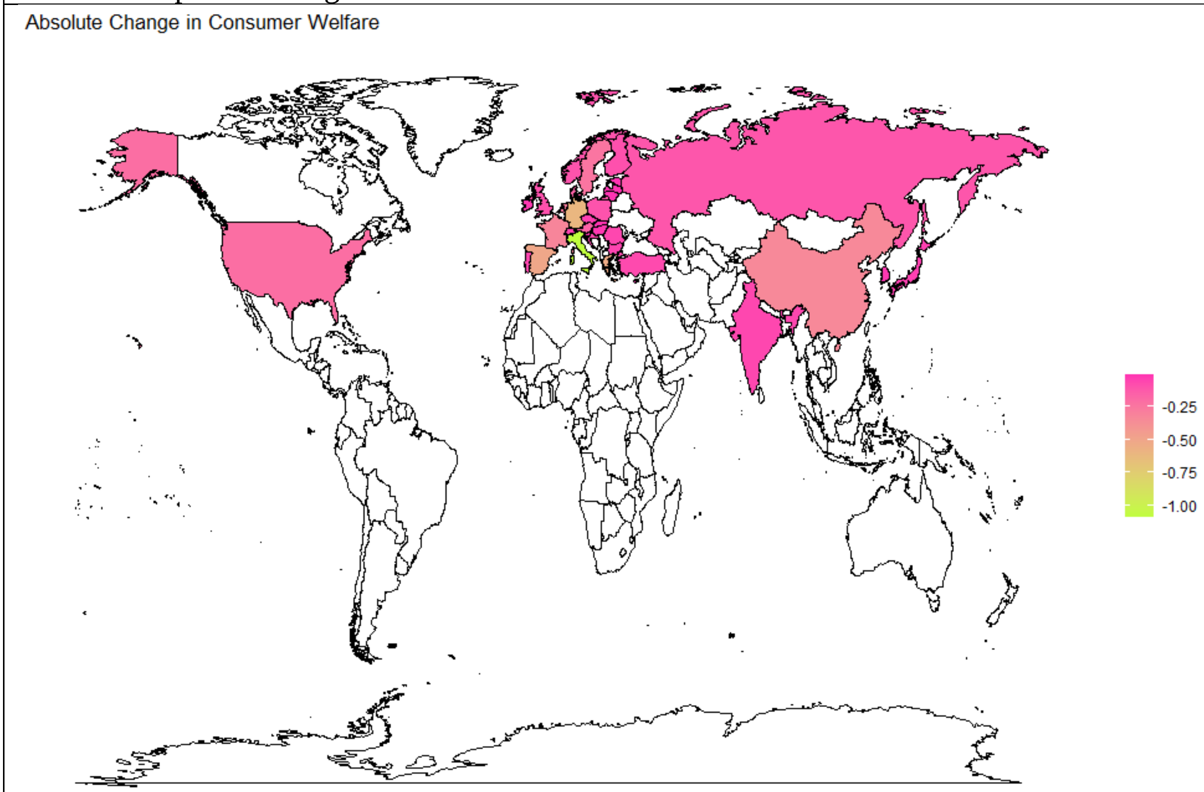
Maps 5.2 & 5.3 show comparative changes in the CPI and consumer welfare across EU countries and the EU's Top 10 Trading Countries, respectively. As Table 5.3 shows, the cost of living in EU countries increased the most. In fact, the only non-EU country in the top 10 is Norway, which, being in continental Europe, is close to the countries of the EU. Moreover, an absolute decrease in consumer welfare is observed in larger economies such as Italy, Germany, Greece, and Spain. Notably, two of the EU's Top 10 Trading Countries (China and USA) are among the countries most affected, in terms of loss of consumer welfare, by the implementation of EU ETS in the shipping industry.

[23] As now, consumers must pay more to consume the same goods and services.

Map 5.2: Percentage increase in the consumer price index for EU countries and the EU's Top 10 Trading Countries.



Map 5.3: Absolute decrease in consumer welfare (in million USD) for EU countries and the EU's Top 10 Trading Countries.



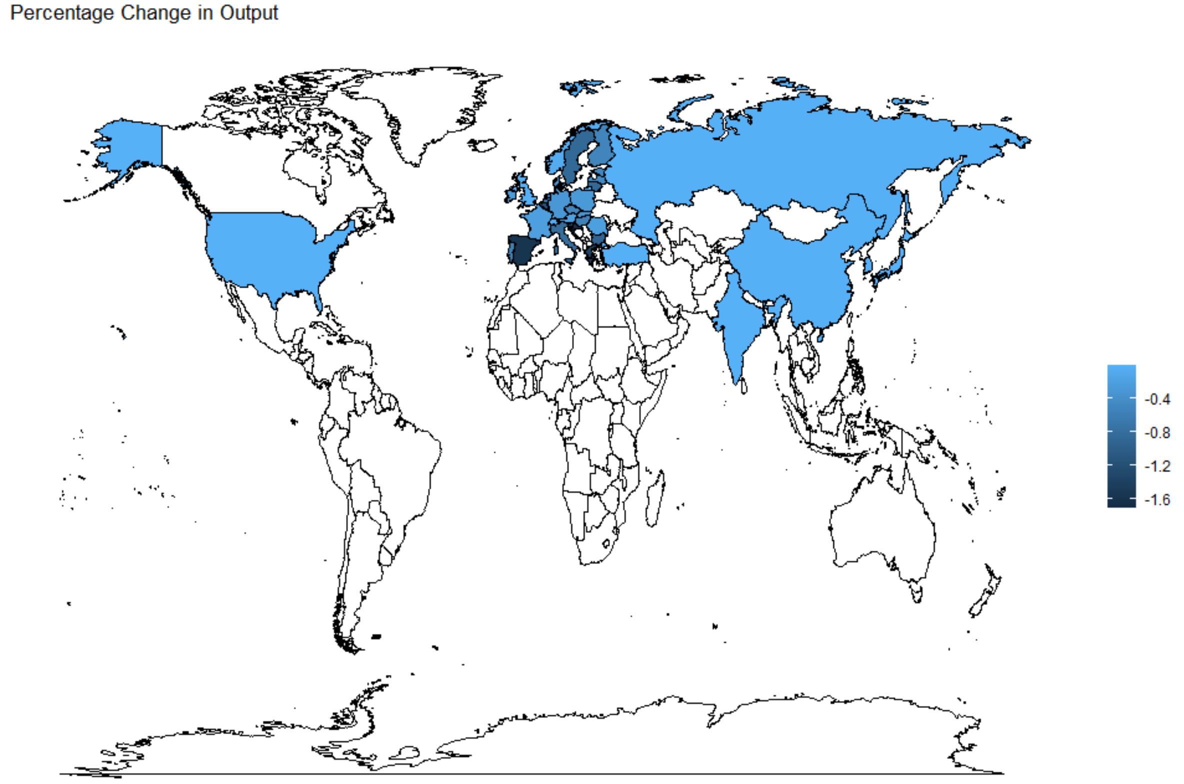
According to the IO model, any increase in production price will lead to a decrease in CO_2 emissions on account of decreased output. This is shown in Table 5.4. Both these changes are most noted for EU countries, while an extremely small percentage decrease is recorded for the EU's Top 10 Trading Countries (in both percentage and absolute terms). Intuitively, EU countries are expected to have to cut more CO_2 emissions, since that is the whole purpose of introducing EU ETS, whereas the EU's Top 10 Trading Countries have to reduce their emissions only by 50% when trading with an EU country.

Table 5.4: Impact on Production

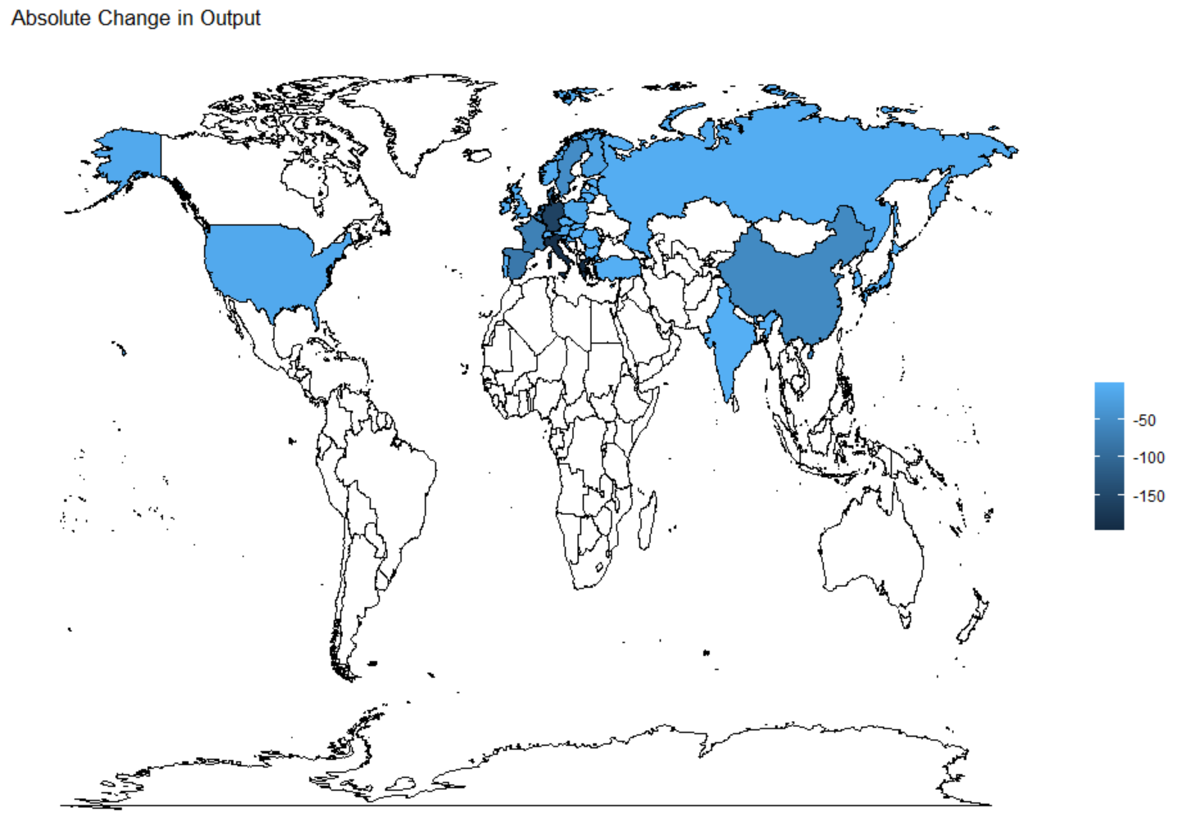
Region	**Case 1**	**Case 2**	**Case 3**
Percentage Change in Output (%)			
EU	-0.70	-1.16	-3.42
EU's Top 10 Trading Countries	-0.02	-0.03	-0.08
World	-0.50	-0.83	-2.45
Absolute Change in Output (in million USD)			
EU	-1,116.25	-1,853.34	-5,489.76
EU's Top 10 Trading Countries	-113.23	-188.53	-566.16
World	-1,331.06	-2,211.01	-6,563.81
Percentage Change in CO_2 Emissions (%)			
EU	-0.69	-1.14	-3.34
EU's Top 10 Trading Countries	-0.02	-0.03	-0.08
World	-0.49	-0.82	-2.40
Absolute Change in CO_2 Emissions (in million tons)			
EU	-1.01	-1.67	-4.89
EU's Top 10 Trading Countries	-0.04	-0.06	-0.18
World	-1.08	-1.80	-5.27

Maps 5.4–5.7 show the comparative decreases in output and CO_2 emissions in both percentage and absolute terms for EU countries and the EU's Top 10 Trading Countries. In percentage terms, the biggest reduction in output is observed in Malta, Croatia, Spain, Greece, and Slovenia, while in absolute terms, the biggest reduction is observed in Greece, Italy, Germany, Netherlands, and Denmark. This implies that Greece must reduce its output the most compared to the rest of the world (i.e., in absolute terms) and compared to its benchmark output (i.e., in percentage terms). In percentage terms, the biggest reduction in CO_2 emissions is seen in Croatia, Spain, Malta, Greece, and Slovenia. In absolute terms, the biggest reduction is seen in Greece, Italy, Spain, Belgium, and the Netherlands. This implies that Greece and Spain must reduce their CO_2 emissions the most compared to the rest of the world (i.e., in absolute terms) and compared to their benchmark CO_2 emissions (i.e., in percentage terms). Among the EU's Top 10 Trading Countries, Norway and Switzerland observe the highest reductions in output and CO_2 emissions in percentage terms, while in absolute terms these reductions are mainly observed for China.

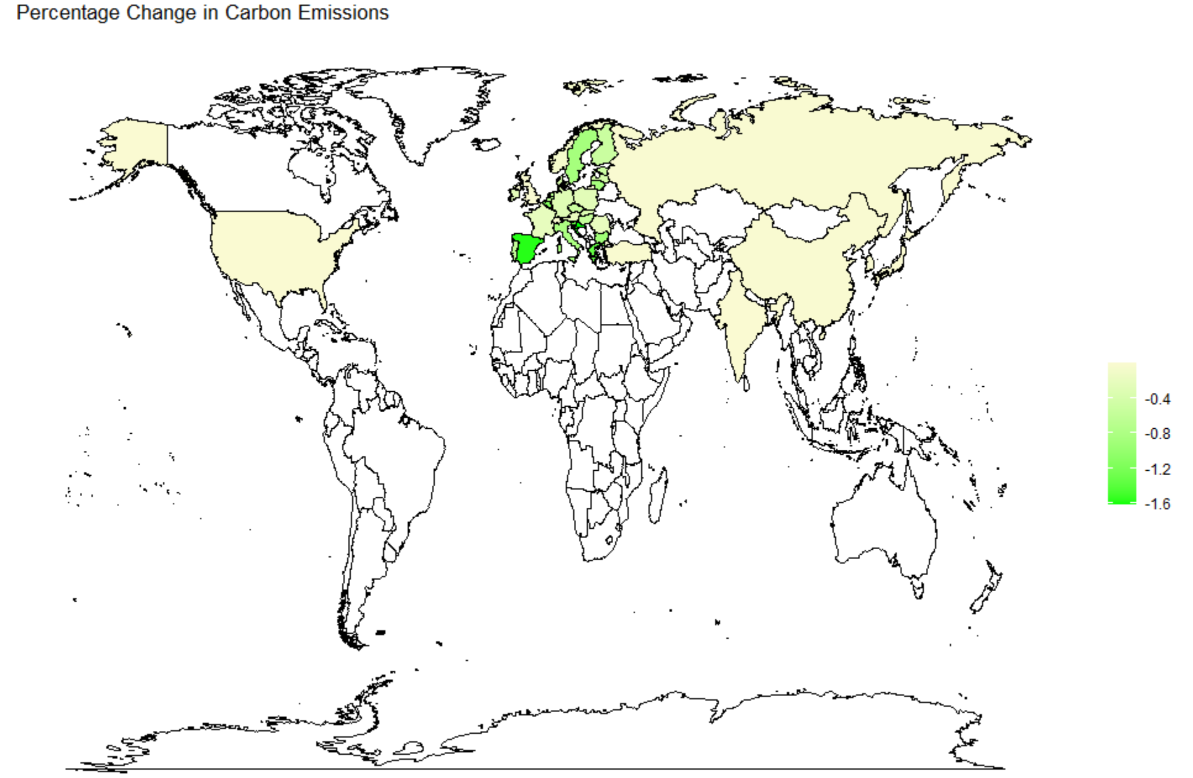
Map 5.4: Percentage decrease in output for EU countries and the EU's Top 10 Trading Countries.



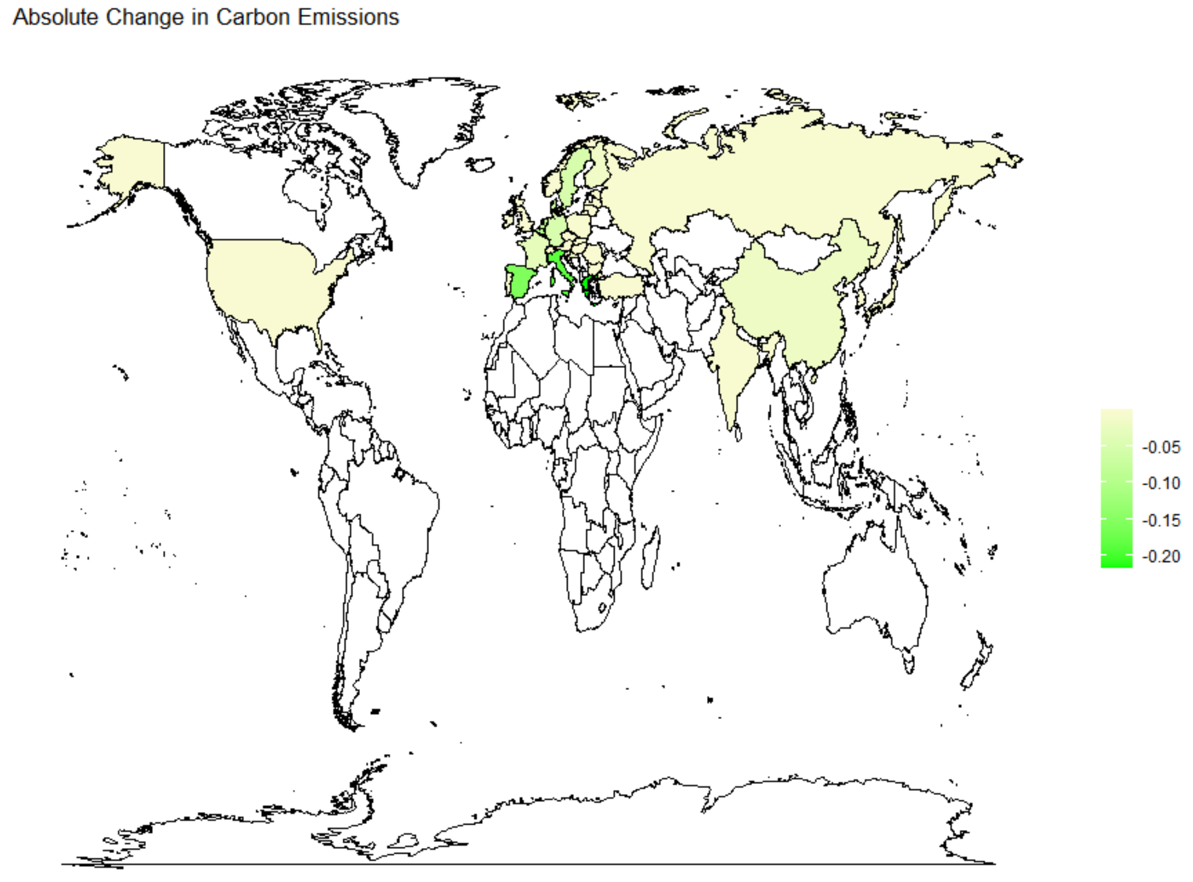
Map 5.5: Absolute decrease in output (in million USD) for EU countries and the EU's Top 10 Trading Countries.



Map 5.6: Percentage decrease in CO_2 emissions for EU countries and the EU's Top 10 Trading Countries.



Map 5.7: Absolute decrease in CO_2 emissions (in million tons) for EU countries and the EU's Top 10 Trading Countries.



Water transport ranks highest on both these parameters, i.e., decrease in output and CO_2 emission. The ranking of the other sectors in terms of decrease in output are the same as those which saw the largest increase in production price. However, the ranking differs when it comes to the decrease in CO_2 emissions, which can be attributed to emissions per unit and dependence on the shipping industry.

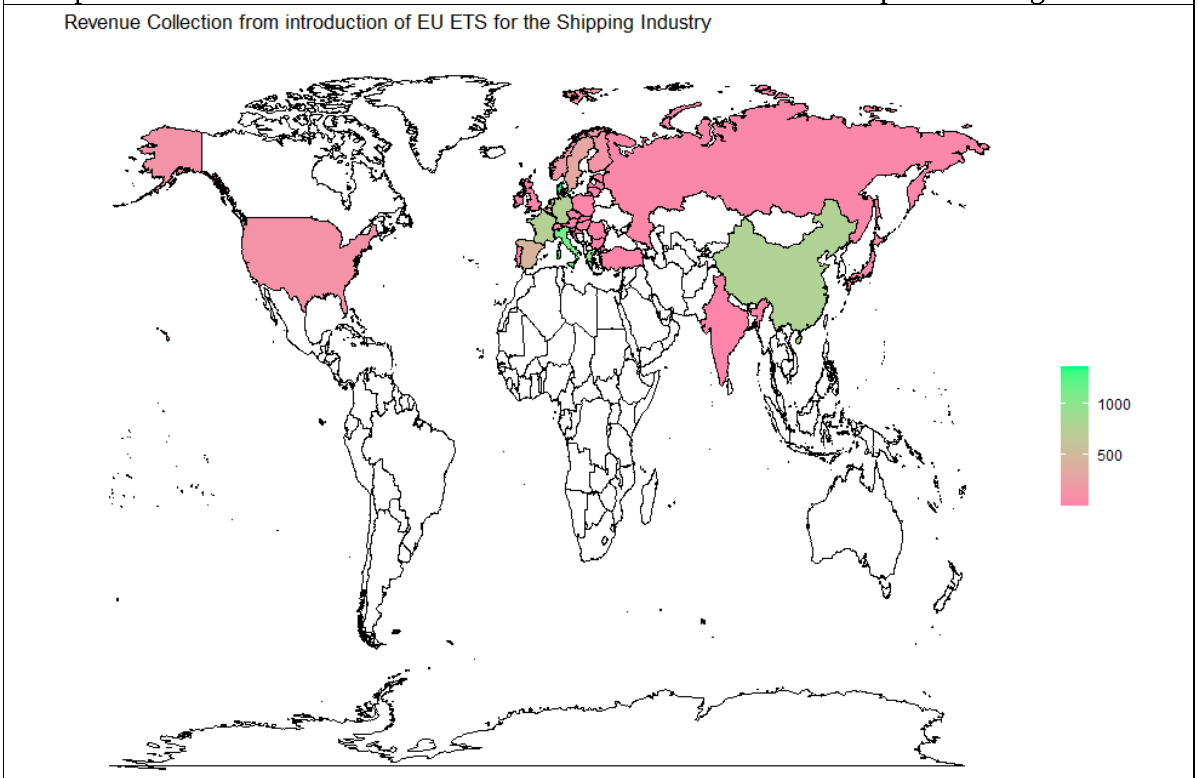
Finally, implementing the EU ETS in the shipping industry will generate revenue for the European Commission. The estimated value of this revenue (6.1% of the gross domestic product (GDP) for the European Union's shipping industry) is shown in Table 5.5. Note that, as more CO_2 emissions from the shipping industry are covered by the EU ETS, the revenue generated decreases on account of the reduction in output.

Table 5.5: Total Revenue from the Shipping Industry EU ETS (in million USD)

Case 1	**Case 2**	**Case 3**
9,644.28	9,615.68	9,476.94

EU countries contribute 75% of this revenue (with Denmark, Italy and Germany leading the way), the EU's Top 10 Trading Countries contribute 14%, and the RoW contributes 11%. Interestingly, China, a non-EU country, is the fourth largest contributor (8%), which makes it the highest contributor of the EU's Top 10 Trading Countries. This could be because China is not only one of the EU's Top 10 Trading Countries but its shipping industry also emits the most CO_2 emissions[24], more in fact than the shipping industries of all EU countries combined (see Figure 5.1). Map 5.8 shows the comparative revenue contribution of the countries through the shipping industry EU ETS.

Map 5.8: Revenue Contributions of EU countries and the EU's Top 10 Trading Partners.



[24] In fact, when referring to total CO_2 emissions (taking all 45 sectors into account), China is the highest emitter (more, even, than the Rest of the World (RoW)).

5.5 Discussion

In 2018, CO_2 emissions from the 45 sectors considered amounted to 28,944 million tons (MTs). EU countries contributed 7.92% (2,293 MTs) of these emissions, while the EU's Top 10 Trading Countries contributed a whopping 66.14% (19,144 MTs). Of these total CO_2 emissions, the *water transport* sector (used for the purposes of this analysis as a synonym for the shipping industry) contributed 3.17% (918 MTs). The EU accounts for 17.59% (161 MTs) of shipping industry emissions, while the EU's Top 10 Trading Countries accounted for 49.13% (451 MTs) of these emissions. It is clear that while the proportion of the EU's total emissions is less than that of the EU's Top 10 Trading Countries, the shipping industry accounts for a significant share of the EU's total CO_2 emissions. In fact, based on the ranking of CO_2 emissions by sector in the EU, shipping is second only to *Electricity, gas, steam and air conditioning supply*.

The results of this chapter suggest that, in the short run, implementing EU ETS in the shipping industry for 20% of CO_2 emissions will reduce both output and CO_2 emissions by 0.5%. If more CO_2 emissions by the shipping industry are held accountable, a greater reduction in CO_2 emissions will be observed in the first year. For example, if 100% of CO_2 emissions from the shipping industry are covered by the EU ETS in the first year, a 2.4% reduction in CO_2 emissions will be noted around the world. Gu et al. (2019) & Zhu et al. (2018) suggest that the impact of ETS for the shipping industry is contingent on factors such as bunker price and allowance cost. Zhu et al. (2018) contend that even in the minimal CO_2 reduction scenario, the annual mitigation ratio can reach 1.5%. On the other hand, Gu et al. (2019) report that ETS does not necessarily guarantee CO_2 emission reduction in the short run and that its effectiveness will be higher with global coverage.

The reductions in CO_2 emissions reported in this study will come at substantial cost to economic agents. This distortion caused by the introduction of the new policy can be measured in terms of loss in welfare (Tol, 2019). For example, consumers will lose welfare to the tune of USD 36 million if the EU ETS covers 100% of CO_2 emissions, as opposed to USD 7 million if it covers 20% (Table 5.3).

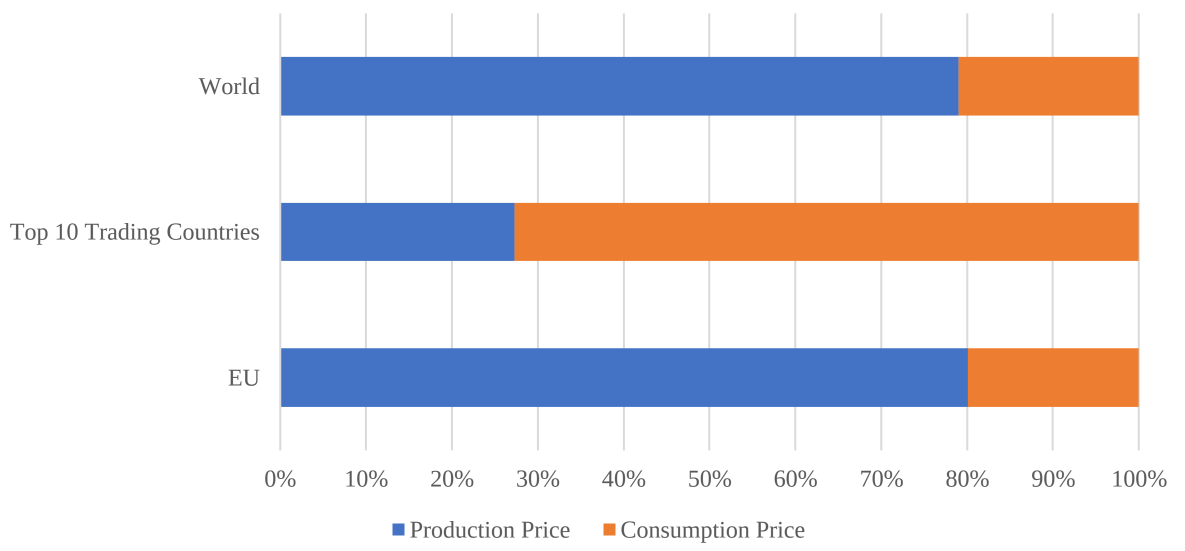
5.5.1 EU Agents versus Agents from the EU's Top 10 Trading Countries

In the EU, the increase in production price (0.02%) is more than the increase in consumption price (0.004%) as depicted by the CPI. This trend is underscored in a World Bank study by Halim et al. (2019), where GHG mitigation policies in the shipping industry led to a notable increase in maritime transportation costs that ranged from 0.4% to 16%. Simultaneously, the uptick in import prices is marginal (below 1%). In our scenario, this dynamic translates into higher production expenses and a corresponding dip in consumption prices. Conversely, Cariou et al. (2021) observed that implementing EU ETS for the shipping industry will substantially increase the cost per voyage, thus potentially leading to a rise in freight costs and consequential higher prices for consumers. In contrast, a study by NZIER (2018) that investigated the effects of higher fuel prices on the New Zealand shipping industry found no significant economic costs.

For the EU's Top 10 Trading Countries, on the other hand, the increase in consumption price (0.0008%) is higher than the increase in production price (0.0003%). This implies that, overall, both consumers and producers in the EU face increased prices. However, in the EU producers

are more worse off, whereas in the EU's Top 10 Trading Countries, consumers are worse off compared to other agents in those countries (Figure 5.2).
The fact that consumers outside the EU are affected more by the implementation of EU ETS is further highlighted by the USD 1 million decrease in consumer welfare in the EU's Top 10 Trading Countries, which is much more (10 times) than the decrease in welfare experienced by EU consumers (Table 5.3). This result shows that changes in import prices have a greater impact on consumer welfare than changes in domestic[25] prices. An important implication of this result is that, although the EU is the policy-deciding agent, in addition to the negative welfare effect inside the EU, there is also a negative welfare impact outside the EU. If the European Parliament's proposal were implemented, consumer welfare in both groups of consumers would decrease five-fold.

Figure 5.2: Change in Production Price Vs Consumption Price



5.5.2 Phased-in versus Immediate Approach

Reducing emissions necessitates addressing both behavioural changes and technological advancements, which can be influenced by the consumption of durable goods and capital investments. An immediate approach (i.e., 100% accountability for the CO_2 emissions) will lead to discomfort to the agents as it will penalize them for the investment decisions made prior to the existence of such a policy. In the very short run, the price inelasticity of supply and demand will not only lead to a hike in price owing to the implementation of EU ETS but also to an inefficient allocation of resources (Pindyck, 1982), leading to a deadweight loss in the economy (Tol, 2019). The phased roll out of the policy, on the other hand, gives economic agents the time to adjust to new changes and provides them with an opportunity to learn and grow.

Moreover, transitioning emission reduction targets from lenient to stringent over time not only ensures a smoother adjustment for economic agents but it also proves cost-effective (Tol, 2019). By gradually increasing the stringency of the targets, industries and businesses can plan and implement emission-reducing measures in a more financially sustainable manner. This

[25] Given that the European Union is "the world's biggest single market" (European Union, 2012).

approach allows for better allocation of resources, promotes innovation, and minimizes sudden financial burdens, ultimately contributing to the overall success and effectiveness of the emission reduction strategy.

Additionally, Table 5.5 shows that revenue collection in the immediate period decreases as more CO_2 emissions are held accountable. As an Ocean Fund is to be created with 75% of the revenue collection, with the objective to make the shipping industry climate resilient and energy efficient (European Parliament, 2022), it would be prudent to have more funds to undertake this transition to greener energy. A phased-in implementation would therefore be a suitable approach.

5.5.3 The Porter Effect

Environmental improvement will lead to economic losses for all agents except the governing body (i.e., the European Commission), who will receive a revenue of roughly 6.1% of the EU shipping industry's GDP (i.e., total output). In the very short run, there is therefore a trade-off between economic development and environmental quality as both producers and consumers incur losses for the reduction in CO_2 emissions and environmental improvement. This trade-off in the short run has also been noted by Gemechu et al. (2013), who studied the impact of environmental tax on Spanish products. Additionally, Wang et al. (2019) underscored this further by revealing that ETS for tramp ships could drive a 17.8% reduction in CO_2 emissions but concurrently lead to a substantial 38.5% decrease in profits for ship operators. However, this trade-off may cease to exist in the long run, as Dong et al. (2019) found when they studied ETS in China. These authors observed a trade-off in the short run but, in the long run, ETS generated the Porter effect, i.e., environmental policies paved the way to improvements not only in environmental quality but also in economic development. Furthermore, Dessens et al. (2014) studied the global ETS scenario for the shipping and aviation industries to reduce emissions by 65% below the BASE levels in 2050 and found that this would lead to a 1.9% increase in GDP on account of investment in research and development. It is also important to stress the long-term benefits of improved environmental quality on health-related issues in terms, for instance, of fewer working hours lost and lower expenditure on healthcare. These benefits in the long run have also been reported by Espinosa (1996) using Environmental Computable General Equilibrium Modelling.

The IO model does not take into account substitution effects on the mode of transportation used or on products consumed from different countries. This feature of the model places our results in the short run (the immediate term), when there is no time to make adjustments to take substitution into account. However, in the long run, where adjustments have time to unfold, cautionary findings emerge. Several studies warn of potential pitfalls such as carbon leakage, regional distortion, and the EU ETS's capacity to undercut the International Maritime Organization's pursuit of a global agreement on emissions control (Lagouvardou & Psaraftis, 2022; Shi, 2016; Hermeling et al., 2015). Despite these challenges, Cariou et al. (2021) assert that the EU ETS for the shipping industry is poised not to expedite the decarbonization of this crucial sector.

In considering policy implications, it becomes essential for policymakers to adopt a balanced approach. Short-term economic sacrifices for environmental gain should be weighed against the prospect of long-term benefits. Policymakers could explore mechanisms to mitigate immediate economic losses, possibly through targeted support programmes or incentives for affected industries during the transitional phase. Moreover, emphasizing the long-term advantages of improved environmental quality, such as potential reductions in healthcare expenditures and increased productivity due to healthier working conditions, provides a robust foundation for sustainable policymaking.

5.6 Conclusion

This chapter has employed IO modelling to analyse the initial impact of extending EU ETS for CO_2 emissions to the shipping industry on economic agents in EU countries and the EU's Top 10 Trading Countries. The EIO model was used to estimate this impact using carbon dioxide emissions based on production, while the price version of the IO model was used to simulate the impact on producers and consumers in EU countries and the EU's Top 10 Trading Countries in 2018.

The use of IO modelling offers a more comprehensive perspective compared to the partial equilibrium approach, capturing broader economic impacts through its consideration of sectoral linkages and interactions. Furthermore, its simplicity and its extensive application in both practical and academic contexts, makes it a valuable tool for informed decision-making in policy formulation and economic analysis. The model used a linear production function with fixed technology, adhering to the principles of homogeneity and proportionality while assuming constant returns to scale. The chapter used water transport as a proxy for shipping industry. As noted by Wang et al. (2015), the shipping industry is not a homogenous sector and the effect on emissions and international trade could differ depending on the carrier. Moreover, as the chapter focused on effectively assessing immediate changes in the economy, the substitution effect, which influences long-term impacts and outcomes, was not taken into account. Notably, the chapter focused on the first-year introduction of the EU ETS for the shipping industry, mapping three cases based on increased CO_2 emissions accountability. Despite its limitations, this approach has provided valuable insights into the initial impact of introducing this new policy on the economic agents in EU countries and the EU's Top 10 Trading Countries.

The results of the chapter suggest that this policy will influence the reduction in CO_2 emissions by increasing production prices, which will reduce output. It will also increase consumption prices, which will reduce consumer welfare in the short term. Due to price inelasticity in the very short term, producers will have to take most of the brunt. However, producers in the EU countries will be worse off, while consumers in the EU's Top 10 Trading Countries will be worse off compared to the other agent in their respective countries. A trade-off was noted between the environmental and economic objectives, which suggests that the Porter effect does not hold in the very short term.

The economic agents in Greece, Italy, Spain, and Germany will be impacted the most by the implementation of EU ETS in the shipping industry. Among the EU's Top 10 Trading Countries, China will be impacted the most. Malta, Croatia, and Slovenia will observe the biggest change in percentage terms since their small economies experience the biggest change in the parameters with respect to their starting points.

The shipping industry will face the direct impact of this new policy. The indirect impact will be felt most by closely related sectors such as *Fishing and aquaculture* and warehousing and other transport, which ultimately will also affect the *Food products, beverages and tobacco* sector.

To comprehensively understand the impact of the phased introduction of the EU ETS into the shipping industry on the global economy and explore the potential long-term presence of the Porter effect, an avenue for future research could involve conducting a Dynamic Computable General Equilibrium analysis. This approach would enable a more nuanced examination of the intricate economic dynamics and long-term implications associated with the implementation of the EU ETS in the shipping industry. This future research would help policymakers design strategies that not only address immediate concerns but also capitalize on the long-term synergies between environmental sustainability and economic prosperity.

Appendix A5

Table A5.1: CO_2 emission from the Shipping Industry and the Revenue Collection				
Country	CO_2 Emissions from the Shipping Industry in 2018 (in MTs)	Revenue collected due to the new policy from the countries (in millions USD)		
		Case 1	**Case 2**	**Case 3**
Rest of the World	305.75	1,058.53	1,058.48	1,058.24
China	258.91	783.33	783.33	783.29
Japan	58.72	62.53	62.53	62.53
United States of America	53.99	132.78	132.78	132.78
Denmark	30.16	1,354.48	1,352.62	1,343.36
Italy	25.42	1,135.73	1,130.39	1,104.34
Greece	21.94	977.84	971.57	941.27
South Korea	20.19	24.58	24.58	24.58
Germany	16.94	760.29	759.02	752.7
Norway	16.93	165.8	165.78	165.73
France	16.51	741.49	740.59	736.08
Netherlands	13.51	604.27	601.85	589.99
Russia	12.57	49.32	49.32	49.32
United Kingdom	10.42	38.62	38.62	38.61
Spain	10.26	454.97	450.51	429.42
Belgium	8.77	390.63	387.97	375.17
Sweden	7.22	322.42	320.88	313.37
Switzerland	7.05	55.54	55.54	55.53
Turkey	6.54	30.13	30.13	30.13
India	6.15	13.34	13.34	13.34
Finland	3.29	147.3	146.87	144.72
Malta	1.53	68.33	67.96	66.15
Portugal	1.08	48.44	48.27	47.46
Croatia	1.04	45.95	45.54	43.6
Estonia	0.72	32.24	32.16	31.77
Austria	0.65	29.3	29.28	29.15
Ireland	0.52	23.13	23.1	22.95
Poland	0.47	21.1	21.07	20.91
Romania	0.25	11.05	11.04	10.98
Lithuania	0.24	10.8	10.74	10.46
Cyprus	0.23	10.38	10.38	10.34
Hungary	0.21	9.36	9.32	9.17
Bulgaria	0.19	8.5	8.46	8.29

Luxembourg	0.18	7.93	7.91	7.81
Slovenia	0.15	6.44	6.39	6.13
Czech Republic	0.09	4.17	4.15	4.09
Latvia	0.06	2.56	2.55	2.52
Slovakia	0.02	0.67	0.67	0.67

Table A5.2: Percentage change in production price by top sectors for the EU, the EU's Top 10 Trading Countries, and the World (%)

Industry	**Case 1**	**Case 2**	**Case 3**
EU			
Water Transport	0.56755	0.94497	2.83775
Fishing and aquaculture	0.01230	0.02047	0.06148
Land transport and transport via pipelines	0.00525	0.00874	0.02624
Warehousing and support activities for transportation	0.00519	0.00864	0.02594
Air transport	0.00499	0.00831	0.02495
Basic metals	0.00498	0.00828	0.02488
Mining and quarrying, energy producing products	0.00526	0.00876	0.02631
Electrical equipment	0.00459	0.00765	0.02297
Other non-metallic mineral products	0.00451	0.00750	0.02254
Coke and refined petroleum products	0.00455	0.00757	0.02273
Food products, beverages and tobacco	0.00420	0.00699	0.02098
EU's Top 10 Trading Countries			
Water Transport	0.0031	0.0051	0.0154
Warehousing and support activities for transportation	0.0008	0.0013	0.0038
Land transport and transport via pipelines	0.0006	0.0011	0.0032
Fishing and aquaculture	0.0006	0.0011	0.0032
Other non-metallic mineral products	0.0005	0.0008	0.0024
Coke and refined petroleum products	0.0004	0.0007	0.0022
Mining and quarrying, non-energy producing products	0.0004	0.0007	0.0022
Paper products and printing	0.0004	0.0007	0.0021
Wood and products of wood and cork	0.0004	0.0007	0.0020
Basic metals	0.0004	0.0007	0.0020
Rubber and plastics products	0.0004	0.0007	0.0020
World			
Water Transport	0.4043	0.6731	2.0213
Fishing and aquaculture	0.0088	0.0147	0.0441
Warehousing and support activities for transportation	0.0039	0.0065	0.0195
Land transport and transport via pipelines	0.0039	0.0065	0.0195
Air transport	0.0037	0.0061	0.0183
Basic metals	0.0036	0.0061	0.0182
Mining and quarrying, energy producing products	0.0037	0.0061	0.0184
Electrical equipment	0.0034	0.0056	0.0168

Other non-metallic mineral products	0.0033	0.0056	0.0167
Coke and refined petroleum products	0.0033	0.0055	0.0166
Food products, beverages and tobacco	0.0031	0.0051	0.0154

Table A5.3: percentage change in CPI by country (%)			
Country	**Case 1**	**Case 2**	**Case 3**
Malta	0.0252	0.0420	0.1260
Greece	0.0142	0.0237	0.0711
Croatia	0.0079	0.0132	0.0396
Italy	0.0052	0.0086	0.0259
Sweden	0.0043	0.0071	0.0214
Norway	0.0042	0.0069	0.0208
Estonia	0.0042	0.0069	0.0208
Denmark	0.0037	0.0062	0.0186
Bulgaria	0.0036	0.0060	0.0180
Luxembourg	0.0033	0.0055	0.0166
Finland	0.0032	0.0053	0.0160
Belgium	0.0029	0.0049	0.0147
Cyprus	0.0029	0.0049	0.0147
Latvia	0.0025	0.0041	0.0124
Netherlands	0.0024	0.0040	0.0121
Portugal	0.0022	0.0036	0.0109
Spain	0.0022	0.0036	0.0108
Slovenia	0.0021	0.0035	0.0104
Lithuania	0.0021	0.0035	0.0104
Germany	0.0016	0.0027	0.0082
Austria	0.0015	0.0026	0.0077
Romania	0.0014	0.0023	0.0070
Hungary	0.0014	0.0023	0.0068
India	0.0011	0.0019	0.0056
Poland	0.0011	0.0018	0.0054
Slovakia	0.0010	0.0017	0.0052
Czech Republic	0.0010	0.0017	0.0050
France	0.0009	0.0016	0.0047
Ireland	0.0009	0.0014	0.0043
Switzerland	0.0007	0.0011	0.0034
United Kingdom	0.0006	0.0010	0.0031
Rest of the World	0.0006	0.0010	0.0029
Turkey	0.0005	0.0008	0.0024
Russia	0.0003	0.0005	0.0015
China	0.0002	0.0003	0.0010
United States of America	0.0002	0.0003	0.0009
South Korea	0.0001	0.0002	0.0006
Japan	0.0001	0.0001	0.0004

Table A5.4: Change in consumer welfare by country						
Country	**Absolute Change (in million USD)**			**Percentage Change (%)**		
	Case 1	**Case 2**	**Case 3**	**Case 1**	**Case 2**	**Case 3**
Rest of the World	-1.27	-2.12	-6.36	-0.0002	-0.0003	-0.001
Italy	-1.09	-1.82	-5.46	-0.0014	-0.0024	-0.0072
Germany	-0.61	-1.02	-3.07	-0.0006	-0.001	-0.0029
Greece	-0.54	-0.9	-2.7	-0.0056	-0.0094	-0.0281
Spain	-0.51	-0.86	-2.57	-0.0009	-0.0015	-0.0046
China	-0.34	-0.57	-1.71	-0.0001	-0.0002	-0.0005
France	-0.32	-0.53	-1.6	-0.0003	-0.0005	-0.0015
Netherlands	-0.28	-0.46	-1.39	-0.0011	-0.0018	-0.0055
Belgium	-0.25	-0.41	-1.25	-0.0017	-0.0028	-0.0084
Sweden	-0.24	-0.4	-1.21	-0.0015	-0.0025	-0.0076
United States of America	-0.21	-0.34	-1.03	0	0	-0.0001
Austria	-0.16	-0.26	-0.79	-0.0011	-0.0018	-0.0055
Denmark	-0.16	-0.26	-0.78	-0.0016	-0.0026	-0.0078
Russia	-0.11	-0.19	-0.56	-0.0002	-0.0003	-0.001
Norway	-0.1	-0.17	-0.51	-0.0008	-0.0014	-0.0042
Poland	-0.1	-0.16	-0.48	-0.0007	-0.0011	-0.0034
Finland	-0.09	-0.14	-0.43	-0.0008	-0.0014	-0.0041
United Kingdom	-0.09	-0.14	-0.43	-0.0001	-0.0001	-0.0003
Turkey	-0.07	-0.12	-0.35	-0.0003	-0.0004	-0.0013
Portugal	-0.06	-0.11	-0.32	-0.0007	-0.0011	-0.0035
Romania	-0.06	-0.1	-0.3	-0.0007	-0.0012	-0.0035
Croatia	-0.06	-0.09	-0.28	-0.0031	-0.0051	-0.0153
India	-0.06	-0.09	-0.28	-0.0001	-0.0001	-0.0003
Switzerland	-0.05	-0.09	-0.27	-0.0002	-0.0003	-0.001
Bulgaria	-0.05	-0.08	-0.24	-0.0027	-0.0044	-0.0133
Japan	-0.04	-0.07	-0.21	0	0	-0.0001
Malta	-0.04	-0.06	-0.18	-0.0177	-0.0295	-0.0885
Czech Republic	-0.04	-0.06	-0.18	-0.0006	-0.001	-0.0031
South Korea	-0.02	-0.04	-0.12	0	-0.0001	-0.0002
Hungary	-0.02	-0.04	-0.11	-0.0007	-0.0012	-0.0035
Ireland	-0.02	-0.03	-0.09	-0.0004	-0.0007	-0.0022
Latvia	-0.01	-0.02	-0.07	-0.0016	-0.0026	-0.0079
Slovenia	-0.01	-0.02	-0.07	-0.0012	-0.0019	-0.0058
Estonia	-0.01	-0.02	-0.06	-0.002	-0.0033	-0.01
Slovakia	-0.01	-0.02	-0.06	-0.0005	-0.0009	-0.0027
Luxembourg	-0.01	-0.02	-0.06	-0.0009	-0.0014	-0.0043

Lithuania	-0.01	-0.02	-0.06	-0.0009	-0.0016	-0.0047
Cyprus	-0.01	-0.02	-0.05	-0.0014	-0.0023	-0.007

Table A5.5: Change in output by country

Country	Absolute Change (in million USD)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Greece	-197.21	-326.49	-953.28	-1.341	-2.223	-6.523
Italy	-188.33	-312.74	-926.88	-0.811	-1.345	-3.958
Germany	-159.7	-265.64	-793.74	-0.3	-0.498	-1.486
Rest of the World	-101.58	-169.13	-507.88	-0.018	-0.03	-0.09
Netherlands	-95.56	-158.67	-470.04	-0.69	-1.146	-3.381
Denmark	-88.91	-147.88	-441.65	-0.374	-0.623	-1.863
Spain	-79.5	-131.71	-386.22	-1.569	-2.588	-7.427
France	-67.15	-111.72	-334.24	-0.215	-0.357	-1.066
Belgium	-63.36	-105.11	-309.94	-1.156	-1.913	-5.575
China	-54.91	-91.43	-274.56	-0.008	-0.013	-0.04
Sweden	-50.95	-84.61	-250.9	-0.863	-1.432	-4.216
Finland	-20.76	-34.51	-102.69	-0.521	-0.865	-2.564
Austria	-12.68	-21.11	-63.36	-0.188	-0.313	-0.936
Poland	-12.3	-20.48	-61.43	-0.273	-0.454	-1.356
United States of America	-11.96	-19.91	-59.79	-0.002	-0.003	-0.01
Croatia	-11.57	-19.16	-56.04	-1.613	-2.665	-7.718
Portugal	-8.99	-14.95	-44.62	-0.586	-0.973	-2.879
Norway	-8.25	-13.74	-41.24	-0.06	-0.101	-0.302
Malta	-8.06	-13.39	-39.86	-1.709	-2.838	-8.409
Ireland	-8.03	-13.37	-40.09	-0.25	-0.416	-1.243
United Kingdom	-7.25	-12.08	-36.27	-0.013	-0.022	-0.067
Russia	-6.94	-11.56	-34.7	-0.017	-0.028	-0.083
Bulgaria	-6.15	-10.23	-30.63	-0.926	-1.536	-4.545
Czech Republic	-5.69	-9.47	-28.4	-0.51	-0.846	-2.506
Switzerland	-5.67	-9.43	-28.33	-0.021	-0.034	-0.103
Luxembourg	-5.24	-8.72	-26.08	-0.548	-0.91	-2.707
Romania	-5.01	-8.34	-25.01	-0.204	-0.339	-1.014
Turkey	-4.93	-8.2	-24.64	-0.018	-0.03	-0.09
South Korea	-4.67	-7.77	-23.33	-0.008	-0.014	-0.042
Japan	-4.37	-7.28	-21.86	-0.003	-0.005	-0.015
Estonia	-4.34	-7.22	-21.55	-0.502	-0.834	-2.483
India	-4.29	-7.14	-21.44	-0.004	-0.007	-0.022

Hungary	-4.01	-6.67	-19.97	-0.563	-0.934	-2.762
Slovenia	-3.16	-5.24	-15.56	-1.359	-2.245	-6.491
Lithuania	-2.63	-4.37	-12.94	-0.867	-1.436	-4.207
Cyprus	-2.63	-4.38	-13.13	-0.213	-0.354	-1.062
Slovakia	-2.58	-4.3	-12.9	-0.336	-0.558	-1.662
Latvia	-1.73	-2.88	-8.63	-0.447	-0.743	-2.214

Table A5.6: Change in CO_2 emissions by country

Country	Absolute Change (in million tons)			Percentage Change (%)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Greece	-0.2177	-0.3602	-1.0486	-1.341	-2.223	-6.523
Italy	-0.1865	-0.3091	-0.9076	-0.811	-1.345	-3.958
Spain	-0.1569	-0.2587	-0.7416	-1.569	-2.588	-7.427
Belgium	-0.0924	-0.1529	-0.4443	-1.156	-1.913	-5.575
Netherlands	-0.0845	-0.1402	-0.4131	-0.69	-1.146	-3.381
Denmark	-0.0638	-0.106	-0.3162	-0.374	-0.623	-1.863
Sweden	-0.0531	-0.088	-0.2583	-0.863	-1.432	-4.216
Germany	-0.0503	-0.0836	-0.2493	-0.3	-0.498	-1.486
Rest of the World	-0.0409	-0.0681	-0.2046	-0.018	-0.03	-0.09
France	-0.032	-0.0533	-0.159	-0.215	-0.357	-1.066
China	-0.0191	-0.0319	-0.0957	-0.008	-0.013	-0.04
Finland	-0.0154	-0.0255	-0.0756	-0.521	-0.865	-2.564
Croatia	-0.0145	-0.0239	-0.0689	-1.613	-2.665	-7.718
Malta	-0.013	-0.0215	-0.0628	-1.351	-2.241	-6.619
Portugal	-0.0064	-0.0107	-0.0316	-0.586	-0.973	-2.879
Poland	-0.0033	-0.0056	-0.0166	-0.273	-0.454	-1.356
Russia	-0.0032	-0.0053	-0.0158	-0.017	-0.028	-0.083
India	-0.0031	-0.0051	-0.0153	-0.004	-0.007	-0.022
Estonia	-0.003	-0.005	-0.0148	-0.502	-0.834	-2.483
Bulgaria	-0.0027	-0.0045	-0.0133	-0.926	-1.536	-4.545
Lithuania	-0.0021	-0.0035	-0.0101	-0.867	-1.436	-4.207
Norway	-0.0021	-0.0035	-0.0104	-0.06	-0.101	-0.302
Slovenia	-0.002	-0.0033	-0.0096	-1.353	-2.235	-6.46
South Korea	-0.0019	-0.0031	-0.0094	-0.008	-0.014	-0.042
United States of America	-0.0018	-0.0029	-0.0088	-0.002	-0.003	-0.01
Austria	-0.0017	-0.0028	-0.0082	-0.188	-0.313	-0.936
Ireland	-0.0016	-0.0026	-0.0078	-0.249	-0.414	-1.235
Turkey	-0.0015	-0.0025	-0.0076	-0.018	-0.03	-0.09

Hungary	-0.0015	-0.0025	-0.0075	-0.563	-0.934	-2.762
Czech Republic	-0.0014	-0.0023	-0.0068	-0.51	-0.846	-2.506
Japan	-0.0011	-0.0018	-0.0055	-0.003	-0.005	-0.015
Romania	-0.001	-0.0016	-0.0049	-0.204	-0.339	-1.014
Luxembourg	-0.001	-0.0016	-0.0047	-0.541	-0.899	-2.674
United Kingdom	-0.0009	-0.0015	-0.0045	-0.013	-0.022	-0.067
Slovakia	-0.0004	-0.0007	-0.0022	-0.334	-0.556	-1.655
Switzerland	-0.0004	-0.0007	-0.0021	-0.02	-0.034	-0.102
Cyprus	-0.0004	-0.0006	-0.0019	-0.197	-0.328	-0.984
Latvia	-0.0003	-0.0006	-0.0017	-0.415	-0.69	-2.056

Table A5.7: Percentage change in output by sector (%)

Sector	Case 1	Case 2	Case 3
Water transport	-15.24	-25.23	-73.78
Fishing and aquaculture	-0.33	-0.54	-1.62
Warehousing and support activities for transportation	-0.15	-0.25	-0.74
Land transport and transport via pipelines	-0.15	-0.25	-0.74
Air transport	-0.14	-0.23	-0.69
Basic metals	-0.14	-0.23	-0.69
Mining and quarrying, energy producing products	-0.13	-0.21	-0.64
Electrical equipment	-0.13	-0.21	-0.64
Other non-metallic mineral products	-0.13	-0.21	-0.63
Coke and refined petroleum products	-0.12	-0.20	-0.61
Food products, beverages and tobacco	-0.12	-0.19	-0.58
Fabricated metal products	-0.11	-0.19	-0.57
Wood and products of wood and cork	-0.11	-0.19	-0.57
Paper products and printing	-0.11	-0.19	-0.56
Chemical and chemical products	-0.11	-0.18	-0.55
Machinery and equipment, n.e.c.	-0.11	-0.18	-0.53
Computer, electronic and optical equipment	-0.10	-0.17	-0.50
Postal and courier activities	-0.10	-0.16	-0.50
Rubber and plastics products	-0.10	-0.16	-0.48
Other transport equipment	-0.09	-0.16	-0.47
Motor vehicles, trailers and semi-trailers	-0.09	-0.16	-0.47
Textiles, textile products, leather and footwear	-0.09	-0.15	-0.46
Wholesale and retail trade; repair of motor vehicles	-0.09	-0.15	-0.46
Mining and quarrying, non-energy producing products	-0.09	-0.14	-0.43
Manufacturing n.e.c.; repair and installation of machinery and equipment	-0.09	-0.14	-0.43
Construction	-0.08	-0.14	-0.42
Mining support service activities	-0.08	-0.14	-0.42
Pharmaceuticals, medicinal chemical and botanical products	-0.08	-0.14	-0.41
Administrative and support services	-0.08	-0.13	-0.39

Electricity, gas, steam and air conditioning supply	-0.07	-0.12	-0.37
Agriculture, hunting, forestry	-0.07	-0.12	-0.37
Accommodation and food service activities	-0.06	-0.11	-0.32
Water supply; sewerage, waste management and remediation activities	-0.05	-0.09	-0.27
Other service activities	-0.05	-0.08	-0.23
Telecommunications	-0.05	-0.08	-0.23
Publishing, audiovisual and broadcasting activities	-0.04	-0.07	-0.20
Professional, scientific and technical activities	-0.04	-0.06	-0.18
Human health and social work activities	-0.03	-0.06	-0.17
Arts, entertainment and recreation	-0.03	-0.05	-0.16
IT and other information services	-0.03	-0.05	-0.16
Financial and insurance activities	-0.03	-0.05	-0.14
Public administration and defence; compulsory social security	-0.03	-0.04	-0.13
Real estate activities	-0.02	-0.03	-0.10
Education	-0.02	-0.03	-0.08
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.00	0.00	0.00

Table A5.8: Percentage change in CO_2 emissions by industry (%)			
Sectors	**Case 1**	**Case 2**	**Case 3**
Water transport	-15.24	-25.23	-73.78
Fishing and aquaculture	-0.32	-0.53	-1.60
Warehousing and support activities for transportation	-0.15	-0.25	-0.74
Land transport and transport via pipelines	-0.15	-0.25	-0.74
Air transport	-0.14	-0.23	-0.69
Other non-metallic mineral products	-0.13	-0.21	-0.63
Food products, beverages and tobacco	-0.12	-0.19	-0.58
Fabricated metal products	-0.11	-0.19	-0.57
Basic metals	-0.11	-0.19	-0.56
Computer, electronic and optical equipment	-0.10	-0.17	-0.50
Postal and courier activities	-0.10	-0.16	-0.50
Rubber and plastics products	-0.10	-0.16	-0.48
Wood and products of wood and cork	-0.09	-0.16	-0.47
Coke and refined petroleum products	-0.09	-0.15	-0.46
Wholesale and retail trade; repair of motor vehicles	-0.09	-0.15	-0.46
Mining and quarrying, non-energy producing products	-0.09	-0.14	-0.43
Manufacturing n.e.c.; repair and installation of machinery and equipment	-0.09	-0.14	-0.43
Chemical and chemical products	-0.08	-0.14	-0.42
Construction	-0.08	-0.14	-0.42
Paper products and printing	-0.08	-0.14	-0.41
Machinery and equipment, n.e.c.	-0.08	-0.13	-0.40

Electrical equipment	-0.08	-0.13	-0.39
Administrative and support services	-0.08	-0.13	-0.39
Electricity, gas, steam and air conditioning supply	-0.07	-0.12	-0.37
Agriculture, hunting, forestry	-0.07	-0.12	-0.37
Other transport equipment	-0.07	-0.12	-0.36
Textiles, textile products, leather and footwear	-0.07	-0.11	-0.34
Motor vehicles, trailers and semi-trailers	-0.07	-0.11	-0.33
Accommodation and food service activities	-0.06	-0.11	-0.32
Mining support service activities	-0.06	-0.10	-0.31
Pharmaceuticals, medicinal chemical and botanical products	-0.06	-0.09	-0.28
Water supply; sewerage, waste management and remediation activities	-0.05	-0.09	-0.27
Other service activities	-0.05	-0.08	-0.23
Telecommunications	-0.05	-0.08	-0.23
Mining and quarrying, energy producing products	-0.04	-0.07	-0.21
Publishing, audiovisual and broadcasting activities	-0.04	-0.07	-0.20
Professional, scientific and technical activities	-0.04	-0.06	-0.18
Human health and social work activities	-0.03	-0.06	-0.17
Arts, entertainment and recreation	-0.03	-0.05	-0.16
IT and other information services	-0.03	-0.05	-0.16
Financial and insurance activities	-0.03	-0.05	-0.14
Public administration and defence; compulsory social security	-0.03	-0.04	-0.13
Real estate activities	-0.02	-0.03	-0.10
Education	-0.02	-0.03	-0.08
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0.00	0.00	0.00

Chapter 6

Concluding Remarks and Future Research

This thesis has provided an in-depth analysis of the complex relationships between economic activities and global CO_2 emissions, focusing on key sectors such as air transport and shipping, as well as international trade. Employing a variety of input-output methodologies, including Structural Decomposition Analysis (SDA), the Hypothetical Extraction Method (HEM), and Input-Output Impact Analysis (IOIA), it has shed light on the driving forces behind emissions trends and their implications for sustainable development.

The findings across the chapters underscore the complexity of reducing emissions in sectors that are deeply embedded in global value chains. Chapter 2 demonstrated through SDA that while developed countries have managed to slow direct emissions growth, emerging economies, particularly China and India, have become significant contributors to global direct emissions. This reflects the challenge of achieving human development and economic growth without accelerating climate change, as these countries experience rising energy consumption and industrial output. It also highlights the global inequality in emissions responsibility, which complicates efforts to design uniform climate policies.

Chapter 3 introduces the Emission Balance of Trade (EBT), a new metric, for assessing the environmental sustainability of trade. The findings show that countries like China and India, which are net exporters of CO_2 emissions, play a crucial role in sustaining global trade while bearing the environmental cost of production. This raises important questions about how to internalize the environmental costs of trade in international climate policy, and how to fairly distribute the responsibility for emissions between producer and consumer countries. Additionally, while the services sector engages in international trade in a limited capacity yet the emissions that become part of such a trade are more than the goods traded. Furthermore, quaternary sectors among the service sectors engage more in emission intensive trade, on the other hand, transport sectors like air and water transports, though globally integrated both in terms of goods and bads, their trade is more balanced.

Chapter 4 revealed the significant contribution of the air transport sector to global emissions, especially given its critical role in global supply chains. The application of the HEM showed that removing the air transport sector from the global economy would drastically reduce emissions. However, the sector's integration into trade and rising global demand for air travel pose substantial challenges to decarbonization, even as the industry explores sustainable fuels and more fuel-efficient aircraft.

Chapter 5, focusing on the shipping industry under the EU Emissions Trading System (ETS), showed that including shipping in emissions trading schemes is a critical step toward regulating one of the most emissions-intensive sectors. However, the inclusion of shipping in the EU ETS also increases costs, particularly in regions that depend on maritime trade, leading to broader economic implications that need to be managed through international cooperation and coordination by ensuring limited trade-off in economic and environmental goals.

6.1 Policy Implications

The findings of this research highlight the need for carefully designed policies that address the systemic, sectoral, and international dimensions of emissions reduction. A critical priority is addressing global emissions inequalities, where emerging economies like China and India bear a disproportionate burden of production-related emissions while enabling the consumption-driven economies of developed nations. Achieving a balance between economic growth and emissions reduction in these countries requires significant investments in technology transfer and financial support for renewable energy infrastructure, enabling these nations to transition to low-carbon pathways without compromising their developmental goals. Additionally, the research underscores the importance of integrating environmental costs into global trade frameworks. Metrics like the EBT provide actionable insights for internalizing these costs, promoting sustainable practices across global value chains. Policymakers must harmonize environmental standards and strengthen regulations in emission-intensive sectors to ensure fair accountability while avoiding carbon leakage and trade distortions. Policymakers could possibly consider implementing carbon border adjustment mechanisms, using metrics like EBT to design equitable and efficient trade policies.

Sector-specific strategies are also vital, particularly for high-emission industries such as air transport and shipping, which are integral to global trade yet significant contributors to CO_2 emissions. The air transport sector requires targeted investments in sustainable aviation fuels, energy-efficient technologies, and stringent emissions standards to reduce its environmental impact. Similarly, the shipping sector needs a phased implementation of emissions trading schemes like the EU ETS, supported by revenue reinvestment into decarbonization projects such as zero-emission vessels and electrified ports. These sectoral interventions must be complemented by measures to mitigate potential economic disruptions, particularly in regions heavily reliant on these industries.

Lastly, harmonizing these efforts with global sustainability objectives is critical. Policymakers should align emissions reduction strategies with the Sustainable Development Goals, particularly Goal 13 on climate action, Goal 10 on reducing inequalities, and Goal 8 on fostering decent work and economic growth. By incorporating these insights, international and national stakeholders can create policies that effectively balance the competing priorities of economic development, environmental sustainability, and social equity, ensuring that global efforts to combat climate change are both impactful and inclusive.

6.2 Limitations and Future Research

While this thesis provides valuable insights into emissions distributions and the role of key sectors in driving global CO_2 emissions, it is important to acknowledge certain limitations of the methodologies employed. The static input-output modeling framework, while effective for analyzing emissions at a macroeconomic level, inherently assumes fixed production technologies and proportional relationships between inputs and outputs. This rigidity limits its ability to capture dynamic adjustments and long-term changes in response to climate policies, technological advancements, or economic transitions. As such, while the results provide a robust snapshot of sectoral linkages and emissions flows, their application is most effective for short- to medium-term planning. Policymakers can leverage these insights to ensure that the systemic impacts of climate policies are well-understood before implementation, but they must remain cautious about the long-term applicability of these findings.

Another significant limitation of static input-output models is their inability to account for the heterogeneity of economic agents, such as households, firms, and governments, which can respond to climate policies in diverse ways. Future research could address these shortcomings by incorporating more sophisticated modeling approaches, such as dynamic Computable General Equilibrium (CGE) models and agent-based models (ABMs). Dynamic CGE models, for instance, are well-suited for simulating how policies evolve over time and influence sectors differently, accounting for shifts in technology, production practices, and policy mechanisms. These models can provide more nuanced insights into the distributional effects of emissions reductions on income, employment, and economic structure, offering a clearer picture of how decarbonization can be achieved without exacerbating social or economic inequalities.

In addition, ABMs could enhance the analysis by representing the heterogeneous behaviors of individual economic actors and exploring how they interact with one another under various policy scenarios. This approach is particularly useful for understanding the social equity implications of climate policies, ensuring that vulnerable populations are not disproportionately burdened by the transition to a low-carbon economy. By modeling the micro-level responses of different groups to climate interventions, ABMs could help design policies that are not only effective but also inclusive and equitable.

Another avenue for future research lies in extending the analysis of the EBT metric. While this thesis demonstrates the potential of EBT as a robust framework for assessing trade-related emissions, its application has been limited to cross-sectional analysis. Future studies could adopt a longitudinal perspective, analyzing temporal changes in EBT values to better understand how trade patterns and their environmental impacts evolve over time. Such an approach would provide deeper insights into the dynamics of trade-related emissions and help policymakers identify long-term trends that could inform more sustainable trade agreements.

Lastly, while the focus of this thesis has been on CO_2 emissions as a primary driver of climate change, future research should explore the broader environmental impacts of economic activities. Extending the analysis to include other dimensions such as greenhouse gas emissions, water usage, biodiversity loss, and land degradation would offer a more comprehensive perspective on global sustainability challenges. By adopting a comprehensive approach, future studies could provide more holistic recommendations for integrating environmental, social, and economic objectives into policy frameworks.

In summary, while this thesis contributes valuable insights to the understanding of emissions and global trade dynamics, addressing its methodological limitations and expanding its analytical scope will be critical for advancing research in this field. Incorporating dynamic and agent-based modeling, extending the temporal analysis of metrics like EBT, and broadening the scope of environmental impacts will ensure that future studies continue to provide actionable and equitable solutions to the challenges of climate change and sustainability.

6.3 Final Remark

In conclusion, this thesis emphasizes the urgent need for coordinated global action to address the dual challenges of climate change and economic development. By examining emissions embedded in international trade and key sectors like air transport and shipping, it underscores the complexities of balancing economic and environmental goals. The findings provide a foundation for designing policies that integrate environmental and social equity considerations, aligning with the broader shift toward "beyond GDP" frameworks. While reducing emissions in deeply embedded sectors poses significant challenges, the insights from this research highlight the potential for innovative policy measures and analytical tools to guide the transition. Moving forward, future research must adopt comprehensive approaches, including the use of more sophisticated modeling techniques, to address the dynamic and interconnected nature of climate change and globalization. These efforts are critical to crafting effective solutions that foster an inclusive and equitable transition to a low-carbon economy. Ultimately, addressing climate change requires not only technical and economic solutions but also a strong commitment to social justice, ensuring that global efforts are both sustainable and inclusive, paving the way for shared prosperity and environmental resilience.

As Berg & Ostry (2011)[1]wisely observed, “[...] a rising tide lifts all boats, and [...] helping raise the smallest boats may help keep the tide rising for all craft, big and small.” This encapsulates the core message of this research, by ensuring that the transition to a low-carbon economy is equitable and inclusive, the benefits of sustainability can be shared by all, fostering collective progress toward a more resilient and harmonious world.

[1] Berg, A. G., & Ostry, J. (2011). Equality and Efficiency. *Finance & Development*, 12-15.

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