CARBON EMISSIONS AND TRADE IN THE SOUTH, EAST, AND SOUTHEAST ASIA: A PANEL DATA APPROACH

A Thesis

Submitted to the Master's Study Program of Sustainable Finance at the Faculty of Economics and Business in partial fulfillment of the requirements for the degree of

Master of Finance (M.Fin.)

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by:

Abdul Saboor

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ABSTRACT

Abdul Saboor
03222320006
abdul.saboor@uiii.ac.id
Masters in Finance
Universitas Islam Internasional Indonesia

The relationship between trade and carbon emissions is a crucial component of global climate discourse, particularly for Asia's rapidly industrializing economies. Trade can either intensify environmental degradation through carbon leakage or serve as a channel for cleaner technologies and decarbonization. Understanding this duality is essential for designing effective, climate-aligned trade policy in the region. This thesis examines the impact of several trade factors on carbon emissions in thirteen countries spanning East, South, and Southeast Asia from 1990 to 2024, considering Asia's increasing emissions and reliance on exports. Employing a panel data methodology based on the Environmental Kuznets Curve (EKC), the Pollution Haven Hypothesis (PHH), and Pollution Halo effect Hypothesis frameworks, four distinct trade-emissions models are developed to evaluate the effects of total trade, merchandise trade, manufacturing exports, and agricultural exports independently. The principal independent variables comprise GDP per capita, power generated from renewable sources, and sector-specific tariff frameworks. The models are evaluated employing fixed effects and Driscoll–Kraay standard errors to guarantee robustness against heteroscedasticity, autocorrelation, and cross-sectional dependency. Empirical findings indicate that trade, especially in merchandise and agriculture, is significantly correlated with heightened emissions, notably in South Asia, where fertilizer use and fossil fuel transportation are prevalent. Conversely, manufacturing exports exhibit varied effects: emissions increase in East Asia while decreasing in ASEAN economies, characterized by more sustainable production methods. Renewable electricity consistently mitigates emissions across all scenarios, whereas tariff liberalization devoid of environmental protections exacerbates carbon leakage. The Environmental Kuznets Curve (EKC) is somewhat substantiated, particularly in the agricultural sector, where wealth development results in reduced emissions. Regionally, ASEAN demonstrates effective trade-emissions decoupling, East Asia reveals industrial vulnerability, and South Asia contends with enduring emission intensities associated with export expansion. Policy recommendations encompass the implementation of carbon-adjusted tariffs, regional Emissions Trading Systems (ETS), ESG-linked export incentives, and CBAM-style transport taxes to internalize embedded emissions. This study offers pragmatic approaches to align trade liberalization with climate objectives and enhances the developing dialogue on sustainable trade governance, green finance, and regional decarbonization plans in the Global South.

Keywords**:** *Carbon Emissions; International Trade; Renewable Electricity; Tariff Policy; East Asia; South Asia; Southeast Asia; Sustainable Finance*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX

ABBREVIATION DIRECTORY

ADB	*: Asian Development Bank*
ASEAN	*: Association of Southeast Asian Nations*
CBAM	*: Carbon Border Adjustment Mechanism*
ESG	*: Environmental, Social, and Governance*
ETS	*: Emissions Trading System*
EU	*: European Union*
FAO	*: Food and Agriculture Organization*
FDI	*: Foreign Direct Investment*
GVC	*: Global Value Chains*
PHEH	*: Pollution Halo Effect Hypothesis*
SAARC	*: South Asian Association for Regional Cooperation*
WTO	*: World Trade Organization*

CHAPTER I

INTRODUCTION

1.1 Background

The intricate relationship between trade, economic growth, and environmental sustainability has become a central issue in global climate policy discussions. While trade promotes economic integration and development, it also contributes significantly to environmental degradation, particularly through energy-intensive production, transportation, and industrial activities. As carbon dioxide (CO_2) emissions one of the main indicators of environmental impact continue to rise sharply in South and Southeast Asia, the need to reconcile trade expansion with climate goals has become increasingly urgent (Rahman et al., 2020; S. Wang et al., 2020).

Understanding the interplay between trade and emissions is especially important in rapidly industrializing regions. Despite geographic proximity and shared economic challenges, South Asia lags in trade integration. Intra-regional trade accounts for just 5.58% of total trade, compared to 23.56% in Southeast Asia. This disparity is largely due to weak infrastructure and inefficient logistics, which make it more expensive to trade within the region than with distant partners. For instance, it is 20% cheaper for India to trade with Brazil than with its neighbor Pakistan (Noor, 2019). Moreover, trade flows between ASEAN, China, and India are largely driven by macroeconomic variables GDP, population, and domestic policies rather than institutionalized regional agreements, highlighting structural limitations in integration efforts (Abbassy et al., 2025)

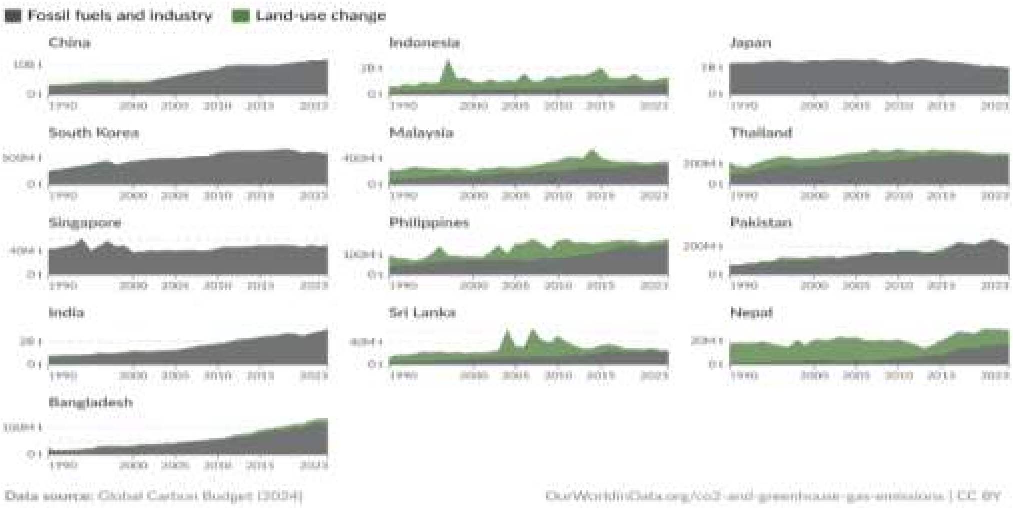

Figure 1. 1 Carbon Emission from Fossil fuels and Land use changes (Ritchie, 2022)

Trade is expected to play a critical role in Asia's path toward net-zero emissions. (Kim et al., 2023) argue for embedding trade into national climate policies by removing tariffs on green technologies, investing in carbon pricing mechanisms, and strengthening regional cooperation. Between 1995 and 2018, Asia's emissions linked to both production and consumption tripled. Notably, production-based emissions have outpaced consumption-based emissions, reflecting the region's role as a global manufacturing hub. With Asia accounting for 37% of global trade in 2021, its emissions profile has become closely tied to its trade-driven economic structure (Kim et al., 2023).

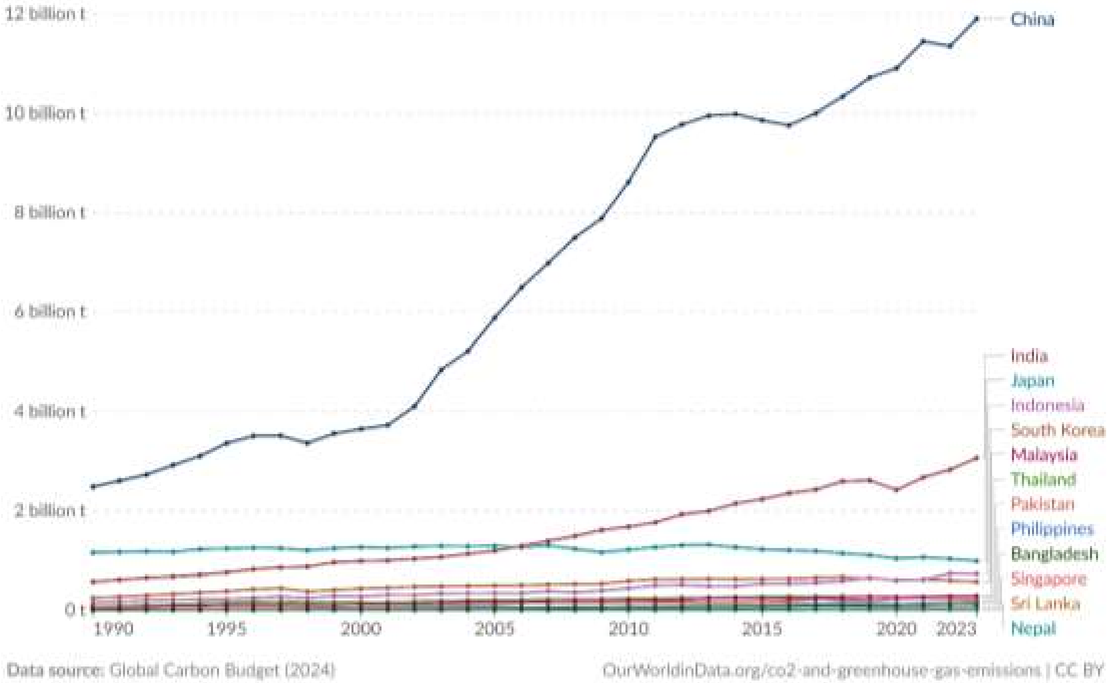

Figure 1. 2 Annual Carbon Emission (Ritchie, 2022)

South Asia, with nearly 2 billion people over 23% of the world's population, contributes only 3.8% to global GDP (approximately $2.9 trillion out of $75.6 trillion) (Noor, 2019). Economic growth in the region has often been fueled by trade openness, but this growth has come at significant environmental cost (Shaikh et al., 2024). In Pakistan, for example, trade openness initially raises CO_2 emissions through increased production (scale effect). However, over time, the adoption of cleaner technologies and increased efficiency helps reduce emissions (technique effect) (A. Khan & Safdar, 2022). Similarly, Southeast Asian economies under the ASEAN umbrella have experienced substantial trade-led growth, yet CO_2 emissions continue to rise, driven by heavy reliance on fossil fuels (Ahmed, Bhattacharya, et al., 2017).

Logistics, a critical enabler of trade, further adds to the region's carbon footprint. Its environmental impact necessitates an urgent shift toward green logistics and the integration of renewable energy sources into supply chains (Sikder et al., 2022). At the same time, rapid urbanization especially in Pakistan, India, China, and Indonesia has exacerbated environmental stress by increasing energy demand and CO_2 emissions. (Pan et al., 2023) emphasize that although trade liberalization can reduce emissions through technology transfer, weak environmental governance in many developing countries often results in carbon leakage. Since 1947, both Pakistan and India have industrialized through carbon-intensive pathways, underscoring the need for a transition toward low-carbon technologies.

Agriculture a cornerstone for South and Southeast Asian economies, introduces another layer of complexity. Climate variability poses significant threats to agricultural productivity and trade, as observed in Pakistan by (Y. Khan et al., 2019), where declining crop yields due to climate impacts jeopardize both economic stability and export potential. Moreover, trade in agricultural products has a dual environmental impact: while exports amplify emissions through intensified production, imports can mitigate domestic resource overuse, showcasing the need for a nuanced understanding of agricultural trade's environmental implications (J. Lu & Dai, 2023). (Villoria et al., 2024) further argue that agricultural trade can act as a buffer during climate shocks, but only if governments adopt supportive policies. They advocate for diversified imports, revised tariff frameworks, and climate-aligned support systems to maintain the resilience and sustainability of agricultural trade.

South and Southeast Asia including China and Japan epitomize the intricate relationship between trade liberalization and environmental sustainability. The phenomenon of "carbon leakage" underscores the displacement of emissions to nations with lenient environmental regulations, necessitating alignment between trade policies and environmental goals (Zhu et al., 2018). While trade's role in emissions has received considerable attention, there is still a lack of sector-specific analysis, particularly regarding logistics, manufacturing, and agriculture. For example, export-led growth in South Asia is often associated with increased energy consumption and emissions, primarily due to outdated infrastructure and dependence on traditional energy sources (Ahmed, Bhattacharya, et al., 2017; Chandra Parida & Sahoo, 2007).

Digital innovation in manufacturing presents a vital opportunity to separate economic progress from environmental harm. (Abbasi et al., 2024) emphasize that the implementation of digital technologies, shown by Canon Inc., resulted in a decrease of more than 435,000 tonnes of CO_2 emissions, concurrently enhancing corporate competitiveness and resource efficiency. This highlights the capacity for digital transformation to improve green manufacturing exports in Asia.

Furthermore, while countries like Pakistan attempt to address emissions through renewable energy projects and urban greening initiatives, these efforts are yet to achieve meaningful scale (Pan et al., 2023). While CBAMs may strengthen competitiveness in regulated economies, their effect on global emissions remains limited. (Tarr et al., 2023) recommend climate clubs and transnational green subsidies as more effective cooperative strategies to address carbon leakage and promote sustainable trade frameworks.

While significant research has explored the relationship between trade and emissions, gaps remain in understanding how specific sectors and regional dynamics influence this relationship. This study aims to contribute to this literature by examining the trade-emissions nexus across total trade, merchandising trade, agriculture export, and manufacturing export in East, South, and Southeast Asia regions central to global trade and increasingly vulnerable to climate risks.

1.2 Research Problem

Despite the prominence of East, South and Southeast Asia in global trade and their increasing contribution to carbon emissions, there remains a lack of comprehensive, sector-specific, and country-level analysis of the trade-emissions nexus. Existing studies emphasize the aggregate effects of trade on emissions but fail to explore the nuances across key sectors such as agriculture, and manufacturing. Moreover, the role of trade policies, energy sources, tariffs and carbon leakage in shaping emissions dynamics remains underexplored. This lack of granular insights hinders the formulation of targeted, sustainable trade policies and climate strategies for the region.

1.3 Research Questions

After reviewing and analyzing the findings previously available in the literature, the following research questions have been formulated in the context of East, South and Southeast Asian regions:

a) How does trade intensity influence carbon emissions across East, South and Southeast Asia?
b) What is the effect of merchandise trade, tariffs, and renewable energy use on carbon emissions in East, South, and Southeast Asia?

c) What is the impact of manufacturing exports, manufacturing tariff and renewable technology on carbon emissions in the region?
d) How does agricultural export, combined with renewable energy and agriculture value addition, affect carbon emissions?

1.4 Research Objectives

a) To examine the relationship between aggregate carbon emissions and trade intensity in East, South, and Southeast Asia.
b) To investigate the contributions of merchandise trade, manufacturing export, and agricultural export to the emissions.
c) To analyze the influence of energy sources and trade policies on emissions trends.
d) To provide policy recommendations for aligning trade-driven economic growth with environmental sustainability.

1.5 Significance of the Study

This study addresses critical gaps in understanding the trade-climate relationship in East, South, and Southeast Asia, offering the following contributions:

a) Policy Formulation: Insights from this research will guide policymakers in designing sustainable trade policies that balance economic growth with environmental stewardship.
b) Sector-Specific Strategies: By highlighting the sectoral contributions of agriculture, manufacturing, and logistics, the study will support targeted interventions for emissions reduction.
c) Energy Transition: The analysis of energy sources and trade policies will provide actionable recommendations for adopting clean energy and green logistics.
d) Regional Collaboration: The study underscores the need for enhanced regional cooperation to address carbon leakage and foster sustainable trade practices.

1.6 Research Outline

This thesis is structured into five chapters, each contributing to the systematic investigation of carbon emissions and trade dynamics in South, East, and Southeast Asia from 1990 to 2024. The study begins with an introductory chapter that establishes the background and context of the research, emphasizing the relationship between trade, tariffs, economic growth, and carbon emissions in the region. It highlights the need for sector-specific insights into the trade emissions nexus and presents the research problem, objectives, and questions, while also outlining the significance of the study. The second chapter reviews the existing academic literature, addressing key concepts and definitions related to trade, carbon emissions, and environmental challenges. It discusses critical frameworks such as green trade, sustainable energy transitions, tariff policies and the impact of trade on carbon leakage. Additionally, this chapter identifies research gaps, particularly the need for sectoral and country-level analyses, thereby justifying the study's importance. The third chapter focuses on the research methodology, detailing the research approach adopted for the study. It describes the data collection methods, data sources, sampling techniques, and econometric models employed for the analysis. The chapter further elaborates on the research design, along with the instruments used for data gathering and the techniques applied for empirical validation. Following this, the results and discussion chapter presents the findings of the data analysis using appropriate visual aids such as tables, graphs, and charts for enhanced clarity. It interprets these results considering the research objectives and questions, providing an in-depth analysis of the study's hypotheses and their implications. The findings are also linked to existing literature, and the results are debated within the context of trade emissions dynamics in the region. Finally, the conclusion and recommendations chapter synthesize the key findings of the study and assesses the hypotheses based on the results. It offers a comprehensive conclusion, reflecting on the implications for trade policies, environmental strategies, and regional collaboration. This chapter also discusses the limitations of the research and provides actionable recommendations for future studies, identifying unexplored areas that could benefit from further investigation.

CHAPTER II

LITERATURE REVIEW

This chapter reviews existing literature exploring the relationship between carbon emissions and international trade, with a focus on South and Southeast Asia. It aims to highlight key findings, methodologies, and gaps in current research while positioning the present study to address these gaps. The studies reviewed span various dimensions, such as the impacts of carbon emissions on trade, the role of trade liberalization, sectoral dynamics, and the implications of policy frameworks.

2.1 Theoretical Foundation

This study is grounded in the Environmental Kuznets Curve (EKC) Hypothesis, which posits an inverted U-shaped relationship between environmental degradation and economic growth. Initially, economic growth leads to increased emissions, but beyond a certain income level, cleaner technologies and stronger environmental regulations reduce emissions (Grossman & Krueger, 1995; Jóźwik et al., 2022; Murshed & Dao, 2022).

Additionally, this study integrates concepts from the Pollution Haven Hypothesis (PHH), which suggests that trade liberalization may shift pollution-intensive industries to developing countries, increasing their carbon emissions (Abbas et al., 2024; Copeland & Taylor, 1994; Tarr et al., 2023). These theories frame the investigation of trade-carbon interactions, considering the dual influence of economic growth and trade policies.

Complementing this, the Pollution Halo effect Hypothesis (PHEH) offers a contrasting perspective proposing that foreign trade and investment can transfer cleaner technologies and better environmental practices to host countries, thereby improving environmental quality despite increased trade activity (Barrows & Ollivier, 2021; Eskeland & Harrison, 2003; J. Wang & Li, 2021). This theory implies that trade may play a mitigating role under the right regulatory and technological conditions.

Together, these theoretical frameworks guide the study's examination of the complex trade–carbon emissions nexus, accounting for both the potential benefits and drawbacks of economic openness in the context of sustainable development.

2.2 Regional Context: East, South and Southeast Asia

East, South, and Southeast Asia represent regions with distinct trade patterns and economic dynamics, but they share common challenges in balancing economic growth and environmental sustainability. Studies like (Ahmed, Rehman, et al., 2017; Dua et al., 2024;

Fatima et al., 2022) highlight how trade openness and energy consumption significantly contribute to CO_2 emissions in South Asia, reflecting the trade-off between economic growth and environmental quality. In Southeast Asia, (Ahmed, Bhattacharya, et al., 2017; Tran et al., 2024) emphasize the role of FDI and regional integration in both driving emissions and facilitating the adoption of cleaner technologies. The Belt and Road Initiative (BRI) has further reshaped trade networks, as (Hu et al., 2020; A. U. Khan, 2020) note its influence on carbon emission efficiency and fossil fuel reliance in energy-intensive industries. East Asia, particularly China, emerges as a focal point in global trade and emissions, with (B. Lu et al., 2023; S. Wang et al., 2020) detailing the region's significant contributions to emissions from shipping and industrial exports. At the intersection of these regional trends, (Christodoulou & Cullinane, 2024; Shepard et al., 2022) explore the potential of carbon pricing mechanisms like Emission Trading Systems (ETS) and green technologies to mitigate emissions across trade sectors. These studies collectively underscore the need for comprehensive, region-specific policies to decarbonize trade while ensuring sustainable economic growth.

2.3 Thematic Review of Literature

2.3.1 Carbon Emissions and Agricultural Exports

(Y. Khan et al., 2019) analyzed the influence of carbon emissions on Pakistan's agricultural export trade using time-series data (1975–2017) by using FMOLS and DOLS methodologies, revealing a negative relationship between CO_2 emissions and agricultural exports. This finding underscores the detrimental effects of carbon emissions on trade competitiveness in agriculture, emphasizing renewable energy and energy-efficient practices. (Dinda, 2014) highlighted the untapped potential for climate-friendly goods (CFGs) trade in South Asia, identifying Pakistan, Sri Lanka, Bangladesh and India as major contributors. The findings underscore the need for trade policies promoting low-carbon agricultural technologies.

2.3.2 Carbon Emissions, Trade Liberalization, Urbanization

The relationship between carbon emissions, trade liberalization, urbanization, and population growth has been a key focus of several studies in South and Southeast Asia. (Shaikh et al., 2024) examined the impact of trade liberalization, economic growth, FDI inflows, and urbanization on carbon emissions across South Asian economies from 1990 to 2022. The study found a positive correlation between trade and carbon emissions, offering a valuable perspective on trade's environmental costs. Similarly, (Rahman et al.,

2020) identified that CO_2 emissions and population density positively impact economic growth, while trade openness has a negative effect, highlighting the complexity of trade's impact on emissions. (Ahmed, Bhattacharya, et al., 2017; S. Wang et al., 2020) extended these findings, exploring sector-specific emission dynamics within trade structures, particularly in the context of ASEAN and China. (Wu et al., 2022) further contributed by analyzing how emission transfers through trade patterns, such as onshoring and offshoring, shape national emission policies. (Pan et al., 2023) found that energy consumption and trade play a significant role in reducing emissions, especially through technology transfer in Pakistan, though urbanization's effect remained inconclusive. (B. Lu et al., 2023) also emphasized trade's role in increasing agricultural carbon emissions in China, dependent on the intensity of environmental regulations. (Ahmed, Bhattacharya, et al., 2017) highlighted how non-renewable energy consumption drives environmental degradation in ASEAN economies, particularly through trade integration and transportation sector emissions. (Tran et al., 2024) found that the CO_2 gap between countries significantly influences trade patterns within ASEAN, supporting the Pollution Haven Hypothesis and pointing to trade's role in exacerbating emissions from export-intensive activities. (Chandra Parida & Sahoo, 2007; Dharmapriya et al., 2024) both emphasized the role of economic growth and trade in shaping carbon emissions, specifically analyzing how trade openness, urbanization, and energy consumption impact emissions across Asia. The study by (Ahmed, Rehman, et al., 2017) confirmed that energy consumption, trade openness, and population density positively contribute to CO_2 emissions in South Asia, while income has a negative effect, aligning with the Environmental Kuznets Curve. The current study extends this body of work by examining the direct relationship between carbon emissions and international trade across a broader temporal scale (1990–2024), incorporating more countries from East, South, and Southeast Asia to offer a comprehensive understanding of carbon-trade dynamics in the region. This broader scope allows for a more detailed exploration of how trade openness, tariffs, energy composition and economic growth contribute to carbon emissions in the context of rapidly growing Asian economies.

2.3.3 Global Trade, Climate Policies and Governance Implications

Several studies emphasize the critical role of policy in mitigating carbon emissions and the interplay between trade policies and climate regulations in shaping global trade networks. (Salman et al., 2018) examined the relationship between Free Trade Agreements (FTAs) and carbon dioxide emissions in Pakistan, finding that trade openness has a long-term negative effect on emissions, while energy consumption significantly drives emissions. This highlights the complex balance between trade and environmental policy, a relationship that this study expands upon by incorporating a broader regional perspective, covering South and Southeast Asia. Similarly, (Tariq et al., 2022) found that trade and economic growth contribute to greenhouse gas emissions in South Asia, while green technologies and energy efficiency measures can mitigate this impact. (Christodoulou & Cullinane, 2024) focused on the potential of Emissions Trading Systems (ETS) in the shipping industry, highlighting their capacity to drive investment in green technologies, though the impact varies across market segments. (B. Lu et al., 2023) extended the decarbonization discourse to global maritime container shipping, noting Asia's major role in emissions and stressing the need for energy efficiency and clean energy transitions to meet net-zero targets by 2050. Meanwhile, (Shepard et al., 2022) explored the effects of carbon taxes on global energy trade networks, finding that such taxes significantly reduce emissions and diversify trade linkages, thus improving energy security and climate outcomes. (Fatima et al., 2022) provided insights into Pakistan's energy consumption and trade's role in CO2 emissions, underscoring the environmental trade-offs inherent in economic growth. While these studies focus on specific regions or industries, they collectively emphasize the need for comprehensive, regionally tailored policy frameworks to balance trade, energy consumption, and carbon emissions. This study seeks to fill a gap by offering a long-term, multi-sectoral analysis of the interplay between trade and emissions in South and Southeast Asia, providing nuanced policy recommendations for fostering sustainable economic growth in the region.

2.3.4 Broader Studies on Trade and Environmental Interactions

(Zhu et al., 2018) explored the characteristics of embodied CO2 emissions in global trade, proposing a shared responsibility principle. While this study focuses on major economies, it provides valuable insights for understanding trade-carbon dynamics. Similarly, (Abbas et al., 2024) investigated globalization's effects on carbon emissions, emphasizing the importance of renewable energy in mitigating adverse environmental impacts. (Murshed & Dao, 2022) confirmed the EKC hypothesis for Bangladesh and India, showing that economic growth initially increases emissions but eventually reduces them, with export quality playing a key role in reducing emissions. (Dua et al., 2024) found that exports and FDI reduce emissions, but high-energy imports contribute to increased emissions in South Asia. (Jóźwik et al., 2022) supported the EKC hypothesis for India and Pakistan, highlighting the significant role of energy consumption in emissions, especially in Pakistan. These studies underline the importance of trade dynamics, export quality, and energy consumption in shaping emissions in South Asia, with a gap in analyzing specific trade flows' direct contribution to emissions.

2.3.5 Logistics and Emission Reduction

(Sikder et al., 2022) explored the relationship between logistics performance, economic growth, FDI, international trade, and CO2 emissions in RCEP and SAARC economies by using EGLS and GMM methodologies. Their study found that economic growth and trade positively influence logistics performance, while renewable energy mitigates emissions in transport logistics. This study highlights the indirect role of logistics in carbon emissions but overlooks direct trade-carbon linkages, a gap this research aims to address.

2.3.6 Renewable Energy and Carbon Emission

(Ullah et al., 2020) found that renewable energy mitigates CO2 emissions and reduces health expenditures in Pakistan, emphasizing its dual benefits in improving public health and environmental quality. Similarly,(A. U. Khan, 2020) highlighted the role of renewable energy in reducing emissions across developing countries and its long-term relationship with economic growth and another study by (Huang et al., 2022) in the ASEAN region analyze the impact of trade, urbanization and environmental degradation on renewable energy and highlight the dual influence of economic activities and institutional factors on renewable energy adoption in the region. This study builds on these insights by examining the broader trade-carbon emissions nexus in East, South and Southeast Asia, with a focus on sectoral and temporal dynamics.

2.3.7 Additional Previous Research

Table 2.1 Additional Literature

No	Author	Title	Data	Method	Findings
1	(Zhou et al., 2025)	"The Impact of Trade Openness on Carbon Emissions: Empirical Evidence from Emerging Countries"	Panel data (2003–2020); World Bank	FMOLS, DOLS, Driscoll–Kraay	Trade openness reduces CO_2 in the long run; energy use increases it.
2	(Rahman & Alam, 2022)	"CO2 Emissions in Asia–Pacific Region: Do Energy Use, Economic Growth, Financial Development, and International Trade Have Detrimental Effects?"	Unbalanced Panel (1960–2020); 17 APEC countries; WDI	Driscoll–Kraay, PCSE	Energy, trade, and GDP raise CO_2; finance impact ambiguous.
3	Zhang et al. (2025)	"Unveiling the environmental impact of corn production in China: evidence from panel ARDL approach"	Panel (1990–2022); China Agri Stats	PMG-ARDL, PQR, PLSQR	Fertilizer, water use, and credit are key CO_2 drivers.
4	Appiah et al. (2022)	"The causal nexus between trade openness and	Panel (1971–2013); WDI	Driscoll–Kraay (pooled OLS)	Imports, GDP raise CO_2; exports reduce it.

		environmental pollution in selected emerging economies”			
5	Liu et al. (2020)	“Can China reduce the carbon emissions of its manufacturing exports by moving up the global value chain?”	Panel (1995–2009); WIOD; 14 industries	Decomposition, panel regression	Manufacturing raises CO_2; moving up GVC helps reduce it.
6	Nwosu et al. (2024)	“Carbon Emissions & Trade in Sub-Saharan Africa”	Panel (1980–2020); 41 countries	Dynamic panel threshold model	CO_2-trade relationship is nonlinear; thresholds matter.
7	Wang (2010s)	“Emissions Transfer: Sino-US Trade Carbon Emission Transfer by International Trade: Taking the Case of Sino—U.S. Merchandise Trade as an Example”	Bilateral trade data (1997–2002); GTAP	Input–Output EEBT	China exports more CO_2 to US than it imports.
8	Yamano & Guilhoto (2020)	“CO2 emissions embodied in international trade and domestic final demand”	OECD-ICIO (2005–2015); 65 countries	EEIO model	Developed country imports carry more CO_2.

9	Zhang et al. (2023)	“Carbon emissions from international trade and consumption Assessing the role of cumulative risk for EU and Chinese economic development”	2011–2021; Our World in Data	Econometric hypothesis testing	Trade restrictions reduce CO_2 in EU; increase it in developing countries.
10	Al-mulali & Sheau-Ting (2014)	“Econometric analysis of trade, exports, imports, energy consumption and CO2 emissions in six regions”	Panel (1990–2011); 189 countries	FMOLS (panel long-run)	Trade increases CO_2 in all regions except Eastern Europe.
11	Fang et al. (2019)	“Effects of the export product quality on carbon dioxide emissions: evidence from developing economies”	Panel (1970–2014); 82 countries	Panel fixed effects	High export quality raises CO_2; supports EKC.
12	Andrikopoulos (2025)	“ESG in the shipping industry a literature review”	Literature review of 94 papers	Semi-systematic review	Focus on "E"; ESG poorly integrated in shipping sector.
13	Wang & Li (2021)	“Exploring the Impact of International Trade on Carbon Emissions: New Evidence from	Panel (2003–2016); China City Stats	Fixed effects, Driscoll–Kraay	Exports reduce CO_2; imports increase it; nonlinear effects.

		China's 282 Cities"			
14	Barbalet et al. (2015)	"Exploring the Links between Bilateral and Regional Trade Agreements and Merchandise Trade"	Panel (1970–2008); 140 countries	Gravity model with fixed effects	BRTAs raise internal trade, may reduce external trade.
15	Mester et al. (2023)	"Exploring The Relationship Between Economic Growth, Trade Openness, Co2 Emissions, And Renewable Energy: Evidence from Eastern European Countries"	Panel (1995–2019); WDI	ARDL Panel	Trade & GDP raise CO_2; renewables reduce it.
16	Barrows & Ollivier (2021)	"Foreign demand, developing country exports, and CO2 emissions: Firm-level evidence from India"	Firm-level (1995–2011); CMIE Prowess	Shift-share IV	Foreign demand raises CO_2; 40% offset by tech upgrades.
17	Ali et al. (2015)	"The Effect of International Trade on Carbon Emissions:	Time-series (1980–2010); Pakistan	VAR, Granger causality	Bi-directional causality between trade and CO_2.

		Evidence from Pakistan”			
18	Chen et al. (2021)	“Trade Openness and CO2 Emissions: The Heterogeneous and Mediating Effects for the Belt and Road Countries”	Panel (2001–2019); 64 BRI countries	Panel quantile regression	Trade openness increases CO_2; effects vary by region.
19	Ling et al. (2020)	“Trade Openness and Environmental Degradation in Asean-5 Countries”	Panel (1995–2014); 5 ASEAN countries	Pedroni cointegration, Granger causality	Bi-directional causality between trade and CO_2 confirmed.
20	Shepherd & Wilson (2009)	“Trade facilitation in ASEAN member countries: Measuring progress and assessing priorities”	Cross-sectional (2000–2006); Doing Business data	Gravity model	Trade flows rise with transport & ICT; no CO_2 focus.
21	Ho & Iyke (2019)	“Trade Openness and Carbon Emissions: Evidence from Central and Eastern Europe”	Panel (1994–2014); 17 CEE countries	Dynamic fixed effects	High trade openness reduces CO_2 in long run.
22	Bakri et al. (2025)	“Trade openness and carbon emissions using threshold	Panel (2000–2019); 22	Panel quantile regression	Inverted U-shaped trade–CO_2 relationship.

		approach: evidence from selected Asian countries”	Asian countries		
23	(Saboor et al., 2025)	“Renewable Energy Consumption and Its Role in Driving Green Economic Growth in BRICS Nations”	Panel (1995–2021), BRICS countries	PMG-ARDL (Pooled Mean Group – Autoregressive Distributed Lag)	Renewable energy consumption, trade openness, and GDP per capita significantly promote long-term green economic growth. In the short run, only GDP and trade openness remain significant.

2.4 Explanation of the Conceptual Framework

The conceptual framework highlights the interconnected relationships among key variables influencing carbon emissions and addresses critical gaps in the existing literature. Many studies focus on aggregate trade-emissions dynamics but often overlook sector-specific nuances and the moderating roles of energy composition and policies (Tariffs). Grounded in theoretical foundations such as the Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH), and Pollution Halo effect Hypothesis, the framework captures the complex interplay of economic, social, and environmental factors shaping carbon emissions in trade-intensive economies. Economic growth, measured by GDP in current USD, drives energy demand and industrial activity, leading to increased carbon emissions during the early stages of development. However, consistent with the EKC hypothesis, higher levels of economic growth eventually enable investments in cleaner technologies and energy-efficient practices, reducing emissions over time. Trade intensity, calculated as the ratio of imports and exports to GDP, amplifies emissions by driving energy-intensive production and transportation. Simultaneously, trade facilitates technology transfer, allowing economies to adopt cleaner and more efficient production techniques.

Energy composition, represented by the share of coal, oil, and renewable energy in total electricity production, directly impacts emissions. A higher reliance on fossil fuels exacerbates emissions, whereas increased adoption of renewable energy mitigates them, underscoring the importance of energy-related policies. Population size also influences emissions by driving energy demand, urbanization, and increased sectoral trade activities such as manufacturing and agriculture, which are often emission intensive. Population growth intensifies these pressures unless moderated by sustainable practices and policy interventions. Policy variables, including tariffs, and renewable energy incentives, play a crucial role in regulating emissions. Policies incentivizing renewable energy encourage cleaner energy use, while taxes and tariffs help regulate trade activities to control emissions. These policy variables are inherently dynamic and contribute to feedback mechanisms within the framework, where higher emissions lead to stricter policies, and these policies reshape energy composition, trade practices, and sectoral growth.

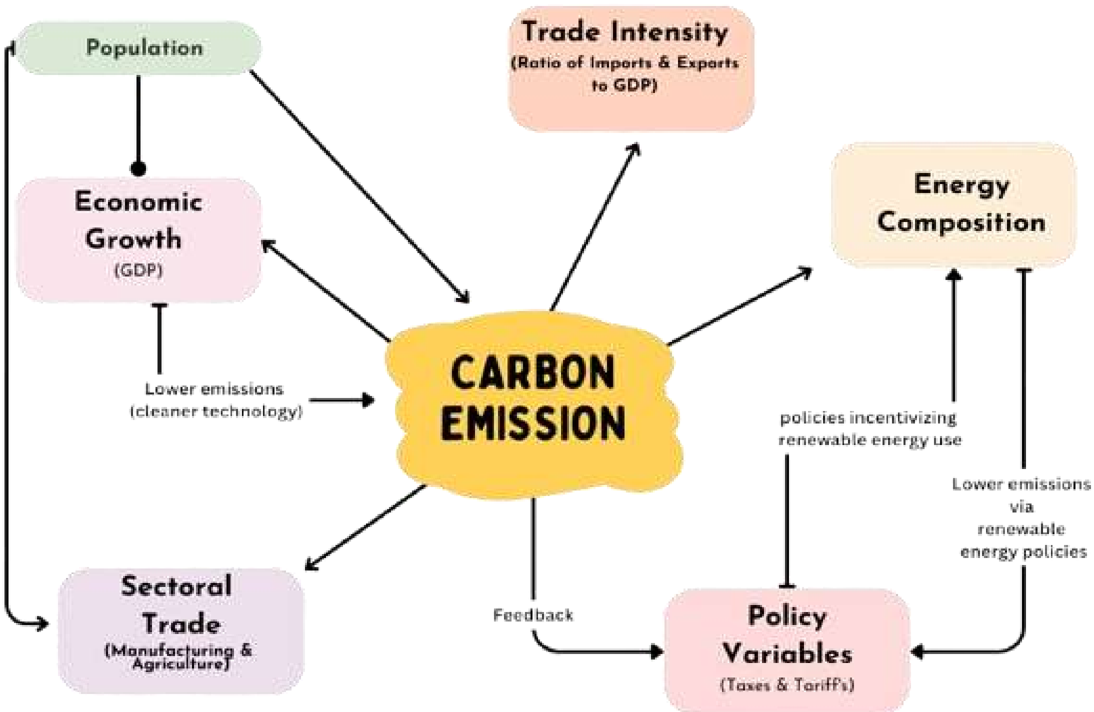

Figure 2.1 Conceptual Framework of Carbon Emission

By emphasizing the relationships among economic growth, trade intensity, energy composition, population dynamics, and policy variables, this framework provides a holistic understanding of carbon emissions. It incorporates sector-specific nuances, such as manufacturing and agriculture, and addresses the critical role of policy interventions, thereby bridging significant gaps in existing research. The framework integrates these variables through dynamic feedback loops, illustrating how rising emissions often trigger stricter policies, which, in turn, influence energy usage, trade practices, and overall economic dynamics. This comprehensive approach offers a robust basis for examining carbon emissions in trade-focused economies.

2.5 Hypotheses Linked to the Framework

a) H1: Trade intensity, GDP per capita, renewable electricity, and tariffs may have a significant impact on carbon emissions.
b) H2: Merchandise trade, GDP per capita, renewable electricity, and tariffs may have a significant impact on carbon emissions.
c) H3: Manufacturing trade, GDP per capita, renewable electricity, and tariffs may have a significant impact on carbon emissions.
d) H4: Agricultural trade, GDP per capita, renewable electricity, and agricultural value addition may have a measurable relationship with carbon emissions.

2.6 Gaps in Existing Literature

While these studies provide significant insights, several gaps remain, while extensive research has been conducted on the relationship between trade, carbon emissions, and economic growth, critical gaps remain, particularly in the context of East, South and Southeast Asia. Most existing studies focus on limited timeframes, single sectors, or specific countries, failing to provide comprehensive regional analysis. For instance, studies by (Ahmed, Rehman, et al., 2017; Rahman et al., 2020) validate the Environmental Kuznets Curve (EKC) hypothesis for selected South Asian countries but do not account for energy composition or sectoral trade patterns. Similarly, (Tran et al., 2024) emphasizes trade-related emissions in ASEAN but overlooks the moderating role of energy sources and policy interventions in shaping emissions.

Additionally, the role of energy composition electricity generated from coal, oil, and hydro as a determinant of trade-related emissions remains underexplored in the literature. Studies such as (Huang et al., 2022) and (A. U. Khan, 2020) highlight the importance of renewable energy but lack integration of sector-specific energy use and its interaction with trade policies. This gap is particularly significant for understanding emissions in energy-intensive sectors like manufacturing and agriculture, where trade and energy consumption are closely linked.

Moreover, few studies investigate the impact of trade intensity and policy variables (e.g., taxes and tariffs) on emissions comprehensively. While (Ullah et al., 2020) discusses the dual role of renewable energy in reducing emissions and improving public health, the relationship between population growth, trade, and energy use is insufficiently examined in a regional context. Existing research also suffers from temporal limitations, with studies like (Huang et al., 2022) analyzing shorter timeframes (e.g., 1980–2018) and failing to capture the long-term effects of evolving trade policies and global climate agreements.

2.7 Positioning of Current Study

To address these gaps, the current study:

a) Incorporates long-term data (1990–2024) to provide a comprehensive temporal analysis of trade-emissions dynamics in South and Southeast Asia.
b) Analyzes the role of sectoral trade (manufacturing and agriculture) and energy composition (electricity from coal, oil, and hydro) in shaping carbon emissions.
c) Integrate trade intensity and policy variables (taxes and tariffs) to explore their moderating effects on emissions.
d) Examine the interaction between population growth, trade patterns, and energy consumption, providing actionable insights into the trade-environment nexus.

By addressing these gaps, this research offers a more holistic understanding of the carbon-trade relationship, accounting for regional diversity, long-term trends, and sectoral impacts to inform sustainable trade and energy policies.

CHAPTER III

METHODOLOGY

This chapter examines the principles of research methodologies, data acquisition, and analytical procedures for data interpretation. Consequently, acquiring precise and relevant data is crucial for any empirical research, and we examine diverse methodologies and factors for efficient data gathering. Panel data analysis enables the examination of several facets of the relationship between trade flow among regions. Panel data helps the factors influencing trade flows, whereas facilitates the examination of how these interactions develop over time and among various nations.

The main reason for employing this research methodology in this study is the complex and multi-regional character of the research issues. Quantitative research may not encompass the comprehensive aspects of trade dynamics, whereas the qualitative approaches require greater generalizability. By integrating qualitative analysis with qualitative insights, we can transcend the limitations of each method and fully leverage their intrinsic benefits. This chapter will delineate the research methodology, the econometric model, a synopsis of the literature review, and the data gathering techniques employed in this study. Figure 3.1 illustrates the research process distinctly.

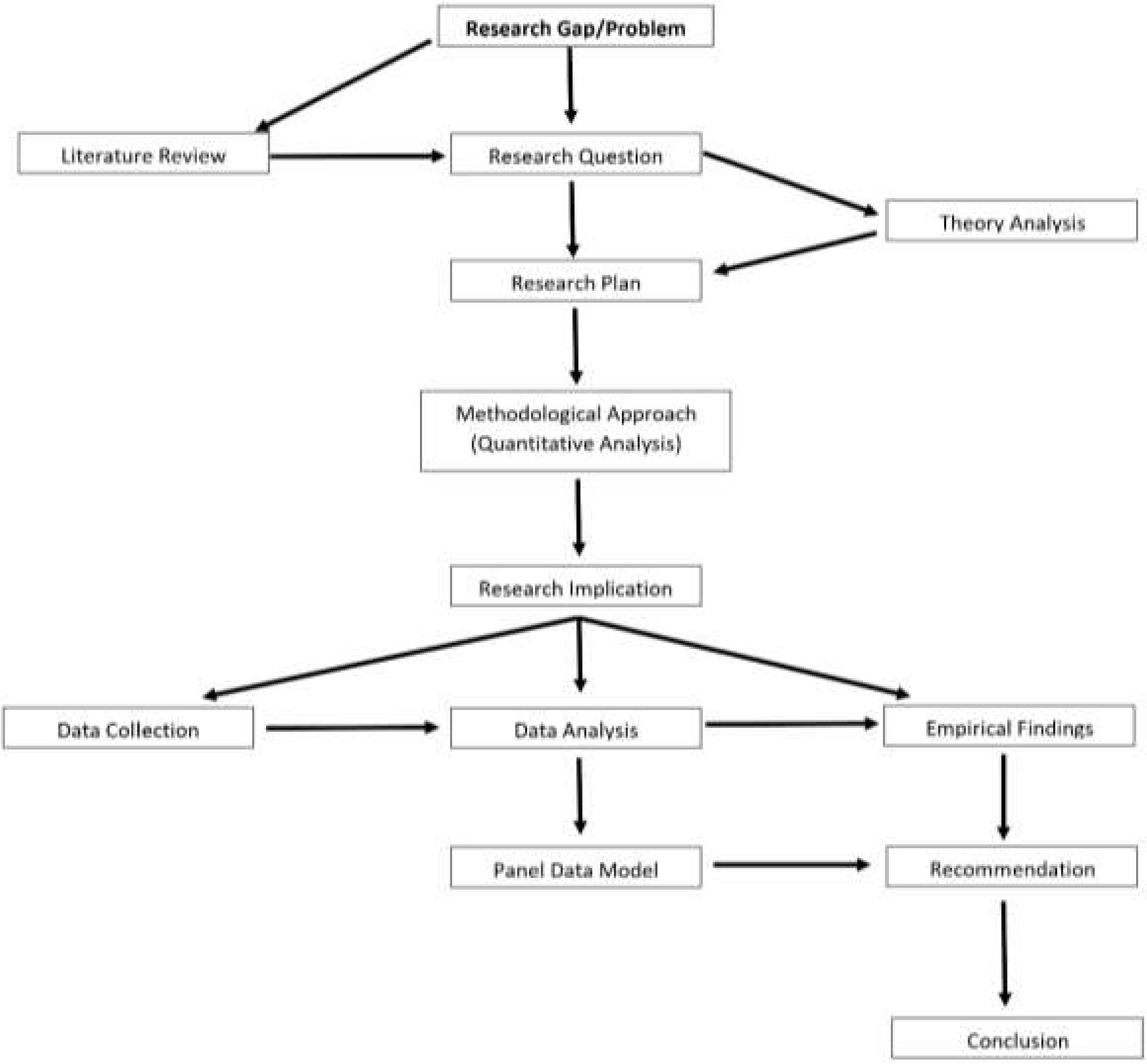

Figure 3.1 Research Chart (Author Computation)

3.1 Data Sources and Study Scope

The data for this study is sourced from the World Bank database, Trade Map, WTO, OECD, Our World in Data, Climate Watch, FAO and esteemed literature, covering the period from 1990 to 2024 for the following 3 regions and 13 countries:

A. South Asia: Pakistan, Bangladesh, India, Nepal and Sri Lanka
B. Southeast: Indonesia, Malaysia, Philippines, Thailand, Singapore
C. East Asia: China, South Korea and Japan

This dataset includes trade, economics, energy, and environmental indicators, providing a comprehensive basis for analyzing the carbon-trade nexus in the region. This study ensures a comprehensive and rigorous analysis by incorporating existing research on the region's economic and financial integration and trade flows. Moreover, the selected variables for inclusion in the investigation have been identified prior by other scholars

(Ahmed, Rehman, et al., 2017; Bakri et al., 2025; Dharmapriya et al., 2024; Dua et al., 2024; Ho & Iyke, 2019; Islam et al., 2019; J. Lu & Dai, 2023; Zhu et al., 2018).

3.2 Data Description

This section explains the data description, which includes the nature of variables, codes, measurement units, and data sources. The independent variables consist of various trade-related indicators. These variables are crucial to understanding how international trade, sectoral contributions, and policy measures influence carbon emissions across the region. The dependent variable carbon emissions (CO2) are aggregated from several sources as a proxy variable of Scope 1 Emissions.

Table 3.1 Variable definition

Nature	Variables	Definition	Unit of measurements	Source of data
Dependent	LN_TCO	"Total Carbon - Carbon dioxide (CO2) emissions (total) excluding LULUCF (Mt CO2e)"	Metric Ton	World Bank
Dependent	LN_MCO	"Manufacturing Carbon - Carbon dioxide (CO2) emissions from Industrial Processes (Mt CO2e)"	Metric Ton	World Bank
Dependent	LN_ACO	"Agriculture Carbon - Carbon dioxide (CO2) emissions from Agriculture (Mt CO2e)"	Metric Ton	World Bank
Independent	LN_TTR	"Total Trade - Imports of goods and services (current US$) Exports of goods and services (current US$)"	US Dollars	WTO
Independent	MTR	"Merchandise trade (% of GDP)"	US Dollars	World Bank
Independent	MEXP	"Manufactures exports (% of merchandise exports)"	Percent	World Bank
Independent	LN_AEXP	"Agriculture exports (1000 USD)"	US Dollars	FAO
Independent	LN_GDP	"GDP Per Capita"	US dollars per capita	World Bank
Independent	ERNE	"Electricity production from renewable sources, excluding hydroelectric (% of total) Electricity production from hydroelectric sources (% of total)"	Percent	Our World in Data

Independent	ATRF	“Tariff rate, applied, weighted mean, all products (%)’’	Percent	WTO
Independent	MTRF	“Tariff rate, applied, weighted mean, manufactured products (%)’’	Percent	WTO
Independent	PTRF	“Tariff rate, applied, weighted means, primary products (%)’’	Percent	WTO
Independent	LN_AVA	“Agriculture, forestry, and fishing, value added (constant 2015 US$)’’	US Dollars	World Bank
Control	LN_FER	“Fertilizer consumption (kilograms per hectare of arable land)’’	Kilograms per hectare	World Bank
Control	FIMP	“Food imports (% of merchandise imports)’’	Percent	World Bank
Control	FFC	“Fossil fuel energy consumption (% of total)’’	Percent	Our World in Data
Control	IVA	“Industry (including construction), value added (% of GDP)’’	Percent	World Bank
Control	LN_ENU	“Energy use (kg of oil equivalent) per $1,000 GDP (constant 2021 PPP)’’	kg per $1,000 GDP	Our World in Data
Control	LN_EXC	“Official exchange rate (LCU per US$, period average)’’	US Dollars	World Bank
Control	LN_TRT	“Net barter terms of trade index (2015 = 100)’’	index (2015 = 100)	World Bank
Control	LN_URP	“Urban population’’	number of people	World Bank
Dummy	Asean	“Dummy variable equal to 1 if country *i* belong to the ASEAN region; 0 otherwise’’	Binary (0 or 1)	Asean Stat
Dummy	South Asia	“Dummy variable equal to 1 if country *i* belong to the South Asia region; 0 otherwise”	Binary (0 or 1)	South Asia Stat
Dummy	East Asia	“Dummy variable equal to 1 if country *i* belong to the East Asia region; 0 otherwise”	Binary (0 or 1)	East Asia Stat

In this study, we seek to understand how various dimensions of a country’s trade profile influence its carbon-emissions trajectory. To that end, our data description is organized around three broad categories: (1) independent (trade) variables, (2) dependent (emissions) variables, and (3) control and policy or mediating variables. Below, we describe each group in narrative form, explaining how and why they are employed in our four empirical models.

3.2.1 Independent Variables: Capturing Trade Intensity and Composition

This study employs a model-specific structure to investigate the link between carbon emissions and key financial and trade drivers in East, South, and Southeast Asia. Each of the four econometric models is tailored to test a specific hypothesis (H1–H4), grounded in the Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH) and Pollution Halo effect Hypothesis frameworks. Accordingly, the selection of independent variables reflects different channels through which trade, energy, and policy structures influence emissions outcomes.

To examine the general effect of trade openness on emissions, Model 1 includes the logarithmic form of total trade (LN_TTR), calculated as the sum of exports and imports of goods and services in current USD. This variable serves as a proxy for trade intensity and globalization. An increase in LN_TTR reflects greater production, transportation, and energy use, which may drive up emissions. It is central to testing H1: whether trade intensity significantly affects emissions and whether other factors mitigate this link. GDP per capita (LN_GDP), measured in USD per person, is included to control for income effects and test for the EKC hypothesis, wherein emissions may initially rise with income but later decline once a country reaches a certain level of development. Renewable electricity production (ERNE) is used to assess the energy transition pathway. This variable measures the percentage of electricity generated from renewables technology and reflects structural decarbonization efforts. Its inclusion helps test whether energy composition mitigates the emissions impact of trade and income growth. Lastly, tariff rates applied for all products (ATRF), expressed as a weighted mean percentage, serve as a trade policy control. Lower tariffs may facilitate greater trade openness but could also increase emissions by stimulating pollution-intensive sectors. Thus, ATRF is included to explore the policy dimension of trade-emissions linkages

Model 2 replaces the total trade measure with merchandise trade as a share of GDP (MTR), which captures the structural dependence of an economy on tangible goods such as machinery, electronics, or raw materials. Unlike absolute trade volumes, this ratio normalizes for economic size and highlights the significance of goods trade in national income. It helps test H2: whether merchandise trade contributes to emissions and whether complementary policies (e.g., tariffs, renewables) offset this impact. GDP per capita (LN_GDP) and renewable electricity (ERNE) are retained to control for income effects and the energy transition, respectively, as in Model 1. Tariff rates on primary products (PTRF), measured as a weighted means, are introduced as a key policy tool. Lower tariffs on primary exports like minerals, fuels, and agricultural commodities can boost extraction and cultivation activities that are often carbon intensive. Including PTRF allows the model to examine how liberalizing raw-material trade influences emissions.

Model 3 focuses on industrial trade by using the share of manufacturing exports in total merchandise exports (MEXP). This variable reflects the prominence of processed and value-added goods (e.g., electronics, textiles, machinery) in a country's export basket. As manufacturing is typically energy-intensive and carbon-emitting, this variable directly tests H3: whether manufacturing trade is a significant driver of emissions. GDP per capita (LN_GDP) is included to examine the income-emissions relationship, particularly in industrialized economies that may be moving along the EKC curve. Renewable electricity (ERNE) again serves to test whether clean energy moderates the emissions impact of manufacturing exports given that industrial emissions are highly dependent on electricity sources. Finally, tariff rates on manufactured products (MTRF) represent trade policy in the context of industrial goods. Lower MTRF may enhance export competitiveness but also promote carbon-intensive production unless green technologies are adopted. Including MTRF allows analysis of how trade policy can reinforce or mitigate environmental externalities from manufacturing.

Model 4 investigates the emissions implications of agricultural exports using the natural log of agricultural export value (LN_AEXP), measured in USD. This variable captures a country's integration into global food and commodity markets. As agricultural expansion often involves deforestation, fertilizer use, and land-use change, this indicator directly supports the test of H4: whether agriculture-driven trade raises emissions. GDP per capita (LN_GDP) continues to test income effects on agricultural emissions and whether higher-income countries are better equipped to decouple agrarian trade from environmental harm. Renewable electricity (ERNE) is particularly relevant in this model, as rural electrification and green energy use in Agri-processing can lower the carbon intensity of agricultural exports. Agricultural value added (LN_AVA), measured in constant USD, reflects the scale and modernization of the agriculture sector. Higher value added may imply more intensive practices or enhanced productivity. Its inclusion allows assessment of whether the structure and depth of agricultural activity exacerbate or mitigate emissions in a trade-driven context.

3.2.2 Dependent Variables: Disaggregating Emissions by Source

Our choice of dependent variables reflects the need to differentiate between broad, economywide carbon outputs and the more localized emissions associated with discrete economic activities. Each dependent measure is linked to one of the four trade indicators to extract the most relevant carbon signal. All dependent variables are derived from World Bank datasets and measured in metric tons of carbon emission equivalent, and primarily serve as proxies for Scope 1 emissions, which include direct emissions from economic sectors such as energy, manufacturing, and agriculture.

Model 1 and Model 2 both use Total Carbon Emissions proxy variable of Scope 1 Carbon emission (LN_TCO), defined as the natural logarithm of total CO_2 emissions from energy, industry, transport, and other sources. This comprehensive indicator provides an economy-wide view of carbon output and is suited for analyzing aggregate trade flows such as total imports/exports or merchandise trade as a percentage of GDP. Total emissions are particularly relevant when evaluating macroeconomic trade openness, as the emissions impact of trade can occur indirectly through industrial expansion, freight transport, increased energy consumption, and shifting consumption patterns. By focusing on total CO_2 emissions, these models allow us to understand the broad climate implications of trade liberalization and economic globalization.

Model 3 uses Manufacturing Carbon Emissions (LN_MCO) as its dependent variable, representing emissions from industrial processes, such as those occurring during the production of cement, steel, chemicals, and metals which are also used as an proxy variable of Scope 1 emission. These emissions do not result from fuel combustion but rather from chemical and physical transformations intrinsic to manufacturing. This category is particularly relevant to Model 3 because the independent variable (MEXP) reflects the share of a country's exports that are manufacturing based. By isolating emissions from manufacturing processes, the model captures the embedded carbon content of industrial output an essential insight for sustainable finance evaluations that seek to understand and mitigate emissions from hard-to-abate sectors.

Model 4 employs Agricultural Carbon Emissions (LN_ACO), defined as the natural logarithm of CO_2 emissions from agriculture. These emissions arise from soil management, fertilizer use, livestock production, on-farm energy use, and land clearing for agricultural expansion. This dependent variable is paired with agriculture export value (LN_AEXP) in the model, allowing us to examine how increased trade in farm commodities may contribute to agriculture-specific emissions. By focusing exclusively on agriculture-related emissions, this model enables a more accurate attribution of environmental pressure to export-oriented agribusiness practices. It also provides key inputs for policy recommendations targeting sustainable agriculture and green commodity chains.

3.2.3 Control and Mediating (Policy) Variables

To ensure that the estimated relationship between trade and emissions is not biased by omitted variables or confounding economic dynamics, this study incorporates a set of carefully selected control and mediating variables. These variables account for broader macroeconomic, demographic, energy-related, and structural conditions that can influence both trade behavior and carbon emissions independently. Their inclusion strengthens the internal validity of the panel regression models and reflects well-established practices in empirical environmental economics and sustainable finance research.

Fossil Fuel Consumption (FFC), defined as the share of fossil fuels in total energy use, captures the carbon intensity of a country's energy mix. This control is crucial across all models, as a fossil-heavy energy profile may amplify the emissions impact of trade-related industrial or transportation activity. Countries with cleaner energy mixes may exhibit weaker emissions responses to trade expansion, underscoring the importance of this variable in environmental modeling.

Exchange Rate (LN_EXC), defined as the local currency units per US dollar (period average), serves as a financial channel that can influence trade competitiveness, import costs, and investment in clean technology. Currency depreciation may stimulate exports but also make clean energy imports more expensive, potentially increasing emissions. Controlling for exchange rate volatility ensures that trade–emission relationships are not conflated with macroeconomic instability.

Terms of Trade Index (LN_TRT), based on net barter terms of trade (2015 = 100), measures the purchasing power of exports relative to imports. Favorable terms of trade can lead to expanded production and export volumes, potentially increasing emissions. Alternatively, they may provide fiscal space for investment in clean infrastructure. Including this index helps the model account for the indirect macroeconomic effects of trade

Industry Value Added (IVA), measured as a percentage of GDP, reflects the structural composition of the economy. A high industrial share often implies elevated process and combustion emissions, particularly in manufacturing-intensive countries. By including IVA in Models 1 and 3, the analysis can better assess whether emissions are tied to industrial output per se or specifically to trade-driven industrialization.

Energy Use (LN_ENU), measured in kilograms of oil equivalent per $1,000 of GDP (constant 2021 PPP), is a macro-level indicator of energy intensity. It captures how much energy is required to generate economic output. Higher energy intensity typically signals inefficiencies and correlates with higher emissions. This control is especially important for comparing emission performance across countries at different development stages.

Urban Population (LN_URP), defined as the total number of people living in urban areas, captures structural demographic dynamics. Urbanization is associated with higher energy consumption, industrial concentration, and transport emissions. By including urban population, particularly in Models 2 and 3, the analysis accounts for the scale and intensity of urban infrastructure and its role in amplifying the carbon effects of trade.

Fertilizer Consumption (LN_FER), measured in kilograms per hectare of arable land, serves as a key agricultural control in Model 4. Fertilizer application is directly linked to emissions, one of the most potent greenhouse gases. It also reflects the intensity of agricultural practices, especially in export-oriented production systems. Including this control allows the model to distinguish between emissions that stem from trade expansion and those driven by input-heavy farming methods.

Food Imports (FIMP), expressed as a percentage of merchandise imports, is used to capture the role of global agricultural supply chains in shaping domestic environmental outcomes. A country that imports a significant share of its food may relieve pressure on domestic land and emissions but simultaneously externalize its carbon footprint. Controlling food imports helps isolate whether rising domestic agricultural emissions are due to increased exports or substitution effects in trade patterns.

Collectively, these control and mediating variables provide a robust empirical framework to isolate the causal effects of trade on carbon emissions. Their inclusion is not only statistically appropriate but also necessary for informing targeted policy interventions and sustainable finance strategies across regions and sectors.

3.3 Estimation Techniques

This study employs unbalanced panel data econometric techniques to investigate the complex relationship between international trade and carbon emissions across thirteen countries in East, South, and Southeast Asia over the period 1990–2024. Given the multidimensional nature of trade and its varying influence on different emission sources and sectors, four distinct regression models are estimated. Each model is theoretically grounded and empirically structured to examine specific aspects of the trade–emissions nexus. Panel data methods are suitable for controlling both unobserved country-specific heterogeneity and variation over time. To ensure robustness and address common panel econometric issues, the following estimation strategies and diagnostic tools are employed: Fixed Effects (FE) and Random Effects (RE) estimators are both considered. The choice between them is determined using the Hausman Test, which tests for correlation between regressors and the error term.

Driscoll-Kraay standard errors are used to correct for heteroscedasticity, serial correlation, and cross-sectional dependence, making the results more reliable in macro panels where countries are economically interconnected. Region dummy variables are included in all models to account for unobservable regional heterogeneity and to evaluate the differential effects of trade on emissions across East, South, and Southeast Asia. The estimation framework does not include year dummies, focusing instead on regional fixed effects to capture structural differences across areas with potentially divergent development and environmental policy profiles.

To further ensure statistical rigor, a series of diagnostic tests is applied:

i. Descriptive statistics to explore central tendencies and dispersion.
ii. Correlation matrices to assess multicollinearity among explanatory variables.

iii. Panel unit root tests to confirm stationarity of variables.

iv. Cross-sectional dependence (CSD) tests to identify regional or global spillovers.

v. Model robustness checks using alternative variable combinations and error structures.

vi. Model fit assessments using R^2, adjusted R^2, and related indicators.

This multi-layered estimation approach enhances both the internal validity and comparative generalizability of the results across trade dimensions, sectors, and regional groupings.

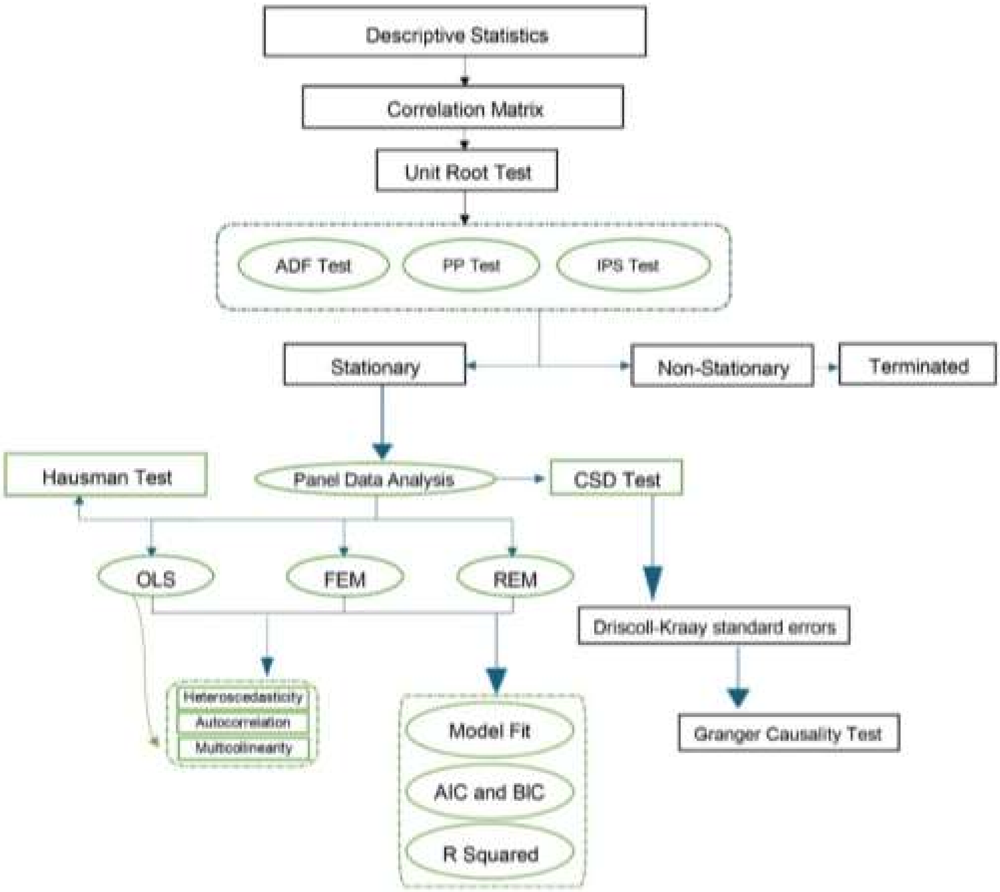

Figure 3.2 Model Estimation (Author Computation)

3.4 Model Specification

The study estimates four separate panel data regression models, each capturing a different channel through which trade may influence carbon emissions. These models differ in dependent variables and the choice of trade and control variables, allowing a comprehensive analysis of both overall and sector-specific emission impacts. Utilizing unbalanced panel data analysis provides insights into the dynamics of cross-border trade as it evolves across various countries over time. This exhibits distinct effects in each nation and unexpected variations, similar to any other process. The panel data framework provides more valuable insights compared to single-equation models. Its growing popularity stems from the ability to examine the same issue across various locations and conduct consistent observations over a defined period. The unbalanced panel data model has been applied using various estimation methods. The conventional OLS estimator addresses factors that are distinct from the complexities of time and space inherent in panel data analysis. To accurately analyze it, we must incorporate the impacts of econometrics to manage them effectively. To consider the diverse effects of errors in our two-way error component model, both FEM (Fixed Effect Model) and REM (Random Effect Model) are accessible. Understanding the factors influencing trade flows and trade behavior can be achieved through the integration of fixed effects models, and random effects models. Additionally, the impact of trade policies on their outcomes is significant. Panel data enables the simultaneous analysis of information spanning various time periods and numerous entities (nations, regions). This takes into consideration the variations among individuals (fixed effects) as well as the trends over time (time effects).

Consequently, in this analysis, we formulate four distinct equations to investigate the relationship between trade and carbon emissions in South, East, and Southeast Asian nations. This method elucidates the impact of trade within the greater Asian region on environmental results. We examine the trade-carbon connection across four distinct categories: Total Trade, Merchandise Trade, Manufacturing Export, and Agricultural Export.

I. Equation for Model 1: Total Trade

$$LN\_TCO_{it} = \alpha + \beta_1 LN\_TTR_{it} + \beta_2 LN\_GDP_{it} + \beta_3 ATRF_{it} + \beta_4 LN\_EXC_{it} + \beta_5 FFC_{it} + \beta_6 ERNE_{it} + \beta_7 LN\_TRT_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

This model examines the effect of general trade intensity on national carbon emissions (Scope 1 Emissions), controlling macroeconomic factors and energy composition to evaluate the investment opportunities. It aims to identify whether increased trade openness is associated with higher emissions or not and how energy-related and trade-cost variables mediate this relationship.

II. Equation for Model 2: Merchandise Trade

$$LN\_TCO_{it} = \alpha + \beta_1 MTR_{it} + \beta_2 LN\_GDP_{it} + \beta_3 ERNE_{it} + \beta_4 PTRF_{it} + \beta_5 LN\_URP_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

This model focuses on overall merchandise trade's (Goods Trade) contribution to emissions (Scope 1 Emissions). By including primary product tariffs and renewable electricity production, the model investigates how structural trade patterns and renewable energy trends shape the emission trajectories.

III. Equation for Model 3: Manufacture Export

$$LN\_MCO_{it} = \alpha + \beta_1 MEXP_{it} + \beta_2 LN\_GDP_{it} + \beta_3 MTRF_{it} + \beta_4 ERNE_{it} + \beta_5 IVA_{it} + \beta_6 LN\_ENU_{it} + \beta_7 LN\_URP_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

This model evaluates the direct industrial impact of manufacturing trade on Scope 1 carbon emissions from industries. By isolating industrial emissions and incorporating variables like energy intensity and manufacturing related tariffs, this specification uncovers the environmental costs of industrialization through manufacturing exports.

IV. Equation for Model 4: Agriculture Export

$$LN\_ACO_{it} = \alpha + \beta_1 LN\_AEXP_{it} + \beta_2 LN\_GDP_{it} + \beta_3 LN\_FER_{it} + \beta_4 LN\_AVA_{it} + \beta_5 ERNE_{it} + \beta_6 LN\_ENU_{it} + \beta_7 FIMP_{it} + \mu_i + \delta_t + \varepsilon_{it}$$

In this model, we investigate the relationship between agricultural export and Scope 1 carbon emissions from the agriculture sector at national level. It considers the impact of agriculture value addition, renewable electricity output, and fertilizer on environmental degradation. The inclusion of food import share and agricultural export intensity allows for examining how international agri-food trade patterns influence sectoral emissions. Although its structural form mirrors the previous models in terms of panel estimation design, Model 4 emphasizes a sectoral shift by focusing entirely on agriculture. It also serves as a robustness strategy, verifying whether the trade–emissions dynamics observed in manufacturing and total emissions also hold within the agricultural context, where the role of inputs like fertilizer and energy is more direct and measurable.

3.4.1 Fixed Effect Model (FEM) and Random Effect Model (REM)

In the overall data framework, the Fixed Effect Model and the Random Effect Model are two principal estimate techniques. We employ the Hausman Test to determine the validity of these effects and choose the correct model accordingly.

The Fixed Effect Model permits varying intercepts among units, so capturing the uniqueness of each unit. In the Random Effect Model, the intercepts are presumed to be randomly sampled from the whole population. The former possesses a greater number of degrees of freedom. The Fixed Effect Model was selected because of its ability to account for both time-varying and fixed variables in the analysis of trade potential between country pairings. The Fixed Effect Model is superior in detecting time-invariant effects. The Random Effect Model elucidates international trade by incorporating both time-varying and fixed variables (Colin Cameron & Miller, 2015; Hoechle, 2007). Nevertheless, the FIXED model significantly reflects the constant impacts.

Fixed Effect Model (FEM)

$Yit = \alpha + \beta 1t + \beta 1 * X2it + \beta 3 * X3it + u$……………………………………………….5

Random Effect Model (REM)

$\beta 1i = \alpha + \beta 1 + \varepsilon 1,\ i = 1,2,3$………………………………………………………...…6

Substituting Equation (6) into (5), the model can be written as:

$Yit = a + \beta 1t + \beta 1 * X2it + \beta 3 * X3it + \varepsilon i + u$………………..…………………………….7

It is commonly believed that FEM provides a reliable method for approximating the equations. But it misses the mark when it comes to time-invariant effects, which are occasionally as crucial as time-varying ones. The REM has been the subject of much study as a means of foretelling future international trade. For this approach to work, at any given time (t) or cross-section (i, j), the variables that describe the connection between i and εi can't be changed by i and εi (Hoechle, 2007).

3.4.2 Driscoll–Kraay Standard Errors

In panel data analyses of macro-economic and environmental relationships, residuals often exhibit heteroskedasticity (unequal variances across observations), serial autocorrelation (correlation of errors over time within each cross-section), and cross-sectional dependence (unobserved shocks that simultaneously affect multiple countries). When present, these issues violate classical Ordinary Least Squares (OLS) assumptions, causing standard errors to be downward biased and t-statistics to be artificially inflated. To address these complications, this study implements the Driscoll–Kraay fixed-effect standard errors nonparametric covariance-matrix estimator, which yields consistent standard errors even under heteroskedasticity, autocorrelation, and cross-sectional dependence (Driscoll & Kraay, 1998).

Driscoll–Kraay standard errors

$$Y_{it} = \alpha_i + X_{it}\beta + \varepsilon_{it}, \qquad i = 1, \ldots, N, t = 1, \ldots, T,$$

Where.,

Yit is the dependent variable (e.g., LN_TCO). α_i captures the unobserved, time-invariant country effect, X_{it} is a vector of regressors (trade, GDP per capita, etc.), β is a vector of slope coefficients, and ε_{it} is the idiosyncratic error term.

3.4.3 Selection of Panel Data Test

3.4.3.1 Descriptive Test

Descriptive statistics provide a summary of the data set, including insights into central tendency, dispersion, and distribution shape (Kaur et al., 2018). Common replies consist of:

a. Mean: The standard value.
b. Median: The central value of data organized in a specified order.
c. Standard deviation: A measure of the dispersion of data relative to the mean.
d. Range: The difference between the smaller and greatest values.

3.4.3.2 Correlation Test

A correlation matrix is a test that presents the coefficients of correlation between a set of variables. Each matrix represents the correlation between two variables. The values range between the -1 to 1, hence indicating the direction and strength of the linear relationship (Frees, 1995):

a. 1: Positive connection.
b. 1: Negative correlation.
c. 0: No connection or Correlation

3.4.3.3 Unit Root Test (Stationary Test)

Determining the sequence of integration for each variable is essential, as testing for cointegration requires all variables to be integrated of order one. Therefore, a panel unit root test must be conducted to meet this objective. Recent literature suggests the application of various panel root tests, which have been predominantly utilized in research studies. Stationarity is a core concept denoting a process characterized by unchanging statistical properties throughout time. Stationary time series exhibit consistent statistical properties, such as mean, variance, and autocorrelation, that remain unchanged over time. Non-stationary time series exhibit trends, cycles, and varying regular patterns that evolve over time. This complicates the modelling and prediction of their behavior (Gujarati & Porter, 2009). Conducting stationarity tests on the data prior to applying any models or analysis methods is crucial for ensuring the accuracy of time series analysis results. The Phillips-Perron (PP), Augmented Dickey-Fuller (ADF), Levin-Lin-Chu (LLC), and Cross-sectional Augmented Implied Spuriousness (CIPS) tests are established methods for assessing stability.

The ADF (Augmented Dickey-Fuller), PP test (Phillips-Perron), Levin-Lin-Chu (LLC), and CIPS (Cross-sectionally Augmented Im-Pesaran-Shin) are essential for assessing the stationarity of panel data variables (Im et al., 2003; Levin et al., 2002). The objective is to determine the presence of a unit root indicating non-stationarity, contrasted with the alternative hypothesis of stationarity. The ADF test incorporates lagged difference terms to address higher order correlation. Conversely, the PP test adjusts for serial correlation and heteroskedasticity in the errors. The CIPS test builds upon the Im-Pesaran-Shin framework by introducing cross-sectional dependence.

3.4.3.4 Hausman Test

The Durbin–Wu–Hausman test, also known as the Hausman specification test, is a statistical hypothesis test utilized in econometrics. The test assesses the consistency of an estimator in relation to an alternative, less efficient estimator that is established as consistent. This facilitates the assessment of the alignment between a statistical model and the data (Hausman, 1978).

3.4.3.5 Cross Sectional Dependence (CSD) Test

The econometric procedure of this study begins with a cross-dependence (CD) test. The identification of CD is the first step in various forms of panel data empirical analysis, and it must be utilized prior to conducting panel unit root tests (Frees, 1995; Hoechle, 2007). Nonetheless, the primary aim of the CSD test is to prevent the means from being included in the correlation calculation. The null hypotheses posit that sectional independence exists within the panel, while the presence of cross-dependence suggests a rejection of the null hypothesis.

3.4.3.6 Robustness Checks

Robustness checks confirm that the findings of the regression analysis are dependable and not affected by alterations in the model or data sample. This test seeks to ascertain whether the conclusions remain valid under varying assumptions or conditions. Additionally, address potential issues regarding model specification, outliers, or omitted variables. The typical Robust checks include:

a. Bootstrap Resampling: A prevalent technique is bootstrap resampling, which is repeatedly sampling from the dataset and re-estimating the model to assess the stability of the coefficients.
b. Subsample Analysis: An alternative method involves examining various subsamples to verify the consistency of results across distinct data segments.

3.4.3.7 Model Fit

Model fit evaluation entails examining the extent to which the regression model accounts for the variation in the dependent variable.

a. R-squared and Adjusted R-squared: These metrics represent the proportion of variance in the dependent variable elucidated by the independent variables. Adjusted R-squared accounts for the quantity of predictors in the model.
b. AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion) serve as metrics for model comparison, reconciling goodness of fit with model complexity. Reduced values signify superior model fit.

3.4.3.8 Model Diagnostics:

A. Heteroscedasticity is tested using the Breusch-Pagan test.
   a) Requirement: Heteroscedasticity occurs when the variance of the error terms is not constant across observations, which can lead to inefficient estimates and unreliable standard errors. To ensure robust results, the Breusch-Pagan test will be employed.

b) Criteria: A p-value greater than 0.05 indicates the absence of heteroscedasticity, meaning the variance of the residuals is constant. If heteroscedasticity is detected (p-value ≤ 0.05), robust standard errors or feasible generalized least squares (FGLS) will be applied to correct the issue.

c) Significance: Ensuring homoscedasticity enhances the efficiency and reliability of the regression coefficients.

B. Autocorrelation is tested using Wooldridge's test.

a) Requirement: Autocorrelation, or serial correlation, arises when error terms are correlated across time, violating the assumption of independence in panel data models. Wooldridge's test for autocorrelation in panel data will be conducted.

b) Criteria: A p-value greater than 0.05 indicates no autocorrelation, fulfilling the assumption of independent errors. If autocorrelation is present (p-value ≤ 0.05), panel-corrected standard errors (PCSE) or a dynamic panel data model, such as GMM, will be employed to account for it (Drukker, 2003).

c) Significance: Addressing autocorrelation ensures that model predictions and hypothesis tests are valid.

C. Multicollinearity is evaluated using the Variance Inflation Factor (VIF).

a) Requirement: Multicollinearity occurs when independent variables are highly correlated, leading to inflated standard errors and unreliable estimates. Variance Inflation Factor (VIF) will be used to assess multicollinearity.

b) Criteria: A VIF value below 10 indicates an acceptable level of multicollinearity. If any variable exceeds this threshold, it may be excluded or transformed to reduce collinearity (O'brien, 2007).

c) Significance: Mitigating multicollinearity improves the precision and stability of the estimated coefficients.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the findings from our panel data models, providing a detailed examination of the factors of trade flow among the selected nations. Our model utilizes data from 1990 to 2024 and applies the Panel Least Squares approach, combining variables such as carbon emissions, trade, GDP, energy consumption, and policy indicators (Tariffs) to assess the intricate relationship between carbon and trade. The results indicate that trade has a mixed impact on carbon emissions, as demonstrated by their statistically significant coefficients. Conversely, some variables also exert a mixed influence and contribute to carbon emissions. The model exhibits substantial explanatory power, with an R-squared value ranging from 0.40 to 0.91, based on the study of 1,377 total observations over four models. Although the model is well-fitted, the Durbin-Watson statistic indicates positive autocorrelation, implying possible avenues for additional improvement. These results highlight the intricate relationship between environmental factors and the formation of international trade patterns, offering significant insights for policymakers and stakeholders.

4.1 Descriptive / Summary Statistics

Descriptive statistics serve as the foundational layer in empirical economic analysis, summarizing raw data into interpretable metrics such as the mean, median, standard deviation, skewness, and kurtosis. These indicators help researchers understand the central tendencies and distributional features of variables across countries and over time. See Appendix A, Table 4.1.1 to 4.1.4 reports descriptive statistics for all the key variables used in the four econometric models, including measures of carbon emissions, trade metrics, and key economic and sectoral indicators across 13 countries in East, South, and Southeast Asia from 1990 to 2024. Table 3.1 presents general statistics for the selected variables, with LN_TTR indicating natural log of trade volume between regions and LN_TCO indicating the natural log of Carbon Emission.

The models in this study incorporate a comprehensive set of variables that reflect critical economic, trade, demographic, and environmental dimensions. In the first model, the focus is on total carbon emissions (LN_TCO), explained by variables such as total trade volume (LN_TTR), GDP per capita (LN_GDP) a proxy for economic productivity, and tariff rates (ATRF) indicating trade openness. Additional controls include the exchange rate (LN_EXC), fossil fuel energy consumption (FFC), renewable electricity (ERNE) a proxy of renewable energy, and terms of trade (LN_TRT). The second model continues to assess total CO_2 emissions but emphasizes merchandise trade (MTR), alongside renewable energy (ERNE), primary product tariffs (PTRF), and urban population size (LN_URP).

The third model shifts focus to CO_2 emissions from industrial processes (LN_MCO), using manufacturing exports (MEXP) and industrial sector value-added (IVA) to capture sectoral trade and output. It also includes energy use (LN_ENU) and tariffs on manufactured goods (MTRF). The fourth model evaluates agriculture-based CO_2 emissions (LN_ACO) using variables such as agricultural exports (LN_AEXP), fertilizer consumption (LN_FER), agricultural value added (LN_AVA), renewable electricity share (ERNE), food imports (FIMP), and energy use per GDP (LN_ENU). Collectively, these models provide a robust framework to examine how trade composition, energy profiles, tariffs, and economic structure influence sectoral carbon emissions across East, South, and Southeast Asia.

4.1.1 Total Trade and Total CO_2 Emissions

In the very first model, the dependent variable, total CO_2 emissions (LN_TCO), has a mean of 5.13 and a median of 5.17, indicating a symmetrical distribution. The minimum value is 0.08 and the maximum reaches 9.49, with a standard deviation of 1.96. The slight left skew (skewness = -0.107) and moderate kurtosis (2.79) suggest a mild spread around the mean, typical for panel data over a large timespan. Total trade (LN_TTR) shows a high mean of 25.79 and median of 25.93, with values ranging from 20.87 to 29.56, indicating high trade intensity in the sample countries. The negative skewness (-0.40) implies a concentration of observations toward the higher end of the distribution, with relatively fewer countries showing very low trade activity. GDP per capita (LN_GDP) appears moderately skewed rightward (0.45), with a mean of 8.25 and standard deviation of 1.37. Trade-related policy variables such as ATRF exhibit extreme variability, with a mean of 9.71 and a staggering standard deviation of 22.77. The very high skewness (15.59) and kurtosis (280.18) suggest outliers or drastic tariff shifts in a few countries.

The exchange rate (LN_EXC) has a moderate mean of 4.05 and is slightly positively skewed (0.52), reflecting some currency volatility over time. In contrast, fossil fuel consumption (FFC) has a high mean of 70.19 with a left skew (-1.08), indicating that while most countries are highly reliant on fossil fuels, some are shifting toward alternatives. Finally, electricity from renewables (ERNE) has a mean of 3.65 but a long right tail (skewness = 1.76), indicating rapid growth in renewable adoption in a subset of countries, for reference see Appendix A - Table 4.1.1 Descriptive Summary of Statistics for Model 1.

4.1.2 Merchandise Trade and CO_2 Emissions

Model 2 examines the relationship between merchandise trade (MTR) and total CO_2 emissions (LN_TCO). Merchandise trade displays a high mean (70.22) and median (42.71), with extreme skewness (2.11) and kurtosis (7.04), suggesting that while trade is generally robust, some economies trade disproportionately more. Renewable electricity (ERNE) shows even more variability, with a mean of 22.89, standard deviation of 26.09, and maximum value of 100%. Its skewness (1.89) and kurtosis (5.85) further reflect its concentration in a few advanced economies. Tariffs on primary products (PTRF) reflect substantial policy differences: the mean is 11.25 but with a very high standard deviation (49.61) and skewness (17.76), likely driven by few countries with extremely protectionist trade policies. The urban population (LN_URP) is normally distributed (skewness = 0.005), with a mean of 17.42 and minimal standard deviation of 1.56, suggesting demographic stability across regions. These statistics offer vital insights into the economic and demographic contexts of trade-related emissions in Asia, for reference see Appendix A - Table 4.1.2 Descriptive Summary of Statistics for Model 2.

4.1.3 Manufacturing Export and Industrial Emissions

See Appendix A - Table 4.1.3 Descriptive Summary of Statistics for Model 3 results in which manufacturing exports (MEXP) analyzed and their link with CO_2 emissions from industrial processes (LN_MCO). The dependent variable has a mean of 2.75, a median of 2.87, and a balanced distribution (skewness = -0.11), indicating moderate emissions across the manufacturing sector. Manufacturing exports themselves are highly clustered around the mean (75.60), with a small standard deviation (14.32) and a slightly left-skewed shape (-0.87). This pattern implies relatively consistent export performance across the sample. Trade and production-related variables such as industry value added (IVA) and tariffs on manufactured goods (MTRF) show distinctive variation. The latter has a mean of 9.14 but very high skewness (8.89) and kurtosis (119.50), suggesting major disparities in industrial trade openness among the countries. Energy use (LN_ENU) is quite consistent (std dev = 0.43), and the low skewness (0.16) confirms a stable pattern of industrial energy consumption. Collectively, these variables reflect structural characteristics of industrial economies and their role in emissions patterns.

4.1.4 Agriculture Export and CO_2 Emissions

The fourth model shifts focus to agriculture-related emissions (LN_ACO). With a mean close to zero (0.13), the data is near symmetrical (skewness = -0.46), though it contains some extremely low values (min = -7.82), likely driven by smaller agricultural economies or methodological reporting issues.

Agricultural exports (LN_AEXP) show a strong central tendency (mean = 15.12, median = 15.27) and low skewness (-0.60), indicating stable export performance across most economies. Fertilizer consumption (LN_FER) also appears balanced (skewness = -0.02), with a mean of 5.35. The agriculture value added (LN_AVA) is right-skewed (-0.97), indicating higher concentration among countries with sizable rural economies. In contrast, renewable electricity (ERNE) is widely spread (std dev = 24.00), again affirming high disparity in green technology penetration. Lastly, food imports (FIMP) have a mean of 8.93, moderate skewness (0.68), and a relatively normal distribution, suggesting similar levels of food import dependence across the region. For reference see Appendix A - Table 4.1.4 Descriptive Summary of Statistics for Model 4.

These descriptive statistics help frame the structural and policy-driven differences across Asian economies, offering necessary insights into the distribution, volatility, and central tendencies of variables critical to this study. As (Gujarati & Porter, 2009) suggest, understanding skewness, kurtosis, and dispersion is essential before proceeding to regression estimations. Many variables in the data show non-normal distributions (e.g., tariffs, renewables), confirming the need for robust estimation techniques, such as the Driscoll–Kraay standard errors used in this study.

4.2 Correlation Matrix

The correlation matrix indicates the strength and direction of linear relationships among the variables in the models. See appendix A tables 4.2.1 to 4.2.4 display the pairwise correlation coefficients for all explanatory and dependent variables utilized in Models 1 to 4. The coefficients are essential for detecting multicollinearity, examining empirical patterns, and guiding regression design. A value of +1 signifies perfect positive correlation, -1 represents perfect negative correlation, and 0 indicates the absence of correlation.

4.2.1 Total Trade and Total CO_2 Emissions

In this model, correlation matrixes indicate robust positive correlations between trade and fossil fuel consumption with total carbon emissions (0.81 and 0.60, respectively), reinforcing the assertion that trade intensity and energy sources are significant contributors to emissions. Conversely, tariff levels exhibit an inverse correlation with emissions, indicating that protectionist trade policies may curtail carbon-intensive trade flows. The tenuous association between renewable energy sources and emissions may suggest gradual shifts to clean energy in the region. For results see **Appendix A - Table 4.2.1 Correlation Matrix for Model 1.**

4.2.2 Merchandise Trade and CO_2 Emissions

The urban population and GDP per capita have positive correlations with CO_2 emissions, with LN_URP demonstrating a notably large connection of 0.89. Simultaneously, power generated from renewable sources exhibits a negative correlation with emissions (-0.58), reinforcing the inverse association between the utilization of clean energy and carbon emissions. Merchandise trade exhibits a negative connection with emissions (-0.24), potentially indicating structural disparities in export/import mix, for results see **Appendix A - Table 4.2.2 Correlation Matrix for Model 2**.

4.2.3 Manufacturing Export and Industrial Emissions

In the Model three (3), Urbanization, industrial value added, and energy consumption have the most significant positive relationships with manufacturing emissions (0.90, 0.48, and 0.58, respectively), highlighting the impact of industrial expansion on carbon emissions. Tariffs on manufactured goods have an inverse correlation, potentially indicating tendencies in trade liberalization, for reference see **Appendix A – Table 4.2.3 Correlation Matrix for Model 3.**

4.2.4 Agriculture Export and CO_2 Emissions

A robust positive correlation of 0.93 is observed between agriculture value-added and agricultural emissions, highlighting the direct environmental cost associated with agricultural production. Agricultural exports and energy use exhibit moderate positive connections. Conversely, GDP per capita and food imports exhibit a negative correlation with emissions, indicating that more developed nations may utilize less carbon-intensive agricultural methods, for results see Appendix A - Table 4.2.4 Correlation Matrix for Model 4.

The correlation matrices across all four models illustrate the intricate relationships between emissions, trade, economic structure, and resource utilization. Favorable connections between energy consumption and value-added sectors, such as industry and agriculture, validate their emission-intensive characteristics. The presence of negative correlations with renewable energy across various models indicates the significant mitigating role that clean energy plays. The relationships identified play a crucial role in guiding the selection of variables and validating theoretical expectations within the context of emission-trade literature.

4.3 Stationarity Test (Unit Root test)

Even before doing regression analysis, it is crucial to ascertain the stationarity characteristics of the dataset, as non-stationary series can yield false outcomes in panel estimations. To validate the robustness of the panel data econometric framework, many unit root tests were utilized: Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Augmented Dickey-Fuller (ADF), and Phillips-Perron (PP). These tests are well acknowledged in econometric literature for evaluating the existence of a unit root in panel datasets (Baltagi, 2021; Im et al., 2003; Pesaran & Yamagata, 2008). See appendix Tables 4.3.1 to 4.3.4 display the unit root findings for all variables utilized in Models 1 to 4. The results indicate that although most variables are non-stationary at their level, they achieve stationarity at the first difference, signifying they are integrated of order one, I (1). This trend is uniform across many testing procedures, with significant thresholds established at 1%, 5%, and 10%.

4.3.1 Total Trade and Total CO_2 Emissions

Model 1 examined the variables LN_TCO, LN_TTR, LN_GDP, ATRF, LN_EXC, FFC, ERNE, and LN_TRT. The LLC and IPS tests indicated that most of these variables are non-stationary at their level but attain significance upon first differencing. For example, LN_TCO exhibited non-stationarity under IPS (statistic = -0.619) but demonstrated significant stationarity at the first difference (statistic = -7.67***). Likewise, LN_TTR exhibited a markedly significant LLC statistic of -11.57*** at the first difference. The PP and ADF tests demonstrated comparable support, with PP statistics above critical levels at the 1% level (e.g., 227.73 for LN_TCO). The consistent findings from several tests affirm that all variables in Model 1 achieve stationarity following first differencing, which is essential for good regression outputs, for table results see Appendix A - 4.3.1 Unit Root Test for Model 1.

4.3.2 Merchandise Trade and CO_2 Emissions

In this model, variables including MTR, LN_GDP, ERNE, PTRF, and LN_URP were subjected to panel unit root testing. Most variables demonstrated non-stationarity at level but attained stationarity upon differencing. MTR (Merchandise Trade) isn't stationary at level for the LLC and IPS tests (stat = -0.33), but indicate the strong stationarity after the first difference, with an IPS statistic of -12.02*** and a PP statistic of 289.03***. LN_GDP, a prevalent variable in several models, consistently indicates the non-stationarity at the level across all tests, achieving stationarity at the first difference. Notably, LN_URP was among the few variables that were stationary at level according to LLC (-5.14***), while IPS remained insignificant, see Appendix A - Table 4.3.2 Unit Root Test for Model 2. This underscores the necessity for a prudent and nuanced strategy when evaluating levels of variable integration.

4.3.3 Manufacturing Export and Industrial Emissions

Model 3 examines carbon emissions from manufacturing and incorporates explanatory variables such as MEXP (Manufacturing Export), LN_GDP, MTRF, IVA, LN_ENU, and LN_URP. In accordance with previous models, all variables exhibited non-stationarity at their level under IPS and LLC but attained stationarity upon differencing. For instance, MEXP had a borderline significant LLC statistic of (-2.13**) and extremely significant IPS and ADF values upon differencing. The MTRF exhibited robust test statistics at both the level and difference under ADF (70.40***) and PP (980.91***), signifying that the transformation successfully stabilized the data. The energy consumption and industrial value-added variables attained statistical significance at the first difference, validating the correction of time-series features, see Appendix A - Table 4.3.3 Unit Root Test for Model 3.

4.3.4 Agriculture Export and CO_2 Emissions

In the fourth model, panel unit root tests were conducted on LN_ACO (Agriculture Export), LN_AEXP, LN_GDP, LN_FER, LN_AVA, ERNE, LN_ENU, and FIMP. Like prior models, nearly all variables showed non-stationarity at the level but became stationary upon initial differencing. LN_ACO did not pass the IPS and ADF tests at the level but achieved strong significance after differencing (LLC = -8.50***). The identical trend persisted for LN_AEXP and LN_FER. Notably, FIMP exhibited moderate significance even at the LLC level (-2.24**), however it was more pronounced at first difference across all test types (PP = 336.72***). This corroborates the concept that agricultural trade and environmental indicators, although first erratic, achieve stability following change, for reference see Appendix A - Table 4.3.4 Unit Root Test for Model 4.

The panel unit root analysis across all four models consistently indicates non-stationarity at the level and stationarity at the first difference. This verifies that the variables are I(1) and substantiates the application of first-differenced panel regressions or models that accommodate integrated series, including panel cointegration or panel error correction models where relevant. The existence of unit roots underscores the necessity of preventing erroneous regressions and advocates for data transformation before model estimate. Furthermore, utilizing several test types (LLC, IPS, ADF, PP, CIPS) improves the reliability of results by accounting for diverse assumptions regarding cross-sectional independence and heterogeneity. The consistency of tests such as PP and CIPS is especially crucial in panel data encompassing various nations with differing trade and emissions characteristics. Consequently, based on these rigorous diagnostic tests, we affirm that all variables utilized in Models 1 to 4 are stationary at first difference, so validating the ensuing regression analysis and preserving the econometric integrity of the study.

4.4 Panel Data Result

This section indicates the empirical findings of the study investigating the correlation between trade and carbon emissions throughout Asia, emphasizing total trade, merchandise trade, manufacturing export, and agricultural export. The analysis employs panel data econometric methods to examine the impact of various trade variables on environmental outcomes in ASEAN, South Asia, and East Asia over time. The dependent variables include overall carbon emissions (Scope 1 Emissions), as well as those from manufacturing and agriculture. The principal independent variables comprise disaggregated trade metrics, GDP per capita, tariff rates, the share of renewable electricity, and additional pertinent control and mediator factors.

The outcomes are organized into five primary sections:

i. Model Diagnostic estimations
ii. Estimates from the Main Panel use pooled Ordinary Least Squares (OLS), Fixed Effects (FE), Random Effects (RE), and robust estimators.
iii. Sectoral Trade Models examine the effects of trade on the merchandise, manufacturing, and agriculture sectors.
iv. Estimates categorized by region, specifically ASEAN, South Asia, and East Asia.

v. Robustness tests employing Driscoll-Kraay standard errors to mitigate cross-sectional dependence and heteroscedasticity.
vi. Summary of findings, emphasizing main statistical trends and empirical patterns.

The result section presents diagnostic tests that validate model selection, variable robustness, and the suitability of panel specifications prior to discussing these estimations.

4.4.1 Model Diagnostics and Pre-estimation Analysis

4.4.1.1 Evaluation of Multicollinearity

Variance Inflation Factors (VIF) were computed to ascertain that the explanatory variables are free from multicollinearity. All models had VIF values beneath the standard threshold of 10, with most values falling between 1.05 and 4.49. This verifies the lack of significant multicollinearity. Variables such as LN_TTR (VIF = 4.49) and LN_AVA (VIF = 3.28) show elevated values, however, remain within acceptable limits (O'brien, 2007). See Appendix A – Table 4.4.1.1

4.4.1.2 Tests for Cross-Sectional Dependence (CSD)

Cross-sectional dependence was analyzed utilizing the Pesaran CD, Friedman, and Frees tests across all four primary models. The findings revealed cross-sectional dependence in Model 2 (Merchandise Trade), as evidenced by a significant Pesaran CD test ($p = 0.0014$) and an indication from the Frees test. Although Models 1, 3, and 4 predominantly succeeded in the Pesaran CD and Friedman tests, the Frees statistics indicate potential dependence in multiple instances. Consequently, estimators that adjust for cross-sectional dependence specifically Driscoll-Kraay were utilized in the robustness assessments (Frees, 1995; Pesaran, 2004). See Appendix A – Table 4.4.1.2

4.4.1.3 Heteroscedasticity and Autocorrelation

The Modified Wald test for groupwise heteroscedasticity decisively rejects the null hypothesis of homoscedasticity across all models, hence affirming the existence of heteroscedasticity ($p < 0.01$). The Wooldridge test for autocorrelation identifies first-order serial correlation in Models 1 and 2, whereas Models 3 and 4 lack substantial evidence of such correlation. The results validate the application of robust standard errors, and the subsequent implementation of Driscoll-Kraay estimates to guarantee efficient and unbiased inference (Drukker, 2003; Wooldridge, 2002). See Appendix A – Table 4.4.1.3

4.4.1.4 Slope Heterogeneity Examination

The slope heterogeneity test by (Pesaran & Yamagata, 2008) validates the presence of statistically significant slope heterogeneity in all models. The modified Δ statistic is significant at the 1% threshold for Models 1 to 4. This substantiates the choice to employ panel estimators capable of addressing structural disparities among nations. See Appendix A - Table 4.4.1.4

4.4.1.5 Model Selection - Hausman Test

The Hausman test was used to ascertain the suitable model specification between fixed effects and random effects for each panel. The findings indicate:

a. In Model 1 Total Trade and Model 3 Manufacturing Export, Fixed Effects are favored ($p < 0.05$).
b. Model 2 Merchandise Trade and Model 4 Agricultural Export: Random Effects are suitable ($p > 0.05$).

Consequently, fixed effects estimates are presented for Models 1 and 3, whilst random effects are utilized for Models 2 and 4 in the primary part, supplemented by robust standard error estimates for consistency (Hausman, 1978). See Appendix A – Table 4.4.1.5

4.4.1.6 Causality Assessment - Dumitrescu & Hurlin Panel Granger Causality

The (Dumitrescu & Hurlin, 2012) panel Granger causality test was utilized to determine the temporal direction of the link. The findings indicate substantial unidirectional causality from trade to carbon emissions in all models.

a. Total Trade, merchandise trade, manufacturing exports, and agricultural exports all Granger-cause CO_2 emissions ($p < 0.01$).
b. Conversely, emissions Granger-cause trade solely in the merchandise and manufacturing models, indicating a more responsive adaptation in trade to environmental deterioration within those sectors.

These tests substantiate the empirical strategy and endorse the designation of trade variables as fundamental explanatory factors. See Appendix A – Table 4.4.1.6

4.4.2 OLS, Fixed Effect, and Random Effect Panel Results

This section defines the principal findings on the influence of total commerce on carbon emissions, employing panel estimating methodologies such as Ordinary Least

Squares (OLS), Fixed Effects (FE), Random Effects (RE), and FE with robust standard errors. The dependent variable in all models is carbon emissions, whereas the principal independent variables are Trade oriented (Import - Export), GDP per capita, tariff rates, and renewable electricity share.

Total Trade (LN_TTR) exhibits a statistically significant and positive correlation with carbon emissions across all models. The OLS model demonstrates that a 1% rise in overall trade correlates with an approximate 1.56% increase in emissions. This effect decreases yet remains substantial and positively significant in the RE (0.315***), FE (0.178***), and FE robust (0.178***) models, indicating resilience to unobserved heterogeneity and adjustments for standard errors.

Table 4.4.2.1 Model 1 Total Trade (Source: Author Computation)

Variables	**Ols**	**re**	**fe**	**fe robust**
	b/t	b/t	b/t	b/t
LN_TTR	1.555***	0.315***	0.178***	0.178**
	0.04	0.04	0.03	0.08
LN_GDP	-0.971***	0.129*	0.413***	0.413***
	0.04	0.07	0.06	0.12
ATRF	0.001	-0.001**	-0.001***	-0.001***
	0.00	0.00	0.00	0.00
LN_EXC	0.060***	0.180***	0.216***	0.216***
	0.02	0.03	0.03	0.06
FFC	-0.004*	0.020***	0.019***	0.019**
	0.00	0.00	0.00	0.01
ERNE	-0.033***	-0.007**	-0.009***	-0.009
	0.01	0.00	0.00	0.01
LN_TRT	1.800***	0.173***	0.109**	0.109
	0.14	0.06	0.05	0.11
_cons	-35.232***	-6.981***	-5.442***	-5.442***
	1.14	0.65	0.53	1.8
r2_a	0.911	0.904	0.911	0.911
N	327	327	327	327

***Notes:** (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

The GDP per capita (LN_GDP) exhibits a pattern contingent upon the model utilized. The OLS analysis reveals a negative coefficient of -0.971, implying that increased income per capita may lead to reduced emissions. Conversely, in the fixed effects and robust fixed effects models, the relationship becomes positive and significant, approximately 0.413, suggesting a potential scale effect after accounting for time-invariant and country-specific factors. Energy-related controls exhibit divergent outcomes. The use of fossil fuels is favorably correlated with emissions, especially under RE and FE (0.019–0.020), whereas the share of renewable electricity (ERNE) has a considerable negative correlation, affirming anticipated environmental advantages.

Tariffs (ATRF) are negligible in OLS but demonstrate a constant negative and significant impact in panel models, indicating that increased trade protection is associated with diminished emissions, possibly due to reduced trade volumes. The exchange rate (LN_EXC) has a positive and substantial correlation with emissions in all models, with greater coefficients observed in the RE and FE models (about 0.18 to 0.22), suggesting that currency depreciation may promote emissions associated with export activities. The terms of trade (LN_TRT) exhibit a positive correlation with emissions, significant across all specifications, albeit with a diminished coefficient under fixed effects and robust fixed effects (0.109).

4.4.3 Sectoral OLS, Fixed Effect, and Random Effect Panel Results Analysis

4.4.3.1 Merchandise Trade

In the merchandise model, merchandise trade (MTR) is consistently positive and statistically significant in all specifications. The coefficients range from 0.001 to 0.003, indicating that increases in merchandise trade contribute to rising emissions, though at a smaller marginal scale compared to total trade. GDP per capita remains a strong positive contributor (0.398–0.493), while renewable electricity shows a significant negative effect, highlighting its role in mitigating emissions across industrial trade sectors. Tariffs on primary products are found to have a negative and significant effect, while urban population (LN_URP) maintains a strong positive influence, reflecting consumption-related emissions in urbanizing economies.

Table 4.4.2.2 Model 2 Merchandise Trade (Source: Author Computation)

Variables	**Ols**	**fe**	**re**	**re robust**
	b/t	b/t	b/t	b/t
MTR	0.002***	0.001**	0.001**	0.001**
	0.001	0.00	0.00	0.00
LN_GDP	0.493***	0.420***	0.398***	0.398***
	0.02	0.04	0.04	0.07
ERNE	0.000	-0.011***	-0.011***	-0.011***
	0.00	0.00	0.00	0.00
PTRF	0.000	-0.001***	-0.001***	-0.001***
	0.00	0.00	0.00	0.00
LN_URP	1.196***	0.978***	1.018***	1.018***
	0.02	0.07	0.05	0.12
_cons	-19.931***	-15.175***	-15.682***	-15.682***
	0.56	0.90	0.72	1.93
r2_a	0.956	0.883	0.883	0.884
N	345	345	345	345

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

4.4.3.2 Manufacturing Export

Manufacturing export intensity (MEXP) demonstrates a significant negative effect across all panel models, suggesting that greater specialization in manufacturing trade might coincide with cleaner technologies or higher energy efficiency, possibly due to stricter standards in international value chains. GDP per capita again shows a strong positive relationship, while renewable electricity share continues to exhibit a negative effect (around -0.016), reinforcing its mitigation role. Tariffs on manufactured goods appear to reduce emissions slightly. Industrial value-added (IVA) is statistically insignificant in most models, while energy use and urban population retain strong, positive significance, particularly under OLS and FE models.

Table 4.4.2.3 Model 3 Manufacturing Export (Source: Author Computation)

Variables	**Ols**	**re**	**fe**	**fe robust**
	b/t	b/t	b/t	b/t
MEXP	-0.001	-0.005***	-0.005***	-0.005*
	0.00	0.00	0.00	0.00
LN_GDP	0.433***	0.537***	0.653***	0.653***
	0.02	0.05	0.09	0.20
ERNE	-0.027***	-0.017***	-0.016***	-0.016*
	0.00	0.00	0.00	0.01
MTRF	-0.004*	-0.003	-0.004**	-0.004**
	0.00	0.00	0.00	0.00
IVA	0.014***	0.001	-0.003	-0.003
	0.00	0.00	0.01	0.02
LN_ENU	0.628***	0.326***	0.353***	0.353
	0.07	0.10	0.13	0.35
LN_URP	1.037***	1.095***	0.883***	0.883***
	0.02	0.05	0.12	0.26
_cons	-21.939***	-21.770***	-18.972***	-18.972***
	0.34	1.02	2.03	4.98
r2_a	0.961	0.758	0.761	0.761
N	334	334	334	334

***Notes:** (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

4.4.3.3 Agricultural Export

Agricultural exports (LN_AEXP) have a positive and significant effect across all specifications (coefficient ~0.17–0.35), indicating that growth in agricultural trade is associated with higher emissions. This supports the premise that agriculture-based exports in the region are still resource-intensive. GDP per capita shows a negative coefficient under OLS and RE, while fertilizer use (LN_FER) becomes significant under panel estimators, contributing to emissions as expected. Agricultural value-added strongly correlates with higher emissions, indicating that expanding agricultural output is emission intensive.

Renewable energy and food imports have expected signs: electricity from renewable sources reduces emissions, while food imports marginally increase them.

Table 4.4.2.4 Model 4 Agriculture Export (Source: Author Computation)

Variables	**Ols**	**fe**	**re**	**re robust**
	b/t	b/t	b/t	b/t
LN_AEXP	0.348***	0.167***	0.187***	0.187***
	0.02	0.033	0.03	0.05
LN_GDP	-0.604***	-0.23**	-0.372***	-0.372***
	0.03	0.09	0.06	0.13
LN_FER	0.025	0.084**	0.065***	0.065
	0.03	0.03	0.03	0.05
LN_AVA	0.560***	0.534***	0.649***	0.649***
	0.02	0.13	0.05	0.07
ERNE	-0.014***	-0.003*	-0.004**	-0.004
	0.00	0.00	0.00	0.00
LN_ENU	0.132*	0.330**	0.242**	0.242
	0.07	0.13	0.11	0.22
FIMP	0.027***	0.012*	0.010	0.010
	0.01	0.01	0.01	0.02
_cons	-14.188***	-15.195***	-16.601***	-16.601***
	0.44	2.70	1.33	2.11
r2_a	0.960	0.420	0.416	0.416
N	371	371	371	371

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

4.4.4 Regional OLS, Fixed Effect, and Random Effect Panel Results Analysis: ASEAN, South Asia, and East Asia

The models are estimated independently for ASEAN, South Asia, and East Asia to account for regional heterogeneity, utilizing both Fixed and Random Effects.

4.4.4.1 Total Trade – Regional Results

Total trade (LN_TTR) shows a positive and statistically significant association with carbon emissions across all three regions. The highest effect is observed in South Asia, where a 1% increase in trade is associated with a 0.249% increase in emissions (0.249***), followed by ASEAN (0.143***) and East Asia (0.122**). The per capita GDP (LN_GDP) exhibits a positive correlation with emissions in ASEAN (0.302***) and East Asia (0.707***). In South Asia, the coefficient is positive (0.157) however lacks statistical significance. Tariffs (ATRF) have a substantial negative correlation in South Asia (-0.001**), a considerable positive correlation in East Asia (0.011***), and a non-significant negative impact in ASEAN (-0.003). The exchange rate (LN_EXC) is markedly favorable in ASEAN (0.104***) and South Asia (0.348***), whereas it is negative and statistically insignificant in East Asia (-0.014). Fossil fuel consumption (FFC) exhibits a substantial positive correlation with emissions across all regions: ASEAN (0.022***), South Asia (0.037***), and East Asia (0.008***). Electricity from renewable sources (ERNE) is positively significant in ASEAN (0.003**), however it is significantly negative in South Asia (-0.012**) and East Asia (-0.023***).

Table 4.4.4.1 Region Model 1 Total Trade (Source: Author Computation)

Variables	**fe Asean**	**fe south asia**	**fe East Asia**
	b/t	b/t	b/t
LN_TTR	0.143***	0.249***	0.122**
	0.02	0.07	0.05
LN_GDP	0.302***	0.157	0.707***
	0.06	0.14	0.07
ATRF	-0.003	-0.001**	0.011***
	0.00	0.00	0.00
LN_EXC	0.104***	0.348***	-0.014
	0.03	0.06	0.04
FFC	0.022***	0.037***	0.008***
	0.00	0.00	0.00
ERNE	0.003**	-0.012**	-0.023***
	0.00	0.01	0.00
LN_TRT	-0.01	0.285***	0.162***
	0.04	0.09	0.04
_cons	-2.634***	-8.525***	-4.068***
	0.4	1.14	0.94
r2_a	0.978	0.931	0.991
N	129	118	79

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

4.4.4.2 Sectoral wise Regional Results

Merchandise trade (MTR) exhibits a positive and substantial correlation with emissions in ASEAN (0.003***) and South Asia (0.002***), but East Asia demonstrates a significant negative correlation (-0.002**). GDP per capita (LN_GDP) exhibits a significantly positive correlation in all regions: ASEAN (0.827***), South Asia (0.562***), and East Asia (0.715***). Electricity from renewables (ERNE) exhibits a statistically significant negative impact across all three regions: ASEAN (-0.008***), South Asia (-0.011*), and East Asia (-0.013***). Product-level tariffs (PTRF) exhibit a statistically significant negative impact in ASEAN (-0.002*) and South Asia (-0.001**), while showing no significant effect in East Asia (-0.002). The urban population (LN_URP) exhibits a considerably positive correlation in ASEAN (0.298***) and South Asia (1.016***), but it is not significant in East Asia (0.036).

Table 4.4.4.2 Region Model 2 Merchandise Trade (Source: Author Computation)

Variables	fe Asean	fe south asia	fe East Asia
	b/t	b/t	b/t
MTR	0.003***	0.002***	-0.002**
	0.00	0.00	0.00
LN_GDP	0.827***	0.562***	0.715***
	0.05	0.18	0.06
ERNE	-0.008***	-0.011*	-0.013***
	0.00	0.01	0.00
PTRF	-0.002*	-0.001**	-0.002
	0.00	0.00	0.00
LN_URP	0.298***	1.016***	0.036
	0.08	0.19	0.16
_cons	-6.463***	-17.366***	0.040
	1.08	2.06	2.49
r2_a	0.961	0.833	0.955
N	127	128	90

***Notes:** (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%*

The Manufacturing exports (MEXP) exhibit a statistically significant negative correlation in ASEAN (-0.004***) and South Asia (-0.010***), while demonstrating a statistically significant positive correlation in East Asia (0.026***). GDP per capita (LN_GDP) exhibits a significantly positive correlation in ASEAN (0.577***), South Asia (1.071***), and East Asia (0.438***). Electricity from renewables (ERNE) is significantly positive alone in East Asia (0.020***), whereas it is not significant in ASEAN (0.002) and South Asia (-0.007). Manufacturing tariffs (MTRF) exhibit a statistically significant negative impact in ASEAN (-0.007***), while showing no significance in South Asia (-0.004) and East Asia (0.006). Industry value added (IVA) is markedly positive in East Asia (0.022***), substantially negative in South Asia (-0.054***), and statistically insignificant in ASEAN (0.007). Energy use (LN_ENU) is significantly positive in South Asia (1.381***) and East Asia (0.895***), but not significant in ASEAN (-0.191). The urban population (LN_URP) exhibits positive significance across all regions: ASEAN (0.351**), South Asia (1.043***), and East Asia (1.431***).

Table 4.4.4.3 Region Model 3 Manufacturing Export (Source: Author Computation)

Variables	**fe Asean**	**fe south asia**	**fe East Asia**
	b/t	b/t	b/t
MEXP	-0.004***	-0.010***	0.026***
	0.00	0.00	0.00
LN_GDP	0.577***	1.071***	0.438***
	0.14	0.32	0.07
ERNE	0.002	-0.007	0.020***
	0.00	0.01	0.01
MTRF	-0.007***	-0.004	0.006
	0.00	0.00	0.00
IVA	0.007	-0.054***	0.022***
	0.01	0.01	0.01
LN_ENU	-0.191	1.381***	0.895***
	0.17	0.29	0.16
LN_URP	0.351**	1.043***	1.431***
	0.17	0.34	0.22
_cons	-7.025**	-27.944***	-33.639***
	2.90	4.33	3.85
r2_a	0.851	0.810	0.967
N	131	117	85

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%)*

Agriculture Trade Model Agricultural exports (LN_AEXP) exhibit a substantial positive correlation just in East Asia (0.600***), but the coefficients are not statistically significant in ASEAN (-0.003) and South Asia (0.017). GDP per capita (LN_GDP) exhibits a considerably negative correlation in South Asia (-0.411***) and East Asia (-1.617***), while demonstrating a significantly positive correlation in ASEAN (0.281**). The utilization of fertilizer (LN_FER) is considerably positive in ASEAN (0.507***) and East Asia (0.534**), but it is not significant in South Asia (0.015). Agricultural value added (LN_AVA) is notably positive in ASEAN (0.413***) and South Asia (0.861***). In East Asia, the coefficient is substantial (0.733) however lacks statistical significance. Electricity from renewables (ERNE) exhibits a markedly negative correlation in South Asia (-0.015***) and East Asia (-0.074***), while being statistically insignificant in ASEAN (0.000). Energy use (LN_ENU) is markedly positive in ASEAN (0.451***), notably negative in South Asia (-0.319*), and profoundly negative in East Asia (-1.810***). Food imports (FIMP) exhibit a substantial positive correlation alone in East Asia (0.107***), while showing no significance in ASEAN (0.005) or South Asia (-0.003).

Table 4.4.4.4Region Model 4 Agriculture Export (Source: Author Computation)

Variables	fe Asean	fe south asia	fe East Asia
	b/t	b/t	b/t
LN_AEXP	-0.003	0.017	0.600***
	0.05	0.04	0.17
LN_GDP	0.281**	-0.411***	-1.617***
	0.11	0.15	0.41
LN_FER	0.507***	0.015	0.534**
	0.06	0.03	0.25
LN_AVA	0.413***	0.861***	0.733
	0.13	0.16	0.51
ERNE	0.000	-0.015***	-0.074***
	0.00	0.01	0.02
LN_ENU	0.451***	-0.319*	-1.810***
	0.15	0.17	0.59
FIMP	0.005	-0.003	0.107***
	0.01	0.01	0.03
_cons	-15.879***	-15.292***	-6.130
	3.21	2.83	11.12
r2_a	0.788	0.749	0.383
N	153	127	90

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%)*

4.4.5 Robustness Checks - Driscoll-Kraay Standard Errors

This section presents the robustness checks performed utilizing Driscoll-Kraay (DK) standard errors, which adjust for cross-sectional dependency, autocorrelation, and heteroscedasticity in panel data. The DK estimator is utilized in all four trade models: total trade, merchandise trade, manufacturing exports, and agricultural exports. Furthermore, each model is evaluated for three regional groups: ASEAN, South Asia, and East Asia. The primary explanatory variables of interest are trade, renewable electricity, tariff rates, agriculture value addition and GDP per capita.

4.4.5.1 Total Trade Model

The estimated coefficient for LN_TTR in the first trade model, utilizing DK standard errors, is 0.178 and is statistically significant at the 1% level. The coefficient aligns with the fixed effects estimation, thereby affirming the robustness of the relationship between total trade and the dependent variable. The coefficient for the variable LN_GDP is 0.413 and is significant at the 1% level. This estimate corresponds with the findings from fixed effects and random effects estimations, suggesting a consistent relationship across specifications. The variable Tariff (ATRF), indicating average tariff rates across all goods, shows a coefficient of -0.001, significant at the 1% level. This estimate is consistent with previous panel models. The share of electricity produced from renewable sources (ERNE) exhibits a coefficient of -0.009, which is statistically significant at the 1% level. The estimated magnitude and significance align with the findings from the fixed effects and random effects estimators by minimizing the standard error and adjusting the cross-sectional dependency, auto-correlation and heteroscedasticity within panel data.

4.4.5.2 Merchandise Trade Model

In the merchandise trade model, Merchandise Trade (MTR) indicates a coefficient of 0.001, which is statistically significant at the 5% level, thereby affirming the stability of its relationship with emissions. The coefficient for GDP per capita (LN_GDP) in this model is 0.420, with significance at the 1% level. This closely resembles earlier estimates derived from Fixed Effects (FE) and Random Effects (RE) models with low standard errors. The variable for renewable electricity (ERNE) exhibits a coefficient of -0.011, which is statistically significant at the 1% level in all models by adjusting the cross-sectional dependency, auto-correlation and heteroscedasticity. This outcome aligns with previous research, indicating consistency in the assessment of this relationship. The coefficient for PTRF is -0.001, demonstrating statistical significance at the 1% level. The uniformity in sign and magnitude across specifications strengthens the reliability of this estimate.

Table 4.4.5.1 Robust Model 1 Total Trade (Source: Author Computation)

Table 4.4.5.2 Robust Model 2 Merchandise Trade (Source: Author Computation)

Variables	**Driscoll-Kraay**	**Variables**	**Driscoll-Kraay**
	b/t		b/t
LN_TTR	0.178***	MTR	0.001**
	0.03		0.00
LN_GDP	0.413***	LN_GDP	0.420***
	0.05		0.05
ATRF	-0.001***	ERNE	-0.011***
	0.00		0.00
LN_EXC	0.216***	PTRF	-0.001***
	0.02		0.00
FFC	0.019***	LN_URP	0.978***
	0.00		0.06
ERNE	-0.009***	_cons	-15.175***
	0.00		0.75
LN_TRT	0.109*	r2_a	0.883
	0.06	N	345
_cons	-5.442***		
	0.82		

r2_a	0.91		
N	327		

***Notes:** (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%)*

4.4.5.3 Manufacturing Export Model

In the manufacturing export model, the MEXP coefficient is -0.005, statistically significant at the 5% level. This validates the steady trend identified in fixed effects and random effects estimations. The coefficient for LN_GDP is 0.653, statistically significant at the 1% threshold. The magnitude remains consistent when juxtaposed with FE and RE estimators. The renewable electricity variable (ERNE) exhibits a coefficient of -0.016, which is statistically significant at the 1% level. This value aligns with previous models. The variable MTRF produces a coefficient of -0.004, significantly at the 1% threshold. This substantiates the strength of the previously identified negative correlation observed by RE and FE estimators.

4.4.5.4 Agriculture Export Model

The Driscoll-Kraay (DK) estimation for the agriculture export model validates the consistency and robustness of previously observed results across fixed and random effects estimators. The coefficient of LN_AEXP is 0.167, statistically significant at the 1% threshold. This signifies that the correlation between agricultural exports and emissions is consistent across several estimate methods, with DK standard errors addressing potential cross-sectional dependence and heteroscedasticity. The variable GDP per capita (LN_GDP) in this model has a coefficient of -0.230, which is statistically significant at the 10% level. This coefficient aligns with the fixed effects results and maintains directional consistency with prior calculations. The coefficient for electricity from renewable sources (ERNE) is -0.003, which is statistically significant at the 5% level. The consistency of this estimate across OLS, FE, and DK models underscores the robustness of the observed association. The agricultural value added (LN_AVA) variable, which reflects the production-based contribution of agriculture to the economy, has a coefficient of 0.534, significant at the 1% level. This study validates previous model estimates and affirms a strong and positive relation between agricultural output and carbon emissions within the agricultural sector. Additional variables, including fertilizer consumption (LN_FER), energy usage (LN_ENU), and food imports (FIMP), maintain consistent coefficient signs and degrees of statistical significance relative to the basic models, despite not being the primary emphasis on this section.

Table 4.4.5.3 Robust Model 4 Agriculture Export (Source: Author Computation)

Table 4.4.5.4 Robust Model 3 Manufacturing Export (Source: Author Computation)

Variables	**Driscoll-Kraay**	**Variables**	**Driscoll-Kraay**
	b/t		b/t
LN_AEXP	0.167***	MEXP	-0.005**
	0.04		0.00
LN_GDP	-0.230*	LN_GDP	0.653***
	0.11		0.07
LN_FER	0.084	ERNE	-0.016***
	0.05		0.00
LN_AVA	0.534***	MTRF	-0.004***
	0.15		0.00
ERNE	-0.003**	IVA	-0.003
	0.00		0.01
LN_ENU	0.330***	LN_ENU	0.353**
	0.11		0.17
FIMP	0.012**	LN_URP	0.883***
	0.01		0.10
_cons	-15.195***	_cons	-18.972***
	2.70		2.09
r2_a	0.42	r2_a	0.761
N	371	N	334

Notes: *(*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%)*

This chapter has provided comprehensive empirical evidence regarding the significant correlation between trade and carbon emissions across various sectors and geographies in Asia. The results provide compelling statistical evidence across total trade, merchandise, manufacturing, and agricultural sectors by employing a combination of panel data methodologies, including fixed and random effects models, along with robust Driscoll-Kraay estimators. Pre-estimation diagnostics validated the model requirements, and causality evaluations substantiated the function of commerce as a catalyst for emissions. The following chapter examines the extensive interpretation of these findings, their correlation with previous literature, and their ramifications for policy and sustainable trading practices.

4.5 Discussion of Findings

This chapter critically discusses the empirical findings on the relationship between trade and carbon emissions across East Asia, South Asia, and Southeast Asia, drawing on the Environmental Kuznets Curve (EKC), Pollution Haven Hypothesis (PHH), and Pollution halo hypothesis (PHH) frameworks. The analysis explores how different trade components total trade, merchandise trade, manufacturing exports, and agricultural exports influence environmental outcomes, while accounting for the roles of GDP per capita, renewable energy, tariff structures, and other control variables through both sectoral and regional lenses. Prior to interpreting these results, robust pre-estimation diagnostic tests including unit root, summary statistics, correlation analysis, multicollinearity, Cross sectional dependency, heteroscedasticity and autocorrelation, Slope heterogeneity, Hausman Test and Dumitrescu & Hurlin Panel Granger Causality Test were conducted to confirm the panel structure, assess data characteristics, and validate the choice of estimation strategies.

Due to the longitudinal characteristics of macroeconomic data, it is imperative to test stationarity to prevent misleading regressions. This analysis utilized four first-generation panel unit root tests Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), ADF-Fisher, and PP-Fisher on each variable within the four emissions models. In all models, most variables indicate non-stationarity at level but demonstrated stationarity at first difference, aligning with I(1) characteristics. In the total emissions model, variables such as LN_TTR and LN_EXC achieved stationarity solely after differencing. This is consistent with previous research indicating that macroeconomic variables, particularly trade and income, typically exhibit stochastic trends. Although several variables (e.g., ATRF, FFC) exhibited stationarity at level in specific tests, the discrepancies between tests such as LLC (which presumes homogeneity) and IPS (which accommodates heterogeneity) warrant a prudent I(1) assumption. Due to the mixed stationarity and structural variations among countries, the study employs estimators capable of addressing non-stationarity and cross-sectional dependence, such as Driscoll-Kraay.

The summary statistics indicate significant skewness and kurtosis in several variables, especially in trade tariff data. For example, tariff (ATRF) demonstrated a kurtosis of 280 and a skewness over 15, signifying extreme values and policy variability among nations. These characteristics warrant the application of logarithmic modifications to alleviate distributional distortions. Transformed variables (e.g., LN_GDP, LN_TTR, LN_URP) exhibited enhanced normality with skewness approaching zero, hence enabling elasticity-based interpretations in log-log models. The existence of substantial standard deviations in variables such as fossil consumption and renewable electricity highlights the disparities in energy transition among regions, particularly between ASEAN and South Asia, a variability essential for environmental policy analysis.

The pairwise correlation matrix provided initial insights into theoretical relationships and probable multicollinearity issues among explanatory factors. The manufacturing emissions model revealed a robust positive correlation between urban population and emissions (r = 0.897), substantiating the theoretical justification for incorporating urbanization as a structural proxy within the Pollution Haven Hypothesis (PHH) and Environmental Kuznets Curve (EKC) frameworks. A moderate connection exists between energy use and carbon emissions from manufacturing (r = 0.58), consistent with literature that identifies energy use as a primary factor influencing emissions in industrial sectors. In contrast, the relationship between electricity generated from renewables and emissions remained under 0.2, indicating that these variable functions as a relatively exogenous factor probably influenced by policy and technological changes rather than direct economic performance thereby endorsing its role as a proxy for green transition.

To officially evaluate multicollinearity, variance inflation factor (VIF) tests were performed, with all values far below the normal threshold of 10, consistent with established econometric norms. The results indicate that multicollinearity is improbable to distort coefficient estimates or undermine the validity of inferences in the provided models. Diagnostics for multicollinearity reveal that all primary explanatory variables in the four models, especially the core variables of interest (trade variables, GDP per capita, renewable electricity, tariffs, and agriculture value addition), demonstrate acceptable levels of independence, with all VIFs significantly below the standard threshold of 10. In Model 1, the total trade variable (LN_TTR) exhibits the highest VIF at 4.49. While this is relatively elevated, it remains within an acceptable range, indicating moderate correlation without significant multicollinearity issues. The variance inflation factors (VIFs) for GDP per capita (LN_GDP) and the renewable energy proxy (ERNE) are 2.31 and 1.12, respectively, suggesting stable estimation. In Model 2, the variance inflation factor (VIF) for merchandise trade (MTR) is 2.28, while GDP per capita is 1.72 and renewable energy is 2.27, all values are significantly below critical thresholds, thereby affirming the independence of estimating the impacts of trade and energy transitions on emissions. Model 3 emphasizes manufacturing exports (MEXP), exhibiting a low VIF of 1.34, in conjunction with GDP per capita (2.01) and renewable energy (1.31). This supports the assertion that emissions from the manufacturing sector can be accurately associated with trade intensity, free from collinearity issues. In Model 4, agricultural exports (LN_AEXP) and agriculture value addition (LN_AVA) exhibit VIFs of 2.75 and 3.28, respectively, which are marginally elevated but remain within acceptable limits. GDP per capita (2.21) and renewable electricity (1.76) exhibit no evidence of multicollinearity, facilitating a clear interpretation of agricultural dynamics in emissions modeling. The multicollinearity results indicate that the core variables of interest across all four models are statistically distinguishable, thereby ensuring robustness in the interpretation of their marginal effects on carbon emissions.

The evaluation of cross-sectional dependence indicates significant spillover effects, particularly in Model 2 (Merchandise Trade). The Pesaran CD test indicates statistical significance ($z = 3.203$, $p < 0.01$), confirming cross-sectional dependence in residuals, which likely reflects economic interlinkages and trade spillovers among countries in the merchandise trade sector. This supports the Driscoll-Kraay (DK) standard errors, which are resilient to these dependencies. In Model 1 (Total Trade), the Pesaran CD test lacks statistical significance ($p = 0.10$), whereas the Frees test indicates significance, implying a degree of dependence that may be influenced by common macroeconomic shocks or regional trade integration impacting GDP per capita and energy patterns. Models 3 (Manufacturing Exports) and 4 (Agricultural Exports) do not exhibit significant cross-sectional dependence according to the Pesaran test ($p > 0.16$). However, the Frees test results for Model 3 are significant, suggesting potential cross-country spillovers in energy use or industrial emissions, despite not being detected by the Pesaran test. The evidence of cross-sectional dependence in merchandise trade (Model 2) and partial signals in other models justifies the Driscoll-Kraay estimators for reliable inference on the effects of trade, GDP per capita, renewable energy, tariffs, and agriculture value addition on emissions across interconnected economies.

The Modified Wald test verifies heteroskedasticity across all four models ($p < 0.01$), signifying country-level disparities in residual variance, which align with differing trade intensity, income levels, and energy transitions. Robust estimation is crucial for precise inference on trade, GDP per capita, renewable energy, tariffs, and agricultural value addition. Serial correlation exists in Model 1 (Total Trade) and Model 2 (Merchandise Trade), as indicated by the Wooldridge test ($p < 0.01$). This indicates that emissions associated with extensive trade flows and economic activity endure over time, either as a result of incremental trade reforms or delayed environmental effects. Conversely, Models

3 (Manufacturing) and 4 (Agriculture) exhibit no notable autocorrelation, indicating more prompt or short-term emission reactions in sector-specific trade dynamics. Although Models 3 and 4 exhibit no autocorrelation, the enduring heteroskedasticity shown in all models underscores fundamental disparities among countries. The study employs Driscoll-Kraay standard errors to enable trustworthy estimate, addressing heteroskedasticity, cross-sectional dependency, and autocorrelation when applicable, thus enhancing the robustness of results across all models.

The Pesaran–Yamagata Δ and Δ_adj tests exhibit statistical significance ($p < 0.01$) in all four models, hence affirming slope heterogeneity. The correlation among trade-related variables, GDP per capita, renewable energy, tariffs, agricultural value addition, and carbon emissions is inconsistent between nations. The results indicate that the emission impact of trade and economic structure differs by country context, likely influenced by variations in industry composition, trade dependency, energy mixtures, and regulatory robustness. The carbon impact of manufacturing exports may be significant in energy-intensive economies, whereas it may be minimal or even negative in service-oriented or environmentally sustainable exporters, Similar Studies showing heterogeneous trade-emissions impacts across countries. The influence of GDP per capita on emissions varies according to developmental stages, in accordance with the principles of the Environmental Kuznets Curve (EKC). This heterogeneity reinforces the rationale for employing robust estimators such as Driscoll-Kraay, which do not enforce uniform slope assumptions. This also indicates the necessity for careful interpretation of aggregated effects, as mean coefficients may obscure significant country-specific trade-emission interactions.

The Hausman test facilitates model selection by identifying correlation between regressors and unobserved effects. Fixed Effects (FE) is favored for Model 1 (Total Trade) and Model 3 (Manufacturing Export), as significant test statistics ($p < 0.05$) indicate that country-specific factors such as institutional strength or policy frameworks are associated with trade, GDP per capita, or renewable energy, thereby necessitating FE to mitigate bias. Conversely, Random Effects (RE) is suitable for Model 2 (Merchandise Trade) and Model 4 (Agriculture Export) ($p > 0.05$), indicating that unobserved heterogeneity is uncorrelated with the regressors. Here, RE offers more efficiency, especially for broad-based merchandise trade and agriculture export, where structural disparities are unlikely to systematically distort estimates. This data-driven model selection ensures reliable coefficient interpretation while aligning with the economic context of each trade–emissions relationship.

The Dumitrescu–Hurlin panel test for Granger causality analysis offers significant insights into the historical direction of interaction between trade and emissions. The findings across all four models establish a unidirectional causality from trade-related variables to CO_2 emissions, signifying that trade dynamics encompassing total, merchandise, manufacturing, or agricultural statistically precede and facilitate the prediction of changes in environmental outcomes. This supports the study's fundamental hypothesis that trade functions as a catalyst for emissions, affirming its designation as an exogenous variable in the panel models. The discovery that manufacturing and agricultural exports are Granger-cause sector-specific emissions supports the Pollution Haven Hypothesis (PHH), indicating that trade-driven growth in carbon-intensive industries exacerbates environmental degradation. Although some reverse causation is shown (e.g., from emissions to merchandise or agricultural trade), these effects are relatively weaker and presumably indicate adaptive reactions, such as alterations in trade policy, competitiveness, or environmental compliance. The Granger causality results reinforce the causal interpretation of the trade-emissions link and validate the econometric approach employed in the study.

4.5.1 Main Model Discussion

4.5.1.1 Total Trade and Carbon Emissions

The fixed-effects regression model, utilizing robust standard errors, exhibits significant explanatory capability, as indicated by an adjusted R^2 of 0.911, this indicates that over 91% of the variation in Carbon emission among Asian nations are accounted for by the model's regressors. The rigorous specification improves the reliability of estimated effects by mitigating heteroskedasticity and serial correlation, therefore enhancing the trustworthiness of findings for policy analysis. Total Trade (LN_TTR) demonstrates a positive and statistically significant relationship with carbon emissions. A 1% rise in trade volume correlates with a 0.18% rise in CO_2 emissions significant at 1% level. This discovery aligns with the Pollution Haven Hypothesis (PHH), which asserts that liberalized trade may incentivize pollution-intensive firms to relocate to countries with more lenient environmental restrictions. The favorable correlation remains evident when accounting for unobserved variability, suggesting that without strong regulatory frameworks, trade expansion may pose environmental hazards.

GDP per capita (LN_GDP) also demonstrates a substantial positive significant link with emissions, as evidenced by a coefficient a of (0.413***). This discovery supports the Environmental Kuznets Curve (EKC) hypothesis, particularly in the ascending phase, where economic expansion leads to increased emissions due to reliance on fossil fuels and industrial production. In various Asian economies, growth is intricately associated with carbon-intensive production, hence sustaining this pattern. Tariff rates (ATRF), indicative of trade policy, demonstrate a consistently negative and statistically significant connection with emissions (–0.001***) at 1% level. Decreased tariffs, suggestive of trade liberalization, correlate with increased emissions, consistent with PHH extensions that emphasize the potential for liberal trade policies to cause environmental degradation when enforcement mechanisms are inadequate. The minimal effect size, along with its statistical significance, highlights the enduring environmental costs linked to trade liberalization. The proportion of renewable electricity (ERNE) displays a negative coefficient (–0.009***), with marginal significance in the fixed effect specification. This phenomenon corresponds with the pollution halo hypothesis, which asserts that participation in international markets and investment might facilitate the adoption of cleaner technologies and improved environmental practices. The lack of major importance may stem from reporting errors or delays between the adoption of renewable energy and the observed reduction in emissions. The robust fixed-effects findings empirically substantiate the theoretical underpinnings of the Pollution Haven Hypothesis, the Environmental Kuznets Curve, and the pollution halo effect hypothesis. Within the Asian regional framework, trade openness, economic expansion, and tariff liberalization exacerbate emissions, but renewable electricity possesses the capacity to reduce carbon output, albeit with constrained efficacy. The results underscore the imperative of integrating environmental goals into trade and economic strategies. The lack of such integration may threaten long-term climate goals in East, South, and Southeast Asia, considering the present course of economic development.

4.5.1.2 Model 2: Merchandise Trade and Carbon Emissions

The impact of merchandise trade, including total exports and imports of tangible products, on carbon emissions is analyzed in this model. The strong random effects findings demonstrate that merchandise trade (MTR) exerts a minor yet statistically significant beneficial influence on emissions (0.001**), hence supporting the Pollution Haven Hypothesis. The physical transportation of commodities generally entails greater embedded carbon due to energy-intensive manufacturing, extensive transportation, and fossil-fuel-dependent logistics, despite the average coefficient being lower than that of total trade. This indicates a complex scenario: merchandise trade contributes to emissions, although disparities in production efficiency and product composition among countries mitigate their overall intensity.

The influence of GDP per capita (LN_GDP = 0.398***) is clearly positive and statistically significant, aligning with previous models. It corroborates the Environmental Kuznets Curve (EKC) hypothesis that increasing wealth in developing and middle-income nations persistently elevate emissions owing to industrialization and energy consumption. Renewable electricity (ERNE) has a substantial negative impact (–0.011***), greater in magnitude than in Model 1. This indicates that in economies reliant on trade, a cleaner energy mix significantly mitigates trade-related emissions. Tariffs on primary goods (PTRF) exhibit a negative and significant coefficient (–0.001***), suggesting that decreases in tariffs within resource-intensive sectors lead to increased emissions, consistent with PHH assumptions. Urbanization (LN_URP) has a robust elasticity (>1), with a positive coefficient of (1.018***). A 1% rise in urban population results in an increase of over 1% in emissions, indicative of scale effects stemming from industry clustering, energy consumption, and transportation emissions in densely populated trade centers. The model accounts for almost 88% of the within-panel variation (R^2 = 0.884), demonstrating robust explanatory capability.

4.5.1.3 Model 3: Manufacturing Export and Carbon Emissions

In Manufacturing model, the relationship between manufacturing exports and carbon emissions are examined. The coefficient for manufacturing exports (MEXP) is negative and statistically significant in the robust fixed-effects model (–0.005***), suggesting that a 1% increase in manufacturing exports correlates with a 0.5% decrease in CO_2 emissions. This may seem counterintuitive from a traditional Pollution Haven perspective; however, it is consistent with firm-level evidence presented by Barrows & Ollivier, (2021), which indicates that export exposure results in technological upgrading and decreased emission intensity in manufacturing firms. Cleaner technologies need not be advanced; they can include energy-efficient boilers, fuel switching, or improved machinery, all of which are encouraged by export standards and foreign direct investment. This demonstrates that even mid-level exporters adopt cleaner production practices in response to regulatory standards, environmental expectations, and competitive pressure from foreign markets. Grether et al., (2010) similarly conclude that global manufacturing trade has not increased SO_2 emissions, attributing this to significant efficiency improvements and a transition to cleaner production methods. A plausible explanation for this pattern in our sample is found in the structural composition of numerous Asian economies, which continue to be predominantly agriculture- or resource-intensive, accompanied by smaller, export-oriented manufacturing sectors. These sectors typically generate higher-value, lower emission-intensive products (e.g., textiles, machinery, electronics), resulting in a more environmentally friendly export composition. This indicates a green comparative advantage, wherein export growth in cleaner manufacturing can effectively decrease emissions per unit of output, particularly when combined with energy-efficient technologies. The coefficient for renewable electricity (–0.016***) is negative and statistically significant, indicating that clean energy is essential in reducing emissions from export-driven manufacturing. This effect surpasses that observed in earlier models, emphasizing that grid decarbonization yields greater advantages for the manufacturing sector compared to general goods trade. Tariffs on manufactured goods (–0.004**) exhibit a negative correlation with emissions, aligning with Pollution Haven theory; further trade liberalization could draw in polluting industries unless countered by environmental policy measures.

GDP per capita (LN_GDP = 0.653***) is a significant positive factor influencing emissions, aligning with the ascending segment of the Environmental Kuznets Curve (EKC). It is probable that numerous manufacturing-oriented Asian economies have not attained the income level at which emissions start to decrease. The urban population (LN_URP = 0.883***) significantly contributes to emissions, indicating the environmental pressures associated with industrial cluster, transportation, and energy requirements in urban manufacturing centers. The model's adjusted R^2 of 0.761 indicates a strong fit, albeit marginally lower than that of the total trade model.

4.5.14 Model 4: Agriculture Export and Carbon Emissions

Model 4 examines the relationship between agricultural exports (LN_AEXP) and total carbon emissions. The coefficient is positive and statistically significant (0.187***), suggesting that a 1% rise in agricultural exports is associated with a 0.187% increase in emissions. Agricultural trade is inherently more resource-intensive than manufacturing, often associated with land-use change, methane emissions from livestock, nitrous oxide emissions from fertilizers, and mechanization reliant on fossil fuels. This supports the Pollution Haven Hypothesis within agriculture, indicating that export expansion absent environmental safeguards leads to increased emissions. GDP per capita (–0.372***) exhibits a significant negative correlation with emissions, indicating that higher-income nations may be implementing cleaner agricultural practices or stricter environmental regulations such as Japan, South Korea, and Singapore, consistent with the declining segment of the Environmental Kuznets Curve (EKC).

The use of fertilizer (LN_FER = 0.065***) and agriculture value added (LN_AVA = 0.649***) both have a positive and significant impact on emissions, highlighting the role of scale and chemical inputs in increasing environmental pressure. Renewable electricity (ERNE = –0.004**) exhibits a weakly significant mitigation effect than previous models, energy intensity (LN_ENU = 0.242**) serves as a moderate yet significant contributor to emissions in agriculture aligning with previous models. Food imports (FIMP = 0.010) indicating intricate trade–carbon relationships, including emissions associated with cold storage, shipping, or concurrent export–import cycles.

The adjusted R^2 of the model is 0.416, which is lower than that of the other three models. This expectation arises from the characteristics of agricultural emissions, which tend to be diffuse, seasonal, and influenced by variables such as methane and nitrous oxide elements not adequately represented in CO_2-only datasets. Notably, analogous studies have indicated similar or reduced explanatory power. Saghaian et al., (2022) report within-R^2 values ranging from 0.02 to 0.30 in models of agricultural exports and emissions in developing countries.

Similarly, (Balogh, 2022) indicates that agricultural trade–environment models frequently fail to surpass R^2 values of 0.4, attributed to measurement gaps, informal activity, and structural heterogeneity. The R^2 of 0.416 is statistically acceptable and typical for cross-national panel studies concerning agriculture and emissions. The robustness, reliability, and importance of essential variables render the findings credible and pertinent to policy, despite the model's inability to account for all residual variation.

4.5.2 Region-wise Discussion

4.5.2.1 Total Trade and Emissions

In ASEAN, total trade has a positive and significant effect on emissions (LN_TTR = 0.143***), meaning that when trade is more open, carbon emissions increase if there are not strong environmental protections in place. This corresponds with the Pollution Haven Hypothesis, particularly in nations such as Indonesia and Thailand, where trade growth is predominantly focused on resource-intensive industries. GDP per capita (LN_GDP = 0.302***) demonstrates a positive correlation, aligning with the region's position in the upward phase of the Environmental Kuznets Curve, wherein income growth remains associated with fossil-fuel-dependent development. The tariff coefficient (ATRF = –0.003) is negative yet insignificant; nevertheless, WTO BND data indicates that Indonesia, Malaysia, and Thailand uphold comparatively elevated non-agricultural average tariffs

(35.5%, 15%, and 24%) and minimal duty-free shares (2.8%, 4.4%, and 5.3%), implying that tariff structures are intricate and may mitigate the environmental effects of liberalization. The renewable electricity variable (ERNE = 0.003**) indicates a modest positive effect, perhaps due to insufficient investment in grid upgrading. Although nations such as Vietnam have augmented their renewable energy sources, the energy portfolios of Indonesia and the Philippines remain predominantly reliant on coal, thus constraining the efficacy of clean electricity in mitigating trade-related emissions.

In South Asia, the emissions effect of total commerce is significant (LN_TTR = 0.249***), mostly influenced by fossil-intensive exports such as clothes and raw materials. Tariffs have a substantial inverse correlation with emissions (ATRF = –0.001**), indicating that protectionist measures may alleviate environmental impact by constraining the trade of commodities with high emissions. The WTO BND data corroborates this assertion: India, Pakistan, and Bangladesh exhibit minimal duty-free shares for non-agricultural goods (2.6%, 0%, 0%) but elevated average duties (36%, 55.2%, 37.6%), suggesting that trade policy may unintentionally mitigate carbon leakage. The GDP per capita (LN_GDP = 0.157) is positive yet not statistically significant, suggesting that certain economies in the region may be approaching the Environmental Kuznets Curve turning point. Renewable electricity (ERNE = –0.012**) exerts a considerable mitigating influence, driven by rising public and private investments in grid-scale solar infrastructure, particularly in Pakistan and India. Countries like Nepal, benefiting from hydropower development, also reflect how energy-sector investment improves the emission profile of trade-intensive growth. Nonetheless, regional inequalities in energy investment and grid integration particularly in Pakistan and Bangladesh persistently hinder comprehensive decarbonization efforts.

In East Asia, the trade-emissions correlation (LN_TTR = 0.122**) is positive yet the lowest among the three regions, indicating a higher degree of structural decoupling. GDP per capita (LN_GDP = 0.707***) is a significant determinant of emissions, given that industrial-scale manufacturing in China and Korea remains energy-intensive. Tariffs exert a positive and significant influence (ATRF = 0.011***), indicating that import substitution, propelled by elevated protection exemplified by Japan's 2.5% non-agricultural average duty with a 55.9% duty-free share and Korea's 9.8% average with an 18.3% duty-free share redirects production domestically, frequently into less efficient and more environmentally detrimental sectors. Renewable electricity (ERNE = –0.023***) significantly lowers emissions, showing that strategic investment in large-scale wind and solar projects especially in China and Korea has begun to decarbonize export-linked energy systems. These outcomes reflect both regulatory frameworks and long-term climate financing strategies.

4.5.2.2 Merchandise Trade and Emissions

Merchandise trade (MTR = 0.003***) exerts a positive influence on emissions, indicating an ongoing dependence on products with significant embedded carbon, including electronics and machinery characterized by extensive supply chains. The GDP (LN_GDP = 0.827***) significantly exacerbates emissions, highlighting that ASEAN's economic growth continues to rely on resources and fossil fuels. Tariffs on primary products (PTRF = –0.002*) are negatively correlated and statistically significant, indicating that mild trade protection may assist in safeguarding cleaner domestic sectors. The WTO BND data corroborates this assertion. Malaysia and Indonesia impose non-agricultural maximum tariffs of 53% and 60%, respectively, with binding coverage ranging from about 81% to 95%, allowing for adaptable policy responses. Renewable power (ERNE = –0.008***) exerts a considerable negative influence, signaling early payoffs from clean energy investment—particularly in Vietnam, where rapid deployment of solar infrastructure has been supported by state incentives and private capital inflows. Nonetheless, discrepancies in energy policy continue to hinder further regional convergence.

The merchandise trade of South Asia is substantially associated with elevated emissions (MTR = 0.002***), aligning with its considerable trade proportion in carbon-intensive goods. Gross Domestic Product once more propels emissions upward (LN_GDP = 0.562***), while renewable energy sources mitigate them (ERNE = –0.011*). Tariffs (PTRF = –0.001**) are once more negative and substantial, indicating that nations such as India and Bangladesh—with non-agricultural average levies of 36% and 37.6%, respectively, and a 0% duty-free share—employ tariff barriers that may restrict the influx of polluting commodities or production outsourcing. Expanding financing channels for distributed renewable systems, especially in rural industrial zones, could significantly enhance the carbon efficiency of merchandise trade across the region.

Merchandise trade in East Asia exhibits a negative and substantial coefficient (MTR = –0.002**), indicating that trade in goods is starting to decouple from emissions, probably due to a transition towards cleaner, high-tech exports. This corresponds with the roles of China and Korea in the manufacturing of electric vehicles, information and communication technology, and renewable energy sources. Nonetheless, GDP continues to exert a favorable influence (LN_GDP = 0.715***). Renewable electricity persistently reduces emissions (ERNE = –0.013***). In this context, tariffs are statistically insignificant (PTRF = –0.002); however, WTO data indicates that East Asia's elevated tariff ceilings (Japan max = 457%; Korea = 887%) provide strategic flexibility to deter the importation of inferior intermediate goods, although actual enforcement remains inconsistent.

4.5.2.3 Manufacturing Export and Emissions

Manufacturing exports (MEXP = –0.004***) greatly diminish emissions, presumably owing to cleaner specialization (e.g., electronics, textiles) and energy-efficient production clusters. GDP per capita (LN_GDP = 0.577***) continues to elevate emissions, indicating that industrialization is outpacing mitigating efforts. Renewable power (ERNE = 0.002) is negligible, possibly due to inconsistent investment throughout the region. Tariffs on manufactured goods (MTRF = –0.007***) markedly diminish emissions, indicating that policy is crucial in limiting inputs. The WTO BND indicates that Malaysia and Thailand impose elevated non-agricultural maximum duties (53% and 101%, respectively) and possess minimal duty-free shares, hence providing policy flexibility to foster clean trade.

Manufacturing exports contribute to emission reductions in this context (MEXP = –0.010***), primarily attributable to small-scale, labor-intensive sectors. GDP (LN_GDP = 1.071***) continues to be a determinant of emissions. Renewable electricity (ERNE = –0.007) is negative yet minor, perhaps attributable to inadequate industrial grid connectivity. Tariffs (MTRF = –0.004) are negligible but exhibit a negative trend. WTO data indicates elevated maximum tariffs in Pakistan (100%), India (157%), and Bangladesh (200%), potentially diminishing dependence on high-emission intermediary commodities; however, implementation is inconsistent.

East Asia experiences a significant positive impact of manufacturing exports on emissions (MEXP = 0.026***), aligning with the substantial industrial exports from China, Korea, and Japan. GDP per capita exerts a favorable influence (LN_GDP = 0.438***). Unexpectedly, renewable energy exhibits a positive and considerable impact (ERNE = 0.020***), possibly indicative of transitional pressure investments in clean energy are increasing but remain insufficient to counterbalance emissions from export-oriented industries. Tariffs (MTRF = 0.006) are negligible, although elevated ceilings (Japan = 457%; Korea = 887%) indicate a capacity to govern future industrial trade.

4.5.2.4 Agricultural Exports and Emissions

Agricultural exports (LN_AEXP = –0.003) are negligible, indicating minimal trade volumes or a slow transition to sustainable methods. Gross Domestic Product (GDP) continues to contribute to emissions (LN_GDP = 0.281**), while agricultural value added (LN_AVA = 0.413***) corroborates that output expansion results in increased emissions. The use of fertilizer (LN_FER = 0.507***) significantly influences outcomes. Renewable electricity is negligible (ERNE = 0.000), indicating minimal clean electrification in agriculture. WTO BND data indicates that agricultural duty-free shares are negligible in Indonesia (0%) and Thailand (2.5%), while maximum agricultural duties are elevated (210% for Indonesia and 806% for Thailand), which constrains the influx of clean agricultural technology.

Agricultural exports are statistically insignificant (LN_AEXP = 0.017), whereas GDP exerts a negative and substantial influence (LN_GDP = –0.411***), suggesting that wealthier nations such as Sri Lanka may be shifting towards more sustainable agricultural trade practices. Value added (LN_AVA = 0.861***) and fertilizer (LN_FER = 0.015) increase emissions. Renewables (ERNE = –0.015***) indicate a minor yet significant decrease, implying initial evidence of cleaner input utilization. The WTO BND data shows that India and Bangladesh have no duty-free agricultural products and very high average agricultural duties (India = 113.1%, Pakistan = 96.2%), which could limit investment in sustainable farming practices.

East Asia exhibits a robust positive correlation between agricultural exports and emissions (LN_AEXP = 0.600***), primarily attributable to elevated carbon intensity within supply chains. GDP per capita decreases emissions (LN_GDP = –1.617***), indicating innovation-driven decoupling in Japan and Korea. The application of fertilizer (LN_FER = 0.534**) persists in increasing emissions. Importantly, Renewable energy (ERNE = –0.074***) has the strongest mitigation effect overall, reflecting how major investments in electrification and automation—backed by high Agri binding coverage (Japan = 99.7%; Korea = 94.9%)—are actively decarbonizing food production. These outcomes are further reinforced by public funding in agricultural R&D, electrified irrigation, and precision farming systems, especially in Japan and Korea, where Agri-trade is gradually decoupling from emissions.

4.5.3 Robustness Check Discussion

This part employs Driscoll–Kraay standard errors to verify the consistency of the basic fixed-effects conclusions, addressing cross-sectional dependency, heteroskedasticity, and autocorrelation—typical issues in macro panel datasets across several nations and time periods. These robust estimators enhance inference by considering both spatial and temporal correlations in the residual structure, which is particularly significant due to the regional variability in East, South, and Southeast Asia.

4.5.3.1 Model 1: Total Trade and Emissions (Driscoll–Kraay)

A positive and statistically significant coefficient on total trade (LN_TTR = 0.178***) under the Driscoll–Kraay estimator confirms that trade openness increases carbon emissions in Asian economies. This supports the Pollution Haven Hypothesis, especially in developing nations where trade liberalization often corresponds with high-emission industry expansion. GDP per capita (LN_GDP = 0.413***) likewise has a strong positive association with emissions, indicating the early upward trajectory of the Environmental Kuznets Curve (EKC), where economic expansion is inherently dependent on fossil fuels and energy-intensive production. The coefficient for renewable power (ERNE = –0.009***) is negative and extremely significant, confirming that clean energy infrastructure investments reduce emissions even in trade-exposed contexts. The Pollution Halo Hypothesis suggests that international trade helps spread cleaner technologies. ERNE's persistent resilience shows grid decarbonization's mitigating potential. Tariffs (ATRF = –0.001***) also negatively affect emissions, confirming the idea that protective trade policies might reduce pollution by deterring high-emission imports or shielding domestic businesses from carbon-intensive competitiveness. In lower-income countries with insufficient regulatory ability, such levies may act as implicit carbon limits notwithstanding their economic inefficiency.

4.5.3.2 Model 2: Merchandise Trade and Carbon Emissions

The merchandise trade variable (MTR = 0.001**) exhibits a positive and statistically significant correlation with emissions, affirming that the physical transportation of commodities continues to be a source of embodied emissions. This correlation is probably influenced by industries including fossil fuel goods, industrial machinery, and mineral-based exports, which possess substantial production and logistics footprints. Renewable power (ERNE = –0.011***) demonstrates a significant mitigating impact, indicating that nations with cleaner energy networks can somewhat alleviate the emission costs associated with commerce trade. Significantly, tariffs on primary goods (PTRF = –0.001***) also mitigate emissions, indicating that nations that uphold tariff protection in resource-based industries may inadvertently curtail emissions by deterring scale-driven extractive exports. This discovery corroborates the burgeoning literature promoting green trade governance, wherein tariff frameworks influence the environmental characteristics of commerce. The urban population variable (LN_URP = 0.978***) is significantly positive, emphasizing that urban concentration via its energy consumption, industrial aggregation, and logistical systems—exacerbates the emissions effects of commerce trade

4.5.3.3 Model 3: Manufacturing Export and Carbon Emissions

The manufacturing export share (MEXP = –0.005**) has a negative and statistically significant correlation with emissions, indicating that in numerous Asian economies, export-oriented manufacturing is less polluting than domestic industrial output. This corresponds with recent research indicating that inclusion into ESG-sensitive global value chains, especially in electronics and textiles, promotes adherence to cleaner technologies and energy efficiency standards. Renewable electricity (ERNE = –0.016***) exhibits the most significant mitigation effect across all models, underscoring the strategic importance of energy transition in promoting sustainable manufacturing-led growth. Tariffs on manufactured products (MTRF = –0.004***) exhibit a negative and significant impact, suggesting that selective protection in this sector—frequently aimed at high-emission imports—may improve carbon performance by reducing reliance on emission-intensive intermediate items. The industry value added (IVA = –0.003) is negligible, indicating that scale alone does not influence emissions; instead, the kind and efficiency of manufacturing output are more critical. The energy usage per unit of GDP (LN_ENU = 0.353**) is a positive and substantial predictor of emissions, highlighting that energy intensity continues to limit the possibility for emission reductions in the industrial sector.

4.5.3.4 Model 4: Agricultural Export and Carbon Emissions

Agricultural exports (LN_AEXP = 0.167***) exhibit a strong and substantial positive association with emissions, indicating the carbon intensity associated with high-input agriculture, particularly about livestock, fertilizers, and crops linked to deforestation. The GDP per capita (LN_GDP = –0.230*) exhibits a negative and weakly significant correlation, aligning with the later stage of the Environmental Kuznets Curve, wherein increasing income initiates a shift towards less carbon-intensive food systems.

Nonetheless, the effect of affluence on lowering emissions seems to be modest and inconsistent among countries. Agricultural value added (LN_AVA = 0.534***) is significantly positive, highlighting that the growth of the agricultural sector, without concurrent investment in green technologies, increases carbon emissions. Renewable electricity (ERNE = –0.003**) consistently provides a tiny yet statistically significant reduction in emissions, highlighting the initial advantages of electrification agricultural processes, cold chains, and irrigation. The use of fertilizer (LN_FER = 0.084) is positive yet only marginally significant, potentially attributable to measurement difficulties or counterbalancing effects between organic and synthetic inputs. Ultimately, food imports (FIMP = 0.012**) exhibit a modest yet significant positive effect, maybe reflecting carbon leakage from worldwide agricultural trade networks encompassing refrigeration, shipping, and re-export processes.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

This final chapter summarizes the key results and insights from the whole study, along with policy recommendations derived from the findings. This part summarizes the study findings and examines the primary objectives and research questions addressed in the preceding sections. We also examined the challenges encountered during the research process and pinpointed areas that necessitate further inquiry. Although the information collected from our study is significant, it is crucial to recognize its limitations and prospective avenues for enhancement. Ultimately, we examine study trajectories that will enhance our comprehension of the topic and facilitate substantial contributions to the field. By the conclusion of this chapter, you will have a comprehensive understanding of the study's implications, policy recommendations, limits, and prospective avenues for further research.

5.1 Summary and Conclusion

This study explored the relationship between carbon emissions and various dimensions of international trade: total trade, merchandise trade, manufacturing exports, and agricultural exports across 13 countries in East, South, and Southeast Asia from 1990 to 2024. Using robust econometric techniques including OLS, Fixed Effects, Random Effects, and Driscoll-Kraay standard errors, the results showed that total trade is positively associated with emissions, supporting the Pollution Haven Hypothesis (PHH). Sectorally, agricultural exports and merchandise trade were found to increase emissions significantly, particularly in South Asia, due to high reliance on fossil fuels, fertilizer use, and limited adoption of green technologies. Manufacturing exports, however, showed a mixed pattern: while they are generally associated with lower aggregate emissions, possibly due to cleaner or high-tech production in advanced economies they were also linked to increased industrial process emissions, highlighting sector-specific environmental risks. GDP per capita showed a largely positive relationship with emissions, but signs of the Environmental Kuznets Curve (EKC) emerged in agriculture, where higher incomes led to emissions reductions through cleaner practices. Renewable electricity consistently reduced emissions across all models, reinforcing its role as a key sustainable finance indicator. Meanwhile, tariff reductions correlated with higher emissions, emphasizing the need for green safeguards in trade liberalization. Regionally, ASEAN countries showed more stable and favorable outcomes due to higher renewable integration, South Asia experienced more carbon-intensive trade patterns, especially in agriculture and merchandise and East Asia's emissions were more responsive to GDP growth and manufacturing structure. Overall, the study underscores the urgency of aligning trade expansion with environmental accountability, sectoral reforms, and clean energy transitions.

5.2 Policy Recommendations

This section presents a series of region-specific policy proposals to transform the empirical findings of this study into effective climate-trade governance. These policies illustrate the diverse strengths, weaknesses, and emission trends of East Asia, South Asia, and Southeast Asia, with a particular focus on advancing renewable energy integration, restructuring tariffs, decarbonizing agricultural exports, and incorporating ESG compliance into trade frameworks. All suggestions are derived and associated with the Carbon Border Mechanism (CBAM) and green finance frameworks, while conforming to the sectoral and geographical trends revealed in the panel research. A central addition to these recommendations is the integration of Emissions Trading Systems (ETS) to create price-based mechanisms that encourage decarbonization across sectors.

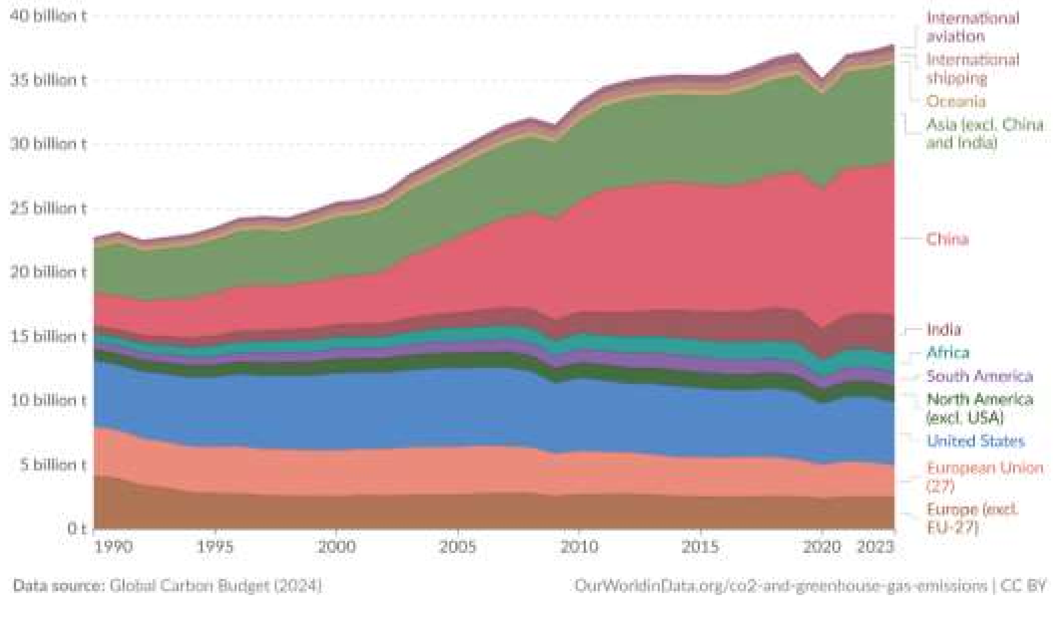

Figure 5. 1 Global Carbon Budget (2024) – source Jones et al. (2024)

A. South Asia: ETS-backed Agricultural and Merchandise Trade Reform

South Asia shows the most carbon-intensive trade-emissions dynamics, particularly within the agriculture and merchandise sectors. High fertilizer use, fossil fuel reliance, and low renewable energy integration drive this pattern. As an initial step, Green

Agriculture Export Bonds and concessional climate loans should be offered to Agri-exporters, conditional on third-party emissions audits and compliance with carbon benchmarks. These incentives would support adoption of low-carbon technologies such as solar irrigation, methane suppression, and organic inputs. In parallel, carbon-adjusted export tariffs should be applied to emission-intensive products like rice and textiles made from synthetic inputs. WTO BND tariff data reveal that countries like Pakistan and India already maintain high agricultural tariffs (e.g., India at 113.1%, Pakistan at 96.2%), creating fiscal space to introduce carbon-based tariff differentiation, in a manner broadly aligned with evolving WTO norms and CBAM precedents. To internalize carbon embedded in trade logistics, a green trade levy is proposed:

a. $100 per 100,000 CBM for maritime cargo
b. $200 for air freight, reflecting higher per-unit emissions
c. $50 for road or rail freight

The accrued money must be designated for investments in rural renewable energy, namely off-grid systems inside logistical hubs and cross-border supply networks. Furthermore, ESG compliance should be a formal requirement for accessing export-related incentives, ensuring alignment with international market standards. Disclosures adhering to GRI or ISSB criteria will enhance carbon transparency and trade credibility.

Importantly, these instruments must be supplemented by a regional ETS framework. South Asia ought to implement an intensity-based emissions trading system, commencing with the energy, textiles, cement, and fertilizer industries. The Carbon Credit Trading Scheme of India may function as a model. ETS coverage may gradually be expanded to include agriculture-linked emissions, particularly via indirect caps on fertilizer application or methane-intensive practices. Proceeds from ETS auctions shall be used to finance solar grids, electric transportation in agricultural regions, and training farmers in carbon-efficient techniques. Connecting ETS credits to export incentives, such as CBAM-aligned exclusions, will establish a viable decarbonization trajectory for South Asia's carbon-intensive exports..

B. Southeast Asia (ASEAN)

In Southeast Asia, empirical evidence indicates that renewable electricity substantially decreases emissions in the trade, merchandise, and manufacturing sectors. In contrast, tariff liberalization correlates with heightened emissions, indicating a deficiency in environmental protections. Consequently, ASEAN nations ought to impose minimum renewable electricity requirements (commencing at 40% by 2030) for energy-intensive exports such as electronics and processed food.

Tariff reforms should implement a carbon-intensity-based framework, granting preferential treatment to eco-certified items, which includes:

a. Expedited customs processing
b. Tariff concessions
c. Streamlined export licensing

Goods with high emissions that lack certification (e.g., ISO 14067, Verified Carbon Standard) should maintain elevated tariff rates. A standardized green logistics tax should be implemented.

a. \$100 per 100,000 CBM for maritime cargo
b. \$200 for air freight, reflecting higher per-unit emissions
c. \$50 for road or rail freight

These funds should facilitate clean logistical corridors at ports such as Jakarta, Manila, and Bangkok via public–private partnerships, consistent with IRENA's renewable infrastructure frameworks. ASEAN should implement a regional carbon market coordinating mechanism for ETS execution. Numerous member states have implemented carbon pricing schemes, including Indonesia, Vietnam, Malaysia, and Thailand. These ought's to be progressively integrated inside an ASEAN ETS interoperability framework, incorporating uniform MRV standards and pricing floors. Proceeds from the ETS auction should finance local clean energy initiatives and assist small enterprises in their transition. Trade-exposed sectors may obtain temporary concessions, like the approach implemented in Singapore's carbon tax legislation. It is essential that ETS integration with trade is transparent: carbon performance under the ETS should dictate eligibility for subsidies, export insurance, and trade advantages linked with CBAM. This strategy will integrate decarbonization within ASEAN's export competitiveness framework..

C. East Asia

East Asia displays a split profile: industry emissions indicate a trend of decoupling, whilst trade emissions associated with agriculture remain elevated. Model findings reveal substantial positive coefficients for agricultural exports (LN_AEXP = 0.600***) and negative impacts from renewable energy sources (ERNE = –0.074***). Consequently, decarbonization must be technology-driven, supported by rigorous carbon accounting.

Initially, governments ought to incentivize exporters to achieve carbon intensity standards by providing green trade facilitation measures, such as duty refunds, expedited clearance, and green export insurance. In agriculture, investment-based assistance should finance cold chain electrification, fertilizer optimization, and methane reduction technologies. Agricultural Emissions Monitoring System must be implemented to facilitate real-time eligibility for carbon-linked financing and to comply with CBAM data stipulations.

East Asian nations, notably China, Japan, and South Korea, now implement or are in the process of establishing sophisticated ETS frameworks. China's Emissions Trading System, including more than 60% of its CO_2 emissions, has the potential to extend to petrochemicals and agriculture via performance-based offsets. Korea's K-ETS encompasses aviation, transportation, and waste management, providing a robust framework. Japan's forthcoming GX-ETS is amalgamating domestic and foreign carbon credits. These systems require enhancement to ensure.

a. Gradual inclusion of agriculture
b. Expanded auctioning (to increase market liquidity)
c. Benchmarked free allocation for export industries
d. Carbon price harmonization to prevent CBAM charges on underpriced exports

ETS revenue should fund R&D for low-carbon manufacturing, CCUS deployment, and farm-based abatement. Moreover, trade agreements (e.g., RCEP) should begin integrating ETS performance as a criterion for tariff reductions and market access. Finally, ESG integration must be made binding. Firms exporting to Europe or OECD markets must disclose Scope 1 and 2 emissions and submit lifecycle carbon assessments under a unified digital platform tied to the ETS registry.

5.3 Limitations of the Study

Notwithstanding the study's extensive time range (1990–2024) and its broad regional coverage encompassing East, South, and Southeast Asia, certain limitations must be acknowledged. Data constraints precluded the inclusion of critical greenhouse gases beyond carbon dioxide specifically methane and nitrous oxide which are essential for fully capturing the environmental impact of agricultural emissions. Additionally, variables such as the stringency of environmental policies, foreign direct investment (FDI), and public environmental expenditures were excluded due to inconsistent data availability across countries and years. The absence of consistently reported ESG disclosures and comprehensive embedded emissions data limited the depth and breadth of the policy analysis. Furthermore, while the study assessed trade in aggregate and across key sectors, it did not disaggregate emissions by mode of transportation: marine, air, or land even though these channels differ substantially in their carbon intensity. These limitations reflect broader data and methodological challenges in cross-national environmental research but do not detract from the scientific validity or policy relevance of the study's findings.

5.4 Future Scope and Direction

To enhance the analytical and policy significance of this study, subsequent research could investigate more sophisticated methods for incorporating sustainability into international trading patterns. A primary focus entails modelling the prospective effects of Carbon Border Adjustment Mechanisms (CBAM) on trade balances, sectoral competitiveness, and emission results in Asia. Investigating the impact of carbon-adjusted pricing on trade flows enables researchers to provide useful insights for policymakers and exporters anticipating climate-aligned global markets. Furthermore, integrating transport mode-specific emission data such as that from maritime, aviation, and rail logistics would improve the precision of trade-related carbon evaluations and facilitate the establishment of green logistics corridors. A further interesting domain entails examining the impact of ESG reporting on companies' trade performance and emissions, as enhanced transparency may draw green finance and affect cross-border sourcing choices. Subsequent research may concentrate on nation-specific solutions in significant emitting economies such as China, India, Indonesia, Japan and Vietnam, where customized interventions could facilitate the equilibrium between trade liberalization and decarbonization. Furthermore, categorizing exports by technology or carbon intensity through product-level trade classifications will facilitate a more detailed comprehension of the sectors contributing to emissions growth. A comprehensive examination of the carbon footprint associated with digital trade and services, coupled with the implementation of blockchain and digital Monitoring, Reporting, and Verification (MRV) systems, may facilitate investment in low-carbon trade infrastructures, thereby aligning climate objectives with economic integration.

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APPENDIX - A

4.1 Descriptive Statistics

4.1.1 Total Trade and Total CO_2 Emissions

Table 4.1.1 Descriptive Summary of Statistics for Model 1 - *Source: Author Computation*

Variable	Observation	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
LN_TCO	442	5.127114	5.173487	9.49248	0.0846168	1.961807	-0.1071949	2.788985
LN_TTR	437	25.79233	25.93451	29.55643	20.87827	1.822652	-0.4004377	2.585501
LN_GDP	442	8.249652	7.993295	11.12653	6.049084	1.372666	0.449852	2.066346
ATRF	384	9.712784	6.165857	421.5	0	22.7731	15.59445	280.1764
LN_EXC	454	4.049134	3.995268	9.671268	0.2228845	2.172768	0.5228667	3.384661
FFC	431	70.19483	76.86	99.39	5.05	22.87989	-1.078457	3.773254
ERNE	416	3.647416	1.246757	25.72815	-15.27143	5.574621	1.761597	6.098515
LN_TRT	381	4.678172	4.60517	5.609748	4.291335	0.2323181	1.916442	6.462345

4.1.2 Merchandise Trade and CO_2 Emissions

Table 4.1.2 Descriptive Summary of Statistics for Model 2 - Source: Author Computation

Variable	Observation	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
LN_TCO	442	5.127114	5.173487	9.49248	0.0846168	1.961807	-.1071949	2.788985
MTR	442	70.22283	42.7094	343.4881	12.94446	66.85318	2.113705	7.040709
LN_GDP	442	8.249652	7.993295	11.12653	6.049084	1.372666	0.449852	2.066346
ERNE	455	22.89746	15.73672	100	0	26.08804	1.897382	5.852206
PTRF	345	11.24565	6.26	917.75	0	49.61559	17.76086	324.8753
LN_URP	442	17.4249	17.49567	20.62994	14.36288	1.559183	0.0051239	2.252746

4.1.3 Manufacturing Export and Industrial Emissions

Table 4.1.3 Descriptive Summary of Statistics for Model 3 - *Source: Author Computation*

Variable	Observation	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
LN_MCO	442	2.748541	2.869488	7.3543	-2.079442	1.957999	-.1134931	3.207101
MEXP	411	75.60172	75.8224	96.06673	30.95134	14.32737	-.8797112	3.386584
LN_GDP	442	8.249652	7.993295	11.12653	6.049084	1.372666	0.449852	2.066346
ERNE	416	3.647416	1.246757	25.72815	-15.27143	5.574621	1.761597	6.098515
MTRF	384	9.145692	5.203029	217.2798	0	14.35715	8.895327	119.5018
IVA	437	31.45938	31.12828	48.53032	11.79204	8.63396	-.0698691	2.399818
LN_ENU	431	4.538502	4.594673	6.14778	3.539555	0.4296413	0.1613659	3.802942
LN_URP	442	17.4249	17.49567	20.62994	14.36288	1.559183	0.0051239	2.252746

4.1.4 Agriculture Export and CO_2 Emissions

Table 4.1.4 Descriptive Summary of Statistics for Model 4 - ***Source:*** *Author Computation*

Variable	Observation	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis
LN_ACO	438	0.13114	0.2344	3.438072	-7.824046	1.935808	-.4632994	3.257946
LN_AEXP	442	15.11685	15.27491	18.22177	9.866045	1.758856	-.6079263	3.121635
LN_GDP	442	8.249652	7.993295	11.12653	6.049084	1.372666	0.449852	2.066346
LN_FER	429	5.353118	5.216514	8.630522	0.3110554	1.094479	-.0215715	6.214705
LN_AVA	437	23.90712	24.0892	27.87173	18.18945	2.07112	-.970306	4.445679
ERNE	407	22.59431	16.01724	99.98597	0.5409189	24.00016	1.965018	6.407877
LN_ENU	431	4.538502	4.594673	6.14778	3.539555	0.4296413	0.1613659	3.802942
FIMP	410	8.930609	7.987727	22.78865	2.235665	4.6051	0.6831664	2.480217

4.2 Correlation Matrix

4.2.1 Total Trade and Total CO_2 Emissions

Table 4.2.1 Correlation Matrix for Model 1 - *Source: Author Computation*

Variables	LN_TCO	LN_TTR	LN_GDP	ATRF	LN_EXC	FFC	ERNE	LN_TRT
LN_TCO	1							
LN_TTR	0.8063	1						
LN_GDP	0.2546	0.7119	1					
ATRF	-0.1713	-0.3019	-0.2762	1				
LN_EXC	0.0593	-0.1181	-0.1758	0.0221	1			
FFC	0.5963	0.8228	0.7048	-0.3095	-0.2677	1		
ERNE	0.0542	0.1254	0.0045	-0.1484	0.1256	-0.0381	1	
LN_TRT	-0.0517	-0.193	0.0079	0.0739	0.1689	-0.0105	-0.128	1

4.2.2 Merchandise Trade and CO_2 Emissions

Table 4.2.2 Correlation Matrix for Model 2 - *Source: Author Computation*

Variables	LN_TCO	MTR	LN_GDP	ERNE	PTRF	LN_URP
LN_TCO	1					
MTR	-0.2406	1				
LN_GDP	0.3059	0.5045	1			
ERNE	-0.5762	-0.2857	-0.524	1		
PTRF	-0.1483	-0.082	-0.1288	0.2059	1	
LN_URP	0.8977	-0.5051	-0.0863	-0.3868	-0.0938	1

4.2.3 Manufacturing Export and Industrial Emissions

Table 4.2.3 Correlation Matrix for Model 3 - *Source: Author Computation*

Variables	LN_MCO	MEXP	LN_GDP	ERNE	MTRF	IVA	LN_ENU	LN_URP
LN_MCO	1							
MEXP	0.2573	1						
LN_GDP	0.2009	0.2614	1					
ERNE	0.0264	-0.1372	-0.0307	1				
MTRF	-0.1464	-0.0268	-0.5981	-0.2478	1			
IVA	0.4761	-0.1133	0.2233	0.1491	-0.2488	1		
LN_ENU	0.579	0.2349	-0.0658	-0.2282	0.1372	0.3437	1	
LN_URP	0.8968	0.161	-0.1614	0.1571	0.051	0.338	0.4808	1

4.2.4 Agriculture Export and CO_2 Emissions

Table 4.2.4 Correlation Matrix for Model 4 - *Source: Author Computation*

Variables	LN_ACO	LN_AEXP	LN_GDP	LN_FER	LN_AVA	ERNE	LN_ENU	FIMP
LN_ACO	1							
LN_AEXP	0.4187	1						
LN_GDP	-0.5744	0.2708	1					
LN_FER	-0.1763	0.2521	0.4853	1				
LN_AVA	0.9279	0.3682	-0.4214	-0.1492	1			
ERNE	0	-0.3298	-0.4669	-0.3781	0.0131	1		
LN_ENU	0.4186	0.2825	-0.024	0.1256	0.5075	-0.0385	1	
FIMP	-0.0175	-0.604	-0.3932	-0.2214	-0.0014	0.4558	-0.4343	1

4.3 Stationarity Test (Unit Root test)

4.3.1 Total Trade and Total CO_2 Emissions

Notes: (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%

Table 4.3.1 Unit Root Test for Model 1 - *Source: Author Computation*

Variables	LLC		IPS		ADF		PP	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
	Statistic		Statistic		Statistic		Statistic	
LN_TCO	-4.33232***	-5.02005***	-0.61973	-7.67416***	35.5378	110.334***	7.2175***	227.735***
LN_TTR	-4.61508***	-11.5744***	-0.24204	-11.2984***	23.2518	168.525***	35.4471	221.222***
LN_GDP	-1.03623	-6.69788***	3.63757	-8.46448***	18.4701	131.374***	37.1269*	210.290***
ATRF	-3.66552***	-6.68331***	-4.60470***	-12.8248***	69.5733***	184.494***	202.279***	874.557***
LN_EXC	-0.29401	-8.55284***	0.44538	-9.48194***	24.8344	137.923***	32.0114	196.862***
FFC	-5.02722***	-4.63038***	2.03822**	-8.40699***	46.0737***	123.064***	49.9077***	224.213***
ERNE	10.0643	0.15549	7.47678	-4.15486***	10.8947	91.4458***	17.3606	180.231***
LN_TRT	-2.05509**	-7.57437***	-1.53210*	-7.90042***	35.1574	114.109***	31.0328	195.005***

4.3.2 Merchandise Trade and CO_2 Emissions

Notes: (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%

Table 4.3.2 Unit Root Test for Model 2 - *Source: Author Computation*

Variables	LLC		IPS		ADF		PP	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
	Statistic		Statistic		Statistic		Statistic	
LN_TCO	-4.33232***	-5.02005***	-0.61973	-7.67416***	35.5378	110.334***	7.2175***	227.735***
MTR	-0.33687	-10.0205***	-0.66750	-12.0240***	31.924	181.388***	35.509	289.039***
LN_GDP	-1.03623	-6.69788***	3.63757	-8.46448***	18.4701	131.374***	37.1269*	210.290***
ERNE	5.21922	3.00351	3.76131	-4.47838***	14.2191	90.7588***	21.0653	272.158***
PTRF	3.64277	17.674	-1.10661	-10.2627***	38.6468*	147.710***	115.391***	1067.85****
LN_URP	-5.14307***	-0.68198	-2.55293***	0.14815	56.7156***	26.4112	190.248***	41.3393**

4.3.3 Manufacturing Export and Industrial Emissions

Notes: (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%

Table 4.3.3 Unit Root Test for Model 3 - *Source: Author Computation*

Variables	LLC		IPS		ADF		PP	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
	Statistic		Statistic		Statistic		Statistic	
LN_MCO	-3.43112***	-8.36553***	-0.08152	-11.0065***	27.0033	166.364***	45.6924***	286.824***
MEXP	-2.13076**	-7.69276***	-3.03363***	-9.60766***	60.8892***	143.634***	82.1748***	221.546***
LN_GDP	-1.03623	-6.69788***	3.63757	-8.46448***	18.4701	131.374***	37.1269*	210.290***
ERNE	10.0643	0.15549	7.47678	-4.15486***	10.8947	91.4458***	17.3606	180.231***
MTRF	-4.14048***	-4.87270***	-4.88677***	-11.5563***	70.3962***	156.324***	188.846***	980.912***
IVA	0.88158	-9.72163***	1.91134	-11.1895***	13.6118	167.177***	11.7627	235.438***
LN_ENU	1.10011	-7.27990***	4.85597	-10.6514***	6.12052	156.388***	11.2232	248.499***
LN_URP	-5.14307***	-0.68198	-2.55293***	0.14815	56.7156***	26.4112	190.248***	41.3393**

4.3.4 Agriculture Export and CO_2 Emissions

Notes: (*) Significant at 10%; (**) Significant at 5%; (***), Significant at 1%

Table 4.3.4 Unit Root Test for Model 4 - *Source: Author Computation*

Variables	LLC		IPS		ADF		PP	
	Level	1st Difference	Level	1st Difference	Level	1st Difference	Level	1st Difference
	Statistic		Statistic		Statistic		Statistic	
LN_ACO	-1.67390**	-8.50705***	-0.04767	-13.6298***	26.1563	210.750***	68.4882***	332.043***
LN_AEXP	-0.43996	-8.67793***	3.11362	-11.3290***	5.91796	170.463***	5.90034	269.765***
LN_GDP	-1.03623	-6.69788***	3.63757	-8.46448***	18.4701	131.374***	37.1269*	210.290***
LN_FER	-2.07918**	-13.7015***	0.34133	-15.3880***	21.3359	236.411***	25.2899	334.263***
LN_AVA	0.25587	-9.51490***	3.59299	-10.3967***	8.5767	154.814***	15.7762	269.944***
ERNE	1.81661	-8.48814***	1.38822	-10.8547***	29.3969	159.556***	34.138	284.342***
LN_ENU	1.10011	-7.27990***	4.85597	-10.6514***	6.12052	156.388***	11.2232	248.499***
FIMP	-2.24624**	-11.5744***	-1.28962*	-13.0271***	34.8406	198.169***	51.4336***	336.720***

4.4.1 Model Diagnostics and Pre-estimation Analysis

4.4.1.1 Variance inflation factors (VIF)

Table 4.4.1.1 - Variance inflation factors (VIF) of explanatory variables.

MODEL 1			MODEL 2		
Variables	VIF	1/VIF	Variables	VIF	1/VIF
LN_TTR	4.49	0.22	MTR	2.28	0.44
LN_GDP	2.31	0.43	LN_GDP	1.72	0.58
ATRF	1.15	0.87	ERNE	2.27	0.44
LN_EXC	1.21	0.83	PTRF	1.05	0.95
FFC	4.22	0.24	LN_URP	2.31	0.43
ERNE	1.12	0.89			
LN_TRT	1.23	0.81			
MODEL 3			MODEL 4		
Variables	VIF	1/VIF	Variables	VIF	1/VIF
MEXP	1.34	0.74	LN_AEXP	2.75	0.36
LN_GDP	2.01	0.50	LN_GDP	2.21	0.45
ERNE	1.31	0.76	LN_FER	1.51	0.66
MTRF	1.80	0.55	LN_AVA	3.28	0.30
IVA	1.55	0.64	ERNE	1.76	0.57
LN_ENU	1.72	0.58	LN_ENU	2.44	0.41
LN_URP	1.60	0.63	FIMP	3.19	0.31

4.4.1.2 Pesaran Cross-Section Dependence Test

Table 4.4.1.2 - Results of Pesaran CD test.

Residual Cross-Section Dependence Test	Model 1		Model 2	
Test	Statistic	Prob.	Statistic	Prob.
Pesaran CD test	-1.644	0.1002	3.203	0.0014
Friedman test	34.145	0.0006	11.772	0.4642
Frees test	2.264	sig	2.135	sig
Residual Cross-Section Dependence Test	Model 3		Model 4	
Test	Statistic	Prob.	Statistic	Prob.
Pesaran CD test	0.168	0.8669	1.399	0.1619
Friedman test	13.421	0.3392	0.615	1.0000
Frees test	2.829	sig	Not available	Not available

4.4.1.3 Heteroscedasticity and Autocorrelation tests

Table 4.4.1.3 - The results of heteroscedasticity and autocorrelation tests.

Test	Model 1			Model 2		
	Test Statistic	*p*-Value	Presence	Test Statistic	*p*-Value	Presence
"Modified Wald test for group-wise heteroscedasticity"	1624.79	0.00	Yes	1391.54	0.00	Yes
"Wooldridge test for autocorrelation in panel data"	217.75	0.00	Yes	21.16	0.00	Yes
Test	**Model 3**			**Model 4**		
	Test Statistic	*p*-Value	Presence	Test Statistic	*p*-Value	Presence
"Modified Wald test for group-wise heteroscedasticity"	4364.59	0.00	Yes	2568.69	0.00	Yes
"Wooldridge test for autocorrelation in panel data"	2.15	0.17	No	4.45	0.06	No

4.4.1.4 Slope Heterogeneity Test

Table 4.4.1.4 - Slope heterogeneity test

Test	Model 1		Model 2	
	Delta	p-value	Delta	p-value
Δ	10.87	0.00	13.56	0.00
ˆ Δadj	13.57	0.00	15.80	0.00
Test	**Model 3**		**Model 4**	
	Delta	p-value	Delta	p-value
Δ	10.57	0.00	7.86	0.00
ˆ Δadj	13.11	0.00	9.50	0.00

4.4.1.5 Hausman Test

Table 4.4.1.5 – Hausman Test

Model	Chi-Square (χ^2)	Degrees of Freedom (df)	Prob > χ^2	Model Selection
Model 1 (Total Trade)	115.54	6	0.000	Fixed Effects
Model 2 (Merchandise Trade)	3.93	4	0.416	Random Effects
Model 3 (Manufacturing Export)	17.1	7	0.016	Fixed Effects
Model 4 (Agricultural Export)	13.59	7	0.059	Random Effects

4.4.1.6 Dumitrescu & Hurlin Panel Granger Causality Test

Table 4.4.1.6 - Dumitrescu & Hurlin Panel Granger Causality Test

Dependent Variable	Independent Variable	Lag	Z-bar	p-value	Granger Causality?
LN_TCO	LN_TTR	1	5.2821	0	Yes
LN_TCO	MTR	1	7.6005	0	Yes
LN_MCO	MEXP	1	2.9632	0.003	Yes
LN_ACO	LN_AEXP	1	10.2797	0	Yes
Reverse Relation					
Dependent Variable	Independent Variable	Lag	Z-bar	p-value	Granger Causality?
LN_TCO	LN_TTR	1	0.2524	0.9505	No
LN_TCO	MTR	1	2.4743	0.0428	Yes
LN_MCO	MEXP	1	6.1916	0	Yes
LN_ACO	LN_AEXP	1	4.9365	0	Yes