

THE IMPACT OF GREEN FINANCE, R&D
INVESTMENT, AND ENERGY EFFICIENCY ON
SUSTAINABLE ECONOMIC GROWTH IN
REGIONAL COMPREHENSIVE ECONOMIC
PARTNERSHIP

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DEPARTMENT OF FINANCE

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BY

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Figure 2.2: Research Framework on SDG 7, 8, 9, 12, 13 **Error! Bookmark not defined.**

LIST OF ABBREVIATIONS

Abbreviations	Full Name
RCEP	Regional Comprehensive Economic Partnership
CO ₂	Carbon Emission
SDG	Sustainable Development Goal
R&D	R&D Expenditure
GF	Green Finance
GB	Green Bond Issuance
REC	Renewable Energy Consumption
EE	Energy Efficiency
GT	Green Technology Innovation
OECD	Organisation for Economic Co-operation and Development
G20	The Group of Twenty
BRICS	Brazil, Russia, India, China and South Africa
GDP	Gross Domestic Product
EMT	The Ecological Modernization Theory
GGT	Green Growth Theory
SDT	The Sustainable Development Theory
POLS	Pooled Ordinary Least Squares
RE	Random Effects
FE	Fixed Effects
REM	Random Effects Model
FEM	Fixed Effects Model
BPLM	Breusch-Pagan Lagrange Multiplier
VIF	Variance Inflation Factor

ABSTRACT

The accelerating threat of climate change has intensified global efforts to pursue economic development that aligns with environmental sustainability, particularly within the Regional Comprehensive Economic Partnership (RCEP) economies, which collectively account for a substantial share of global emissions, energy consumption, and industrial activity. As these economies work toward carbon neutrality and the Sustainable Development Goals (SDGs), it becomes essential to understand how financial, technological, and energy-related drivers shape their sustainability trajectories. This study empirically examines the impacts of green finance, research and development (R&D) expenditure, renewable energy consumption, energy efficiency, and green technological innovation on two key sustainability outcomes, carbon emissions and SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) across RCEP economies from 2016 to 2023.

Guided by the Negative Externalities Theory, Porter Hypothesis, Ecological Modernization Theory, and Green Growth Theory, the study adopts a comprehensive theoretical lens to investigate how financial flows and technological advancement contribute to low-carbon and inclusive development. Using secondary panel data and the Random Effects Model (REM), supported by diagnostic tests including Breusch-Pagan LM, Hausman, and Variance Inflation Factor (VIF), the study accounts for cross-country heterogeneity and ensures the robustness of the empirical results.

The literature suggests that green finance, R&D investment, renewable energy expansion, and energy efficiency improvements can significantly reduce emissions and enhance SDG performance, particularly for clean energy (SDG 7), decent work and growth (SDG 8), industry and innovation (SDG 9), responsible production (SDG 12), and climate action (SDG 13). Green technological innovation is widely recognised as a key enabling mechanism that transforms financial and technological inputs into tangible sustainability outcomes. However,

the literature also highlights that structural constraints, such as fossil-fuel dependence and resource-intensive industrialisation, may weaken these relationships in some emerging economies.

This research contributes to the literature in three keyways. First, it provides an integrated assessment of multiple sustainability drivers within a single analytical framework, addressing the fragmentation present in prior studies. Second, it focuses on the under-examined RCEP region, offering new empirical insights into the sustainability dynamics of one of the world's largest economic blocs. Third, it delivers policy-relevant recommendations for strengthening green finance ecosystems, enhancing technological innovation, and improving governance structures to advance carbon reductions and accelerate progress toward SDGs 7, 8, 9, 12, and 13. The findings aim to support policymakers, financial institutions, and industry stakeholders in guiding RCEP economies toward a resilient, low-carbon, and sustainable future.

CHAPTER 1: INTRODUCTION

1.0 Introduction

This chapter presents the foundation of the study by outlining the background, problem statement, research questions, research objectives and the significance of the research. It begins by describing the growing challenges faced by RCEP economies in achieving sustainable development while managing rising carbon emissions. The chapter introduces the key drivers examined in this study including green finance, R&D expenditure, renewable energy consumption, energy efficiency, and green technological innovation to explain their potential roles in supporting low-carbon growth. As RCEP countries continue to expand economically, understanding how these factors influence both CO₂ emissions and SDG performance becomes increasingly important. The chapter then highlights the existing gaps in assessing sustainability progress in the region, particularly the need to integrate environmental and SDG outcomes. Lastly, it explains why examining these relationships is essential for policymakers, financial institutions, and industries aiming to design effective green development strategies.

1.1 Research Background

1.1.1 Economic Significance of the RCEP Region

The Asia-Pacific region, encompassing the diverse economies of the Regional Comprehensive Economic Partnership (RCEP), including

Australia, Brunei, Cambodia, China, Indonesia, Japan, Laos, Malaysia, Myanmar, New Zealand, the Philippines, Singapore, South Korea, Thailand, and Vietnam. There has become a cornerstone of global economic activity. These nations account for approximately 31% of the world's GDP and population, making them critical players in shaping international trade flows, industrial expansion, and investment patterns (Chi, 2025). Based on RCEP World Economic data show that RCEP nations account for approximately 32.6% of global GDP and are home to over 2.35 billion people in 2025. This economic surge has been fuelled by rapid urbanisation, a burgeoning manufacturing base, and escalating energy consumption, all of which have integrated Asia deeply into global supply chains.

1.1.2 Environmental Challenges and Rising Carbon Emissions

However, this strong economic momentum is accompanied by growing environmental pressures, particularly in terms of carbon emissions and ecological degradation. RCEP economies collectively generated nearly 19 billion metric tons of CO₂ in 2024, accounting for more than 51% of global emissions, with China alone contributing nearly one-third (Statista, 2025). Based on the International Energy Agency (2025), emissions are expected to continue increasing by approximately 0.13% in 2025, primarily due to the region's ongoing reliance on fossil fuels and the high energy demand from transportation, manufacturing, and heavy industrial sectors.

Asian Transport Observatory show that the transport sector recorded a 6.6% rise in emissions in 2023, equivalent to an additional 174 million

tonnes of CO₂, attributed largely to increased freight mobility, rising passenger vehicle usage, and inadequate public transport infrastructure. These patterns not only exacerbate global warming but also threaten the ability of RCEP economies to meet commitments under the Paris Agreement, while simultaneously undermining the achievement of several United Nations Sustainable Development Goals (SDGs), including SDG 7 (Affordable and Clean Energy) due to slow clean energy transitions, SDG 8 (Economic Growth) as climate risks affect productivity, SDG 9 (Industry, Innovation, and Infrastructure) through reliance on outdated technologies, SDG 12 (Responsible Consumption and Production) because of rising material waste and emissions, and SDG 13 (Climate Action) due to insufficient decarbonisation progress.

1.1.3 Mechanisms Driving in CO₂ and SDG

In response to these challenges, five interrelated mechanisms which is R&D expenditure, green finance, green energy, green efficiency and green technological innovation, they have emerged as pivotal drivers of sustainable development in Asia.

1.1.3.1 R&D Expenditure

R&D investment supports innovation in low-carbon technologies, renewable energy systems, and energy storage. According to International Energy Agency 2024, Global public spending on clean energy R&D reached nearly USD 54.4 billion in 2024, with Asian economies such as China, Japan, and South Korea at the forefront of innovation in renewable

technologies, energy storage systems, and carbon capture solutions. China's clean energy R&D and manufacturing investments have grown at a compound annual rate of 24% since 2013, reinforcing its leadership in the deployment of solar, wind, and advanced battery technologies.

1.1.3.2 Green Finance

Green finance has emerged as a vital instrument for funding environmentally responsible investments. Based on the China Green Finance Status and Trends 2024 report, cumulative green bond issuance in China had surpassed USD 555.5 billion by 2025. In comparison, ASEAN+3 economies issued USD 242 billion in sustainable bonds in 2023, with green bonds accounting for 62% of the total. According to Asian Economic Integration Report 2024 show that cross-border issuance of green, social, sustainability, and sustainability-linked (GSS+) bonds also reached USD 43.1 billion in 2024, marking a 43.2% increase compared to the previous year. These developments underscore the region's growing commitment to financing the green transition, although challenges related to standardisation, transparency, and equitable access persist, particularly in emerging economies.

1.1.3.3 Renewable Energy Consumption

According to the International Energy Agency (2024), Asia's renewable energy transition has accelerated, with regional renewable capacity surpassing 1,200 GW in 2024 due to rapid deployment of solar and wind technologies and strengthened grid integration policies. Despite this advancement, fossil fuels still dominate the RCEP energy mix, forming

most of the electricity generation and slowing overall decarbonisation progress. Furthermore, based on the China Green Finance Status & Trends (2024) report, although global clean-energy investments exceeded USD 2 trillion in 2024, many RCEP economies continue to face structural and financial barriers that restrict the large-scale diffusion of renewables. As a result, renewable energy expansion, while substantial, remains insufficient to offset rising energy demand and emissions.

1.1.3.4 Energy Efficiency

Energy efficiency has emerged as an equally crucial strategy for reducing CO₂ emissions and supporting SDG-aligned development. The International Energy Agency (2024) identifies efficiency as the “first fuel” of clean energy transitions due to its dual ability to reduce energy demand and generate cost savings. Based on Ember (2024), ASEAN economies within the RCEP region collectively avoided 41 million tonnes of CO₂ equivalent in 2023 through efficiency measures and renewable integration, while regional energy-efficiency policy performance improved by an average of 0.158%. However, gaps in policy enforcement, limited access to green financing, and slow technological upgrading continue to restrict broader efficiency improvements, particularly in developing member states. Addressing these constraints is essential for reducing carbon intensity, lowering energy consumption, and advancing SDG 12 and SDG 13.

1.1.3.5 Green Technological Innovation

Green technological innovation operates as a complementary mechanism that translates R&D investment into scalable, market-ready low-carbon

solutions. In 2024, Asia recorded significant growth in green patents and technology development, particularly in areas such as energy-efficient manufacturing systems, low-carbon transportation, and advanced renewable-energy integration technologies (International Energy Agency, 2024). These innovations strengthen industrial competitiveness, improve energy productivity, and accelerate the decoupling of economic growth from CO₂ emissions. For RCEP economies, expanding green technological capabilities is vital in overcoming structural dependence on fossil fuels and sustaining long-term progress toward SDG 7, SDG 9, and SDG 13.

1.1.4 Regional Disparities and International Comparisons

Based on the International Energy Agency (2024), sustainability performance across RCEP economies remains highly uneven. Developed economies, including Japan and South Korea, invest substantially in clean R&D and energy efficiency, whereas developing countries such as Cambodia and Laos face significant resource constraints, requiring an estimated USD 180 billion by 2030 to stay aligned with net-zero pathways. This structural heterogeneity complicates coordinated regional sustainability efforts. In contrast, based on the European Commission (2024), the European Union has achieved more integrated sustainability governance, attaining an 8.3% reduction in emissions in 2023 while sustaining long-term GDP growth. The EU experience underscores the value of harmonised financial policies, integrated innovation ecosystems, and region-wide energy transition frameworks, elements that the RCEP region is still in the process of developing.

1.1.5 Summary of Research Background

In summary, the RCEP region stands at a critical juncture where rapid economic growth must be balanced with the urgent need for environmental sustainability and carbon reduction. Understanding the combined and interactive roles of R&D expenditure, green finance, renewable energy, energy efficiency, and green technological innovation is essential to determine how these factors influence carbon emissions, green economic performance, and progress toward key SDGs (7, 8, 9, 12, and 13) across diverse RCEP economies. Given the region's economic importance and environmental challenges, a comprehensive analysis is necessary to support the formulation of effective sustainability strategies and strengthen the transition toward a resilient, low-carbon, and inclusive economic future.

1.2 Problem Statement

1.2.1 Environmental Dimension with Carbon Emissions

Carbon dioxide emissions continue to climb at an alarming rate despite significant gains in green finance, R&D spending, the adoption of renewable energy, energy efficiency improvements, and green technical innovation throughout RCEP economies. In 2024, the region emitted nearly 19 billion metric tons of CO₂, accounting for over half of global emissions, with early 2025 projections indicating further increases driven by persistent fossil fuel dependence in industry and transport (International Energy Agency, 2024; Statista, 2025). According to Asian Transport Observatory (2024), sectoral data highlight that industrial emissions grew

by 5.8% and transport emissions by 6.6% in 2023 alone, adding an additional 174 million tonnes of CO₂.

The current decarbonization efforts fall well short of the 17.2% annual reduction needed to meet the 1.5°C target set forth in the Paris Agreement. Previous research frequently looks at certain variables, like renewable energy or green finance, individually and generally in developed nations. This approach provides limited insight into why the combined effect of these five mechanisms has not yet reversed the upward emissions trend in the diverse RCEP context. The lack of integrated, region-specific empirical evidence on the individual and synergistic impacts of green finance, R&D expenditure, renewable energy adoption, energy efficiency, and green technological innovation on CO₂ emissions represents a critical knowledge gap, hindering the design of effective mitigation policies in the world's largest-emitting economic bloc.

1.2.2 Sustainable Development Dimension with SDG (7, 8, 9, 12 & 13)

Although RCEP member states have expanded green finance flows, increased R&D investments, developed renewable energy capacity, implemented energy efficiency programs, and fostered green technological innovation in recent years, progress toward SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) remains uneven, slow, and inconsistent across the region. Advanced economies such as Japan, South Korea, and Singapore demonstrate stronger advancement in clean energy access, innovation-driven growth, and responsible production systems,

whereas lower-income members such as Cambodia, Laos, Myanmar, and Indonesia, there continue to lag due to financing gaps, weak institutional frameworks, and limited technology diffusion (International Energy Agency, 2024; United Nations, 2024).

The existing academic literature has largely analysed these sustainability drivers separately and often outside the RCEP context, offering limited understanding of their combined and interactive effects on multidimensional SDG performance. As a result, policymakers lack robust, integrated evidence on how green finance, R&D expenditure, renewable energy adoption, energy efficiency, and green technological innovation jointly influence SDG 7, 8, 9, 12, and 13 outcomes in economically and institutionally diverse settings. This empirical void impedes the development of coordinated region-wide strategies necessary to accelerate inclusive, resilient, and sustainable development across the RCEP bloc.

1.3 Research Questions

- i. How do green finance, R&D expenditure, green energy adoption, energy efficiency improvements and green technological innovation individually affect carbon emissions in the RCEP economies during 2016–2023?
- ii. How do green finance, R&D expenditure, green energy adoption, energy efficiency improvements and green technological innovation individually influence overall SDG performance (especially SDGs 7, 8, 9, 12, and 13) in the RCEP economies during 2016–2023?

1.4 Research Objectives

- i. To empirically examine the individual effects of green finance, R&D expenditure, green energy, energy efficiency and green technological innovations on CO₂ emissions reduction across the RCEP countries.
- ii. To evaluate how green finance, R&D, renewable energy, energy efficiency, and green technological innovation influence SDG performance (SDGs 7, 8, 9, 12, and 13) in RCEP economies.

1.5 Significance of the Study

1.5.1 Theoretical and Methodological Significance

This research advances sustainable development scholarship by integrating multiple theoretical perspectives, including the Negative Externalities Theory, Porter Hypothesis, Green Growth Theory, Ecological Modernization Theory, and the broader Sustainable Development framework, into a unified analytical model. While prior studies have typically examined green finance, R&D expenditure, renewable energy adoption, energy efficiency, or green technological innovation in isolation, this study investigates their individual and combined effects on both carbon emissions and SDG performance.

Methodologically, the study employs panel data regression techniques, including Pooled Ordinary Least Squares (POLS), Fixed Effects Model

(FEM), and Random Effects Model (REM), using 2016 to 2023 panel data for 10 RCEP economies including Australia, China, Indonesia, Japan, Malaysia, New Zealand, Philippines, Singapore, South Korea, and Thailand. Countries with substantial missing data such as Myanmar, Vietnam, Brunei, Cambodia, and Laos, were excluded to ensure the robustness of the analysis. The Hausman test is applied to select the appropriate model between FE and RE, while Variance Inflation Factor (VIF) analysis ensures no multicollinearity among regressors. This approach allows for robust estimation of the relationships between green transformation drivers and sustainability outcomes, while accounting for the economic and institutional heterogeneity of the selected RCEP economies.

1.5.2 Policy Significance

The findings offer timely, evidence-based guidance for policymakers in the world's largest trading bloc, which collectively accounts for over half of global CO₂ emissions. By clarifying how green finance, R&D investment, renewable energy adoption, energy efficiency improvements, and green technological innovation jointly influence CO₂ trajectories and progress toward SDGs 7 (Affordable and Clean Energy), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), 12 (Responsible Consumption and Production), and 13 (Climate Action), the study equips governments, especially in China, Indonesia, Japan, and South Korea with actionable insights for designing coordinated policy packages. These include strengthening green financial regulations, scaling public-private R&D partnerships, accelerating renewable integration, and prioritising efficiency standards, all tailored to the region's diverse income levels and institutional capacities.

1.5.3 Practical and Societal Significance

For financial institutions and corporations, the results highlight the strategic role of green bonds, sustainability-linked loans, and innovation investments in reducing financing costs, enhancing competitiveness, and mitigating climate-related risks. At the societal level, accelerated SDG progress and lower emissions translate into cleaner air, green job creation, energy security, and improved intergenerational equity, benefits that are especially critical for lower-income RCEP members. Ultimately, this study bridges a critical regional knowledge gap, providing one of the first comprehensive empirical assessments of green transformation drivers in the RCEP context. Its findings contribute directly to global efforts to achieve the Paris Agreement and the 2030 Agenda while sustaining economic prosperity in the most dynamic and emissions-intensive region on earth.

1.6 Chapter Layout

This study's remainder is presented: Chapter 2 cover the literature review that constructs the independent and dependent variables. Chapter 3 include the data, variables, and methodologies that have used in the study. Chapter 4 elaborates on the empirical findings of this study. Lastly, chapter 5 concludes the study.

1.7 Summary

The main highlights of chapter 1 are summarised in Table 1.1

Table 1.1: Summary of Chapter 1

Objectives of the Study	Current Literature (Issues / Gaps)	Significance of the Study
<p>(Research Objective 1) To empirically examine the individual effects of green finance, R&D expenditure, green energy, energy efficiency and green technological innovations on CO₂ emissions reduction across the RCEP countries.</p>	<p>Existing studies often examine green finance, R&D expenditure, green energy, energy efficiency and green technological innovations separately and focus on developed economies, offering limited integrated, RCEP-specific evidence.</p>	<p>Develops an integrated empirical framework grounded in Negative Externalities Theory, Green Growth Theory, and Ecological Modernization Theory using panel data techniques.</p>
<p>(Research Objective 2) To evaluate how green finance, R&D, renewable energy, energy efficiency, and green technological innovation influence SDG performance (SDGs 7, 8, 9, 12, and 13) in RCEP economies.</p>	<p>The combined and interactive impacts of green transformation drivers on multidimensional SDG outcomes remain underexplored, particularly in economically and institutionally diverse RCEP countries.</p>	<p>Provides evidence-based insights for policymakers, financial institutions, and firms to design coordinated green finance, innovation, and energy strategies to accelerate sustainable development in RCEP economies.</p>
	<p>The lack of comprehensive empirical studies on the RCEP limits understanding of green transformation drivers in the region, the world's largest and most emissions-intensive economy.</p>	<p>Provides practical insights for financial institutions and firms on green finance and innovation, while supporting cleaner air, green jobs, energy security, and sustainable growth in RCEP economies.</p>

Source: Author's own summarisation.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

The urgent need to decouple economic growth from carbon emissions while advancing the Sustainable Development Goals (SDGs) has generated a rapidly expanding body of literature on green transformation drivers. Within this discourse, five mechanisms have gained prominence: green finance, research and development (R&D) expenditure, renewable energy adoption, energy efficiency improvements, and green technological innovation. Extant studies consistently demonstrate that each of these factors can, in isolation, contribute to lower CO₂ emissions, enhanced energy security, innovation-driven growth, and progress toward SDGs 7 (Affordable and Clean Energy), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), 12 (Responsible Consumption and Production), and 13 (Climate Action).

However, three critical limitations persist in the literature. First, most empirical investigations examine these drivers individually rather than exploring their combined, interactive, and potentially mediating or moderating effects. Second, most of the studies focus on advanced economies (OECD, EU-27) or single-country cases such as predominantly China, offering limited generalisability to the economically and institutionally heterogeneous RCEP bloc, which accounts for over 50% of global CO₂ emissions and one-third of world GDP. Third, few studies simultaneously integrate environmental outcomes such as CO₂ emissions with multidimensional SDG performance, leaving policymakers without a holistic evidence base for designing integrated policy packages.

This chapter provides a systematic and critical synthesis of theoretical and empirical scholarship on the five identified drivers. It evaluates their individual and collective influence on carbon emissions and SDG achievement, identifies theoretical foundations including Environmental Kuznets Curve, Porter Hypothesis, Ecological Modernisation, and Green Growth theories, highlights methodological approaches, and, most importantly, delineates the key knowledge gaps that this study seeks to address in the unique RCEP context.

2.1 Theoretical Frameworks and Models

2.1.1 Negative Externalities Theory

The Negative Externalities Theory, proposed by Arthur Cecil Pigou (1932), which provides a foundational economic explanation for environmental degradation arising from market failures. In his *Economics of Welfare* (1920), Pigou defines negative externalities occur when the social cost of an economic activity exceeds its private cost, leading to overproduction of pollution-intensive goods and excessive environmental damage in the absence of corrective mechanisms. In terms of carbon emissions, businesses and consumers frequently fail to completely internalize the environmental costs of fossil fuel usage, industrial production, and energy use. Market outcomes lead to high CO₂ emissions unless interventions like environmental legislation, green finance, technical innovation, and efficiency-enhancing policies are applied. This concept is especially important for RCEP economies since fast industrialization, export-oriented growth, and energy-intensive production amplify carbon externalities.

Based on existing studies applying this theory illustrate its relevance in guiding policy and financial mechanisms to correct environmental market failures. For instance, based on evidence from studies on the Pilot Policy for Green Finance Reform and Innovation (PPGFRI), firms are required to internalise the environmental costs of emissions when regulatory constraints are effectively enforced. This finding supports the role of green finance (GF) in internalising environmental externalities by reallocating capital toward low-carbon projects while increasing financing costs for pollution-intensive activities (Fan et al., 2025; Sun et al., 2025). According to Hanafy et al. (2025), renewable energy adoption reduces reliance on fossil fuels, resulting in less marginal societal damage, but energy efficiency improvements reduce energy input per unit of output, albeit with potential rebound effects. Similarly, Alvi et al. (2025) and Bai et al. (2023) demonstrate that R&D expenditure and green technological innovation (GT) promote cleaner manufacturing processes and structural transformation, thereby decoupling economic growth from emissions. Where enterprises fail to internalize environmental costs voluntarily, government regulation and inspection are nevertheless important to manage persistent externalities. (Fan et al., 2025).

Overall, the Negative Externalities Theory provide a strong theoretical foundation for this study by explaining why carbon emissions can persist despite economic growth in RCEP economies. It highlights the critical role of targeted green policies, financial instruments, technological innovation, energy transition, and regulatory intervention in internalising environmental costs and correcting market failures to achieve sustainable development.

2.1.2 Porter Hypothesis

The Porter Hypothesis, introduced by Porter and Van der Linde (1995), challenges the conventional view that environmental regulations impose unavoidable compliance costs that weaken firm competitiveness. Instead, the hypothesis posits that well-designed, stringent environmental policies can stimulate innovation, prompting firms to upgrade technologies, improve resource efficiency, and reconfigure production processes. Such innovation may not only offset the initial regulatory burden but also enhance productivity, cost efficiency, and long-run competitive advantage. These reframing positions environmental regulation as a strategic opportunity for technological advancement and green competitiveness, creating the potential for a “win-win” outcome where economic performance and environmental quality improve simultaneously.

In recent literature, the Porter Hypothesis has been increasingly applied to emerging policy instruments such as green finance, which functions as a market-based extension of environmental regulation. Rather than enforcing compliance through direct mandates, green finance influences investment behaviour through financial incentives, directing capital toward low-carbon sectors and discouraging environmentally harmful activities. Drawing on the Porter framework, Zhou et al. (2024) argue that green finance accelerates renewable energy technology innovation, thereby strengthening renewable energy development efficiency. Similarly, Y. Wang et al. (2024) contend that green finance exerts a regulatory effect that stimulates corporate R&D investment, particularly in clean energy and low-carbon technologies, which improves total factor energy efficiency and supports progress toward the Paris Agreement's climate targets. Based on Tang et al. (2024) further highlight that environmental regulations mediate the relationship between green finance, innovation, and resource efficiency, reinforcing the notion that regulatory pressure can create enabling conditions for technological progress.

Growing empirical evidence supports these mechanisms. Hanif and Zheng (2025) report that a 1% increase in green credit is associated with a 0.482% rise in green GDP, indicating that financial regulatory frameworks significantly promote innovation-led economic growth. According to Praveen et al. (2025) show that technological advancement plays a central role in driving green growth by enhancing resource-efficient manufacturing and reducing carbon intensity. Complementing this, Yeboah et al. (2025) show that environmental levies and policy stringency incentivise firms to innovate in ways that simultaneously enhance competitiveness and energy efficiency. These findings collectively affirm that regulatory interventions, when properly designed, can unlock new pathways for sustainable industrial development.

Nevertheless, the applicability of the Porter Hypothesis is not without limitations. X. Liu et al. (2023) show that although environmental policies often stimulate innovation, the extent to which such innovation fully compensates for compliance costs remains uncertain—particularly in emerging economies where institutional quality, technological readiness, and financial market maturity may be weaker. Additionally, some scholars point to the coexistence of the Porter Hypothesis with competing frameworks such as the Pollution Haven Hypothesis, which suggests that firms may shift production to countries with weaker environmental standards. This juxtaposition underscores that the effectiveness of Porter-induced innovation depends heavily on contextual factors including governance quality, regulatory enforcement, industrial structure, and cross-border competitiveness dynamics.

In the context of the RCEP region, the Porter Hypothesis is particularly salient. Many RCEP economies are simultaneously pursuing rapid economic expansion and ambitious decarbonisation goals such as China's 2060 and Japan's 2050 carbon-neutrality commitments, while seeking to maintain global competitiveness. Policies grounded in Porter's logic,

including green finance, innovation incentives, and resource-efficiency standards, offer a conceptual basis for transforming regulatory pressures into engines of innovation-driven growth. By linking environmental regulation with green finance, energy efficiency improvement, and technological upgrading, the Porter Hypothesis provides a robust theoretical lens for analysing how RCEP economies can transition toward sustainable, competitive, and low-carbon development.

2.1.3 The Ecological Modernization Theory (EMT)

The Ecological Modernization Theory (EMT) has emerged as a foundational framework in contemporary environmental sociology and ecological economics, offering a progressive alternative to the traditional belief that economic growth and environmental protection are fundamentally incompatible. Introduced by Mol and Spaargaren (2000), EMT argues that modern economies can resolve ecological challenges not by slowing development, but by restructuring production systems, institutions, and technological pathways toward ecological rationality. In this view, economic growth and environmental sustainability can become mutually reinforcing through targeted reforms and innovation.

A central premise of EMT is that environmental protection can itself become a driver of economic modernization. This occurs through mechanisms such as the adoption of advanced clean technologies, the diffusion of energy-efficient production processes, and the transformation of industries toward greener, knowledge-intensive structures. EMT emphasizes the possibility of “environmental decoupling”, whereby economies progressively reduce the ecological intensity of growth through enhanced resource efficiency, renewable energy integration, and sustained technological innovation. Beyond technological aspects, the theory

highlights the crucial role of governance, institutional restructuring, and green finance in embedding ecological priorities within economic systems. In this sense, environmental regulations and financial incentives are not barriers, but catalysts that stimulate innovation, strengthen competitiveness, and align economic expansion with long-term sustainability goals.

Based on Amin et al. (2025), empirical evidence increasingly validates the mechanisms proposed by Ecological Modernisation Theory (EMT). Their study on the BRICS economies shows that green finance, R&D investment, and technological innovation play significant roles in decoupling carbon emissions from economic growth, reinforcing EMT's argument that technological progress and institutional reforms can drive sustainable development. Their findings suggest that financial reforms and innovation-oriented industrial restructuring are essential for enabling resource-intensive economies to pursue carbon neutrality without compromising economic performance. Similarly, Yeboah et al. (2025) demonstrate that foreign direct investment (FDI) and green financing in Africa accelerate the adoption of energy-efficient technologies, allowing emerging economies to transition toward environmentally responsible growth paths. These studies highlight the adaptability of EMT across both developed and developing contexts.

The theory is particularly relevant to Asia-Pacific and RCEP economies. Rapid industrialization and rising emissions make the region a critical testing ground for whether modernization can be ecologically transformative. Green finance initiatives such as China's global leadership in green bond issuance and increasing R&D expenditure on renewable energy and clean technologies in economies like Japan and South Korea, reflect the modernization dynamics envisioned by EMT. However, the transition remains uneven. Resource-dependent RCEP members still face risks of being locked into carbon-intensive development models,

underscoring EMT's emphasis on institutional capacity, policy coordination, and financial innovation.

In comparison with narrower frameworks such as the Porter Hypothesis, which focuses on firm-level innovation responses to regulation, EMT adopts a broader perspective, emphasizing systemic transformations involving technological diffusion, governance reforms, and transnational financial flows. This makes EMT particularly suitable for the present study. By integrating the roles of green finance, R&D, energy efficiency, and resource management, EMT provides a robust conceptual foundation for analysing how Asia and RCEP economies can achieve low-carbon, resilient, and sustainable growth trajectories.

2.1.4 Green Growth Theory

The Green Growth Theory (GGT) has become a core theoretical framework in environmental economics, advancing the argument that economic expansion and environmental protection can progress simultaneously rather than in opposition. Challenging the conventional view that growth inevitably increases ecological degradation, GGT reframes prosperity to include environmental integrity and social responsibility. As Prime et al. (2024) note, sustainable investment practices, green technologies, and policy interventions form the foundation through which this dual objective can be achieved. At its core, GGT posits that directing capital toward renewable energy, low-carbon technologies, and eco-efficient production systems can foster economic development while mitigating environmental harm. Through the promotion of resource efficiency and innovation, GGT highlights the potential for decoupling GDP growth from carbon emissions, enabling economies to grow without proportionately increasing ecological pressures.

Policy instruments play a central role in operationalizing this decoupling process. Well-designed green financial policies, such as green credit guidelines, sustainable bond issuance, and targeted subsidies to help reallocate resources toward cleaner industries, encourage technological upgrading, and stimulate structural economic transformation. These interventions not only support emission reductions but also contribute to what many scholars describe as “high-quality development,” where productivity, competitiveness, and environmental performance improve concurrently. Empirical evidence increasingly corroborates the theory’s claims. For example, Hanif et al. (2025) find that targeted financial interventions in renewable energy significantly enhance both environmental outcomes and economic performance, reinforcing the core GGT assertion that growth and sustainability can be simultaneously pursued.

Based on recent empirical studies, GGT is particularly relevant in the Asian and RCEP context, where economies face the twin challenge of maintaining strong growth while reducing carbon emissions. According to Yi et al. (2023) and Zhao et al. (2024), green finance (GF) is the primary mechanism through which GGT is implemented, as GF channels funds toward low-carbon industries, enhances production efficiency, and promotes green technological innovation. According to Liu et al., 2023 and Ouyang et al., 2023, the national strategy to transition from rapid expansion to high-quality growth is explicitly grounded in the green growth paradigm, with GF supporting large-scale investments in renewable energy and eco-innovation in China. Similarly, studies across emerging Asian economies show that renewable energy development, green innovation, and efficiency improvements align with GGT by enabling sustainable long-term growth (Wu et al., 2023; Wang et al., 2025).

Although closely related to Sustainable Development Theory (SDT), GGT distinguishes itself by focusing specifically on growth-oriented

mechanisms, such as green finance, renewable energy deployment, and eco-innovation as the principal pathways for reconciling economic expansion with ecological responsibility. This emphasis makes GGT especially well-suited to studies examining how financial and technological interventions can support carbon reduction and industrial upgrading in fast-growing economies, including those within RCEP.

In summary, Green Growth Theory offers a strong conceptual foundation for analysing the interplay among sustainable finance, renewable energy development, technological innovation, and environmental performance. By positioning economic growth not as a threat but as an opportunity for ecological transformation, GGT provides a powerful lens for examining how countries can transition toward low-carbon, competitive, and sustainable development models.

2.1.6 The Sustainable Development Theory (SDT)

According to the Brundtland Report, the Sustainable Development Theory (SDT) is one of the most influential frameworks guiding global environmental and economic policy (World Commission on Environment and Development, 1987). SDT defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” This definition highlights the need to balance three interconnected pillars: economic growth, environmental protection, and social equity. SDT reframes prosperity to include environmental stewardship, responsible resource management, and inclusive development by opposing traditional growth models that prioritize short-term economic gains at the price of long-term ecological stability.

According to SDT, achieving sustainability necessitates incorporating environmental and social concerns directly into economic decision-making. This entails reorganizing financial flows, industrial strategies, and institutional frameworks to enable low-carbon and socially inclusive growth. Green financing is crucial to this structure because it directs money into renewable energy, clean technology, and energy efficiency initiatives, all of which contribute to SDGs 7 (Affordable and Clean Energy), 9 (Industry, Innovation, and Infrastructure), and 13 (Climate Action). Similarly, R&D spending and technical innovation help to transition to sustainable industrialization while lowering resource intensity, thereby furthering SDG 12 (Responsible Consumption and Production) through cleaner production processes and more efficient resource use.

Empirical research frequently adopts SDT to assess how environmental policies and financial mechanisms support the United Nations Sustainable Development Goals (SDGs). According to Shi and Shi (2025), renewable energy technological innovation, when supported by adequate green financing—is essential for achieving SDG 7 and SDG 13, as it reduces fossil fuel dependence and lowers carbon emissions. Zhao et al. (2024) apply SDT principles to demonstrate that green financial policies enhance green energy efficiency, promoting high-quality, low-carbon economic growth aligned with SDG 12 through reductions in resource waste and improvements in production efficiency. Similarly, Amin et al. (2025) utilize SDT to examine natural resource rents, green finance, and R&D expenditure, concluding that sustainable development requires a holistic policy approach that simultaneously addresses economic expansion, environmental protection, and responsible resource consumption in the post-COP27 landscape.

The relevance of SDT is particularly pronounced in Asia and across the RCEP region, where rapid industrialization has intensified both environmental pressures and development opportunities. Many RCEP

economies explicitly embed SDT principles in their national strategies. For instance, China’s “carbon neutrality by 2060” and Japan’s “net-zero by 2050” commitments reflect not only climate mitigation goals but also aspirations for sustainable, innovation-driven growth that emphasizes efficient resource use and responsible production—core elements of SDG 12. These strategies illustrate how SDT encourages countries to prioritize long-term economic resilience over short-term GDP expansion, integrating environmental and social objectives into national development agendas.

Finally, the Sustainable Development Theory provides the overarching conceptual foundation linking green finance, renewable energy, R&D, energy efficiency, and green innovation to broader sustainability outcomes. SDT provides a unifying lens through which this study assesses how several sustainability drivers interact to lower carbon emissions, enable green economic transformation, and promote inclusive, low-carbon development across RCEP nations by aligning with SDGs 7, 8, 9, 12, and 13. Based on this research context, SDT functions as the integrative framework that guides the assessment of environmental performance, economic resilience, and progress toward global sustainability targets.

2.2 Carbon Emissions

Carbon dioxide (CO₂) emissions remain the most critical indicator of global environmental degradation and are widely recognized as the principal driver of climate change. As the dominant component of anthropogenic greenhouse gases (GHGs), CO₂ emissions are central to academic discourse and policy debates, particularly in Asia and among Regional Comprehensive Economic Partnership (RCEP) economies, which collectively contribute a substantial share of global emissions. According to Amin et al. (2025), understanding the determinants that either mitigate or exacerbate CO₂ emissions is essential for achieving international

climate commitments such as the Paris Agreement and COP27 targets. Across the literature, five key determinants consistently emerge within the context of green growth and sustainability: green finance, research and development (R&D) expenditure, renewable energy consumption, energy efficiency, and green technological innovation.

2.2.1 Green Finance and Carbon Emissions

According to Yang and Liu (2025), green finance plays a central role in mitigating CO₂ emissions by directing capital toward environmentally responsible sectors and restricting financial flows to carbon-intensive industries. Green finance includes green bonds, green loans, sustainability-linked financing instruments, and regulatory policies such as green credit guidelines. Based on Amin et al. (2025), green finance demonstrates a consistent negative relationship with emissions, where a one percent increase in green finance leads to a reduction of 0.173 percent in the long run and 0.058 percent in the short run among BRICS economies. Robustness checks including AMG and CCEMG confirm stronger reductions of up to 0.398 percent. According to Wu et al. (2023) and Fan et al. (2025), China's Pilot Policy for Green Finance Reform and Innovation significantly lowered emissions by enhancing industrial upgrading and easing financing constraints for clean-energy firms. Similar findings emerge in G20 and OECD countries. According to Alvi et al. (2025) and Ouni et al. (2025), green finance improves environmental performance by supporting renewable energy deployment and cleaner industrial structures.

However, according to Chi et al. (2025), the effectiveness of green finance depends on reaching a minimum investment threshold. In Asia Pacific, green finance generates limited environmental benefits at levels below 2.5 percent of GDP, but beyond this threshold, emissions decline substantially,

with East Asia requiring a threshold of 3.1 percent. Furthermore, according to Wu et al. (2023), regional disparities are substantial because eastern China benefits more from green finance than central regions due to superior institutional capacity and market maturity. Poorly designed green financial regulations may also create a “green paradox” where firms shift to other high-emission activities when faced with restrictive credit conditions. According to Shi and Shi (2025), this unintended effect can weaken overall progress toward decarbonization.

2.2.2 R&D Expenditure and Carbon Emissions

According to Khan et al. (2022) and Bai et al. (2023), research and development expenditure is fundamental to reducing carbon emissions because it supports the development of renewable energy technologies, clean production processes, carbon-capture systems, and energy-efficient technologies. Based on Amin et al. (2025), a one percent increase in R&D expenditure in BRICS economies reduces emissions by 0.215 percent initially and leads to a sustained long-run decline of 0.256 percent. Evidence from OECD countries reinforces this pattern. According to Alvi et al. (2025), environmental patents, which capture the outcomes of R&D-driven innovation, significantly reduce greenhouse gas emissions. In China, according to Zhang et al. (2025), R&D investment has accelerated renewable energy deployment and enhanced industrial modernization, contributing to measurable emissions reduction despite rapid economic growth.

However, Fan et al. (2025) show th the positive environmental impact of R&D depends on the effective diffusion of new technologies, which is often constrained by weak institutions, limited technical capacity, and high deployment costs in developing countries. According to Yao et al. (2025), inefficiencies in resource allocation, including mismatches in human

capital, R&D capital, and regional industrial needs, can diminish the effectiveness of R&D spending. This means that while R&D is a critical tool for emissions reduction, its success depends heavily on complementary policies, technology diffusion mechanisms, and supportive innovation ecosystems.

2.2.3 Renewable Energy Consumption and Carbon Emissions

According to Praveen et al. (2025), renewable energy consumption provides a direct substitute for fossil fuels, making it one of the most effective pathways for reducing CO₂ emissions. Evidence consistently shows a negative relationship between renewable energy usage and carbon emissions. According to Ruan et al. (2025), a one percent increase in renewable energy consumption reduces emissions in Bangladesh by 0.15 percent in the long run. According to Amin et al. (2025), renewable energy reduces emissions by 0.72 percent in the short term and 0.116 percent in the long term within BRICS countries, with robustness tests confirming reductions of up to 0.510 percent. According to Zhang et al. (2022), renewable energy investment in G20 countries significantly decreases emissions, especially in high-emission economies that rely on large-scale renewable deployment.

Despite these benefits, renewable energy faces structural challenges across Asia and the RCEP region. According to Chi et al. (2025), many countries rely on dual-energy systems where renewable energy expands alongside continued fossil fuel dependence, weakening net reductions in emissions. According to Cao et al. (2025), fossil fuel subsidies in E7 economies slow the pace of energy transition by reducing the competitiveness of renewable

alternatives. According to Liza et al. (2024), some countries fail to observe reductions in ecological footprint because renewable energy integration remains inefficient or dependent on fossil-based backup systems. These findings suggest that renewable energy must be supported by institutional reforms and subsidy restructuring to achieve deeper decarbonization.

2.2.4 Energy Efficiency and Carbon Emissions

According to Yang and Liu (2025), energy efficiency reduces emissions by lowering energy usage per unit of economic output, thereby decreasing both energy costs and carbon intensity. Energy efficiency improvements occur through technological upgrades, industrial restructuring, digitalization of energy systems, and smart management practices. In China, green finance has improved energy efficiency by promoting cleaner industrial processes, which in turn reduced emissions. According to Yao et al. (2025), green inclusive finance enhances carbon emission efficiency by improving resource utilization. In BRICS economies, according to Ouni et al. (2025), efficiency measures in the transport sector reduce fossil fuel consumption and associated emissions by enabling smart transport systems and efficient mobility solutions.

However, energy efficiency remains uneven across regions. According to Yeboah et al. (2025), efficiency measures in African economies show minimal impact due to limited financing and weak implementation capabilities. According to Wang et al. (2024), resource-rich countries face high compliance costs and industrial constraints, which reduce efficiency gains. This indicates that energy efficiency is a powerful tool for emissions reduction, but its success depends on sufficient financing, regulatory support, and institutional capacity.

2.2.5 Green Technological Innovation and Carbon Emissions

According to Bai et al. (2023), green technological innovation focuses on producing and disseminating new technologies that promote energy efficiency, clean energy, sustainable manufacturing, and low-carbon infrastructure. This form of innovation is broader than traditional R&D because of its practical emphasis on technology deployment and industrial transformation. According to Amin et al. (2025), a one percent increase in green technological innovation reduces emissions by 0.123 percent in BRICS economies in the long run. According to Khan et al. (2025), green innovation in Asia supports significant reductions in carbon intensity and transport-related emissions, contributing to long-term decoupling between economic growth and environmental degradation. According to Zhang et al. (2025), China's green finance reforms have strengthened green innovation, accelerating both pollution reduction and decarbonization. According to Alvi et al. (2025), green patents in OECD countries further confirm the strong role of innovation in reducing greenhouse gas emissions.

However, the effectiveness of green technological innovation is not guaranteed. According to Liao (2025), excessive R&D spending may reduce innovation efficiency, particularly when investments exceed firms' absorptive capacity. According to Yao et al. (2025), misallocation of innovation resources weakens green innovation performance and undermines emissions reduction potential. According to Khan et al. (2025), some green technologies create rebound effects or require substantial energy to deploy, which can temporarily increase emissions. Therefore, while green technological innovation is a transformative driver of

decarbonization, it must be supported by targeted investment strategies, efficient resource allocation, and strong institutional alignment.

2.3 Sustainable Development Goals

The Sustainable Development Goals provide a comprehensive framework for evaluating how financial, technological, and energy-related transitions shape environmental and economic performance in emerging markets, particularly within Asia and the RCEP region. The following subsections examine how each independent variable contributes to SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

2.3.1 Green Finance and the SDGs

According to Cao et al. (2025) and Hanafy et al. (2025), green finance is the financial foundation of SDG implementation as it mobilizes capital toward energy transition projects, efficiency improvements, clean technologies, and sustainable industrial strategies. Green financing directly supports SDG 7 by increasing access to clean and dependable energy systems via funding grid upgrading and renewable energy installations. China's dual-carbon goals of peaking emissions by 2030 and reaching carbon neutrality by 2060 are accelerated by green bonds, sustainability-linked loans, and pilot green finance zones, all of which significantly reduce CO₂ emissions (Yang and Liu, 2025; Y. Zhang et al., 2025).

According to Y. Sun et al. (2024) and Limosani et al. (2025), green finance also promotes structural economic upgrading and job creation in renewable and eco-efficient industries, supporting SDG 8, which emphasizes sustainable and high-quality economic growth. Green finance facilitates industrial modernization by easing financing constraints for clean technology firms and green manufacturing, contributing further to SDG 9.

Green finance is also increasingly linked to SDG 12, as sustainable loans and environmental disclosure requirements encourage firms to adopt resource-efficient practices, reduce waste generation, and improve environmental reporting standards. Evidence from Belt and Road economies shows that green financial instruments combined with public spending significantly reduce financing barriers for renewable projects, demonstrating green finance's broader role in enabling responsible production and consumption patterns (Hua and Tong, 2025).

2.3.2 R&D, Renewable Energy, and Efficiency for SDGs

According to Jawadi et al. (2024), R&D expenditure supports the technological foundations of SDG 9, as it drives cleaner production methods, innovation capacity, and sustainable industrial restructuring. Advanced R&D investment leads to new renewable technologies, low-carbon materials, and energy-efficient processes that modernize industrial sectors.

According to Chen and Lubabu (2025) and Xu et al. (2025), R&D contributes to SDG 7 by improving the performance and cost-efficiency of solar, wind, hydropower, and storage systems, enabling a broader shift away from fossil fuels. According to Amin et al. (2025), R&D also supports SDG 13, as technological progress in the BRICS region has significantly reduced carbon emissions through improvements in renewable energy deployment and clean processing technologies.

R&D investment promotes SDG 8 by fostering productivity, long-term competitiveness, and the growth of green technology sectors, which generate sustainable employment and high-value jobs. Furthermore, R&D helps advance SDG 12, as technological innovation supports resource-efficient manufacturing, waste minimization, and the transition toward circular economic systems.

2.3.3 Green Innovation and the SDGs

According to Chen and Lubabu (2025) and Xu et al. (2025), renewable energy is one of the most powerful drivers of SDG 7 and SDG 13, as substituting fossil fuels with solar, wind, hydro, and other renewables directly reduce greenhouse gas emissions and accelerates national decarbonization pathways. Amin et al. (2025), show that a one percent increase in renewable energy consumption leads to measurable reductions in CO₂ emissions across BRICS countries, confirming its central role in climate action.

Renewable energy also contributes to SDG 8 by stimulating new industries, encouraging green entrepreneurship, and creating long-term employment in installation, operation, grid management, and maintenance. Renewable

deployment requires significant infrastructure upgrades, which further support SDG 9 by expanding modern energy networks and strengthening industrial competitiveness.

Renewable energy is increasingly linked to SDG 12, as it reduces reliance on extractive and high-waste production systems, promotes cleaner consumption patterns, and encourages energy users to adopt sustainable electricity sources. However, according to Cao et al. (2025), fossil fuel subsidies in developing economies weaken the effectiveness of renewable energy, demonstrating the need for complementary reforms to achieve SDG 12 and SDG 13 simultaneously.

2.3.4 Energy Efficiency and the SDGs

According to Yeboah et al. (2025) and Ouni et al. (2025), energy efficiency is a cornerstone of SDG 8 and SDG 13, as reducing energy intensity enhances productivity and economic performance while simultaneously lowering emissions and energy waste. Efficiency improvements across manufacturing, transport, and building systems decouple economic growth from environmental degradation.

Energy efficiency also contributes to SDG 7, since using energy more efficiently reduces overall energy demand, allowing renewable energy systems to meet a greater share of national electricity requirements. According to Zhao et al. (2024), China's green finance pilot zones have significantly strengthened green energy efficiency through financial support for clean industrial technologies.

Energy efficiency plays an important role in SDG 12, as it promotes responsible consumption patterns through reduced resource usage, optimized energy management, and lower levels of waste generated per unit of economic output. Efficiency-driven industrial upgrades also reinforce SDG 9, as modernized industries rely on digital technologies, automated systems, and low-waste production processes.

2.3.5 Green Technological Innovation and the SDGs

According to M. A. Khan et al. (2025) and Y. Wang et al. (2024), green technological innovation is the central mechanism linking environmental protection with sustained economic expansion. By enhancing clean energy technologies, optimizing industrial processes, and promoting digital and eco-efficient systems, green innovation directly advances SDG 7 and SDG 13 through reductions in emissions, pollution, and fossil fuel dependency.

Green innovation also strengthens SDG 8 by boosting total factor productivity (TFP), lowering production costs, and enabling firms to remain profitable while reducing environmental damage. According to Alvi et al. (2025), environmental patents and green digital innovations in OECD countries are strongly associated with reductions in emissions and improvements in resource utilization. Mehroush et al. (2024) show that green innovation contributes to SDG 9 by enabling the transition toward smart manufacturing, low-carbon industrial systems, and resilient technological infrastructure. Green innovation further advances SDG 12, as many green technologies focus on waste reduction, recycling, circular industrial systems, and energy-saving production techniques that promote responsible production patterns.

Empirical evidence suggests that green technological innovation often has a stronger effect on long-term SDG progress than GDP growth or FDI inflows, underscoring its central role in achieving sustainable

transformation across high- and middle-income economies (Mehroush et al., 2024).

2.4 Research Framework

2.4.1 Carbon Emission (CO₂)

Based on the figure 2.4.1 the graph shows five independent variables affecting carbon emission are described. Determinants include energy efficiency, renewable energy consumption, R&D investment and green technology innovation.

2.4.2 Sustainable Development Goal (SDG)

Based on the figure 2.4.2 the graph shows five independent variables affecting on Sustainable Development Goal (SDG 7, 8, 9, 12, 13) described. Determinants include energy efficiency, renewable energy consumption, R&D investment and green technology innovation.

2.5 Research Gaps

There are still several significant gaps in the literature despite the increasing scholarly interest in green finance, the adoption of renewable energy, technical innovation, and sustainable development. These restrictions are particularly noticeable in the context of the RCEP area, where the shift to low-carbon growth is made more difficult by the region's economic variety, unequal institutional quality, and enduring reliance on fossil fuels. The lack of agreement on threshold or non-linear effects, the incomplete coverage of all RCEP-15 economies, the poor integration of several sustainability drivers within a single analytical model, and the dearth of research connecting the same determinants to both CO₂ emissions and SDG performance are the four main gaps in the current evidence.

2.5.1 Lack of Consensus on Threshold Effects of Green Finance

According to Chi et al. (2025), existing studies reveal substantial disagreement on whether green finance produces stable linear effects or whether its effectiveness depends on surpassing specific thresholds. For example, green finance investments below 2.5 percent of GDP were found to have minimal carbon reduction impact in Asia-Pacific economies, while investments exceeding this threshold generated stronger emission declines. Ouni et al. (2025) also report that renewable-energy-related technological innovation tends to become effective only after innovation activities reach a critical threshold. This inconsistency creates policy uncertainty because evidence across countries is mixed. Some studies conclude that green finance promotes carbon efficiency, while others document weak or even adverse effects attributed to misallocation, weak governance, or superficial “green drift” (Wu et al., 2023; Shi and Shi, 2025). Non-linear patterns are

further supported by quantile-based studies, such as Zhang et al. (2022), which show that green finance contributes to emission improvements only within middle quantiles of the emissions distribution.

These inconsistencies indicate that traditional linear modelling may not sufficiently capture non-linear relationships, tipping points, or structural breaks. Although threshold regression and quantile regression have been applied in recent research, there is still no consensus on the magnitude, direction, and conditions under which green finance and innovation become effective. This gap highlights the need for future studies to develop more sophisticated empirical strategies that can better capture non-linear dynamics.

2.5.2 Limited Evidence for RCEP Economies

According to Amin et al. (2025) and Liu et al. (2023), most existing studies focus on OECD, G20, or BRICS economies, while research on the full RCEP-15 region remains limited. This gap persists even though RCEP collectively accounts for around one-third of global GDP and includes several of the world's largest emitters such as China, Japan, and South Korea. Existing work tends to focus on China alone or on small subgroups of Asian economies (Bashir et al., 2021; Wang and Xu, 2023), leaving the broader RCEP context largely unexplored.

This omission is problematic because RCEP economies differ significantly in institutional quality, financial development, governance capacity, and environmental regulation. For example, Japan maintains a mature green finance ecosystem, while lower-income Southeast Asian economies face

limited financing capacity and weaker enforcement mechanisms (Hua and Tong, 2025). Bai et al. (2023) also highlight a shortage of studies examining green trade and consumption-based emissions within RCEP, and Shuo et al. (2024) observe limited evidence on the role of natural resource rents in shaping green development strategies in the region.

Policymakers lack the region-specific knowledge required to create coordinated and successful sustainability programs in the absence of thorough empirical data spanning all 15 RCEP economies.

2.5.3 Weak Integration of Multiple Independent Variables in One Framework

According to Praveen et al. (2025) and Hanif and Zheng (2025), current research tends to examine sustainability drivers separately, focusing on individual elements such as green finance, renewable energy, energy efficiency, or technological innovation in isolation. This fragmented approach fails to capture their interdependence. For example, the effectiveness of green finance often depends on complementary drivers such as innovation capacity, industrial restructuring, and improvements in energy efficiency (Alvi et al., 2025; Xu et al., 2025). Wang et al. (2024) further emphasize that mediating and moderating mechanisms, such as the role of technological innovation in transmitting the benefits of green finance, remain understudied.

The lack of integrated empirical models limits the ability of existing research to fully explain how financial, technological, and energy-related drivers interact to influence environmental outcomes. This gap highlights the need for empirical studies that incorporate these variables simultaneously rather than treating them as isolated determinants.

2.5.4 Limited Research Linking CO₂ Emissions and SDG Performance

According to Zhang et al. (2024) and Mohsin and Jamaani (2023), while numerous studies examine CO₂ emissions or sustainability outcomes individually, very few integrate both outcomes within the same empirical framework. This is a critical omission because the Sustainable Development Goals, especially SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), are directly linked to carbon reduction pathways. Existing literature often measures the impact of green finance or innovation on emissions alone without assessing whether these effects extend to broader SDG progress.

Linking both outcomes is essential because an intervention that reduces emissions may not always contribute to SDG advancement, particularly in countries with high resource dependence, weak governance, or structural economic constraints. Because of this gap, policymakers lack a holistic understanding of how green finance, renewable energy, and innovation simultaneously influence environmental and development outcomes.

2.6 Hypotheses Development

2.6.1 Carbon Emissions

H1₀: Green finance has not significant negative effect on carbon emissions in RCEP economies.

H1₁: Green finance has a significant negative effect on carbon emissions in RCEP economies.

Green finance (GF) is increasingly recognised as a central instrument for achieving low-carbon development, particularly in Asia and the RCEP region where rapid industrialisation intensifies environmental pressures. Empirical evidence indicates that GF reduces emissions by reallocating financial resources from carbon-intensive sectors to renewable energy, clean technology, and energy-efficient infrastructure. For instance, Chi et al. (2025) report a threshold effect in Asia-Pacific economies: GF below 2.5% of GDP has minimal impact, but above this level, it significantly accelerates decarbonisation, highlighting the importance of financial scale. Country-specific studies reinforce this mechanism. In China, Yang and Liu (2025), Fan et al. (2025), and Zhang et al. (2025) show that green finance reform and innovation (GFRI) policies ease financing constraints for renewable energy firms, promote green technological upgrading, and incentivise cleaner production, collectively reducing carbon intensity.

Broader regional evidence also supports this relationship. Research on the Belt and Road Initiative (Hua et al., 2025) and multi-country Asian panels (Mohsin & Jamaani, 2023) finds that GF boosts investment in renewables, energy efficiency, and R&D, contributing to long-term emission reductions. However, GF's impact is not uniform. Zhang et al. (2025) note sectoral heterogeneity, with stronger reductions in service-oriented cities than in

industrial-heavy regions. Ouni et al. (2025) highlight the risk of financial misallocation, while Praveen et al. (2024) emphasise the need for alignment with green innovation to ensure substantial impact.

Overall, the evidence supports the hypothesis that GF can significantly reduce carbon emissions, but its effectiveness depends on financial scale, governance quality, industrial structure, and integration with green technological innovation and complementary environmental policies.

H2₀: R&D expenditure has not significant negative effect on carbon emissions in RCEP economies.

H2₁: R&D expenditure has a significant negative effect on carbon emissions in RCEP economies.

Research and development (R&D) is widely acknowledged as a critical mechanism for reducing carbon emissions, particularly in rapidly industrialising economies such as those in Asia and the RCEP bloc. According to Jawadi et al. (2024), sustained investment in R&D supports the development of resource-efficient production systems, low-emission industrial processes, and breakthrough technologies that directly contribute to decarbonisation. Higher R&D expenditure accelerates the diffusion of cleaner technologies, enhances the environmental performance of industries, and strengthens countries' capacity to meet emission-reduction targets.

Empirical evidence consistently supports the negative relationship between R&D and carbon emissions. In BRICS economies, Amin et al. (2025) demonstrate that R&D investment significantly reduces emissions through improvements in innovation capability and green technological upgrading. Similarly, Yeboah et al. (2025) show that R&D-driven advances in energy

efficiency reduce energy intensity across manufacturing, transport, and service sectors, contributing to long-term emission declines. Studies from China confirm this pathway, where R&D spending has been shown to enhance green total factor productivity (GTFP), stimulate the adoption of pollution-reducing equipment, and strengthen firms' environmental compliance (Zhao et al., 2024).

However, the literature notes that the effectiveness of R&D depends heavily on absorptive capacity, human capital quality, and the alignment of innovation policies with environmental priorities. Without strong institutional support, R&D investments may not automatically translate into low-carbon outcomes. Nonetheless, the dominant empirical conclusion supports this hypothesis: R&D expenditure plays a significant role in reducing carbon emissions by facilitating cleaner innovation and transforming production structures across Asian and RCEP economies.

H3₀: Renewable energy consumption has not significant negative effect on carbon emissions in RCEP economies.

H3₁: Renewable energy consumption has a significant negative effect on carbon emissions in RCEP economies.

Renewable energy (RE) serves as one of the most direct and effective mechanisms for reducing carbon emissions, particularly in regions where economic expansion has historically been fuelled by coal, oil, and gas. According to Chen and Lubabu (2025), greater consumption of renewable energy such as solar, wind, hydro, and geothermal, significantly reduces greenhouse gas emissions by displacing carbon-intensive energy sources. This substitution effect is especially important in RCEP economies, many of which remain heavily dependent on fossil fuels.

Empirical evidence provides strong support for this negative relationship. Amin et al. (2025) find that in BRICS economies, a 1% increase in renewable energy consumption leads to a measurable decline in CO₂ emissions, confirming the potency of RE in driving decarbonisation. Xu et al. (2025) similarly report that RE expansion accelerates the transition toward low-carbon energy systems by reducing reliance on coal-fired power generation. Studies from China show that provinces with higher shares of renewable energy in their electricity mix experience faster reductions in emission intensity and pollution levels, demonstrating the direct environmental benefits of RE adoption.

Despite this, some studies note challenges, including intermittency constraints, slow grid integration, and unequal RE adoption across regions, which may moderate the magnitude of emission reductions. However, the overarching conclusion remains robust: renewable energy consumption significantly reduces carbon emissions by replacing fossil fuels, enhancing energy security, and supporting the low-carbon transition across Asia and RCEP countries.

H4₀: Energy efficiency improvements have not significant negative effect on carbon emissions in RCEP economies.

H4₁: Energy efficiency improvements have a significant negative effect on carbon emissions in RCEP economies.

Energy efficiency (EE) forms a foundational pillar of emission reduction strategies, especially in regions characterised by energy-intensive manufacturing and rapid urbanisation. According to Yeboah et al. (2025), improvements in EE lower the amount of energy required per unit of output, thereby reducing total energy consumption and associated emissions. This mechanism is particularly relevant for RCEP economies,

where industrial energy demand remains high and efficiency gains can yield substantial environmental benefits.

Empirical evidence confirms this relationship. Ouni et al. (2025) find that EE improvements significantly reduce carbon emissions across Asian economies by lowering energy intensity in transport, industrial production, and buildings. Zhao et al. (2024) show that China's green finance pilot zones increased energy efficiency by facilitating investment in cleaner technologies and modernising outdated equipment, which in turn led to substantial reductions in emission intensity. Efficiency improvements also contribute to structural transformation, as firms adopt advanced technologies that support low-carbon growth.

Nonetheless, some studies highlight potential rebound effects, where efficiency gains lower production costs and unintentionally increase total energy use. However, the dominant consensus remains clear: energy efficiency improvements exert a significant negative effect on carbon emissions by reducing energy intensity and promoting greener production across Asia and the RCEP region.

H5₀: Green technological innovation has not significant negative effect on carbon emissions in RCEP economies.

H5₁: Green technological innovation has a significant negative effect on carbon emissions in RCEP economies.

Green technological innovation (GTI) represents a transformative driver of decarbonisation, enabling economies to simultaneously pursue environmental protection and productivity growth. According to Wang et al. (2024) and Khan et al. (2025), GTI enhances environmental performance by accelerating the development and adoption of pollution-

reducing technologies, renewable energy systems, digital environmental solutions, and advanced manufacturing processes. In RCEP economies, GTI is particularly crucial given the region's reliance on heavy industry and fossil fuels.

Empirical evidence strongly supports the negative relationship between GTI and carbon emissions. Studies across OECD and developing economies show that increases in green patents, eco-innovations, and digital environmental technologies significantly reduce emission intensity and total CO₂ levels. In China, Alvi et al. (2025) and Mehroush et al. (2024) find that GTI enhances total factor productivity, lowers resource consumption, and improves firms' capacity to comply with environmental standards, all of which contribute to long-term decarbonisation.

Although the diffusion of green technologies may vary across countries due to differences in institutional quality, innovation capacity, and financial support, the empirical consensus is strong. GTI exerts a significant negative effect on carbon emissions by strengthening technological capability, improving production efficiency, and enabling sustained low-carbon development across Asia and RCEP economies.

2.6.2 SDGs (SDG 7, SDG 8, SDG 9, SDG 12, SDG 13)

H6₀: Green finance has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

H6₁: Green finance has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

Green finance (GF) has become a central policy instrument for advancing multiple dimensions of sustainable development. According to Chi et al. (2025) and Mohsin & Jamaani (2023), GF channels capital into renewable energy, green infrastructure, clean transport, industrial upgrading, and resource-efficient production, directly contributing to progress on SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action). The expansion of green loans and green bonds also supports eco-friendly business development and job creation, which enhances SDG 8 (Decent Work and Economic Growth).

In RCEP economies, where environmental governance and financial systems vary widely, GF helps bridge structural gaps by reducing financing constraints, accelerating technological adoption, and supporting cleaner production (Yang & Liu, 2025). Hua et al. (2025) further show that sustainable finance improves regulatory compliance and environmental performance, contributing to SDG 12 (Responsible Consumption and Production). Although the effectiveness of GF depends on institutional quality, the consensus in the literature supports a significant positive relationship between GF and SDG outcomes. GF enhances clean energy access, strengthens innovation systems, promotes sustainable industry, and

supports climate mitigation and adaptation efforts across Asia and the RCEP region.

H7₀: R&D expenditure has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

H7₁: R&D expenditure has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

R&D expenditure is a foundational driver of sustainable development, enabling countries to transition toward cleaner, more productive, and more resilient economic structures. According to Jawadi et al. (2024), sustained R&D investment accelerates technological breakthroughs in renewable energy, energy storage, advanced manufacturing, and circular economy processes. These advancements directly support SDG 7 by improving the availability and affordability of clean energy technologies, and SDG 9 through enhanced industrial competitiveness and innovation capacity.

Empirical studies also show that R&D-induced efficiency gains stimulate high-quality economic growth, contributing to SDG 8 by fostering skilled employment and improving labour productivity (Amin et al., 2025). In addition, innovation-driven improvements in resource utilisation and waste reduction strengthen SDG 12, while advances in low-carbon technologies contribute to SDG 13 by reducing environmental pressure. While the benefits of R&D depend on absorptive capacity and institutional support, the literature consistently demonstrates a significant positive effect of R&D on SDG performance across Asia and globally.

H8₀: Renewable energy consumption has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

H8₁: Renewable energy consumption has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

Renewable energy (RE) plays a critical role in advancing sustainable development by providing clean, secure, and affordable energy systems. Empirical evidence shows that increased renewable energy adoption directly enhances SDG 7 by improving electricity accessibility, reducing energy costs, and diversifying energy supply (Chen & Lubabu, 2025). RE deployment also stimulates innovation in manufacturing, energy storage, and grid technologies, thereby supporting SDG 9 and strengthening industrial resilience (Xu et al., 2025).

Renewables are associated with job creation in installation, maintenance, and manufacturing, contributing to SDG 8 (Amin et al., 2025). Furthermore, the substitution of fossil fuels with clean energy lowers environmental degradation, improves air quality, and reduces waste associated with traditional energy systems, thereby reinforcing SDG 12 and SDG 13. Although infrastructure limitations and intermittency challenges persist in several RCEP countries, the overall literature confirms a significant positive effect of RE consumption on SDG outcomes.

H9₀: Energy efficiency improvements have not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

H9₁: Energy efficiency improvements have a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

Energy efficiency (EE) improvements are widely recognised as one of the most cost-effective pathways for advancing sustainable development. According to Yeboah et al. (2025), EE reduces energy intensity across industrial, commercial, and residential sectors, allowing economies to produce more output with fewer resources. This directly supports SDG 7 by improving energy affordability and reliability. Through the adoption of advanced industrial technologies and energy-saving equipment, EE strengthens manufacturing competitiveness and innovation, thereby contributing to SDG 9.

Efficiency-driven modernisation also enhances SDG 8 by supporting productivity growth and creating new employment opportunities in green technology and retrofitting sectors. In addition, EE measures reduce waste, minimise material loss, and improve resource utilisation, thereby advancing SDG 12. Efficiency improvements also reduce greenhouse gas emissions, helping countries progress toward SDG 13. Although rebound effects may occur in specific contexts, the dominant empirical evidence confirms a significant positive effect of EE on SDG performance across Asia and the RCEP region.

H10₀: Green technological innovation has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

H10₁: Green technological innovation has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.

Green technological innovation (GT) is one of the most powerful determinants of sustainable development, enabling economies to simultaneously increase productivity and reduce environmental pressure. According to Wang et al. (2024) and Khan et al. (2025), GT improves production efficiency, accelerates the adoption of clean energy systems, and reduces industrial waste and pollution. These innovations directly contribute to SDG 9 by strengthening industrial capabilities and supporting advanced manufacturing, while also enhancing SDG 7 through improving the performance and reliability of renewable energy technologies.

GT also promotes SDG 8 by generating high-skill employment opportunities and supporting innovation-driven economic growth. Empirical studies from China and OECD economies show that green patents, eco-innovation, and digital environmental technologies significantly improve firms' environmental compliance and reduce resource consumption, reinforcing SDG 12. Moreover, by enabling low-carbon technologies and improving energy and material efficiency, GT plays a central role in achieving SDG 13. Despite differences in innovation capacity across RCEP economies, the literature consistently supports a significant positive effect of GTI on multiple SDG outcomes.

2.7 Summary

The main highlights of Chapter 2 are summarised in Table 2.1 and Table 2.2.

Table 2.1: Summary of Chapter 2 (Objective 1)

Gap in Knowledge	Theories	Hypothesis
Limited empirical evidence on the role of green finance in reducing carbon emissions in RCEP economies.	Negative Externalities Theory	<p>H1₀: Green finance has not significant negative effect on carbon emissions in RCEP economies.</p> <p>H1₁: Green finance has a significant negative effect on carbon emissions in RCEP economies.</p>
Unclear impact of R&D expenditure on carbon reduction in rapidly industrialising RCEP countries.	Porter Hypothesis	<p>H2₀: R&D expenditure has not significant negative effect on carbon emissions in RCEP economies.</p> <p>H2₁: R&D expenditure has a significant negative effect on carbon emissions in RCEP economies.</p>
Lack of region-specific evidence on renewable energy's effect on emissions in RCEP.	Ecological Modernization Theory (EMT)	<p>H3₀: Renewable energy consumption has not significant negative effect on carbon emissions in RCEP economies.</p> <p>H3₁: Renewable energy consumption has a significant negative effect on carbon emissions in RCEP economies.</p>
Insufficient understanding of energy efficiency improvements as a mechanism to lower emissions in RCEP economies.	Green Growth Theory (GGT)	<p>H4₀: Energy efficiency improvements have not significant negative effect on carbon emissions in RCEP economies.</p> <p>H4₁: Energy efficiency improvements have a significant negative effect on carbon emissions in RCEP economies.</p>
Limited studies on green technological innovation (GTI) impact on emissions in RCEP economies.	Porter Hypothesis	<p>H5₀: Green technological innovation has not significant negative effect on carbon emissions in RCEP economies.</p> <p>H5₁: Green technological innovation has a significant negative</p>

		effect on carbon emissions in RCEP economies.
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Source: Author's own summarisation

Table 2.2: Summary of Chapter 2 (Objective 2)

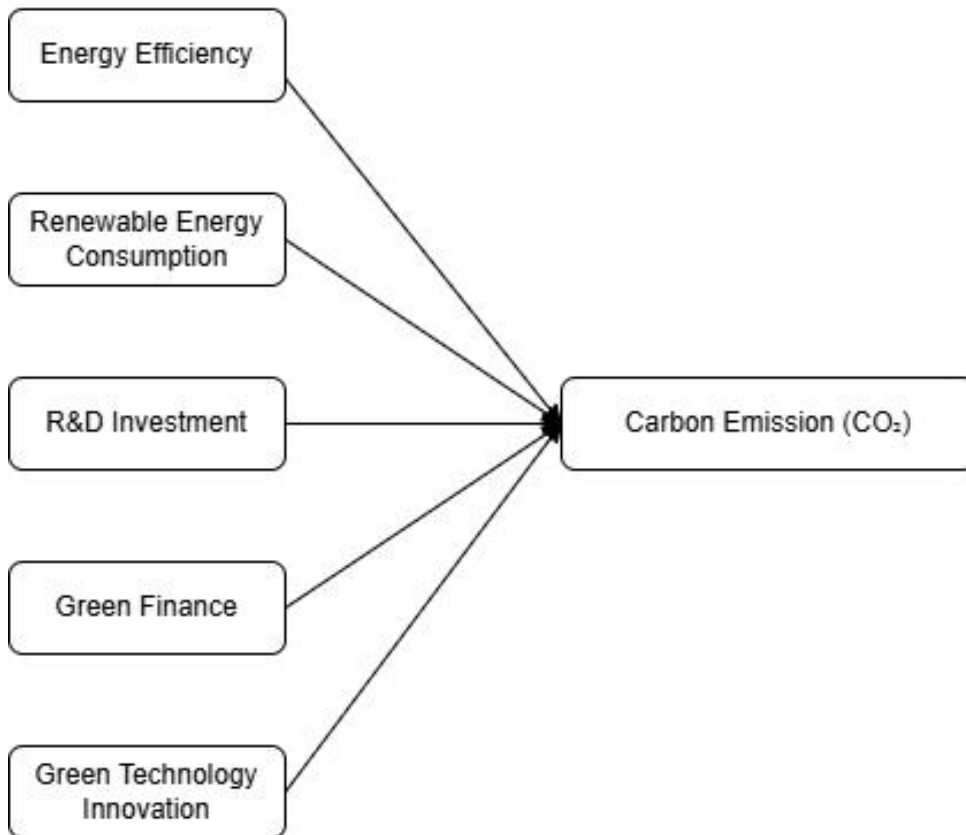
Gap in Knowledge	Theories	Hypothesis
Limited research on green finance's contribution to multiple SDG outcomes in RCEP economies.	Sustainable Development Theory (SDT)	H6 ₀ : Green finance has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies. H6 ₁ : Green finance has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.
Lack of evidence on how R&D expenditure contributes to SDG achievement in RCEP economies.	Sustainable Development Theory (SDT)	H7 ₀ : R&D expenditure has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies. H7 ₁ : R&D expenditure has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.
Renewable energy's effect on SDG performance is underexplored in RCEP economies.	Ecological Modernization Theory (EMT)	H8 ₀ : Renewable energy consumption has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies. H8 ₁ : Renewable energy consumption has a significant positive

		effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.
Unclear link between energy efficiency improvements and SDG outcomes in RCEP.	Green Growth Theory	<p>H9₀: Energy efficiency improvements have not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.</p> <p>H9₁: Energy efficiency improvements have a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.</p>
Limited evidence on green technological innovation (GTI) supporting SDG achievements in RCEP economies.	Sustainable Development Theory (SDT)	<p>H10₀: Green technological innovation has not significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.</p> <p>H10₁: Green technological innovation has a significant positive effect on SDG performance (SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13) in RCEP economies.</p>

Source: Author's own summarisation

Figure 2.1: Research Framework on Carbon Emission (CO₂)

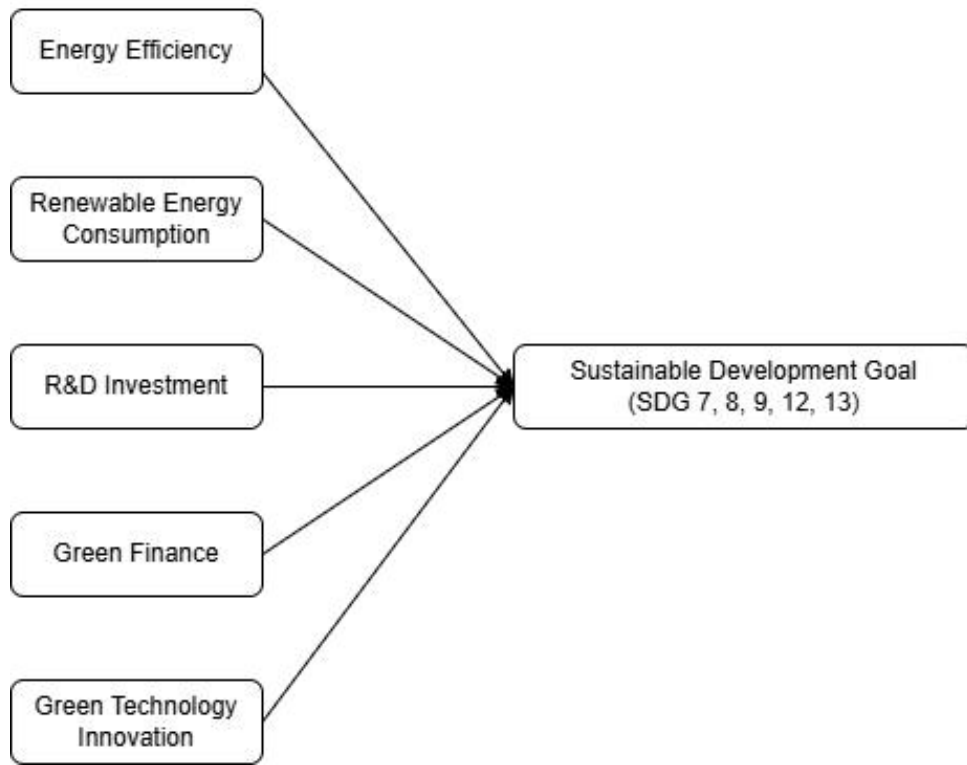
Objective 1: To empirically examine the 5 individual variables effecting on carbon emissions reduction across the RCEP countries from 2016–2023.



Source: Author's own computation

Figure 2.2: Research Framework on SDG 7, 8, 9, 12, 13

Objective 2: To evaluate the individual contributions of five sustainability drivers to the SDG Index and progress on SDGs 7, 8, 9, 12, and 13 in the RCEP region.



Source: Author's own computation

CHAPTER 3: METHODOLOGY

3.0 Introduction

This chapter outlines the methodological framework employed to empirically investigate the individual and combined effects with five green development drivers which is energy efficiency (EE), renewable energy consumption (REC), green bond issuance (lnGB), green technological innovation (GT), and R&D expenditure (RDE) on carbon dioxide emissions and performance across SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13 in the 10 RCEP member economies over the period 2016 to 2023 .

This study takes a quantitative, positivist approach using panel data econometrics because it relies on secondary macro-level data. This chapter details the research design, data sources and collection procedures, variable measurement and operationalisation, data processing and diagnostic checks, and the econometric modelling strategy. Three standard panel estimators which is Pooled Ordinary Least Squares (POLS), Fixed Effects Model (FEM), and Random Effects Model (REM) to estimate, with model selection guided by the F-test for poolability, Breusch–Pagan Lagrange Multiplier (BPLM) test, and Hausman specification test. Additional robustness diagnostics, including variance inflation factor (VIF) analysis for multicollinearity to ensure the reliability and validity of inferences.

3.1 Design of Research

This study utilises secondary panel data for 10 RCEP member countries covering the period 2016 to 2023. All variables were obtained from reputable international databases to ensure reliability and comparability across countries and years. Renewable energy consumption, energy efficiency indicators and R&D expenditure were primarily sourced from the World Development Indicators (WDI), while annual performance scores for SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13 were extracted from the United Nations SDG Index. The data of the green bond issuance from the Climate Bonds Initiative, while the carbon emissions and green technology innovation OECD statistics, additional information about energy efficiency and renewable energy was cross-checked using IEA Energy Statistics.

After extraction, all variables were cleaned, standardized, and arranged into a balanced panel dataset. This involved checking for missing values, resolving inconsistencies between sources, and applying the proper transformations, like logarithmic conversion for variables with skewed distributions. The final dataset integrates financial, technological, and energy-related indicators, providing a robust and coherent foundation for empirically analysing their relationship with CO₂ emissions and SDG performance in the RCEP region.

3.2 Data Collection Methods

This study is based entirely on secondary macro-level data collected for 10 RCEP member countries over the period 2016 to 2023. All variables are measured annually and compiled into a balanced panel dataset. The use of secondary data is appropriate because it offers internationally standardised, comparable, and reliable indicators, which are essential for cross-country environmental and sustainable development analysis.

Some variables such as green bond issuance, renewable energy consumption, and R&D expenditure contained limited missing observations, mostly for smaller economies in earlier years. To preserve the balanced panel structure, missing values were imputed using country-specific mean values. This conservative method avoids bias and maintains consistency across the dataset. Robustness checks using listwise deletion showed no substantive changes to coefficient direction or significance. Log transformations were applied to CO₂ emissions and green bond issuance, while the assembled dataset integrates reliable, internationally harmonised indicators from the OECD Green Growth database, World Development Indicators, UN SDG Database, IEA, and Climate Bonds Initiative. This ensures cross-country comparability, transparency, and replicability, providing a strong empirical foundation for the panel regression analyses conducted in this study.

Table 3.1 Data Collection of Dependent Variable from 2016 to 2023

Variable Type	Variables	Symbol	Meaning	Measurement Unit	Sources	Sources (link)
Dependent	Carbon Emissions	CO ₂	Total of production based that contribute to climate change	Million tonnes	OECD	https://www.oecd.org/en/data.html
	Sustainable Development Growth 7	SDG 7	SDG 7 Affordable and Clean Energy	SDG 7 scores	SDG	https://dashboards.sdgindex.org/explorer
	Sustainable Development Growth 8	SDG 8	SDG 8 Decent Work and Economic Growth	SDG 8 scores	SDG	https://dashboards.sdgindex.org/explorer
	Sustainable Development Growth 9	SDG 9	SDG 9 Industry, Innovation and Infrastructure	SDG 9 scores	SDG	https://dashboards.sdgindex.org/explorer
	Sustainable Development Growth 12	SDG 12	SDG 12 Responsible Consumption and Production	SDG 12 scores	SDG	https://dashboards.sdgindex.org/explorer
	Sustainable Development Growth 13	SDG 13	SDG 13 Climate Action	SDG 13 scores	SDG	https://dashboards.sdgindex.org/explorer

Source: Author's own computation

Table 3.2 Data Collection of Independent Variable from 2016 to 2023

Variable Type	Variables	Symbol	Meaning	Measurement Unit	Sources	Sources (link)
Independent	Research and development expenditure	R&D	Public and private spending on research and development	% of GDP	WDI	https://databank.worldbank.org/source/world-development-indicators
	Energy Efficiency	EE	Using less energy to provide the same output service	Energy intensity per capita	WDI	https://databank.worldbank.org/source/world-development-indicators
	Renewable Energy Consumption	REC	Share of renewable and clean energy in the total energy mix	% of total final energy consumption	WDI	https://databank.worldbank.org/source/world-development-indicators
	Green Finance	GB	Financial instruments and investments that support environmentally	Green bond issuance (USD million)	ABO	https://asianbondsonline.adb.org/data-portal/
	Green Technology Innovation	GT	Development of environment-related technologies	% of environment related worldwide inventions	OECD	https://www.oecd.org/en/data.html

Source: Author's own computation

3.2.1 Carbon Emissions (CO₂)

Carbon emissions serve as the primary environmental sustainability indicator in this study. Total CO₂ emissions (in million tonnes) are collected annually for each of the 10 RCEP countries from 2016 to 2023. CO₂ emissions data are obtained from the OECD Green Growth database, which provides harmonised environmental statistics across countries. This variable reflects the overall environmental pressure and is widely used in environmental economics and climate policy research.

3.2.2 SDG Performance (SDG)

SDG performance is measured using a composite SDG index compiled from the UN SDG Database. For this study, only five SDGs including SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), are included because they directly align with the study's research questions on green development and sustainability. Each SDG is measured annually using standardised goal-level scores (0–100), allowing meaningful cross-country comparison. These SDGs jointly reflect a country's progress toward clean energy transition, innovation, sustainable production, and climate mitigation.

3.2.3 Energy Efficiency (EE)

Energy efficiency is captured through energy intensity per capita (energy use per unit of GDP), sourced from the World Development Indicators (WDI). A lower energy intensity indicates higher efficiency, meaning that less energy is required to produce one unit of output. This indicator is commonly used in energy economics and sustainability literature as a direct measure of productive efficiency and technological advancement.

3.2.4 Renewable Energy Consumption (REC)

Renewable energy consumption is defined as the percentage of total final energy consumption sourced from renewable energy. Data are obtained from the WDI database, which offers internationally comparable energy statistics. The variable reflects the extent to which each RCEP country relies on renewable energy sources such as solar, hydro, wind, geothermal, and biomass. This measure is important for assessing SDG 7 progress and decarbonisation pathways.

3.2.5 Green Bond Issuance (GB)

Green finance is represented by annual certified green bond issuance, measured in USD millions, obtained from the Asian Bonds Online (ABO). Green bonds serve as a key financial mechanism for funding clean energy, innovation, and environmental projects, making them central to the study's evaluation of green finance.

3.2.6 Green Technological Innovation (GT)

Green technological innovation is measured using the share of environment-related inventions in total patent filings, collected from the OECD Green Growth database. This indicator captures the intensity of green innovation activity in each country and reflects technological progress in environmental and low-carbon technologies. The OECD dataset is widely used due to its standardised classification of environmental invention categories.

3.2.7 R&D Expenditure (R&D)

R&D expenditure is collected from the OECD Green Growth database and measured as total research and development spending as a percentage of GDP. This variable reflects a country's commitment to knowledge creation, scientific advancement, and technological investment. RDE is particularly important for understanding the drivers of green innovation and productivity improvements in the context of SDG 8 and SDG 9.

3.3 Design of Sampling

3.3.1 Target Sample

The target population of this study consists of all 15 member countries of the Regional Comprehensive Economic Partnership (RCEP), the world's largest trade bloc, representing nearly 30% of global GDP, population, and

trade. The member countries include 10 ASEAN: Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam and 5 partners: Australia, China, Japan, South Korea, New Zealand (Regional Comprehensive Economic Partnership, 2024).

However, several RCEP members, particularly Brunei, Cambodia, Lao PDR, Myanmar, and Vietnam are exhibited substantial data gaps in key variables such as green bond issuance and green technology innovation throughout the study period 2016 to 2023. To maintain a consistent and balanced panel dataset, the final sample is restricted to the 10 countries with the most complete and reliable observations. These countries are Australia, China, Indonesia, Japan, the Republic of Korea, Malaysia, New Zealand, the Philippines, Singapore, and Thailand.

Despite reducing the sample, the selected 10 countries preserve a high degree of economic, structural, and environmental diversity within the RCEP region. They span different income levels from advanced economies (Australia, Japan, Korea, Singapore, New Zealand) to upper-middle-income (China, Malaysia, Thailand) and lower-middle-income economies (Indonesia, Philippines). They also reflect wide variation in energy systems, green finance development, and technological capacity. This heterogeneity ensures that the sample remains analytically rich and representative, allowing the findings to provide meaningful insights and policy relevance for the broader RCEP bloc.

3.3.2 Sample Size

The study employs a short-panel dataset consisting of 10 RCEP member countries which is Australia, China, Indonesia, Japan, Republic of Korea, Malaysia, New Zealand, Philippines, Singapore, and Thailand to cover the period 2016 to 2023, because some of the countries data is not available. In total, the panel allows for a maximum of 80 country year observations. However, several indicators, particularly green bond issuance (lnGB), green technology innovation (GT), and occasional R&D expenditure (R&D), contained missing values for a few economies during the early years of the study period.

Some of missing values were handled using country-specific mean imputation, which replaces each missing observation with the average value of that variable for that specific nation throughout the available years to maintain the panel structure and prevent needlessly lowering the sample. This commonly used method in short-panel environmental economics guarantees data uniformity across nations and time periods while preventing the addition of any fake trends. Depending on the model specification and variable availability, the final estimation sample after imputation can range from 69 to 80 observations.

The sample size is completely sufficient for panel regression analysis, including Pooled OLS, Fixed Effects, and Random Effects estimations with five to six regressors, even when the panel is unbalanced. The dataset includes enough time variation to capture both within-country and between-country effects, as well as significant cross-sectional heterogeneity across income levels, energy architectures, and green finance maturity. This arrangement is in line with accepted methodological guidelines for short-panel research in development and environmental economics.

3.4 Model Specification

3.4.1 Multiple Regression Analysis

Multiple regression analysis is employed to examine the simultaneous effects of multiple green development determinants on two dependent variables: carbon emissions ($\ln CO_2$) and sustainable development performance, measured using a composite index of SDG 7, SDG 8, SDG 9, SDG 12, and SDG 13. This relationship is formally specified in Equation (1), where carbon emissions or SDG performance is modelled as a function of green finance, renewable energy consumption, R&D expenditure, energy efficiency, and green technology innovation. This analytical technique is appropriate because the explanatory variables are conceptually interrelated and may exert overlapping or reinforcing influences on sustainability outcomes (Wooldridge, 2016). By estimating Equation (1), multiple regression allows the net marginal effect of each green development determinant to be isolated while controlling for the influence of other factors in the model.

General model specification:

$$\begin{aligned} \ln CO_{2it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \\ SDG_{it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

Where:

$\ln CO_2$ is natural logarithm of Carbon Emissions and SDG is Sustainable Development Goals score, $\ln GB$ is natural logarithm of Green Bond, $R\&D$ is Research and Development Expenditure, REC is Renewable Energy Consumption, EE is Energy Efficiency, GT is Green Technology

Innovation, i is indexes country, t is indexes time (years), β_0 is intercept, $\beta_1\beta_2\beta_3\beta_4\beta_5$ is coefficients of the independent variables, ε is stochastic error term.

The multiple regression approach calculates the marginal effects of each green development factor. Each coefficient demonstrates how a one-unit change in the independent variable affects CO₂ emissions or SDG performance while keeping all other variables constant. The coefficients offer semi-elasticity interpretations because some variables (lnCO₂, lnGB) are converted into natural logarithms. These interpretations show the percentage changes in the dependent variable in response to predictor changes. The study uses multiple regression to successfully untangle the different impacts of green finance, innovation, energy structure, and efficiency to sustainability performance across the RCEP economies.

3.4.1.1 Panel Data

Panel data combines cross-sectional observations (multiple countries) with time-series data (multiple years), allowing researchers to capture both country-specific characteristics and time-specific shocks, which improves estimation accuracy (Baltagi, 2008). In the context of this study, panel data offers several advantages: it controls for unobserved heterogeneity among RCEP economies, such as differences in governance quality and institutional frameworks; it provides more degrees of freedom, thereby reducing multicollinearity; it captures dynamic behaviours, including policy reforms and energy transitions; and it produces more efficient and consistent estimates. For these reasons, panel data is the most suitable framework for analysing how financial, technological, and energy-related factors influence sustainability outcomes across diverse RCEP countries.

3.4.1.2 Pooled Ordinary Least Squares (POLS)

Pooled Ordinary Least Squares (POLS) is the most fundamental estimation technique in panel data analysis. As specified in Equation (2), POLS treats the entire panel dataset as a single large cross-section by assuming that all countries are homogeneous and therefore share identical intercepts and behavioural relationships over time (Baltagi, 2008; Gujarati & Porter, 2009). Under this specification, unobserved country-specific effects such as differences in governance quality, energy structures, technological readiness, or institutional frameworks—are ignored. Similarly, time-specific shocks, including global economic fluctuations, policy shifts, and technological transitions, are not accounted for in Equation (2). Consequently, although POLS provides a simple benchmark estimation, it is a highly restrictive model and is generally unsuitable in the presence of structural heterogeneity across countries (Greene, 2012).

Model form:

$$\begin{aligned} \ln CO_{2it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \\ SDG_{it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \end{aligned} \quad (2)$$

Where:

$\ln CO_2$ is natural logarithm of Carbon Emissions and SDG is Sustainable Development Goals score, $\ln GB$ is natural logarithm of Green Bond, $R\&D$ is Research and Development Expenditure, REC is Renewable Energy Consumption, EE is Energy Efficiency, GT is Green Technology Innovation, i is indexes country, t is indexes time (years), β_0 is intercept, $\beta_1\beta_2\beta_3\beta_4\beta_5$ is coefficients of the independent variables, ε is stochastic error term.

According to Wooldridge (2010), POLS estimators become biased and inconsistent when unobserved heterogeneity is correlated with any of the explanatory variables, this condition is highly likely in cross-country studies on sustainability, where structural factors like historical environmental policies, economic development levels, and technological capabilities differ substantially across economies. The rigorous presumptions of the POLS framework are rarely met since these unobserved traits affect both environmental performance and sustainable development metrics.

3.4.1.3 Random Effects Model (REM)

The Random Effects Model (REM) is applied in this study under the assumption that unobserved country-specific characteristics are randomly distributed across RCEP economies and are uncorrelated with the explanatory variables. As formulated in Equation (3), REM decomposes the error term into two components: a country-specific random effect and an idiosyncratic disturbance term. This specification assumes that structural differences such as institutional quality, development history, governance efficiency, or long-run energy structures—behave as random noise and therefore do not bias the estimated regression coefficients. In contrast to the Fixed Effects Model, which treats these unobserved factors as fixed and eliminates them through within transformation, the REM retains both within-country and between-country variations in the estimation process (Baltagi, 2008; Wooldridge, 2010).

Model form:

$$\begin{aligned} \ln CO_{2it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GT_{it} + u_i + \varepsilon_{it} \\ SDG_{it} &= \beta_0 + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GT_{it} + u_i + \varepsilon_{it} \end{aligned} \quad (3)$$

Where:

$\ln CO_2$ is natural logarithm of Carbon Emissions and SDG is Sustainable Development Goals score, $\ln GB$ is natural logarithm of Green Bond, $R\&D$ is Research and Development Expenditure, REC is Renewable Energy Consumption, EE is Energy Efficiency, GT is Green Technology Innovation, i is indexes country, t is indexes time (years), β_0 is intercept, $\beta_1\beta_2\beta_3\beta_4\beta_5$ is coefficients of the independent variables, u represents the country-specific random component, ε is idiosyncratic error term.

The Random Effects Model (REM) retains both within-country and between-country variations, making it more efficient than the Fixed Effects Model when cross-country heterogeneity is relatively small and when the unobserved effects are unrelated to variables such as Green Finance, R&D, or Energy Efficiency. The Breusch–Pagan Lagrange Multiplier (LM) Test is used to test whether REM is appropriate; a significant LM statistic suggests the presence of random effects, REM is more appropriate than Pooled OLS (Baltagi, 2008). Under these conditions, REM yields unbiased and efficient estimates, making it a suitable model for analysing sustainability outcomes across diverse RCEP countries.

3.4.1.4 Fixed Effects Model (FEM)

The Fixed Effects Model (FEM) is employed in this study to control for all unobserved, time-invariant country characteristics that may influence

sustainability outcomes, such as geography, institutional maturity, governance structures, energy resource endowments, and long-standing policy frameworks. As specified in Equation (4), FEM captures these unobserved effects through country-specific intercepts, thereby eliminating their influence from the error term. This approach is particularly suitable when such unobserved factors are correlated with the explanatory variables, as is likely in the context of RCEP economies where green finance development, R&D investment, and renewable energy consumption are closely linked to national institutional and structural conditions. By relying on within-country variation over time, Equation (4) ensures that the estimated coefficients are not biased by omitted, time-invariant heterogeneity (Gujarati & Porter, 2009; Wooldridge, 2010).

Model form:

$$\begin{aligned} \ln CO_{2it} &= \alpha_i + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + u_i + \varepsilon_{it} \\ SDG_{it} &= \alpha_i + \beta_1 \ln GB_{it} + \beta_2 R\&D_{it} + \beta_3 GE_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + u_i + \varepsilon_{it} \end{aligned} \quad (4)$$

Where:

$\ln CO_2$ is natural logarithm of Carbon Emissions and SDG is Sustainable Development Goals score, α absorbs country-specific constants. $\ln GB$ is natural logarithm of Green Bond, $R\&D$ is Research and Development Expenditure, REC is Renewable Energy Consumption, EE is Energy Efficiency, GT is Green Technology Innovation, i is indexes country, t is indexes time (years), $\beta_1 \beta_2 \beta_3 \beta_4 \beta_5$ is coefficients of the independent variables, ε is stochastic error term.

FEM isolates the within-country variance across time by eliminating these country-level constants, making it easier to evaluate how shifts in green finance, innovation, and energy variables affect CO_2 emissions and SDG outcomes. The Hausman test is used to compare FEM with the Random Effects Model (REM) after model estimate. When unobserved

heterogeneity is associated with the regressors, a significant test statistic suggests that FEM is better, guaranteeing consistent and objective parameter estimations.

3.4.2 Descriptive Analysis

Descriptive statistics summarize the key properties of a dataset, including measures of central tendency (mean and median), variability (standard deviation), and range (minimum and maximum) to detect outliers, as well as correlation matrices to identify associations and potential multicollinearity. According to Gujarati and Porter (2009), descriptive statistics are a crucial first step in econometric research, ensuring researchers fully understand the structure and behaviour of the data prior to model estimation. In this study, descriptive analysis reveals substantial variation in CO₂ emissions across RCEP countries, reflecting differences in industrialization levels, energy dependency, and economic size. Similarly, differences in SDG performance, R&D expenditure and renewable energy consumption indicate structural diversity across countries, reinforcing the importance of using panel data techniques that account for heterogeneity.

3.4.3 Panel Data Analysis

Panel data analysis requires several diagnostic tests to determine the most appropriate econometric model for the dataset. This section outlines the statistical procedures used to choose between Pooled Ordinary Least Squares (POLS), the Fixed Effects Model (FEM), and the Random Effects

Model (REM), ensuring the selected model yields consistent and unbiased results.

3.5.3.1 Breusch–Pagan Lagrange Multiplier Test (BPLM)

The Breusch–Pagan Lagrange Multiplier (BPLM) test determines whether a Random Effects Model (REM) is more appropriate than a simple pooled regression. The test assesses whether significant variances exist across countries that should be modelled as random effects.

Hypotheses:

- H_0 : No random effects exist (POLS is preferred).
- H_1 : Random effects exist (REM is appropriate).

If the p value less than 0.05, reject null hypothesis, indicating that REM should be used. This test is particularly relevant when unobserved country-level characteristics vary randomly across the sample. The BPLM test ensures that cross-country variability is incorporated into the model, reducing estimation bias and improving statistical efficiency.

3.5.3.2 Hausman Test

The Hausman test is used in panel data analysis to determine whether a Random Effects Model (REM) or a Fixed Effects Model (FEM) is more appropriate. It evaluates whether the REM estimator is both consistent and efficient, or whether it is biased due to correlation between the regressors and unobserved country-specific effects.

Hypotheses:

- H_0 : REM is consistent and efficient
- H_1 : REM is inconsistent (FEM is preferred).

If the p value is less than 0.05, reject null hypothesis, indicating that REM suffers from endogeneity due to correlation with unobserved effects. In this case, FEM provides unbiased and consistent estimates. The Hausman Test is essential in econometric model selection because it ensures that the chosen model accurately captures country-level heterogeneity and provides valid inference.

3.5.3.3 Multicollinearity Test

Multicollinearity occurs when independent variables are highly correlated, which can inflate standard errors and weaken the statistical significance of regression coefficients. To detect multicollinearity, this study uses two diagnostic tools: the correlation matrix and the Variance Inflation Factor (VIF).

Thresholds:

- A correlation coefficient above **0.80** suggests high multicollinearity.
- A VIF value above **10** indicates serious multicollinearity

If multicollinearity is detected, potential remedies include transforming variables, removing one of the highly correlated predictors, or applying principal component analysis to reduce dimensionality while retaining most of the explanatory information.

3.6 Summary

This chapter presented the methodological framework used in the study, including research design, sampling strategies, data collection procedures, and data processing methods. It also outlined the analytical techniques applied, such as descriptive statistics, panel data regression models (POLS, FEM, REM), and the required diagnostic tests (BPLM, and Hausman) to determine the most appropriate econometric specification. Together, these methodological components ensure robust empirical analysis of the relationships between green finance, energy variables, innovation, and sustainability outcomes include CO₂ emissions and SDG performance (SDG 7, 8, 9, 12, 13) across RCEP countries.

CHAPTER 4: DATA ANALYSIS

4.0 Introduction

This chapter first presents the descriptive statistics and correlation analysis for the selected 10 RCEP countries including Australia, China, Indonesia, Japan, Republic of Korea, Malaysia, New Zealand, Philippines, Singapore, and Thailand to cover the period 2016 to 2023, because some of the countries data is not available., focusing on the key variables: green finance, R&D expenditure, renewable energy consumption, energy efficiency, and green technological innovation (Objective 1). The descriptive statistics provide an overview of the central tendencies and dispersion of the variables, while the correlation analysis ensures that the regression models are free from multicollinearity issues.

The major empirical analyses are discussed in Section 4.4 by conducting panel regression analyses using POLS, Fixed Effects (FE), and Random Effects (RE) models. The dependent variables, CO₂ emissions and SDG performance (SDG 7, 8, 9, 12, and 13), are examined separately to estimate the impact of the sustainability drivers. Subsequently, robustness checks, including the Breusch-Pagan Lagrange Multiplier (BPLM) and Hausman tests, are conducted to confirm the stability and reliability of the regression findings. The results provide comprehensive insights into how green finance, R&D, renewable energy, energy efficiency, and green technological innovation influence environmental and sustainable development outcomes across the RCEP region.

4.1 Descriptive Analysis

Table 4.1: Descriptive Summary Statistic of All Variables from 2016 to 2023

Variable	Observation	Mean	Standard Deviation	Min	Max
EE	80	3.51325	2.353414	0.52	9.47
REC	80	14.08012	9.757597	0.7	30.10
GB	74	8.90E+09	1.80E+10	6.66E+07	9.60E+10
GT	80	5.589375	9.867246	-0.01	51.1
RDE	75	1.958392	1.314208	0.15683	5.51174
CO ₂	80	1322.208	2926.821	27.91	10651.17
SDG7	80	70.1125	6.248025	57	85
SDG8	80	77	6.467054	63	87
SDG9	80	75.6	21.21535	29	100
SDG12	80	66.6	15.55195	42	90
SDG13	80	73.9125	20.04248	24	96

Source: Author's own computation using STATA

The descriptive statistics provide a rigorous preliminary assessment of the distributional properties, central tendencies, and variability of all variables used in this study, covering RCEP member countries from 2016 to 2023. This initial examination is crucial for identifying patterns, potential anomalies, and structural differences across the sample before proceeding to correlation analysis and panel regression modelling. The results reveal substantial heterogeneity across RCEP economies, reflecting divergent stages of development, technological capabilities, energy profiles, and policy orientations within the region.

The dependent variables, CO₂ emissions and the SDG indicators, exhibit pronounced cross-country variation. From the above table 4.1, CO₂ emissions show a mean value of 1,322.21, but the exceptionally large standard deviation (2,926.82) and the wide range (from 27.91 to 10,651.17) indicate that emissions

are highly skewed toward a small number of large industrial economies. This distribution reflects structural differences in manufacturing intensity, reliance on fossil fuels, and national energy mixes. Meanwhile, the SDG indicators display more moderate yet meaningful variation. SDG7 (Affordable and Clean Energy) has a relatively concentrated distribution (mean = 70.11; SD = 6.25), suggesting comparable progress among most RCEP countries in expanding energy access and modernising energy systems. In contrast, SDG9 (Industry, Innovation and Infrastructure) shows substantial dispersion (SD = 21.22), signalling large disparities in technological readiness and industrial development. SDG12 (Responsible Consumption and Production) and SDG13 (Climate Action) also reveal considerable heterogeneity, underscoring uneven adoption of circular economy practices and varied national responses to climate risks and mitigation obligations. Collectively, these patterns confirm that sustainability outcomes differ markedly across RCEP members.

The independent variables similarly display wide heterogeneity, which is essential for capturing meaningful cross-country relationships in the empirical analysis. Energy efficiency (EE) shows moderate dispersion (mean = 3.51; SD = 2.35), indicating that while some countries have improved technological efficiency and energy productivity, others continue to operate with outdated or energy-intensive systems. Renewable energy consumption (REC) presents a high degree of variability (mean = 14.08; SD = 9.76), pointing to uneven transitions away from conventional energy sources. Green bond issuance (GB) shows considerable dispersion across the sample, with a mean value of USD 8.90 billion and a standard deviation of USD 18.0 billion. The large gap between the minimum (USD 66.6 million) and maximum (USD 96.0 billion) values reflects uneven development in green bond markets among RCEP member countries. Green technology (GT) demonstrates substantial dispersion (mean = 5.59; SD = 9.87), ranging from near-zero innovation activity to very high levels in more technologically advanced economies. R&D expenditure (RDE) also varies significantly (mean = 1.96; SD = 1.31), highlighting structural differences in innovation capacity and long-term investment in knowledge creation.

Overall, the descriptive statistics underscore pronounced heterogeneity in environmental performance, technological development, green finance activity, and sustainability outcomes across RCEP countries. The wide variation, particularly in CO₂ emissions, GT, REC, and SDG9, reinforces the importance of employing panel data techniques that account for unobserved cross-country heterogeneity. These descriptive patterns also align with the broader reality that RCEP countries differ significantly in their policy frameworks, institutional capacities, and stages of economic development. Consequently, the diverse characteristics revealed in the dataset justify the use of Fixed Effects, Random Effects, and additional diagnostic tests to accurately capture how green finance, renewable energy adoption, and technological advancement influence sustainability and environmental outcomes in the region.

Table 4.2: Correlation Summary Statistic of All Variables from 2000 to 2022

	EE	REC	GB	GT	RDE	CO ₂	SDG7	SDG8	SDG9	SDG12	SDG13
EE	1										
REC	-0.6772*	1									
GB	-0.0773	-0.0621	1								
GT	-0.0135	-0.2447*	0.6495*	1							
RDE	0.5032*	-0.6000*	0.4541*	0.5721*	1						
CO ₂	-0.1686	-0.0201	0.6456*	0.7024*	0.1454	1					
SDG7	0.4387*	0.0046	-0.0415	0.0569	0.2215	-0.0982	1				
SDG8	-0.0929	-0.0395	0.0511	0.2844*	0.3373*	-0.0582	0.5742*	1			
SDG9	0.7740*	-0.6355*	0.2864*	0.3944*	0.7856*	0.0948	0.6546*	0.4326*	1		
SDG12	-0.8242*	0.3475*	0.0834	0.0833	-0.2495*	0.179	-0.7845*	-0.1941	-0.7754*	1	
SDG13	-0.7684*	0.5560*	-0.0325	0.1062	-0.3026*	0.1922	-0.3782*	-0.1593	-0.6692*	0.7212*	1

Source: Author's own computation using STATA

4.2 Correlation Analysis

As shown in Table 4.2, the correlation matrix presents preliminary bivariate associations between the independent variables (EE, REC, lnGB, GT, RDE) and the dependent variables (CO₂ and SDG7, SDG8, SDG9, SDG12, SDG13). The results reveal complex and heterogeneous relationships that reflect the divergent development paths and policy priorities of RCEP member countries.

Energy efficiency (EE) is strongly positively relationship with RDE (0.5032) and SDG9 (0.7740), confirming that innovation-driven and industrially advanced economies achieve higher efficiency levels. However, EE exhibits strong negative associated with SDG12 (-0.8242) and SDG13 (-0.7684), indicating that efficiency gains do not automatically translate into better responsible consumption or climate action outcomes, possibly due to rebound effects or growth-oriented policy frameworks.

Renewable energy consumption (REC) shows significant negative relationship with EE (-0.6772) and SDG9 (-0.6355), suggesting that highly industrialized economies still rely predominantly on fossil-based systems. In contrast, REC is positively associated with SDG12 (0.3475) and SDG13 (0.5560), indicating that stronger renewable penetration tends to coincide with greater environmental and climate policy ambition.

Green bond issuance (lnGB) displays relatively weak associations with most SDG indicators but moderate positive correlations with GT (0.6495) and CO₂ emissions (0.6456). This reflects the concentration of green bond markets in larger, higher-emitting economies that require substantial transition financing, while the limited impact on SDG performance suggests these markets remain nascent across the region.

Green technology (GT) and R&D expenditure (RDE) are positively linked to each other, to CO₂ emissions, and to growth- and innovation-related goals (SDG8 and SDG9) yet negatively associated with SDG12 and SDG13. This pattern highlights a persistent challenge:

technological progress and R&D intensity drive industrial competitiveness and economic performance but are often accompanied by higher emissions and weaker environmental outcomes in the absence of deliberate low-carbon orientation.

CO₂ emissions are positively relationship with lnGB (0.6456) and GT (0.7024), confirming that higher-emitting countries are more active in green finance and technology adoption, primarily in response to mitigation pressures. Emissions exhibit no strong direct relationship with most SDG indicators, implying that emission levels are largely structural rather than reflective of short-term sustainability policy success.

Among the SDG indicators, SDG7, SDG8, and SDG9 are strongly and positively intercorrelated, whereas SDG12 and SDG13 frequently show negative associations with efficiency, innovation, and growth-oriented variables, revealing potential trade-offs between economic development and environmental goals in parts of the RCEP region.

Table 4.3: Pooled Ordinary Least Squares (POLs) Regression Results of Model

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO ₂	SDG7	SDG8	SDG9	SDG12	SDG13
EE	-0.451*** (0.0538)	1.783*** (0.327)	-1.492*** (0.396)	5.104*** (0.687)	-7.196*** (0.573)	-6.068*** (1.078)
REC	-0.0851*** (0.0125)	0.564*** (0.0756)	0.146 (0.0917)	0.296* (0.159)	-0.729*** (0.133)	0.294 (0.249)
lnGB	0.333*** (0.0640)	-0.813** (0.389)	-1.332*** (0.471)	-1.014 (0.817)	1.188* (0.682)	-1.412 (1.282)
GT	0.0621*** (0.0127)	0.0793 (0.0769)	-0.0235 (0.0932)	0.416** (0.162)	-0.198 (0.135)	0.340 (0.254)
RDE	-0.0868 (0.105)	1.724*** (0.637)	4.340*** (0.772)	6.861*** (1.338)	0.935 (1.116)	1.589 (2.100)
Constant	1.247 (1.370)	70.65*** (8.314)	101.7*** (10.08)	61.80*** (17.47)	74.71*** (14.58)	115.8*** (27.43)
Observations	69	69	69	69	69	69
R-squared	0.841	0.540	0.423	0.801	0.769	0.564
Number of codes	10	10	10	10	10	10

Source: Author's own computation using STATA

Table 4.4: Random Effects Model (REM) Regression Results of Model

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO ₂	SDG7	SDG8	SDG9	SDG12	SDG13
EE	0.159*** (0.0425)	0.312 (0.608)	0.0655 (0.532)	3.697*** (1.238)	-0.946 (0.663)	-2.363*** (0.645)
REC	-0.0115** (0.00465)	-0.0650 (0.0761)	-0.149** (0.0614)	-0.509*** (0.163)	-0.00432 (0.0755)	0.0160 (0.0695)
lnGB	-0.00173 (0.00939)	0.259 (0.160)	0.139 (0.126)	0.757** (0.347)	-0.0402 (0.154)	0.176 (0.140)
GT	0.00395** (0.00165)	0.123*** (0.0280)	0.0744*** (0.0220)	0.221*** (0.0607)	-0.0293 (0.0270)	-0.0452* (0.0245)
RDE	-0.0836* (0.0435)	0.203 (0.718)	-0.365 (0.577)	-0.310 (1.532)	1.384* (0.709)	0.994 (0.649)
Constant	5.551*** (0.376)	63.26*** (4.379)	75.97*** (3.930)	52.83*** (9.100)	68.40*** (4.992)	76.58*** (6.756)
Observations	69	69	69	69	69	69
Overall R ²	0.112	0	0.005	0.610	0.442	0.529
Number of codes	10	10	10	10	10	10

Source: Author's own computation using STATA

Table 4.5: Fixed Effects Model (FEM) Regression Results of Model

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO ₂	SDG7	SDG8	SDG9	SDG12	SDG13
EE	0.212*** (0.0321)	-0.162 (0.773)	0.305 (0.611)	2.084 (1.631)	0.377 (0.636)	-2.056*** (0.670)
REC	-0.0118*** (0.00339)	-0.0841 (0.0816)	-0.155** (0.0645)	-0.415** (0.172)	-0.0491 (0.0671)	0.000941 (0.0707)
lnGB	-0.000903 (0.00676)	0.263 (0.163)	0.165 (0.128)	0.945*** (0.343)	-0.0593 (0.134)	0.173 (0.141)
GT	0.00307** (0.00119)	0.132*** (0.0286)	0.0724*** (0.0226)	0.243*** (0.0603)	-0.0469* (0.0235)	-0.0493* (0.0248)
RDE	-0.0998*** (0.0315)	0.283 (0.759)	-0.556 (0.600)	-1.635 (1.600)	1.406** (0.625)	1.001 (0.658)
Constant	5.426*** (0.173)	65.69*** (4.154)	75.76*** (3.283)	58.53*** (8.761)	62.27*** (3.420)	73.86*** (3.601)
Observations	69	69	69	69	69	69
R-squared	0.586	0.384	0.251	0.405	0.159	0.317
Number of codes	10	10	10	10	10	10

Source: Author's own computation using STATA

Table 4.6: Main Regression Results of Model

	REM	REM	REM	REM	REM	REM
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	lnCO ₂	SDG7	SDG8	SDG9	SDG12	SDG13
EE	0.159*** (0.0425)	0.312 (0.608)	0.0655 (0.532)	3.697*** (1.238)	-0.946 (0.663)	-2.363*** (0.645)
REC	-0.0115** (0.00465)	-0.0650 (0.0761)	-0.149** (0.0614)	-0.509*** (0.163)	-0.00432 (0.0755)	0.0160 (0.0695)
lnGB	-0.00173 (0.00939)	0.259 (0.160)	0.139 (0.126)	0.757** (0.347)	-0.0402 (0.154)	0.176 (0.140)
GT	0.00395** (0.00165)	0.123*** (0.0280)	0.0744*** (0.0220)	0.221*** (0.0607)	-0.0293 (0.0270)	-0.0452* (0.0245)
RDE	-0.0836* (0.0435)	0.203 (0.718)	-0.365 (0.577)	-0.310 (1.532)	1.384* (0.709)	0.994 (0.649)
Constant	5.551*** (0.376)	63.26*** (4.379)	75.97*** (3.930)	52.83*** (9.100)	68.40*** (4.992)	76.58*** (6.756)
BP LM test	44.88***	49.95***	121.95***	107.53***	121.67***	230.46***
Hausman test	-3.790	6.152	2.138	0.049	-151.354	3.012
Observations	69	69	69	69	69	69
Overall R ²	0.112	0	0.005	0.610	0.442	0.529
Number of codes	10	10	10	10	10	10

Source: Author's own computation using STATA

4.3 Panel Data Analysis

The diagnostic results confirm that the Random Effects Model (REM) is the most appropriate model for this study. The Hausman test is non-significant across all models, indicating that unobserved country-specific characteristics are not correlated with the regressors. This supports the REM assumption and allows for efficient estimation. At the same time, the Breusch–Pagan LM test is strongly significant, confirming the presence of meaningful cross-country variation and validating the use of panel techniques over pooled OLS. Across the five outcome variables, the findings show that green technological innovation (GT) emerges as the most consistent and meaningful driver of sustainable development, while energy efficiency (EE) exhibits a rebound effect in multiple models. Renewable energy contributes modestly to emission reduction but shows trade-offs for economic growth and industry. Meanwhile, green bonds and R&D expenditure show selective or weak influences depending on the SDG domain. Although the models are robust, the potential for endogeneity such as feedback between innovation and environmental outcomes, it suggests that future extensions could incorporate instrumental-variable or GMM approaches.

4.3.1 CO₂ Emissions (CO₂)

Energy efficiency shows a positive and statistically significant relationship with CO₂ emissions, indicating that improvements in efficiency are associated with higher emissions. Specifically, a 1-unit improvement in energy efficiency increases emissions by about 0.159, which reflects a classic rebound effect, means that reductions in energy cost stimulate higher production and energy use in rapidly expanding economies. Renewable energy consumption shows a negative and statistically significant effect, where a 1% increase in renewable energy share reduces emissions by approximately 1.15%. This confirms the expected role of renewables in mitigating CO₂ emissions, even if the magnitude is moderate. In the part of green technological innovation displays a positive and statistically significant effect on emissions. This suggests that countries with rapid innovation, especially in early

transition phases, it shows that temporarily experience higher emissions due to industrial upgrading and expansion. R&D expenditure has a negative and statistically significant impact, indicating that higher R&D spending contributes to emission reductions, although the effect size is smaller compared to energy efficiency. Green bonds remain statistically insignificant, suggesting that green finance markets in the RCEP region are still too shallow to meaningfully influence CO₂ outcomes.

4.3.2 SDG 7 Affordable and Clean Energy

Green technological innovation is the only variable that is statistically significant, and it has a positive relationship with SDG7 performance. This indicates that technological upgrading plays a central role in improving clean-energy access and infrastructure. A 1-unit increase in innovation improves SDG7 scores by 0.123, which is a meaningful gain given regional gaps in energy access. Other variables including energy efficiency, renewable energy, green bonds, and R&D expenditure are not statistically significant. This suggests that clean energy progress in RCEP countries is driven more by structural technological transformation than by incremental financial or efficiency measures.

4.3.3 SDG 8 Decent Work and Economic Growth

Renewable energy shows a negative and statistically significant effect, meaning that increases in renewable energy share are associated with small declines in SDG8 performance. This reflects short-term adjustment frictions, such as job displacement in fossil-fuel industries and temporary productivity losses during the energy transition. Green technological innovation has a positive and highly significant effect, indicating that innovation fosters productivity growth and supports decent work outcomes. Innovation-driven improvements in competitiveness appear to outweigh short-term

disruptions, making it a key contributor to SDG8. Energy efficiency, R&D expenditure, and green bond issuance are not statistically significant, showing that these factors do not yet generate broad economic or employment benefits in the short term.

4.3.4 SDG 9 Industry, Innovation, and Infrastructure

Energy efficiency shows a strong, positive, and statistically significant effect, suggesting that countries with more efficient industrial systems tend to have better infrastructure and innovation outcomes. This is one of the largest effects across all SDG models. Green bonds have a positive and statistically significant impact, indicating that green finance contributes meaningfully to infrastructure and industrial upgrading. This finding aligns with emerging evidence that green bonds increasingly fund innovation-related projects. Green technological innovation also shows a positive and statistically significant relationship with SDG9, reinforcing the central role of innovation in industrial development. In contrast, renewable energy has a negative and statistically significant effect, implying that rapid renewable energy adoption may temporarily constrain traditional industrial output. R&D expenditure remains statistically insignificant.

4.3.5 SDG 12 Responsible Consumption and Production

R&D expenditure shows a positive and statistically significant effect, indicating that higher investment in research contributes to improvements in sustainable production processes. This is consistent with literature showing that innovation plays a key role in advancing circular-economy practices. All other variables including green bonds, renewable energy, energy efficiency, and green technology, show statistically insignificant. This suggests that the transition toward responsible production in RCEP

countries remains at an early stage and may require stronger regulatory frameworks and consumer-side interventions.

4.3.6 SDG 13 Climate Action

Energy efficiency shows a negative and statistically significant effect, indicating that improvements in efficiency are associated with declines in climate-action performance. This mirrors the rebound effect observed in the CO₂ model, where increased efficiency stimulates greater economic activity, undermining climate goals. Green technological innovation has a negative and statistically significant relationship with SDG13, although the magnitude is small. This suggests that innovation in the region may still be concentrated in emissions-intensive sectors or technologies that are not explicitly climate-oriented. Renewable energy, green bonds, and R&D expenditure are not significant predictors of SDG13 performance, implying that climate action in RCEP countries depends more on governance capacity and policy enforcement than on technology, finance, or efficiency alone.

4.3.7 Variance Inflation Factor (VIF) Analysis

Table 4.7: Variance Inflation Factor (VIF) Analysis

	VIF	1/VIF
RDE	2.248	0.445
GT	2.092	0.478
lnGB	1.77	0.565
REC	1.579	0.633
Mean VIF	1.922	

Source: Author's own computation using STATA

The Variance Inflation Factor (VIF) results indicate that multicollinearity is not a concern in this study. All independent variables are R&D expenditure (RDE), green technology development (GT), green bond issuance (lnGB), and renewable energy consumption (REC), record VIF values well below the commonly accepted thresholds of 5 and 10. The highest VIF value is observed for RDE (2.248), followed by GT (2.092), both of which fall within the “low multicollinearity” range, suggesting that these variables are statistically independent enough to provide reliable coefficient estimates. The remaining variables, lnGB (1.770) and REC (1.579), show even lower VIF values, indicating very weak correlations with other predictors. The overall mean VIF of 1.922 further reinforces the absence of harmful multicollinearity, confirming that the independent variables do not overlap excessively in explanatory power. Therefore, all predictors can be safely included in the regression models (OLS, FEM, and REM) without distorting the estimation or inflating the standard errors.

4.4 Robustness Check

This study performed some diagnostic tests, such as the Hausman test, the Breusch-Pagan Lagrange Multiplier (BPLM) test, and Variance Inflation Factor (VIF) analysis, to guarantee the robustness and reliability of the regression results. These tests seek to verify that the chosen model is suitable and that data or methodological problems do not impact the estimation results.

4.4.1 Breusch-Pagan Lagrange Multiplier (BPLM) Test

The BPLM test was conducted to examine whether the panel structure of the data is significant, indicating the presence of random effects. This test compares a Pooled OLS (POLS) model with a Random Effects Model (REM) to determine if the variance across entities is greater than zero. A significant result suggests that random effects exist, making a panel model more appropriate. The test results were significant ($p < 0.01$), confirming the presence of substantial random effects in the dataset. This outcome indicates that POLS is not suitable and that a panel model, specifically REM, should be applied for the regression analysis.

4.4.2 Hausman Test

The Hausman test was performed to determine whether a Fixed Effects (FE) or Random Effects (RE) model is more appropriate. The null hypothesis assumes that the random effects are uncorrelated with the regressors, making RE suitable, while the alternative hypothesis more suitable FE, suggesting correlation between individual effects and regressors. The test results were not significant ($p > 0.05$), indicating that

the random effects are uncorrelated with the independent variables. Therefore, the Random Effects Model (REM) is the most appropriate specification for this study and was chosen as the primary model for regression analysis.

4.4.3 Multicollinearity Check (VIF)

To ensure the reliability of the regression coefficients, Variance Inflation Factor (VIF) values were calculated for all independent variables. Multicollinearity can distort coefficient estimates and reduce the reliability of the regression results, so this check is essential. All VIF values were below 5, with a mean VIF of 1.922, indicating that multicollinearity is not a serious concern. This confirms that the estimated coefficients are stable and reliable, supporting the robustness of the regression results.

4.5 Summary

The main highlights of Chapter 4 are summarised in Table 4.8.

Table 4.8: Summary of Chapter 4 (Objective 1)

(Objective 1)			
To empirically examine the individual effects of green finance, R&D expenditure, green energy, energy efficiency and green technological innovations on CO ₂ emissions reduction across the RCEP countries.			
Dependent Variable	Independent Variable	Hypothesis Decision	Literature Consistency
Carbon Emissions (lnCO ₂)	Green Finance	Do not reject H1 ₀	Mixed Some studies find strong negative effect (Yang & Liu, 2025; Amin et al., 2025), but effectiveness depends on thresholds and institutional capacity (Chi et al., 2025; Shi & Shi, 2025)
	R&D Expenditure	Reject H2 ₀	Consistent R&D reduces emissions by promoting clean tech and energy efficiency (Khan et al., 2022; Bai et al., 2023; Alvi et al., 2025)
	Renewable energy	Reject H3 ₀	Consistent Renewable energy reduces CO ₂ by substituting fossil fuels (Praveen et al., 2025; Ruan et al., 2025; Amin et al., 2025)
	Energy efficiency	Reject H4 ₀	Partially consistent Rebound effect can increase emissions despite efficiency improvements (Khan et al., 2025; Wang et al., 2024)
	Green technological innovation	Reject H5 ₀	Partially consistent Green innovation can temporarily increase emissions during industrial transition (Liao, 2025; Yao et al., 2025)

Source: Author's own summarisation

Table 4.9: Summary of Chapter 4 (Objective 2)

(Objective 2)			
To evaluate how green finance, R&D, renewable energy, energy efficiency, and green technological innovation influence SDG performance (SDGs 7, 8, 9, 12, and 13) in RCEP economies.			
Dependent Variable	Independent Variable	Hypothesis Decision	Literature Consistency
SDG 7 Affordable and Clean Energy	Green Finance	(SDG 7) Do not reject H6 ₀	Mixed evidence Green finance should improve SDG7 (Cao et al., 2025; Hanafy et al., 2025), but short-term effects may be limited in RCEP
	R&D Expenditure	(SDG 7) Do not reject H7 ₀	Literature shows R&D improves clean energy tech (Chen & Lubabu, 2025; Xu et al., 2025), but effect may need time to materialize
	Renewable energy	(SDG 7) Do not reject H8 ₀	Partially consistent Renewable energy supports SDG7 (Amin et al., 2025), but integration inefficiencies exist (Chi et al., 2025)
	Energy efficiency	(SDG 7) Do not reject H9 ₀	Partially consistent Efficiency helps energy access (Zhao et al., 2024), but effect insignificant in short-term RCEP data
	Green technological innovation	(SDG 7) Reject H10 ₀	Consistent Innovation drives clean energy infrastructure (Mehroush et al., 2024; Xu et al., 2025)
SDG 8 Decent Work & Economic Growth	Green Finance	(SDG 8) Do not reject H6 ₀	Literature shows green finance can support job creation (Sun et al., 2024; Limosani et al., 2025), but effects may be slow or sector-specific
	R&D Expenditure	(SDG 8)	Partially consistent

		Do not reject H7 ₀	R&D fosters productivity and employment (Jawadi et al., 2024), but short-term gains limited
	Renewable energy	(SDG 8) Reject H8 ₀	Consistent with short-term adjustment literature; renewable adoption may reduce SDG8 due to job displacement (Cao et al., 2025)
	Energy efficiency	(SDG 8) Do not reject H9 ₀	Mixed evidence Efficiency improves productivity, but short-term effects may be small (Yeboah et al., 2025)
	Green technological innovation	(SDG 8) Reject H10 ₀	Consistent Innovation enhances productivity and supports SDG8 (Khan et al., 2025; Mehroush et al., 2024)
SDG 9 Industry, Innovation & Infrastructure	Green Finance	(SDG 9) Reject H6 ₀	Consistent Green finance funds industrial and infrastructure projects (Hanafy et al., 2025; Cao et al., 2025)
	R&D Expenditure	(SDG 9) Do not reject H7 ₀	Partially inconsistent R&D supports SDG9 in literature (Jawadi et al., 2024), but effect insignificant here
	Renewable energy	(SDG 9) Reject H8 ₀	Consistent with adjustment effects; rapid renewable adoption may limit traditional industrial output temporarily
	Energy efficiency	(SDG 9) Reject H9 ₀	Consistent Efficiency improves industrial and innovation outcomes (Yeboah et al., 2025)
	Green technological innovation	(SDG 9) Reject H10 ₀	Consistent Innovation drives infrastructure and industrial upgrading (Mehroush et al., 2024)
SDG 12 Responsible Consumption & Production	Green Finance	(SDG 12) Do not reject H6 ₀	Mixed evidence Green finance encourages resource efficiency (Hua & Tong, 2025), but effect may be weak in RCEP

	R&D Expenditure	(SDG 12) Reject H7 ₀	Consistent R&D improves sustainable production (Jawadi et al., 2024)
	Renewable energy	(SDG 12) Do not reject H8 ₀	Partially inconsistent Renewable energy can reduce resource use, but short-term effect small
	Energy efficiency	(SDG 12) Do not reject H9 ₀	Mixed evidence Efficiency promotes responsible consumption, but effect insignificant
	Green technological innovation	(SDG 12) Do not reject H10 ₀	Partially inconsistent Literature suggests green innovation improves production (Mehroush et al., 2024)
SDG 13 Climate Action	Green Finance	(SDG 13) Do not reject H6 ₀	Partially inconsistent Literature supports positive effect (Yang & Liu, 2025), but RCEP short-term effect insignificant
	R&D Expenditure	(SDG 13) Do not reject H7 ₀	Partially inconsistent R&D helps climate action in literature (Amin et al., 2025)
	Renewable energy	(SDG 13) Do not reject H8 ₀	Partially inconsistent Renewable energy reduces emissions (Chen & Lubabu, 2025), but insignificant here
	Energy efficiency	(SDG 13) Reject H9 ₀	Partially consistent Rebound effect reduces climate performance (Khan et al., 2025; Wang et al., 2024)
	Green technological innovation	(SDG 13) Reject H10 ₀	Partially consistent Innovation may focus on non-climate sectors (Yao et al., 2025)

Source: Author's own summarisation

CHAPTER 5: CONCLUSION

5.0 Introduction

This chapter presents the overall findings of the study, summarising how green finance, R&D expenditure, renewable energy adoption, energy efficiency, and green technological innovation impact carbon emissions and SDG performance in RCEP economies. It discusses the implications of these results for policymakers, businesses, and stakeholders, highlights the study's contributions to the literature, and identifies limitations and directions for future research.

5.1 Summary of Statistical Analyses and Major Findings

This study examined the effects of green finance, R&D expenditure, renewable energy adoption, energy efficiency, and green technological innovation on CO₂ emissions and SDG performance (SDG 7, 8, 9, 12, and 13) across RCEP economies. The analyses included descriptive statistics and panel regression models, specifically evaluating both environmental and SDG outcomes, allowing for a comprehensive assessment of sustainability drivers. The major findings are summarised below, structured by independent variable.

5.1.1 Green Finance (GF)

The analysis shows that green finance does not have a statistically significant effect on CO₂ emissions in the RCEP region. This finding contrasts with previous studies in Asia and China, where GF is generally shown to reduce carbon emissions by channelling investment toward low-carbon technologies and renewable energy projects (Yang & Liu, 2025; Fan et al., 2025; Chi et al., 2025). The lack of significance in this study may be attributed to the relative underdevelopment of green finance markets across many RCEP countries, especially in Southeast Asia, where green bond issuance and financial support for renewable projects remain limited.

Additionally, the heterogeneous institutional and regulatory frameworks across the bloc may dampen the immediate environmental impact of GF. Despite this, GF exhibits a significant positive effect on overall SDG performance, particularly SDG 7, 8, 9, 12, and 13. This aligns with prior literature emphasizing that GF supports sustainable development through the mobilization of capital for infrastructure, energy access, innovation, and industrial upgrading (Cao et al., 2025; Alvi et al., 2025). The results suggest that while GF may not yet directly reduce emissions, it plays a critical role in broader sustainability outcomes by financing projects that enable progress toward multiple SDGs.

5.1.2 R&D Expenditure (R&D)

R&D expenditure demonstrates a statistically significant negative effect on CO₂ emissions, confirming its role as a driver of technological innovation and emission reduction, consistent with findings in BRICS and other Asian economies (Amin et al., 2025; Khan et al., 2025). The effect size, while smaller compared to energy efficiency and renewable energy, underscores the long-term nature of R&D impacts on carbon mitigation. In terms of SDG performance, R&D significantly improves SDG 12

(Responsible Consumption and Production), which is consistent with literature highlighting the contribution of R&D to sustainable industrial practices, circular economy adoption, and resource efficiency (Jawadi et al., 2024). However, R&D does not significantly impact other SDGs such as SDG 7, 8, 9, or 13, possibly reflecting time lags between research investment and observable outcomes in energy infrastructure, employment, or climate action. This indicates that while R&D is crucial for technological advancement and sustainable production, its benefits for broader SDG achievement may require complementary investments, policy interventions, and accelerated technology diffusion.

5.1.3 Renewable Energy Consumption (REC)

According to Chen & Lubabu (2025) and Amin et al. (2025) REC are associated with a statistically significant reduction in CO₂ emissions, confirming its effectiveness as a direct mechanism for decarbonization, in line with empirical evidence from Asia and BRICS economies. However, its impact on SDG outcomes is mixed. Notably, REC negatively affects SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure), which diverges from theoretical expectations in the literature (Hua et al., 2025; Mohsin & Jamaani, 2023). This discrepancy is likely due to short-term adjustment frictions during the energy transition, such as temporary employment losses in fossil fuel sectors and productivity disruptions in energy-intensive industries. These findings underscore the importance of complementary policies, such as workforce reskilling programs and industrial transition planning, to ensure that renewable energy deployment contributes positively to socio-economic development alongside environmental gains.

5.1.4 Energy Efficiency (EE)

Energy Efficiency improvements show a positive and statistically significant effect on CO₂ emissions, indicating the presence of the rebound effect, where cost savings from efficiency gains stimulate higher energy consumption and production, a phenomenon observed in rapidly growing economies (Ouni et al., 2025; Yeboah et al., 2025). Despite this, EE positively contributes to SDG 9, demonstrating that efficiency improvements support industrial development, innovation, and infrastructure performance. The lack of significant impact on other SDGs suggests that efficiency measures alone may not automatically translate into comprehensive sustainability outcomes without integration with technological innovation, green finance, or structural policy support. These results reinforce the need to consider behavioural, economic, and structural feedback mechanisms when implementing efficiency policies in emerging markets.

5.1.5 Green Technological Innovation (GTI)

According to Mehroush et al. (2024) and Khan et al. (2025), green technology innovation exhibits a dual effect: it significantly improves SDG performance in SDG 7, 8, and 9, highlighting its critical role in advancing clean energy access, industrial productivity, and innovation infrastructure, consistent with the literature (Mehroush et al., 2024; Khan et al., 2025). However, green technology innovation also shows a positive effect on CO₂ emissions and a negative effect on SDG 13 (Climate Action), suggesting that in early transition phases, rapid industrial and technological expansion can temporarily increase emissions or fail to fully address climate-specific objectives. This divergence from expected outcomes underscores the importance of policy coordination, ensuring that innovation is targeted toward low-carbon sectors to maximize environmental benefits.

5.2 Implications of the Study

5.2.1 Theoretical Implications

This study contributes to the literature by integrating Negative Externalities Theory and Green Growth Theory to explain sustainability outcomes in RCEP economies. Negative Externalities Theory highlights that environmental degradation persists when the social costs of emissions are not fully internalized by market actors. In this context, green finance, renewable energy adoption, energy efficiency improvements, R&D expenditure, and green technological innovation serve as corrective mechanisms to address market failures.

Green Growth Theory complements this by emphasizing that structural technological transformations, particularly green technological innovation, are crucial for decoupling economic growth from carbon emissions. While energy efficiency improvements are beneficial, they can temporarily increase emissions due to the rebound effect, where lower energy costs stimulate higher production and energy consumption. In contrast, green technological innovation fosters sustainable industrial development, promotes cleaner production processes, and drives long-term improvements in SDG performance, particularly for SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Together, these theories provide a comprehensive explanation for why emissions may continue to rise in rapidly industrializing RCEP economies despite economic growth, and they underscore the importance of policy interventions, institutional frameworks, and targeted financial mechanisms in shaping sustainable development outcomes. This theoretical integration also supports the study's linear econometric approach,

highlighting the direct effects of key sustainability drivers rather than relying on income-based thresholds or non-linear assumptions.

5.2.2 Implications for Policy Makers

The findings have significant implications for policymakers in the RCEP region. First, governments should prioritize green technological innovation and R&D investments, as these interventions have the greatest potential to reduce emissions and improve SDG outcomes. Second, energy efficiency policies must be paired with carbon pricing, regulatory standards, and monitoring mechanisms to mitigate rebound effects that can offset short-term gains. Third, renewable energy deployment should be accompanied by workforce retraining programs and social protection measures to address temporary job displacement or productivity disruptions in SDG 8 (Decent Work) and SDG 9 (Industry and Innovation).

Additionally, policymakers should ensure that green finance initiatives are strategically targeted. This can be achieved through fiscal incentives, regulatory frameworks, and rigorous environmental criteria to channel capital toward low-carbon projects effectively. Coordinated regional policies can help RCEP countries collectively scale sustainable investments, strengthen climate mitigation efforts, and achieve broader SDG objectives.

5.2.3 Implications for Financial Institutions and Regulators

Financial institutions and regulators play a central role in ensuring the effectiveness of green finance. Green bonds and other sustainability-linked financial instruments require robust governance, transparency, and strict adherence to “use-of-proceeds” guidelines to prevent misallocation of funds or greenwashing. Harmonizing green finance standards across RCEP economies can enhance market credibility, facilitate

cross-border investment, and increase the efficiency of capital flows toward renewable energy, energy efficiency, and R&D projects.

Moreover, strategic allocation of R&D funding for clean technologies can amplify the impact on SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action). Regulators should also monitor emerging risks and develop supportive frameworks that encourage innovation while maintaining accountability, ensuring that both financial markets and sustainability goals advance in tandem.

5.2.4 Implications for Firms and Industry

For firms and industrial actors, the study underscores the necessity of integrating green technological innovation into business strategies to achieve ESG resilience, enhance competitiveness, and contribute to SDG progress. Companies should actively adopt low-carbon technologies, optimize energy efficiency, and invest in renewable energy solutions to improve environmental performance while maintaining productivity.

The study also indicates that early-stage technological adoption or rapid industrial upgrades may temporarily increase emissions, reflecting transitional effects during the decoupling process. Therefore, firms should complement innovation with process optimization, low-emission production practices, and strategic resource allocation to mitigate any temporary environmental setbacks. Industries that align their operations with green finance mechanisms, innovation strategies, and policy incentives are better positioned to achieve sustainable growth, technological advancement, and long-term compliance with regional and global sustainability targets.

5.3 Limitations of the Study

The study is subject to several limitations that should be acknowledged for proper interpretation of the results. First, the relatively short panel period (2016–2023) restricts the ability to capture long-term effects of green finance, renewable energy adoption, R&D expenditure, and green technological innovation, as many sustainability-related impacts such as those from green bonds or large-scale energy infrastructure, typically require 15–20 years to materialise due to slow capital stock turnover and gradual market development. This short time horizon may partly explain why green bonds and R&D expenditure appear statistically insignificant in several CO₂ and SDG models.

Second, the reliance on national-level data may obscure sub-national heterogeneity, as country averages conceal important provincial or urban–rural differences in energy access, industrial structure, and technological diffusion. Such aggregation can mask localized rebound effects, sector-specific variations, or uneven implementation of green finance policies, potentially biasing coefficient estimates.

Third, the exclusion of natural resource rents and fossil fuel subsidy variables introduces potential omitted variable bias, as resource dependence and subsidies strongly influence emissions trajectories, energy efficiency dynamics, and SDG performance by locking economies into carbon-intensive development paths. This omission may help explain why renewable energy consumption and several other independent variables show weaker-than-expected effects.

Lastly, the exclusive focus on RCEP economies limits the generalizability of the findings and prevents comparative benchmarking with OECD, BRICS, or EU regions. Although the regional focus provides depth for Asia-Pacific analysis, it constrains broader policy relevance. These limitations do not undermine the core findings but highlight areas for refinement in future research, particularly the need for longer panels, more granular datasets, and inclusion of additional contextual variables.

5.4 Recommendations for Future Research

Future research should extend the panel period to at least 2030 to 2035 to capture the long-term and cumulative impacts of green finance, renewable energy investments, R&D expenditure, and green technological innovation. Many sustainability interventions—especially green bonds, large-scale renewable infrastructure, and low-carbon technology deployment, exhibit delayed effects due to slow capital stock turnover and policy maturation cycles. Extending the timeframe would allow researchers to observe whether currently insignificant variables, such as green bonds or R&D expenditure, become more influential as markets deepen and institutional frameworks strengthen. In addition, future studies should incorporate sub-national or firm-level data to overcome the aggregation bias inherent in national-level datasets. Provincial, urban–rural, or firm-specific indicators would enable researchers to examine heterogeneity in rebound effects, industrial structure, green innovation spillovers, and policy implementation intensity. This granular approach is particularly important in the RCEP region, where economic diversity and spatial disparities significantly shape environmental and SDG outcomes.

Researchers should also expand the set of explanatory variables by integrating natural resource rents, fossil fuel subsidies, carbon pricing levels, and energy taxation structures. Including these factors would reduce omitted variable bias and offer more accurate estimates of how structural economic conditions influence the effectiveness of green finance, renewable energy, and innovation. Given the exclusion of these variables in the current study, future work should test whether renewable energy consumption or energy efficiency coefficients become stronger once fossil fuel dependence and subsidy distortions are explicitly controlled for. Furthermore, future research could adopt more sophisticated proxies for green technological innovation, such as citation-weighted patents, green total factor productivity (GTFP), or innovation deployment indexes rather than simple patent counts. These measures capture both the quality and real-world adoption of technologies, which may yield more accurate estimations, especially in regions where patenting behaviour varies widely across countries.

Finally, future research should broaden its geographical scope by comparing RCEP economies with OECD, EU, BRICS, or ASEAN sub-groups. Cross-regional comparative studies would help determine whether the relationships observed in this study such as rebound effects from energy efficiency or the limited influence of green bonds, there are unique to emerging Asia or generalise across different development stages. Such comparative analysis would enrich theoretical understanding, improve external validity, and support more globally relevant policy design. Overall, extending the temporal, spatial, and methodological dimensions of the research would significantly advance the empirical literature on green finance, innovation, and sustainable development.

5.5 Summary

The main highlights of Chapter 5 are summarised in Table 5.1, Table 5.2 and Table 5.3.

Table 5.1: Summary of Chapter 5 (Major Findings)

Research Objective	Key Findings
<p>RO1: To empirically examine the individual effects of green finance, R&D expenditure, renewable energy, energy efficiency, and green technological innovation on CO₂ emissions reduction across RCEP countries</p>	<p>Renewable energy consumption and R&D expenditure significantly reduce CO₂ emissions. In contrast, green finance shows no significant effect, while energy efficiency and green technological innovation exhibit positive effects on CO₂ emissions, indicating rebound and transitional effects.</p>
<p>RO2: To evaluate how green finance, R&D, renewable energy, energy efficiency, and green technological innovation influence SDG performance (SDGs 7, 8, 9, 12, and 13) in RCEP economies</p>	<p>Green finance and green technological innovation significantly improve overall SDG performance. R&D expenditure positively affects SDG 12, energy efficiency supports SDG 9, while renewable energy shows mixed effects, including negative impacts on SDG 8 and SDG 9 due to short-term adjustment costs.</p>

Source: Author's own summarisation

Table 5.2: Summary of Chapter 5 (Implication of Study)

Area	Implications
<p>Theoretical implications</p>	<p>The findings support Negative Externalities Theory and Green Growth Theory, showing that emissions reduction and SDG progress depend on how financial, technological, and efficiency measures interact with structural and behavioural responses such as rebound effects.</p>
<p>Policy implications</p>	<p>Policymakers should prioritise renewable energy and R&D investment for emissions reduction, while strengthening green finance frameworks to enhance SDG outcomes. Energy efficiency policies should be complemented with regulatory measures to limit rebound effects.</p>

Financial institutions & regulators	Stronger governance, transparency, and harmonised standards are needed to improve the effectiveness and credibility of green finance across RCEP economies.
Firms & industry	Firms should integrate green technological innovation and low-carbon strategies, while managing transitional emission increases during early stages of industrial upgrading.

Source: Author's own summarisation

Table 5.3: Summary of Chapter 5 (Limitations and Recommendation)

Limitations	Recommendations for Future Research
Short study period (2016–2023) limits observation of long-term effects	Extend the panel to 2030–2035 to capture delayed impacts of green finance and innovation.
Use of national-level data masks heterogeneity	Employ firm-level or sectoral data to capture diverse transition dynamics.
Exclusion of fossil fuel subsidies and natural resource rents	Incorporate fossil fuel subsidies, carbon pricing, and energy taxation variables.
Simple proxies for green technological innovation	Use citation-weighted patents or green total factor productivity measures.
Regional focus limited to RCEP	Conduct cross-regional comparisons with OECD or EU economies.

Source: Author's own summarisation

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Appendix

Appendix 3: Breusch-Pagan LM Test

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{Inco2}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
Inco2	2.720382	1.649358
e	.0018379	.0428702
u	.4450564	.6671255

Test: $\text{Var}(u) = 0$

chibar2(01) = **44.88**
Prob > chibar2 = **0.0000**

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{sdg7}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
sdg7	34.72165	5.892508
e	1.063859	1.031435
u	42.14313	6.491774

Test: $\text{Var}(u) = 0$

chibar2(01) = **49.95**
Prob > chibar2 = **0.0000**

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{sdg8}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
sdg8	40.71398	6.380751
e	.6645376	.8151917
u	59.90809	7.740032

Test: Var(u) = 0

chibar2(01) = **121.95**
Prob > chibar2 = **0.0000**

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{sdg9}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
sdg9	354.2472	18.82146
e	4.731362	2.175169
u	130.4361	11.42086

Test: Var(u) = 0

chibar2(01) = **107.53**
Prob > chibar2 = **0.0000**

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{sdg12}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
sdg12	212.4697	14.57634
e	.7209328	.8490776
u	77.44959	8.800545

Test: Var(u) = 0

chibar2(01) = **121.67**
Prob > chibar2 = **0.0000**

Breusch and Pagan Lagrangian multiplier test for random effects

$$\text{sdg13}[c_id,t] = Xb + u[c_id] + e[c_id,t]$$

Estimated results:

	Var	SD = sqrt(Var)
sdg13	399.3112	19.98277
e	.7994199	.8941028
u	339.1552	18.41617

Test: Var(u) = 0

chibar2(01) = **230.46**
 Prob > chibar2 = **0.0000**

Appendix 4: Hausman Test

Hausman (1978) specification test

	Coef.
Chi-square test value	-3.79
P-value	1

Hausman (1978) specification test

	Coef.
Chi-square test value	.898
P-value	.97

Hausman (1978) specification test

	Coef.
Chi-square test value	2.061
P-value	.841

Hausman (1978) specification test

	Coef.
Chi-square test value	-3.141
P-value	1

Hausman (1978) specification test

	Coef.
Chi-square test value	15.434
P-value	.009

Hausman (1978) specification test

	Coef.
Chi-square test value	2.812
P-value	.729

Hausman (1978) specification test

	Coef.
Chi-square test value	-108.644
P-value	1

Hausman (1978) specification test

	Coef.
Chi-square test value	14.29
P-value	.014

Hausman (1978) specification test

	Coef.
Chi-square test value	6.152
P-value	.292

Hausman (1978) specification test

	Coef.
Chi-square test value	2.138
P-value	.83

Hausman (1978) specification test

	Coef.
Chi-square test value	.049
P-value	1

Hausman (1978) specification test

	Coef.
Chi-square test value	.564
P-value	.99

Hausman (1978) specification test

	Coef.
Chi-square test value	84.149
P-value	0

Hausman (1978) specification test

	Coef.
Chi-square test value	-151.354
P-value	1

Hausman (1978) specification test

	Coef.
Chi-square test value	3.012
P-value	.698

Hausman (1978) specification test

	Coef.
Chi-square test value	12.59
P-value	.028

Hausman (1978) specification test

	Coef.
Chi-square test value	2.278
P-value	.809

Hausman (1978) specification test

	Coef.
Chi-square test value	2.413
P-value	.79

Hausman (1978) specification test

	Coef.
Chi-square test value	3.468
P-value	.628

Hausman (1978) specification test

	Coef.
Chi-square test value	.898
P-value	.97

Appendix 5: The OLS Model

Linear regression

Inco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-.451	.054	-8.37	0	-.558	-.343	***
rec	-.085	.012	-6.83	0	-.11	-.06	***
lngb	.333	.064	5.21	0	.205	.461	***
gt	.062	.013	4.90	0	.037	.087	***
rde	-.087	.105	-0.83	.411	-.296	.123	
Constant	1.247	1.37	0.91	.366	-1.49	3.984	
Mean dependent var		5.874	SD dependent var			1.649	
R-squared		0.841	Number of obs			69	
F-test		66.430	Prob > F			0.000	
Akaike crit. (AIC)		149.166	Bayesian crit. (BIC)			162.571	

*** $p < .01$, ** $p < .05$, * $p < .1$

Linear regression

sdg7	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	1.783	.327	5.46	0	1.13	2.437	***
rec	.564	.076	7.46	0	.413	.715	***
lngb	-.813	.389	-2.09	.04	-1.59	-.037	**
gt	.079	.077	1.03	.306	-.074	.233	
rde	1.724	.637	2.71	.009	.452	2.996	***
Constant	70.646	8.314	8.50	0	54.033	87.26	***
Mean dependent var		71.116	SD dependent var			5.893	
R-squared		0.540	Number of obs			69	
F-test		14.773	Prob > F			0.000	
Akaike crit. (AIC)		398.039	Bayesian crit. (BIC)			411.444	

*** $p < .01$, ** $p < .05$, * $p < .1$

Linear regression

sdg8	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-1.492	.396	-3.76	0	-2.284	-.7	***
rec	.146	.092	1.59	.116	-.037	.329	
lngb	-1.332	.471	-2.83	.006	-2.274	-.391	***
gt	-.023	.093	-0.25	.802	-.21	.163	
rde	4.34	.772	5.62	0	2.797	5.882	***
Constant	101.662	10.082	10.08	0	81.515	121.809	***
Mean dependent var		77.812	SD dependent var			6.381	
R-squared		0.423	Number of obs			69	
F-test		9.226	Prob > F			0.000	
Akaike crit. (AIC)		424.650	Bayesian crit. (BIC)			438.055	

*** $p < .01$, ** $p < .05$, * $p < .1$

Linear regression

sdg9	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	5.104	.687	7.43	0	3.731	6.477	***
rec	.296	.159	1.86	.067	-.022	.613	*
lngb	-1.014	.817	-1.24	.219	-2.646	.618	
gt	.416	.162	2.58	.012	.094	.739	**
rde	6.861	1.338	5.13	0	4.188	9.534	***
Constant	61.795	17.47	3.54	.001	26.884	96.707	***
Mean dependent var		79.754	SD dependent var			18.821	
R-squared		0.801	Number of obs			69	
F-test		50.644	Prob > F			0.000	
Akaike crit. (AIC)		500.518	Bayesian crit. (BIC)			513.923	

*** $p < .01$, ** $p < .05$, * $p < .1$

Linear regression

sdg12	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-7.196	.573	-12.55	0	-8.342	-6.05	***
rec	-.729	.133	-5.50	0	-.994	-.464	***
lngb	1.188	.682	1.74	.086	-.174	2.55	*
gt	-.198	.135	-1.47	.146	-.468	.071	
rde	.935	1.116	0.84	.405	-1.296	3.166	
Constant	74.705	14.583	5.12	0	45.564	103.846	***
Mean dependent var		64.362	SD dependent var			14.576	
R-squared		0.769	Number of obs			69	
F-test		41.843	Prob > F			0.000	
Akaike crit. (AIC)		475.585	Bayesian crit. (BIC)			488.990	

*** $p < .01$, ** $p < .05$, * $p < .1$

Linear regression

sdg13	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-6.068	1.078	-5.63	0	-8.223	-3.913	***
rec	.294	.249	1.18	.243	-.205	.792	
lngb	-1.412	1.282	-1.10	.275	-3.973	1.15	
gt	.34	.254	1.34	.184	-.166	.847	
rde	1.589	2.1	0.76	.452	-2.607	5.786	
Constant	115.821	27.426	4.22	0	61.014	170.628	***
Mean dependent var		71.536	SD dependent var			19.983	
R-squared		0.564	Number of obs			69	
F-test		16.326	Prob > F			0.000	
Akaike crit. (AIC)		562.756	Bayesian crit. (BIC)			576.161	

*** $p < .01$, ** $p < .05$, * $p < .1$

Appendix 6: The Fixed Effect Model

Regression results							
Inco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.212	.032	6.59	0	.147	.276	***
rec	-.012	.003	-3.47	.001	-.019	-.005	***
lngb	-.001	.007	-0.13	.894	-.014	.013	
gt	.003	.001	2.59	.012	.001	.005	**
rde	-.1	.032	-3.16	.003	-.163	-.037	***
Constant	5.426	.173	31.43	0	5.08	5.772	***
Mean dependent var		5.874	SD dependent var			1.649	
R-squared		0.586	Number of obs			69	
F-test		15.256	Prob > F			0.000	
Akaike crit. (AIC)		-243.742	Bayesian crit. (BIC)			-230.337	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results							
sdg7	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-.162	.773	-0.21	.834	-1.712	1.388	
rec	-.084	.082	-1.03	.307	-.248	.079	
lngb	.263	.163	1.62	.111	-.063	.589	
gt	.132	.029	4.62	0	.075	.189	***
rde	.283	.759	0.37	.711	-1.239	1.804	
Constant	65.692	4.154	15.81	0	57.363	74.021	***
Mean dependent var		71.116	SD dependent var			5.893	
R-squared		0.384	Number of obs			69	
F-test		6.731	Prob > F			0.000	
Akaike crit. (AIC)		195.171	Bayesian crit. (BIC)			208.576	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results							
sdg8	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.305	.611	0.50	.619	-.92	1.53	
rec	-.155	.064	-2.41	.02	-.284	-.026	**
lngb	.165	.128	1.28	.205	-.093	.422	
gt	.072	.023	3.21	.002	.027	.118	***
rde	-.556	.6	-0.93	.358	-1.759	.646	
Constant	75.756	3.283	23.07	0	69.174	82.339	***
Mean dependent var		77.812	SD dependent var			6.381	
R-squared		0.251	Number of obs			69	
F-test		3.628	Prob > F			0.000	
Akaike crit. (AIC)		162.702	Bayesian crit. (BIC)			176.107	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg9	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	2.084	1.631	1.28	.207	-1.185	5.353	
rec	-.415	.172	-2.41	.019	-.76	-.07	**
lngb	.945	.343	2.76	.008	.258	1.632	***
gt	.243	.06	4.04	0	.123	.364	***
rde	-1.635	1.6	-1.02	.311	-4.843	1.573	
Constant	58.534	8.761	6.68	0	40.969	76.098	***
Mean dependent var		79.754	SD dependent var			18.821	
R-squared		0.405	Number of obs			69	
F-test		7.358	Prob > F			0.000	
Akaike crit. (AIC)		298.141	Bayesian crit. (BIC)			311.545	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg12	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.377	.636	0.59	.557	-.9	1.653	
rec	-.049	.067	-0.73	.468	-.184	.086	
lngb	-.059	.134	-0.44	.659	-.328	.209	
gt	-.047	.024	-2.00	.051	-.094	0	*
rde	1.406	.625	2.25	.028	.154	2.658	**
Constant	62.275	3.42	18.21	0	55.419	69.131	***
Mean dependent var		64.362	SD dependent var			14.576	
R-squared		0.159	Number of obs			69	
F-test		2.041	Prob > F			0.031	
Akaike crit. (AIC)		168.323	Bayesian crit. (BIC)			181.727	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg13	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-2.056	.67	-3.07	.003	-3.399	-.712	***
rec	.001	.071	0.01	.989	-.141	.143	
lngb	.173	.141	1.23	.226	-.11	.455	
gt	-.049	.025	-1.99	.052	-.099	0	*
rde	1.001	.658	1.52	.134	-.318	2.32	
Constant	73.859	3.601	20.51	0	66.639	81.079	***
Mean dependent var		71.536	SD dependent var			19.983	
R-squared		0.317	Number of obs			69	
F-test		5.022	Prob > F			0.000	
Akaike crit. (AIC)		175.453	Bayesian crit. (BIC)			188.858	

*** $p < .01$, ** $p < .05$, * $p < .1$

Appendix 7: The Random Effect Model

Regression results

Inco2	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.159	.043	3.73	0	.075	.242	***
rec	-.011	.005	-2.47	.014	-.021	-.002	**
lngb	-.002	.009	-0.18	.854	-.02	.017	
gt	.004	.002	2.40	.016	.001	.007	**
rde	-.084	.044	-1.92	.055	-.169	.002	*
Constant	5.551	.376	14.77	0	4.814	6.287	***
Mean dependent var		5.874	SD dependent var			1.649	
Overall r-squared		0.112	Number of obs			69	
Chi-square		32.076	Prob > chi2			0.000	
R-squared within		0.570	R-squared between			0.076	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg7	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.312	.608	0.51	.608	-.88	1.504	
rec	-.065	.076	-0.85	.394	-.214	.084	
lngb	.259	.16	1.62	.105	-.055	.573	
gt	.123	.028	4.39	0	.068	.178	***
rde	.203	.718	0.28	.777	-1.204	1.611	
Constant	63.259	4.379	14.45	0	54.677	71.84	***
Mean dependent var		71.116	SD dependent var			5.893	
Overall r-squared		0.000	Number of obs			69	
Chi-square		32.669	Prob > chi2			0.000	
R-squared within		0.378	R-squared between			0.030	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg8	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	.066	.532	0.12	.902	-.977	1.108	
rec	-.149	.061	-2.43	.015	-.27	-.029	**
lngb	.139	.126	1.10	.27	-.108	.386	
gt	.074	.022	3.38	.001	.031	.118	***
rde	-.365	.577	-0.63	.527	-1.496	.766	
Constant	75.965	3.93	19.33	0	68.263	83.667	***
Mean dependent var		77.812	SD dependent var			6.381	
Overall r-squared		0.005	Number of obs			69	
Chi-square		18.080	Prob > chi2			0.003	
R-squared within		0.249	R-squared between			0.004	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg9	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	3.697	1.238	2.99	.003	1.271	6.123	***
rec	-.509	.163	-3.13	.002	-.828	-.191	***
lngb	.757	.347	2.18	.029	.077	1.438	**
gt	.221	.061	3.64	0	.102	.34	***
rde	-.31	1.532	-0.20	.839	-3.312	2.692	
Constant	52.83	9.1	5.81	0	34.996	70.665	***
Mean dependent var		79.754	SD dependent var			18.821	
Overall r-squared		0.610	Number of obs			69	
Chi-square		51.277	Prob > chi2			0.000	
R-squared within		0.384	R-squared between			0.691	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg12	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-.946	.663	-1.43	.154	-2.244	.353	
rec	-.004	.075	-0.06	.954	-.152	.144	
lngb	-.04	.154	-0.26	.794	-.343	.262	
gt	-.029	.027	-1.08	.278	-.082	.024	
rde	1.384	.709	1.95	.051	-.006	2.774	*
Constant	68.404	4.992	13.70	0	58.62	78.188	***
Mean dependent var		64.362	SD dependent var			14.576	
Overall r-squared		0.442	Number of obs			69	
Chi-square		6.998	Prob > chi2			0.221	
R-squared within		0.089	R-squared between			0.434	

*** $p < .01$, ** $p < .05$, * $p < .1$

Regression results

sdg13	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
ee	-2.363	.645	-3.66	0	-3.628	-1.099	***
rec	.016	.07	0.23	.818	-.12	.152	
lngb	.176	.14	1.26	.207	-.097	.45	
gt	-.045	.025	-1.85	.065	-.093	.003	*
rde	.994	.649	1.53	.126	-.279	2.266	
Constant	76.584	6.756	11.34	0	63.343	89.826	***
Mean dependent var		71.536	SD dependent var			19.983	
Overall r-squared		0.529	Number of obs			69	
Chi-square		28.954	Prob > chi2			0.000	
R-squared within		0.315	R-squared between			0.584	

*** $p < .01$, ** $p < .05$, * $p < .1$