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Impact of Green Finance on Environmentally Sustainable Development Goals

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Abstract

In this context, climate change represents a real phenomenon with significant implications for economies, industries, and societies worldwide. In the context of the Regional Comprehensive Economic Partnership (RCEP) agreement, these implications are significant, given that the countries in question cumulatively account for a considerable share of global emissions, energy consumption, and industrial production. As these countries aim for a carbon-neutral future and continue the path toward the achievement of the Sustainable Development Goals (SDGs) set for 2030, the question for these countries, therefore, is not whether they should act but how they can act in a sustainable manner toward a cleaner future for themselves and for the world. In this context, this study seeks to understand the determinants that can help these countries achieve a sustainable future for themselves and the world at large. In this context, the role of green finance, research and development expenditure, renewable energy, energy efficiency, and green technology innovation in the context of carbon emissions and the achievement of SDG 7, 8, 9, 12, and 13 from 2016 to 2023 will be specifically analysed, keeping in mind the established theories of economics and environment, which suggest that economic growth can be a pressure on the environment, and innovation and financial systems can be a solution for these problems as well.

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1.0 Introduction

The Asia-Pacific region comprises different economies of the Regional Comprehensive Economic Partnership (RCEP) countries, including Australia, Brunei, Cambodia, China, Indonesia, Japan, Laos, Malaysia, Myanmar, New Zealand, the Philippines, Singapore, South Korea, Thailand, and Vietnam. This region has become a cornerstone of global economic activity. These countries account for approximately 31% of the world's GDP and population, making them key players in shaping global trade, industrialisation, and investment growth. According to the RCEP World Economic, RCEP countries are estimated to contribute about 32.6% of global GDP and to have a population of more than 2.35 billion in 2025. This economic growth can be attributed to urbanisation, the expansion of the manufacturing economy, and rising energy consumption, which have enabled countries in the Asia-Pacific region to integrate more deeply into the global economy. However, this economic growth in the region is accompanied by rising environmental concerns, particularly regarding carbon emissions and ecological degradation. For example, according to ESCAP, the Asia-Pacific region accounts for more than 50% of global energy-related CO2 emissions. This indicates that this region is at the core of the issues surrounding global climate change. As key constituents of this region, RCEP countries account for a significant share of global carbon emissions, which is a key indicator of the environmental concerns surrounding economic growth in the region. According to the International Energy Agency (2025), carbon emissions are expected to rise by 0.13% by 2025, driven by the region's dependence on fossil fuels and rising energy demand in transportation, manufacturing, and other industries.

According to the Asian Transport Observatory (2024), the transport sector grew by 6.6% in 2023, resulting in an additional 174 million tons of CO_2 emissions. The main factors contributing to this growth include increased freight movement, higher passenger volumes per vehicle, and a lack of public transport infrastructure. These developments not only accelerate global warming but also undermine the capacity of RCEP countries to deliver on their Paris Agreement commitments and several United Nations Sustainable Development Goals (SDGs). Specifically, SDG 7 (Affordable and Clean Energy) is undermined by inadequate transitions to clean energy; SDG 8 (Economic Growth) is undermined by climate-related threats to productivity; SDG 9 (Industry, Innovation, and

Infrastructure) is undermined by inadequate transitions to modern technologies; SDG 12 (Responsible Consumption and Production) is undermined by inadequate transitions to clean energy; and SDG 13 (Climate Action) is undermined by inadequate transitions to clean energy. The information was based on peer-reviewed literature.

However, the current rate of decarbonisation remains significantly lower than the required 17.2% to meet the Paris Agreement's 1.5°C target. Current research on the subject has often focused on individual factors, including green finance, green finance expenditure, renewable energy adoption, energy efficiency, and green technological innovation, primarily in developed economies. The current research has provided limited knowledge on the reasons behind the failure of the cumulative effect of the five mechanisms to bring the increasing rate of emissions down in the heterogeneous context of the Regional Comprehensive Economic Partnership (RCEP) countries, as no empirical evidence has been presented on the individual and cumulative effect of green finance, expenditure on green finance, the adoption of renewable energy, energy efficiency, and green technological innovation on the level of CO_2 emissions in the world's largest emitting economic group.

Despite the fact that the member countries of the RCEP have increased green finance, research and development, renewable energy, energy efficiency, and green technology innovation in recent years, progress towards 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 in the region has been slow, inconsistent, and uneven. However, the rate of progress on these SDGs in advanced countries such as Japan, South Korea, and Singapore is higher than that in lower-income countries such as Cambodia, Laos, Myanmar, and Indonesia (International Energy Agency, 2024; United Nations, 2024). The extant literature on the subject has largely examined the sustainability drivers individually and, to some extent, outside the purview of the RCEP, resulting in limited knowledge of the joint and complementary impact of green finance, expenditure on R&D, the adoption of RE, energy efficiency, and green technological innovation on the performance of SDG 7, 8, 9, 12, and 13 in the region as a whole, which is essential for the formulation of coordinated region-wide approaches to fast-track the development process in the region.

This research aims to evaluate the impact of green finance on the performance of the Sustainable Development Goals (SDGs), namely SDG7, SDG8, SDG9, SDG12, and SDG13, as well as carbon emissions in the economies of the member countries of the Regional Comprehensive Economic Partnership (RCEP). This study contributes significantly to the literature by developing an integrated empirical model that examines the joint impact of green finance, R&D, renewable energy consumption, energy efficiency, and green technological innovation on SDG performance and carbon emissions across RCEP member economies. Unlike previous studies, this study examines sustainability drivers as integrated factors, past literature focuses on regional groupings rather than on the RCEP, which is the most prominent contributor to global carbon emissions and economic activity. This research also extends the literature by incorporating different sustainability drivers as determinants of environmental performance, namely carbon emissions, as well as SDG performance. This is another significant contribution of the current research to the literature, as it focuses solely on the impact of sustainability drivers on environmental performance, whereas the current research offers a holistic view of sustainable development by incorporating SDG performance as outcomes of those drivers. By employing panel data analysis on recent data, this study offers significant policy implications that reflect the structural and developmental differences among the member countries of the RCEP, a highly dynamic region in the world.

2.0 Literature Review Hypotheses Development

However, the need to decouple economic growth from carbon emissions while achieving the SDGs has increased the research focus on these important sustainability drivers. Among these, green finance, research and development, renewable energy consumption, energy efficiency, and green technological innovation are generally considered important mechanisms for facilitating low-carbon and sustainable development. Despite considerable research on these important mechanisms, three important limitations are observed in the literature: first, the majority of the literature focuses on the analysis of these important mechanisms in isolation, ignoring the potential combined and interactive impacts of these mechanisms; second, the literature mostly focuses on the analysis of these important mechanisms in the context of developed countries or a single country, that is, China, which makes the literature less relevant to the complex Regional Comprehensive Economic Partnership (RCEP) region; and, finally, the literature mostly does not consider the important dimension of environmental outcomes, that is, CO_2 emissions, in the context of multidimensional SDG performance. Therefore, in this study, an effort was made to address these important limitations by providing an integrated analysis of important mechanisms in the context of the RCEP region.

2.1 Theoretical Frameworks

2.1.1 The Environmental Kuznets Curve Hypothesis (EKC)

Grossman and Krueger (1995) introduced the concept of the Environmental Kuznets Curve (EKC), which depicts the link between environmental deterioration and economic growth as an inverted U-curve. The idea is that environmental quality worsens during the early stages of economic growth; however, after a certain income threshold, it begins to improve as cleaner technologies are adopted and stringent environmental regulations are implemented (Almeida et al., 2024). However, empirical evidence indicates that the relationship between environmental degradation and economic growth varies across countries. For instance, developing countries have witnessed rising CO_2 emissions during their economic growth, whereas developed countries have managed to decouple their economic growth from their CO_2 emissions. Recent research has also introduced the concept of an N-shaped curve, which depicts the link between environmental deterioration and economic growth (Liu, 2025). If the rate of improvement of cleaner technologies lags behind the rate of economic growth, environmental degradation may increase in the later stages of economic growth.

2.1.2 Negative Externalities Theory

The theory of negative externalities provides a basis for analysing environmental degradation in the context of market failure, where social costs exceed private costs (Pigou, 1952). Firms tend to engage in more certain activities that cause environmental degradation, leading to increased carbon emissions into the atmosphere. Therefore, the theory highlights the importance of green finance mechanisms in mitigating external costs. Empirical analysis shows that green finance mechanisms have a positive effect on capital allocation to green activities and disincentivise polluting activities. According to an analysis of the RCEP's impact on the countries involved, industrialisation has generated significant negative externalities, necessitating government intervention and laying the groundwork for the theory's emphasis on green finance mechanisms to mitigate greenhouse gas emissions and ensure sustainable development.

2.1.3 Porter Hypothesis

The Porter Hypothesis, as proposed by Porter and Van der Linde (1995), suggests that environmental policies can spur innovation and improve a firm's competitiveness. Environmental pressure may not always translate into cost pressure, but it can drive innovation and efficiency. Recently, this argument has been extended to green finance as a possible source of innovation. From a theoretical standpoint, green finance can be regarded as an indirect form of environmental control. Empirical evidence shows that green funding is positively associated with R&D investment, energy efficiency, and the development of new renewable energy technologies. This argument is subject to certain conditions and applies to developing economies. The Porter Hypothesis holds particular importance for the RCEP region because member countries are seeking to achieve their economic and environmental goals simultaneously.

2.1.4 Ecological Modernisation Theory

According to the Ecological Modernisation Theory (EMT), economic progress and environmental sustainability are inextricably linked. This theory can be distinguished from other theories in that it does not view economic development as a negative factor for environmental sustainability. This theory is supported by empirical evidence showing that green finance, innovation, and upgrading can help decouple economic development from carbon emissions. This theory can be applied to the RCEP member states as they move to clean production while maintaining their path to economic development.

2.2 Literature Review on Carbon Emissions

Carbon dioxide (CO_2) emissions have emerged as the most prominent contributor to climate change, attracting substantial research attention in the field of sustainability, particularly in Asian countries and RCEP member states. The empirical analysis identified the five most significant factors affecting CO_2 emissions: green finance (GF), research, development, and expenditure (RDE), renewable energy consumption (REC), energy efficiency (EE), and green technological innovation (GTI).

2.2.1 Green Finance with CO_2

Green finance (GF) is a key driver in mitigating carbon dioxide emissions, especially in Asian countries and in the Regional Comprehensive Economic Partnership (RCEP) countries, where high rates of industrialisation increase environmental pressure. GF includes green bonds, green loans, sustainability-linked finance, and financial regulations that redirect financial flows from high-emission sectors towards renewable energy, clean technologies, and energy-saving infrastructure. For BRICS countries, a 1% increase in green finance yields long-run CO2 emission reductions of 0.173% and short-run reductions of 0.058%. Robustness tests predict emission reductions of up to 0.398% (Amin et al., 2025). Country-specific estimates for China suggest that GF and innovation policies help clean energy firms overcome financial constraints, drive technology upgrades, and foster clean production, thereby mitigating carbon emissions (Fan et al., 2025; Yang & Liu, 2025; Zhang et al., 2025). However, the effectiveness of GF depends on certain conditions.

For instance, a threshold effect of GF on emission reductions can be observed, where GF levels of less than 2.5% of the GDP in the Asia-Pacific region are not significant, whereas higher levels of GF can drive emission reductions, especially in East Asian countries, where the threshold is 3.1% (Chi et al., 2025). Regional and sectoral heterogeneity in the effectiveness of GF is also evident, with eastern China and service-based cities benefiting from improvements in governance, financial market development, and sectoral composition (Wu et al., 2023; Zhang et al., 2025). Inappropriate financial policies can even result in a 'green paradox', in which high credit constraints drive high-emission sectors (Shi & Shi, 2025). Aligning GF with green innovation can enhance its effectiveness across regions (Praveen et al., 2025; Ouni et al., 2025). In conclusion, GF significantly contributes to mitigating carbon emissions, although its effectiveness depends on the scale of finance, financial governance, and industrial structure, as well as alignment with green innovation policy.

H1a: Green finance has a significant negative effect on carbon emission in RCEP economies.

2.2.2 R&D Expenditure with CO_2

Research and development (R&D) is essential to reducing carbon emissions, especially in rapidly developing countries, such as those in Asia and the RCEP. R&D spending is used for renewable energy sources, energy-saving production techniques, carbon capture technologies, and low-carbon technologies (Bai et al., 2023; Khan et al., 2022). The empirical results showed that R&D is negatively related to carbon emissions. In developing countries, R&D is a critical factor in reducing carbon emissions. In the case of BRICS countries, as 1% increase in R&D expenditure will reduce CO_2 emissions by 0.215% initially and 0.256% in the long term (Amin et al., 2025). Environmental patents also contribute greatly to reducing carbon emissions (Alvi et al., 2025). The Chinese experience has demonstrated that R&D investment significantly affects renewable energy development, industrial structure, and carbon intensity, even in a rapidly developing economy (Zhao et al., 2024; Zhang et al., 2025). However, for R&D to be effective, it is necessary to transfer technology, build institutional capacity, and implement innovation policy (Fan et al., 2025; Yao et al., 2025). Another factor is the allocation of resources to affect R&D for environmental protection. The empirical data show that ongoing R&D investment promotes cleaner innovation and considerably decreases carbon emissions for Asia and the RCEP economies.

H1b: R&D expenditure has a significant negative effect on carbon emission in RCEP economies.

2.2.3 Renewable Energy Consumption with CO_2

Renewable energy (RE) is a direct and effective means of reducing CO_2 emissions, especially for countries that have been heavily reliant on fossil fuels. The use of REC reduces carbon emissions and supports the transition to a low-carbon energy system by displacing coal, oil, and gas (Chen & Lubabu, 2025; Praveen et al., 2025). Studies have shown a negative relationship between RE and emission levels. In the BRICS countries, for every 1% increase in the use of RE, the emission level decreases by 0.72% in the short term and 0.116% in the long term. Robustness checks show a reduction of 0.510% (Amin et al., 2025). In Bangladesh, the long-run emission reduction is 0.15% per 1% increase in RE use (Ruan et al., 2025). For investments in G20 countries, especially high-emission economies, the use of RE reduces emissions (Zhang et al., 2022). Despite all these advantages, structural issues will continue to limit the potential of RE in Asia and the RCEP region. The presence of dual-energy systems, in which RE is developed alongside fossil-fuel-based systems, limits the overall potential for emission reductions (Chi et al., 2025). Fossil fuel subsidies in E7 countries slow the energy transition, which negatively affects the competitiveness of RE (Cao et al., 2025). Similarly, issues of inefficient grid integration and regional differences will continue to limit the overall environmental impacts of RE (Liza et al., 2024).

H1c: Renewable energy consumption has a significant negative effect on carbon emissions in RCEP economies.

2.2.4 Energy Efficiency with CO_2

Energy efficiency (EE) is one of the mechanisms for reducing carbon emissions, and it is particularly important for regions with high energy consumption and rapid urbanisation, such as Asia and RCEP countries. By improving energy efficiency, carbon emissions and energy costs decline due to technological advancements and industrial restructuring with digitalisation and smart management (Yang & Liu, 2025; Yeboah et al., 2025). Various empirical studies have shown that improving energy efficiency reduces carbon emissions by a considerable amount. In BRICS countries, improving efficiency in the transport sector through smart mobility reduces fossil fuel use and, consequently, carbon emissions (Ouni et al., 2025). In China, green finance initiatives have been shown to improve energy efficiency by promoting green industrial activities and modernising equipment, thereby reducing carbon intensity (Yao et al., 2025; Zhao et al., 2024). However, the success of EE in these regions varies due to financial constraints, poor implementation capacity, and high compliance costs in certain developing and resource-rich countries (Wang et al., 2024; Yeboah et al., 2025). In addition, the phenomenon of 'rebound effects,' in which EE results in cost savings and increased energy consumption, should also be considered. Nevertheless, the overall evidence suggests that EE improvements have a significant negative impact on carbon emissions through decreased energy intensity, the promotion of clean production, and support for structural transformation in the Asian region and RCEP countries.

H1d: Energy efficiency has a significant negative effect on carbon emissions in RCEP economies.

2.2.5 Green Technology Innovation with CO_2

Green technological innovation (GTI) is a revolutionary force for decarbonization, enabling countries to improve their environmental performance and maintain productivity. GTI is particularly focused on the development and use of energy-efficient technologies, clean energy, sustainable manufacturing, and carbon-free infrastructure, moving beyond traditional R&D to emphasise implementation and transformation (Bai et al., 2023; Wang et al., 2024). The empirical data presented above show that GTI and carbon emissions have a consistent, negative connection. In BRICS nations, for example, a 1% increase in green technology innovation reduces CO2 emissions by 0.123% over time (Amin et al., 2025). In Asia, GTI helps decouple economic growth from carbon emissions in the long term, especially in transportation and energy-intensive industries (Khan et al., 2025). In China, for instance, reforms in green finance have accelerated green innovation, increasing efficiency across industries and reducing pollution levels (Zhang et al., 2025), while OECD studies also confirm the significance of green patents in reducing greenhouse gas emissions (Alvi et al., 2025). However, the success of GTI depends on the availability of institutional support and absorptive capacity. Excessive R&D investment can negatively impact the efficiency of innovation resources. In addition, certain technologies may cause temporary rebound effects because of the energy required for deployment (Khan et al., 2025; Liao, 2025; Yao et al., 2025). Nevertheless, the prevailing evidence shows that GTI can effectively mitigate carbon emissions by improving technological capabilities and production efficiency in the Asian region and RCEP economies.

H1e: Green technological innovation has a significant negative effect on carbon emissions in RCEP economies.

In summary, the literature shows inconsistent results, largely due to differences in institutional quality, policies, and their implementation. From a methodological point of view, it can also be noted that earlier research relied on elementary cross-sectional methods, whereas more recent research employs more sophisticated panel data methods, including robustness checks such as AMG and CCEMG, as well as approaches to differentiate short-run and long-run dynamics. More recent research, however, also employs more sophisticated approaches such as the Generalised Method of Moments (GMM), Fully Modified OLS (FMOLS), and Dynamic OLS (DOLS) to address issues of endogeneity and heterogeneity. Jawadi et al. (2024), for instance, employed the System GMM to examine issues of green finance and sustainable industrialisation, whereas Bai et al. (2023) and Khan et al. (2025) employed FMOLS and DOLS to examine long-run relationships between green innovation and CO2 emissions. In contrast, the present research employs a Random Effects Model, which is more appropriate for short panel data and focuses on cross-country variation, although it is less effective at addressing endogeneity.

2.3 Literature Review on Sustainable Development Goals

Sustainable Development Goals (SDGs) can serve as a comprehensive framework for assessing the impacts of financial, technological, and energy transitions on the environment and economic performance in emerging countries, particularly in the RCEP region. According to literature, GF, RDE, REC, EE, and GTI are key drivers in achieving SDG 7 (Affordable and Clean Energy), SDG 8 (Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Despite all this, the results have proved inconsistent over time, as seen across different studies. For instance, while it is true that financial development might not yield immediate results in the pursuit of environmental sustainability, it is more likely to yield positive outcomes in the long run, thereby indicating that financially developed nations play a crucial role in pursuing sustainable development. Furthermore, while the Environmental Kuznets Curve (EKC) Hypothesis indicated that economic development might not support the quest for sustainability at the outset, later findings on green technological innovations might not yield positive outcomes, especially for nations that adopt foreign technological innovations. Furthermore, the discouraging effects might stem from climate policy uncertainty, while a nation's capacity to attract capital is a major driver of the quest for sustainable development, thereby leading to the following hypotheses.

2.3.1 Green Finance with Sustainable Development Goal

Green financing (GF), a vital facilitator for sustainable development, is critical in mobilising capital for renewable energy, energy efficiency, clean technology, and green industrial strategies. GF can play a direct role in the achievement of SDG 7, which includes investments in grid upgrade infrastructure, renewable energy deployment, and pilot green finance zones (Yang & Liu, 2025; Zhang et al., 2025), supporting China's dual carbon targets to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060. Moreover, GF can play a supporting role in achieving SDG 8 by promoting structural upgrading and high-quality growth in green sectors (Sun et al., 2024), and in achieving SDG 9 by helping to address the financing constraints faced by clean technologies and green manufacturing sectors. Furthermore, GF supports the achievement of SDG 12 by promoting efficient resource use, environmental reporting, and sustainable production (Hua & Tong, 2025). GF bridges the structural gaps in RCEP countries by accelerating technological advancement, promoting clean production, and strengthening regulatory compliance, thereby improving environmental outcomes (Yang & Liu, 2025; Hua & Tong, 2025). However, the success of GF is contingent upon institutional factors, and the literature has consistently shown that GF is instrumental in promoting sustainable development outcomes, thus enhancing clean energy access, innovation, sustainable industry, and climate change mitigation and adaptation in Asia and RCEP countries.

H2a: Green finance has a significant positive effect on SDG 7

H2b: Green finance has a significant positive effect on SDG 8

H2c: Green finance has a significant positive effect on SDG 9

H2d: Green finance has a significant positive effect on SDG 12

H2e: Green finance has a significant positive effect on SDG 13

2.3.2 R&D Expenditure with Sustainable Development Goal

R&D expenditure is the primary driver of sustainable development, as it enables cleaner, more productive, and more sustainable economic structures to emerge. It is the backbone of SDG 9, as it enables cleaner production practices, technological modernisation, and the sustainable restructuring of the industrial sector (Jawadi et al., 2024). Advanced R&D leads to the development of renewable energy technologies, low-carbon materials, and energy-efficient technologies, thereby modernising the industrial sector. It also helps achieve SDG 7 by enhancing the performance and cost-effectiveness of solar, wind, hydropower, and storage systems, thereby advancing cleaner energy (Chen & Lubabu, 2025; Xu et al., 2025). In the BRICS countries, technological progress driven by R&D reduces CO_2 emissions, thereby advancing SDG 13 (Amin et al., 2025). Additionally, R&D contributes to SDG 8 by creating sustainable, high-value jobs in green technologies and increasing productivity. R&D also helps to SDG 12 by improving industrial efficiency, reducing waste, and promoting the circular economy. Because the success of R&D depends on absorptive capacity and institutional support, the research has demonstrated that R&D is crucial for achieving SDG goals, improving economic and technical capacities, and supporting sustainable, low-carbon economic growth in Asia and beyond.

H3a: R&D expenditure has a significant positive effect on SDG 7 in RCEP economies.

H3b: R&D expenditure has a significant positive effect on SDG 8 in RCEP economies.

H3c: R&D expenditure has a significant positive effect on SDG 9 in RCEP economies.

H3d: R&D expenditure has a significant positive effect on SDG 12 in RCEP economies.

H3e: R&D expenditure has a significant positive effect on SDG 13 in RCEP economies.

2.3.3 Renewable Energy Consumption with Sustainable Development Goal

Renewable energy consumption (REC) is an important factor in global sustainable development, as it helps meet several SDGs by providing clean, secure, and economical energy systems. Renewable energy directly contributes to the attainment of SDG 7 by replacing traditional energy sources with solar, wind, hydro, and other renewables, thereby lowering greenhouse gas emissions and accelerating countries' decarbonization (Chen & Lubabu, 2025; Xu et al., 2025). The empirical evidence confirms that a 1% increase in REC reduces CO_2 emissions in BRICS countries, thereby highlighting its importance for climate change action (Amin et al., 2025). Renewable energy also plays a role in SDG 8 by promoting green economies, entrepreneurship, and jobs. The development of Renewable energy infrastructure also contributes to SDG 9 by promoting modern energy access and improving industrial competitiveness. In addition, Renewable energy plays a role in SDG 12 by promoting cleaner, less wasteful consumption of natural resources. Although renewable energy faces several challenges in low-income countries, including intermittency, infrastructure constraints, and fossil fuel subsidies (Cao et al., 2025), the literature indicates that it is critical to achieving SDG goals. The research demonstrates that renewable energy has a favourable influence on SDG targets by supporting low-carbon growth and development in Asia and the RCEP.

H4a: Renewable energy consumption has a significant positive effect on SDG 7 in RCEP economies.

H4b: Renewable energy consumption has a significant positive effect on SDG 8 in RCEP economies.

H4c: Renewable energy consumption has a significant positive effect on SDG 9 in RCEP economies.

H4d: Renewable energy consumption has a significant positive effect on SDG 12 in RCEP economies.

H4e: Renewable energy consumption has a significant positive effect on SDG 13 in RCEP economies.

2.3.4 Energy Efficiency with Sustainable Development Goal

Energy efficiency (EE) is a key driver of sustainable development, supporting several SDGs by reducing energy intensity, increasing productivity, and fostering economic growth. Energy efficiency is a direct contributor to achieving SDG 7, as it reduces overall energy consumption, enabling renewable energy systems to provide a greater share of a nation's electricity supply (Yeboah et al., 2025; Zhao et al., 2024). Energy efficiency also contributes to achieving SDG 13 by reducing the link between economic growth and environmental degradation. Energy efficiency also contributes to achieving SDG 9 by supporting the modernisation of industry through digital technologies, automated systems, and low-waste production techniques. Energy efficiency contributes to achieving SDG 8 by increasing production and creating jobs in the green technologies industry. Energy efficiency also contributes to achieving SDG 12 by improving overall energy management, reducing material loss, and increasing responsible consumption behaviours.

H5a: Energy efficiency has a significant positive effect on SDG 7 in RCEP economies.

H5b: Energy efficiency has a significant positive effect on SDG 8 in RCEP economies.

H5c: Energy efficiency has a significant positive effect on SDG 9 in RCEP economies.

H5d: Energy efficiency has a significant positive effect on SDG 12 in RCEP economies.

H5e: Energy efficiency has a significant positive effect on SDG 13 in RCEP economies.

2.3.5 Green Technological Innovation with Sustainable Development Goal

Green technological innovation (GTI) is important in sustainable development because it allows the economy to increase production while protecting the environment. As a result, green technology innovation directly contributes to the fulfilment of SDGs 7 and 13 by reducing greenhouse gas emissions, pollutants, and dependence on non-renewable energy (Khan et al., 2025; Wang et al., 2024). Moreover, green technological innovation contributes to achieving SDG 8 by improving productivity, reducing production costs, and creating high-skill, innovation-based employment opportunities. In addition, green technological innovation contributes to achieving SDG 9 by promoting smart manufacturing, sustainable industrialisation, and robust technological infrastructure (Mehroush et al., 2024). In addition, green technological innovation supports SDG 12, which focuses on responsible consumption and production, as it entails waste reduction, recycling, and energy-saving production (Alvi et al., 2025). Furthermore, empirical evidence indicates that green technological innovation has a longer-term impact on SDG progress than GDP growth or FDI inflows, underscoring its importance for sustainable development. GTI can positively help to increase environmental compliance in the Asian, RCEP, and OECD regions, serving as a catalyst for multidimensional sustainable development.

H6a: Green technological innovation has a significant positive effect on SDG 7 in RCEP economies.

H6b: Green technological innovation has a significant positive effect on SDG 8 in RCEP economies.

H6c: Green technological innovation has a significant positive effect on SDG 9 in RCEP economies.

H6d: Green technological innovation has a significant positive effect on SDG 12 in RCEP economies.

H6e: Green technological innovation has a significant positive effect on SDG 13 in RCEP economies.

Despite the availability of empirical evidence, existing studies have generally focused on environmental outcomes or individual SDGs, without a comprehensive assessment of the various dimensions of sustainability, especially in the context of RCEP. This study attempts to bridge this gap by exploring CO_2 emissions and various SDGs within a single empirical model, thereby developing a comprehensive understanding of sustainability dynamics.

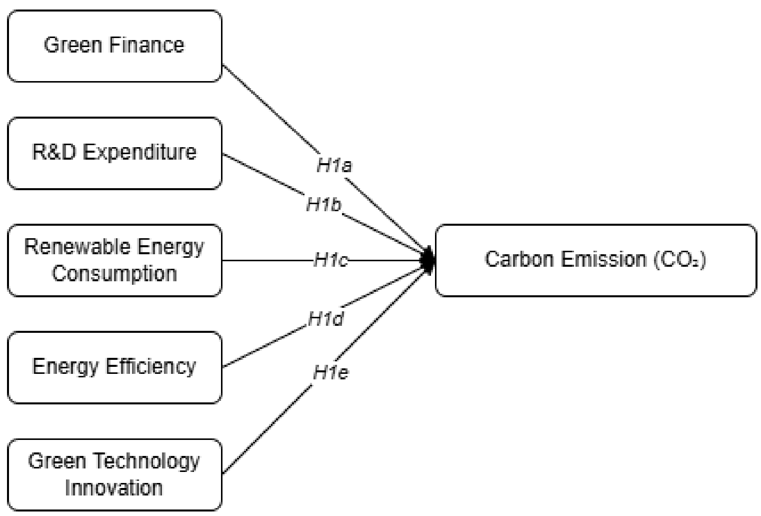

Figure 1: Research Framework on Carbon Emission (CO_2)

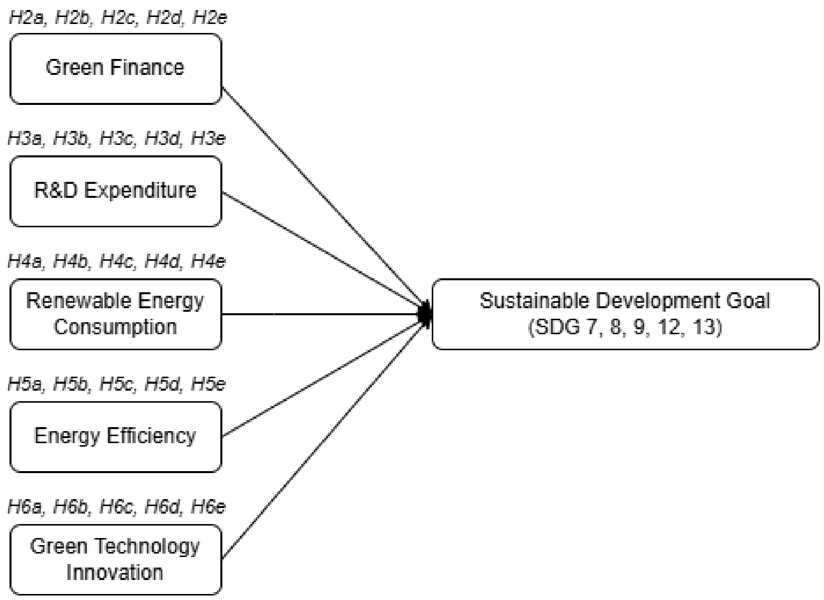

Figure 2: Research Framework on SDG 7, 8, 9, 12, 13

3.0 Methodology

The research employed secondary panel data covering 10 RCEP member countries from 2016 to 2023. The data was sourced from reliable international sources for all variables. This was done to ensure the reliability of the data. Renewable energy consumption, renewable energy indicators, and research and development expenditure were sourced from reliable international sources, including the World Development Indicators. The performance data for SDG7, SDG8, SDG9, SDG12, and SDG13 were sourced from reliable international sources, including the United Nations. The data on green bond issuance was sourced from reliable international sources, including the Climate Bond Initiative. The data on carbon emissions and green technology innovation were sourced from reliable international sources, including the OECD.

To measure SDG performance, a composite index is used, based on the UN SDG database. For this research, only five SDGs, namely, 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 considered for this research, as they directly relate to the research questions of this study, which are based on the concepts of green development and sustainability. The measurement of each of the SDGs is done on an annual basis, and a composite index is used for this purpose, which ranges from 0 to 100 for each of the goals.

Table 1: Data and Variables

Variable Type	Variables	Symbol	Meaning	Measurement Unit	Sources	Sources (link)
Dependent	Carbon Emissions	CO_2	The total production that contributes to climate change	Million tonnes	OECD	Link
	Sustainable Development Growth 7	SDG 7	SDG 7 Affordable and Clean Energy	SDG 7 scores	SDG	Link
	Sustainable Development Growth 8	SDG 8	SDG 8 Decent Work and Economic Growth	SDG 8 scores	SDG	Link
	Sustainable Development Growth 9	SDG 9	SDG 9 Industry, Innovation and Infrastructure	SDG 9 scores	SDG	Link
	Sustainable Development Growth 12	SDG 12	SDG 12 Responsible Consumption and Production	SDG 12 scores	SDG	Link
	Sustainable Development Growth 13	SDG 13	SDG 13 Climate Action	SDG 13 scores	SDG	Link
Independent	Research and development expenditure	R&D	Public and private spending on research and development	% of GDP	WDI	Link
	Energy Efficiency	EE	Using less energy to provide the same output service	Energy intensity per capita	WDI	Link
	Renewable Energy Consumption	REC	Share of renewable and clean energy in the total energy mix	% of total final energy consumption	WDI	Link
	Green Finance	GB	Financial instruments and investments that support environmentally	Green bond issuance (USD million)	ABO	Link
	Green Technology Innovation	GTI	Development of environment-related technologies	% of environment-related worldwide inventions	OECD	Link

3.2 Sample and Data

The study initially considers all 15 RCEP member countries. However, due to significant data gaps in key variables, particularly green bond issuance and green technological innovation, five countries (Brunei, Cambodia, Lao PDR, Myanmar, and Vietnam) were excluded. The final sample consists of 10 countries, which are Australia, China, Indonesia, Japan, the Republic of Korea, Malaysia, New Zealand, the Philippines, Singapore, and Thailand. These countries represent diverse economic structures, income levels, and energy systems, ensuring the sample remains representative of the broader RCEP region. Some variables contained limited missing observations, mainly in earlier years. These were addressed using country-specific mean imputation to maintain a balanced panel structure. Robustness checks using listwise deletion confirmed that this approach did not materially affect the results.

3.3 Model Specification

The panel regression model is used to examine the study's objective. Equation 1 specifies the model.

$$lnCO_{2_{it}} = \beta_0 + \beta_1 lnGB_{it} + \beta_2 R\&D_{it} + \beta_3 REC_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it}$$

$$SDG_{it} = \beta_0 + \beta_1 lnGB_{it} + \beta_2 R\&D_{it} + \beta_3 REC_{it} + \beta_4 EE_{it} + \beta_5 GTI_{it} + \varepsilon_{it} \qquad (1)$$

$lnCO_2$ is the natural logarithm of Carbon Emissions and SDG is the Sustainable Development Goals score, $ln\,GB$ is the natural logarithm of Green Bond, $R\&D$ is Research and Development Expenditure, REC is Renewable Energy Consumption, EE is Energy Efficiency, GTI is Green Technology Innovation, i is the index country, t is the index time (years), β_0 is intercept, $\beta_1\beta_2\beta_3\beta_4\beta_5$ are the coefficients of the independent variables, ε is a stochastic error term. The Breusch-Pagan LM Test tests for the presence of panel effects, thereby justifying the use of panel data models over pooled OLS. Although the Hausman Test generally supports the Random Effects Model (REM), it can also yield negative results for short panels with small sample sizes, which is not necessarily a problem for the model but rather a limitation of the test. To ensure the robustness of results, we use robust standard errors that account for heteroskedasticity and cross-sectional dependence, making the inference more reliable.

4.0 Results and Discussion

4.1 Descriptive Analysis

Table 2: Descriptive Results

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
GTI	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

Table 2 shows the descriptive analysis for the SDGs, key variables, and their respective values for the RCEP member states. From the table, it is evident that SDG7: Affordable and Clean Energy has relatively lower dispersion (Mean = 70.11; SD = 6.25), implying that the member states have relatively similar progress in accessing clean and affordable energy. Conversely, SDG9 (Industry, Innovation, and Infrastructure), SDG12 (Responsible Consumption and Production), and SDG13 (Climate Action) have relatively high dispersion among the member states, implying that the development pace for industries, circular economy development, and mitigation of climate change is heterogeneous among the RCEP member states. In addition, the analysis of the energy efficiency (EE) indicator reveals relatively moderate dispersion (Mean = 3.51; SD = 2.35), whereas the dispersion for the REC, GB, GTI, and RDE indicators is relatively high across RCEP member states.

Table 3: Correlation Summary Statistic of All Variables

	EE	REC	GB	GTI	RDE	CO_2	SDG7	SDG8	SDG9	SDG12	SDG13
EE	1										
REC	-0.6772*	1									
GB	-0.0773	-0.0621	1								
GTI	-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

Table 4: Main Regression Results of Model

	REM (1)	**REM (2)**	**REM (3)**	**REM (4)**	**REM (5)**	**REM (6)**
VARIABLES	$\ln CO_2$	SDG7	SDG8	SDG9	SDG12	SDG13
EE	0.159***	0.312	0.0655	3.697***	-0.946	-2.363***
	(0.0425)	(0.608)	(0.532)	(1.238)	(0.663)	(0.645)
REC	-0.0115**	-0.0650	-0.149**	-0.509***	-0.00432	0.0160
	(0.00465)	(0.0761)	(0.0614)	(0.163)	(0.0755)	(0.0695)
lnGB	-0.00173	0.259	0.139	0.757**	-0.0402	0.176
	(0.00939)	(0.160)	(0.126)	(0.347)	(0.154)	(0.140)
GTI	0.00395**	0.123***	0.0744***	0.221***	-0.0293	-0.0452*

	REM	**REM**	**REM**	**REM**	**REM**	**REM**
	(0.00165)	(0.0280)	(0.0220)	(0.0607)	(0.0270)	(0.0245)
RDE	-0.0836*	0.203	-0.365	-0.310	1.384*	0.994
	(0.0435)	(0.718)	(0.577)	(1.532)	(0.709)	(0.649)
Constant	5.551***	63.26***	75.97***	52.83***	68.40***	76.58***
	(0.376)	(4.379)	(3.930)	(9.100)	(4.992)	(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

Note of Table 4: **Main Regression Results of Model**

*The table reports regression results estimated using Pooled Ordinary Least Squares (OLS), Fixed Effects Model (FEM), and Random Effects Model (REM). Model selection is based on the Breusch–Pagan Lagrange Multiplier (BPLM) test and the Hausman test, which determine the most appropriate specification. Robust standard errors are reported in parentheses. Statistical significance is denoted as follows: *** indicates significance at the 1% level (p < 0.01), ** indicates significance at the 5% level (p < 0.05), and * indicates significance at the 10% level (p < 0.1).*

4.2 Correlation Analysis

The correlation matrix shown in Table 3 indicates diverse relationships across variables in RCEP economies. Energy efficiency (EE) is positively associated with R&D expenditure (RDE) and SDG9, reflecting the role of innovation in enhancing industrial efficiency, but is negatively related to SDG12 and SDG13, suggesting limited environmental gains. Renewable energy consumption (REC) shows negative links with EE and SDG9 but positive associations with SDG12 and SDG13, indicating stronger alignment with environmental objectives. Green bond issuance (lnGB) is moderately correlated with green technology innovation (GTI) and CO_2 emissions, implying concentration in high-emission economies. Both GTI and RDE are positively associated with CO_2 and growth-related SDGs but negatively associated with environmental SDGs, highlighting trade-offs. Overall, SDG7–SDG9 are strongly interrelated, while SDG12–SDG13 exhibit weaker or negative associations with growth-oriented variables.

4.3 Panel Data Analysis

The results of the panel diagnostics support the Random Effects Model (REM). The Breusch-Pagan LM test confirms the presence of significant panel effects. However, the results of the Hausman test indicate that the unobserved country-specific effects are not significantly correlated with the regressors. However, the results should be interpreted cautiously due to the short panel nature, and robust standard errors are used to correct for potential heteroskedasticity and cross-sectional dependency. Table 4 presents the regression results for all SDG models. Overall, GTI appears as the most consistent and significant factor for sustainable development, particularly for SDG7, SDG8, and SDG9, underscoring the importance of innovation-driven growth in the RCEP region. In the case of SDG7, GTI is the only statistically significant factor, underscoring the importance of technological upgrading for enhancing access and infrastructures for clean energy, whereas other factors such as energy efficiency (EE), renewable energy consumption (REC), green bonds (lnGB), and R&D expenditure (RDE) fail to achieve statistical significance.

Under the SDG8 equation, a negative and significant effect is shown for REC, which could represent the short-run costs of transitions, such as labor displacement and productivity adjustments, while a strong positive effect is shown for GTI, which could indicate that innovation is positively related to economic and work-related outcomes. Under the SDG9 equation, a positive and significant effect is shown for EE, lnGB, and GTI, which could indicate that industrial efficiency, green finance, and innovation development are positively interrelated, but a negative effect is shown for REC, which could indicate that a high rate of energy transition could negatively affect traditional industrial output. For SDG12, only RDE is statistically significant and positively related, underscoring its importance as a facilitator of sustainable production and a circular economy, whereas the other variables are insignificant. In contrast, under SDG13, EE and GTI are statistically significant and negative, indicating a possible rebound effect, whereby the pursuit of efficiency and innovation-driven growth could offset environmental benefits. REC, lnGB, and RDE are insignificant as determinants of climate action.

In line with this, the results for EE have mixed effects, which complement the rebound effect observed in the analysis of CO_2, where efficiency leads to more emissions. REC, on the other hand, has some impact on emissions reduction, but at the cost of economic and industrial performance. Lastly, the results for lnGB show that it has limited impact, which may be interpreted that green finance markets are still relatively underdeveloped in the RCEP countries, whereas the results for RDE show that it has some, although relatively small, impact on sustainable production. In conclusion, the overall results of the analysis show that, although technological innovation is one of the most important factors that can enable sustainable development, the process of achieving sustainable development comes at the cost of trade-offs between economic and environmental performance in the short run, and that there may be some endogeneity, particularly between innovation and sustainability, which may be subject to further research using more advanced techniques, including the use of GMM.

4.4 Robustness Check

The reliability of the estimates obtained from the regression analysis is assessed using diagnostic tests. The Variance Inflation Factor (VIF) analysis indicates that the problem of multicollinearity is at a minimum, as the values of the independent variables, namely, R&D expenditure (RDE), green technology development (GTI), green bond issuance (lnGB), and renewable energy consumption (REC), are well below the mean value of 1.922. The highest values of the VIF are observed for the variables RDE (2.248) and GTI (2.092), indicating low levels of intercorrelation between the independent variables, whereas the values of lnGB (1.770) and REC (1.579) are observed to be extremely low, indicating that these variables are not correlated with the other independent variables. Since the panel effects are significant, as indicated by the Breusch-Pagan Lagrange Multiplier (BPLM) test, the Random Effects Model (REM) appears to be suitable, as indicated by the Hausman test, where the value of p is greater than 0.05. Since tests for serial correlation, cross-sectional dependence, and heteroskedasticity were not conducted, the diagnostic tests indicate that the regression analysis is reliable.

Table 5: Variance Inflation Factor (VIF) Analysis

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

5.0 Conclusion and Future Research

5.1 Findings

This study aims to assess the impact of green finance (GF), R&D expenditure (RDE), renewable energy consumption (REC), energy efficiency (EE), and green technological innovation (GTI) on the performance of the Sustainable Development Goals (SDGs), specifically on SDG 7, 8, 9, 12, and 13, and the emission of CO_2 for the RCEP economies. The findings indicate a mixed outcome, affirming both the potential and limitations of the sustainability strategies implemented in the RCEP economies. GF does not have a statistically significant impact on CO_2 emissions; this may be attributed to the underdevelopment of green finance markets and regulatory diversity. Nevertheless, GF positively contributes to the performance of the SDGs, specifically SDG 7, 8, 9, 12, and 13.

On the other hand, RDE has a significant effect on controlling CO_2 emissions and on SDG 12; however, it has an insignificant effect on other SDGs due to long-run investment in research. REC is found to control CO_2 emissions, thus proving its role as a direct measure of decarbonization; however, it is also found to have adverse effects on SDG 8 and SDG 9. EE has a positive effect on CO_2 emissions; however, it also supports SDG 9. The weak influence of EE on other SDGs highlights the importance of supporting measures. GTI has a strong influence on the SDGs; it enhances SDGs 7, 8, and 9; however, it also has a temporary positive effect on CO_2 emissions and a negative effect on SDG 13 during the transition period. Interestingly, the models for SDG 7 and SDG 8 have very low R^2 values. This means that independent variables contribute very little to the variation of these two outcomes. This emphasises the need to be cautious with interpreting these results and underlines the role of supplementary policies in influencing these SDGs. This result is consistent with the findings of other studies that imply that the relationship between financial development and economic growth and sustainability can be time-dependent. In this regard, the EKC approach implies that economic growth can be a barrier to sustainability in the short term but can be a driver in the long term. In addition, the insignificant result for green innovation can be due to the imported nature of innovation (Wang & Xu, 2023).

5.2 Theoretical Implications

The findings are discussed within the framework of Sustainable Development Theory (SDT), supplemented by Negative Externalities Theory and Green Growth Theory. The three theories provide a framework for understanding how financial, technological, and energy-based interventions can lead to sustainable development outcomes. The Negative Externalities Theory argues that environmental degradation is a problem of externalities because the costs of emissions are not factored into production. The interventions of GF, REC, EE, RDE, and GTI are externalities aimed at solving environmental degradation. The Green Growth Theory focuses on structural technological change, particularly GTI, as a means of decoupling economic growth from carbon emissions. Although EE can lead to increased emissions due to the rebound effect, GTI promotes clean production, sustainable growth, and improvements across all aspects of the Sustainable Development Goals.

5.3 Practical Implications

The implications of the results for policymakers, financial intermediaries, and firms are as follows such as policymakers should invest in GTI and R&D interventions because they have the highest mitigation potential for reducing emissions and advancing SDGs. EE interventions should be supported with carbon pricing, regulation, and monitoring to manage the rebound effect. Renewable energy should be supported by workforce retraining and social protection measures to manage short-term employment changes, especially for SDG 8 and SDG 9. GF initiatives should be strategically supported by fiscal incentives, environmental criteria, and regional standards to effectively mobilise capital for green finance. For financial institutions, strong governance, transparency, and strict adherence to “use-of-proceeds” guidelines are essential. Strategically directing R&D funding toward clean technologies can significantly advance progress on SDG 12 and SDG 13. To strengthen competitiveness, ESG performance, and long-term sustainability, firms should embed green technology innovation (GTI) into their core business strategies, improve energy efficiency (EE), and increase investments in renewable energy solutions. Furthermore, recognising the regulatory and market diversity across RCEP member countries is crucial to ensure that recommendations remain regionally relevant rather than overly generic.

5.4 Limitations and Future Research

However, there are certain limitations in this research as well. The panel period, which spans from 2016 to 2023, limits this research to observing long-run impacts, as green bonds, large-scale renewable infrastructure, and R&D investments take around 15-20 years to materialise in the economy. Moreover, the aggregated form of the dataset might be used, which might not capture the sector-specific impact of the rebound phenomenon in the economy. The absence of certain variables, i.e., natural resource rents, fossil fuel subsidies, and carbon pricing, might also result in omitted variable bias in the results of this research. The results of this research may not be generalizable to the rest of the world, as the analysis focuses on the economies of the RCEP countries.

Further research can also explore extending the sample period to 2030-2035, using sub-national or firm-level data, incorporating more contextual information to address bias, and adopting a more sophisticated measure of GTI, for example, citation-weighted patents and green total factor productivity. A comparison of the data from the developed economies from the OECD, BRICS, and the European Union can also be done to improve the external validity of the study and evaluate whether the findings, including the existence of the rebound effect and the weak impact of green finance, are unique to the sample from the emerging Asian economies. Using more advanced panel data estimation techniques, such as system GMM and Driscoll-Kraay standard errors, can also improve the findings from relatively limited and unbalanced panel data.

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