

# A Review on Green Technology Innovation and Carbon Emissions in Selected Emerging Asian Economies

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**Abstract:** *Innovation in green technology has become an essential approach to the reduction of carbon emissions and the promotion of the adoption of renewable energy. The global economy is in the process of transitioning to sustainable and cost-effective energy systems, where technological innovation is facilitating the reduction of fossil fuel dependency and the enhancement of renewable energy production. The analysis is grounded in key theoretical frameworks, particularly the Induced Innovation Theory, which helps explain how environmental pressures and economic incentives drive technological change. The paper compares the methodologies employed across empirical studies to assess how different approaches capture the dynamics between innovation and environmental outcomes. It also highlights the variations in variable selection, proxies for green innovation, and treatment of endogeneity across research. The paper concludes by proposing a more integrated theoretical-methodological framework to guide future research in Emerging Asian Economies.*

**Keywords:** Green Technology Innovation, Carbon emissions, Emerging Asian Economies

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## 1. Introduction

The reduction of carbon emissions has emerged as a primary focus in the environmental agendas of both global and national authorities, driven by the escalating urgency to address climate change (UNFCCC, 2015). Green technology innovation, defined as the development and application of environmentally sustainable technologies aimed at enhancing energy efficiency and diminishing greenhouse gas emissions, is a crucial tool for fostering sustainable growth (Chen & Lee, 2020). Green innovation offers a dual advantage in rapidly advancing Asian economies, such as China, India, Malaysia, Indonesia, Thailand, the Philippines, and Vietnam: it fosters economic growth while concurrently alleviating environmental deterioration (Godil *et al.*, 2021; Dong *et al.*, 2022). Nonetheless, in light of international climate accords like the Kyoto Protocol and the Paris Agreement, these nations must reconcile economic growth with environmental obligations, a formidable task (Rogelj *et al.*, 2016; UNFCCC, 1998).

Global climate accords have profoundly shaped the approaches of nations. The Kyoto Protocol, established in 1997, set forth legally binding emission reduction targets for developed nations and introduced mechanisms such as the Clean Development Mechanism (CDM), which aids in the transfer of technology to developing countries (UNFCCC, 1998). The Paris Agreement (2015) further developed commitments by encompassing both developed and developing

nations, advocating on all signatories to present Nationally Determined Contributions (NDCs) with the goal of restricting global temperature increase to well below 2°C above pre-industrial levels (UNFCCC, 2015; Rogelj *et al.*, 2016). The implementation of these frameworks has encouraged developing Asian economies to incorporate green technologies into their national development strategies (IEA, 2023; OECD, 2021).

Despite these efforts, there is still complexity in the relationship between carbon emissions and the development of green technologies. Empirical studies suggest that green technologies are often advocated as means to lower emissions; however, the results are frequently inconsistent. Su *et al.* (2023) discovered that in developing economies, the relationship between technological innovation and carbon emissions adheres to an Environmental Kuznets Curve (EKC) pattern, where emissions first rise in conjunction with economic and technological progress before eventually decreasing. The non-linear trend is evidenced by the findings of Shahbaz *et al.* (2020) and Godil *et al.* (2021), indicating that green innovation by itself does not ensure prompt reductions in emissions and may be affected by contextual elements like industrial structure, energy mix, and economic scale.

Nonetheless, a significant amount of the current literature primarily emphasises developed economies or the least-developed nations. Investigations into the impact of green technology innovation in OECD nations and Sub-Saharan Africa, for example, are prevalent in the current discourse (Chen *et al.*, 2022; Dogan & Seker, 2016; Sarkodie & Strezov, 2019). Conversely, studies focused on the distinct dynamics of emerging Asian economies are limited, even though these nations play a substantial role in global carbon emissions and are undergoing swift technological and industrial changes (Wang *et al.*, 2021; Nguyen *et al.*, 2023). The absence of targeted investigation highlights a significant void in comprehending the dynamics of green innovation within these swiftly evolving settings, where regulatory frameworks, institutional integrity, and developmental objectives frequently diverge from those found in both high-income and low-income scenarios.

Recent empirical studies provide a detailed insight into the impact of green technology innovation on carbon emissions in emerging Asian economies, including China, India, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. The findings indicate an encouraging potential for green innovation in reducing carbon emissions, though its effectiveness can vary significantly based on different institutional and regulatory environments. A study conducted by Nguyen *et al.* (2024) studying seven emerging Asian countries from 1995 to 2022 found that green technological innovation plays a significant role in reducing CO<sub>2</sub> emissions, particularly when reinforced by robust institutional frameworks. In a similar vein, a study conducted by Li *et al.* (2023) revealed that within China's construction sector, the intensity of environmental regulations significantly drives green innovation, leading to considerable reductions in emissions. Rahman *et al.* (2022) highlighted the importance of foreign direct investment in promoting sustainable technology adoption in ASEAN countries, revealing that green innovation driven by external technology spillovers played a significant role in reducing emissions.

However, research conducted by Tran and Do (2023) suggests a mixed impact, suggesting that technological innovation may initially increase emissions due to scale effects before reductions are observed. This pattern is consistent with the Environmental Kuznets Curve (EKC) hypothesis. Moreover, findings from Malaysia, Indonesia, and the Philippines suggest that although technological progress fuels economic development, it simultaneously perpetuates reliance on non-renewable energy, thus undermining environmental advantages (Yusof *et al.*,

2025). Liu *et al.* (2023) contend that investment-based and command-and-control environmental regulations are more effective in enhancing the positive environmental impact of green innovations, especially when considering regional spillover effects. While there is an increasing amount of literature available, most previous studies have predominantly concentrated on OECD countries or the least-developed areas like Sub-Saharan Africa (Chen *et al.*, 2022; Sarkodie & Strezov, 2019). This has resulted in a notable gap in comprehending the unique challenges and outcomes faced by emerging Asian nations, where factors such as institutional quality, energy infrastructure, and policy capacity frequently differ markedly from both high- and low-income settings (Wang *et al.*, 2021; Nguyen *et al.*, 2023).

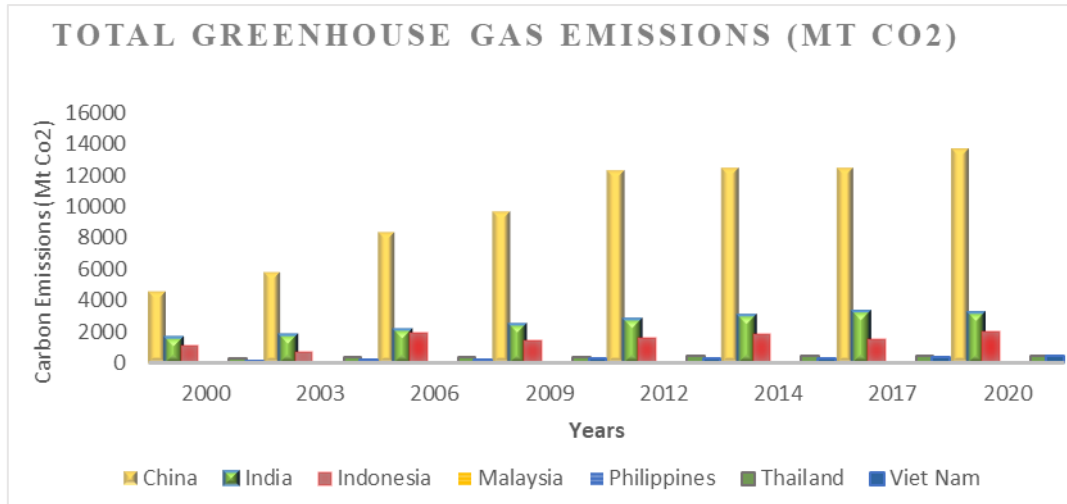
In addition, some research shows that there are cases where innovations in environmentally friendly technologies could unintentionally cause emissions to rise. According to Chen and Lee (2020), there was no discernible reduction in CO<sub>2</sub> emissions because of technical innovation, which raises the possibility that, in certain situations, more R&D effort could lead to higher emissions. The rebound effect was pointed out by Kashyap and Hussain (2024) in Asia-Pacific economies, whereby increases in energy efficiency using renewable energy sources resulted in higher overall energy consumption, negating the desired reductions in emissions.

Recent study has also highlighted the relevance of environmental restrictions in mitigating the impact of green innovation. Liu *et al.* (2023) highlight that investment-based and command-and-control regulations are more effective in fostering the connection between green innovation and emissions reduction, whereas expenditure-based regulations might lead firms to prioritize short-term advantages. Further evidence supports the idea that carbon emissions in one region can have an impact on emissions in nearby areas, especially in the presence of strong legislation.

Technological innovation and institutional quality are crucial in the setting of growing Asian economies. According to Dong *et al.* (2022), the reliance on fossil fuels in these countries, coupled with technological backwardness and weak institutions, leads to an increase in carbon dioxide emissions. Consequently, improving institutional frameworks and allocating resources towards green technology innovation are crucial for attaining environmental sustainability.

The significance of sustainable development is becoming increasingly apparent as emerging Asian economies undergo another substantial phase of structural transformation, which is fuelled by industrial modernization, urban expansion, and environmental challenges (Green & Stern, 2016). Within this framework, green technology innovation is commonly seen as a possible driver of economic growth while also addressing climate problems. Nonetheless, the current empirical findings regarding its efficacy in lowering carbon emissions yield inconsistent outcomes, especially in the framework for emerging and transition economies. Therefore, this study aims to elucidate an important inquiry: Is there a significant effect of green technology innovation on carbon emissions in specific emerging Asian economies?

There are numerous justifications for selecting emerging Asian nations for this investigation. The past decade has witnessed robust economic trends, rapid technological advancements, and globalisation in emerging Asian countries, including China, India, Thailand, the Philippines, Vietnam, Malaysia, and Indonesia. Nevertheless, the environmental consequences of such extensive economic development are also significant (Zaidi *et al.*, 2019). As productivity levels in emerging Asian countries increase environmental pollution problems worsen, as illustrated in **Figure 1**.



**Figure 1: Total Greenhouse Gas Emissions**  
Source: IEA (2023)

Figure 1 shows a statistic on total greenhouse gas emissions in million metric tonnes of CO<sub>2</sub> (Mt CO<sub>2</sub>) from 2000 to 2020, providing insight into the carbon emission trajectory of selected emerging Asian countries. Over the past decades, various countries such as China, India, Indonesia, Malaysia, The Philippines, Thailand and Viet Nam have undergone variable degrees of urban expansion and industrialization. At this juncture, there still have a consistent upward trend in carbon emissions across all countries, China being the primary emitter throughout the period. IEA (2023) found that by 2020, China's emissions had increased from approximately 5,000 Mt CO<sub>2</sub> in 2000 to nearly 13,500 Mt CO<sub>2</sub>. This significant improvement is mostly due to fast economic expansion, urbanization and persistent reliance on fossil fuels, mainly coal.

India, which is the second-largest emitter in the region, demonstrated a consistent increase from less than 2,000 Mt CO<sub>2</sub> in 2000 to approximately 3,500 Mt CO<sub>2</sub> in 2020. This development reflects the country's growing population, industrial base, and energy demand, which is outpacing the renewable energy transition (Shahbaz *et al.*, 2020). Indonesia and Malaysia followed with small emissions, but exhibited gradual increases over time, reflecting increased economic activity and energy consumption. In comparison, Vietnam, Thailand, and the Philippines had lower emissions; nonetheless, their emission trajectories have also exhibited increased momentum, with Vietnam experiencing considerable increases after 2014, which is consistent with its industrial growth that is focused on exports (Nguyen *et al.*, 2023).

A critical insight is revealed by these trends: despite the promotion of green technology initiatives in policy discourse, their practical impact on emissions reduction is still limited. The broader challenge that emerging Asian economies face in achieving decoupling between economic development and environmental degradation is reflected in this. The figure is consistent with the existing empirical literature, which emphasises the difficulty of achieving emissions reductions solely through technological innovation, particularly in the absence of adequate regulatory frameworks and structural transitions (Godil *et al.*, 2021; Dong *et al.*, 2022).

This study's remaining section is structured as follows. Section 3 presents an in-depth analysis of the current literature, emphasising the effects of green technology innovation on carbon emissions in specific emerging Asian economies. A theoretical overview is also provided in this section, which emphasises the critical economic and environmental frameworks that underpin the relationship between innovation and emissions. Following this, Section 4

provides specific recommendations and policy solutions based on the literature's findings and insights. The following recommendations are designed to guide decision-makers and stakeholders in the effective implementation of green technology strategies that promote economic development alongside environmental sustainability.

## 2. Theoretical Overview

A key component of the global climate change mitigation plan is the creation and spread of green technological innovation, especially in economies that must balance environmental sustainability with economic growth. The Induced Innovation Theory, first developed by John Hicks in 1932, is one of the most important theoretical foundations for understanding the causes of green innovation (Grubb et al., 2021). According to the theory innovation is not wholly exogenous but rather induced by relative factor scarcity or regulatory pressures. In economic terms, as specific inputs become more expensive, either owing to market dynamics or legislative limits, manufacturers are encouraged to develop or use technologies that save money on those inputs.

Meanwhile, the application of Induced Innovation Theory generally adopted to study the induced innovation in climate change. This mechanism provides a theoretical foundation for combining rigorous environmental rules with economic incentives to encourage innovation that is consistent with sustainable development goals. In most study, researchers examine the relationship between technology innovation and environment using the  $I=P*A*T$  equation. This equation was developed by biologist Paul Ehrlich and environmental scientist John Holdren in 1971. The “impact” (I) of any group or nation on the environment is given by the interaction of its population size (P), per capita affluence (A), expressed in terms of real per capita GDP, and level of Technology (T).

The equation suggests that more innovation will lead to better environmental quality, especially when new technologies are designed to use fewer resources, produce less pollution, and improve energy efficiency. In this context, innovation acts as a tool to reduce the negative impact of growing populations and higher consumption levels which supported the induced innovation theory.

## 3. Discussions of Literature Review

### 3.1 Green Technology Innovation and Carbon Emissions in Emerging Asian Countries

The potential of green technology innovation to reduce carbon emissions and promote sustainable development has recently attracted a lot of attention. Most of the existing literature has primarily concentrated on developed countries, which have more sophisticated technological infrastructure, institutional support, and environmental awareness. In OECD countries, low-carbon innovation substantially contributes to emissions reductions, as demonstrated by empirical evidence provided by Fankhauser *et al.* (2013). Similarly, Du *et al.* (2019) discovered that environmental patenting decreases CO<sub>2</sub> emissions in high-income countries.

In contrast, research on emerging Asian countries remains scarce. Ahmad *et al.* (2021) conducted comprehensive research of ASEAN countries, demonstrating that, while eco-innovation promotes sustainable development, its impact on carbon emissions is less substantial than in developed countries. The significance of institutional and policy support was also emphasized by Nguyen *et al.* (2023), who emphasised the necessity of renewable

energy integration and green R&D for effective outcomes. According to Yu (2022), the effectiveness of green innovation in Asia is influenced by factors such as energy dependence, regulatory maturity, and industrial structure. Countries that rely heavily on fossil fuels often encounter challenges when trying to innovate.

When combined with industrial upgrading, green technological innovation can reduce emissions, according to a study of Chinese regions conducted by Gao *et al.* (2022). In contrast, Wang and Dong (2022) advised against the homogenisation of innovation effects, emphasising that the environmental consequences of product-based and process-based innovations are distinct. These findings highlight the need for more detailed and context-specific investigations in emerging Asia. There is a noticeable lack of empirical attention to the topic of green technology innovation in emerging Asian economies, as most prior studies have focused on developed economies. Therefore, it is essential to examine the distinctive obstacles and motivators of green innovation in these countries, taking into account their distinct institutional and economic frameworks.

Green technology innovation has potential as a strategy for decreasing carbon emissions in emerging Asian Countries however its current effectiveness is limited by economic, institutional, and legislative obstacles. Although innovation initiatives are present, they are frequently inadequately supported in terms of their environmental impact, as evidenced by the reviewed studies. Future research should further explore country-specific case studies and implement mixed-method approaches to gain a more comprehensive understanding of the relationship between environmental outcomes, policy, and innovation. Furthermore, governments and stakeholders must prioritise structural reforms and targeted investments to create an environment conducive to green technological advancement. In order to make green innovation a central strategy for climate resilience and sustainable growth in Asia, it is necessary to fill these gaps.

### **3.2 Green Technology Innovation and Carbon Emissions: A Methodological Comparison in Emerging Asian Economies**

There is an increasing body of empirical research that has investigated the correlation between carbon emissions and green technology innovation in certain emerging Asian countries. However, the methods and analytical approaches employed in these studies differ significantly. A dynamic panel Generalised Method of Moments (GMM) framework was implemented by Bhuiyan, Al Mamun, and Uddin (2022) to evaluate South and Southeast Asian countries from 2000 to 2018. Their results emphasise that the consumption of green energy contributes to a substantial reduction in CO<sub>2</sub> emissions, although the scale of this effect differs across countries due to differences in economic structures, energy dependency, and policy contexts.

Similarly, Nguyen, Le, and Nguyen (2023) used panel data regression techniques to investigate ASEAN countries, highlighting the importance of green technology innovation in mitigating carbon emissions, particularly when combined with renewable energy deployment and R&D investment. However, their research found that the effectiveness of green innovation is significantly influenced by governance quality, institutional frameworks, and regulatory support. Through Dumitrescu–Hurlin panel causality tests, Yu (2022) added to the discussion by showing that there is a two-way causal link between technological progress and environmental sustainability in Southeast Asia. This implies that, although technological advancements facilitate environmental enhancements, they are concurrently affected by socioeconomic factors, including destitution and uncertainty regarding economic policy.

Despite the obvious evidence that green technology plays a role in emission reductions, the range of methodologies ranging from dynamic panel data models to causality tests as well as the different time frames and sample countries analysed highlight the nexus's complexity. The variation in results demonstrates how contextual factors such as economic development, institutional capability, and industrial structure influence the impact of innovation on environmental outcomes. This highlights the importance of specialised, country-specific policies that take these underlying variables into account while promoting green technology as a sustainable development strategy. Furthermore, research by Fankhauser *et al.* (2013) and Gao *et al.* (2022) indicates that although green innovation has great potential, sectoral limitations and institutional stagnation can reduce the effectiveness in many emerging economies. Taken as a whole, the literature study proves that developing environmentally friendly technologies have great potential to help developing Asian economies cut their carbon emissions. Its effectiveness is dependent on a number of mediating factors, including as the quality of governance, the policy environment, and the economic structure. Methodological differences emphasise the multidimensional nature of this relationship, implying that one-size-fits-all techniques may be counterproductive. As an illustration, the utilisation of dynamic panel GMM enables researchers to account for endogeneity and capture dynamic effects, while causality tests facilitate comprehension of directional relationships. Nevertheless, both methodologies demonstrate that innovation is not a standalone phenomenon; rather, it operates within a system that is influenced by institutional factors, energy consumption patterns, and economic growth.

#### 4. Discussion and Recommendations

Innovation in green technology is crucial for the reduction of carbon emissions and the promotion of sustainable development. The results in emerging Asian countries are inconsistent, even though its advantages are well-documented in developed countries with robust institutions and sophisticated infrastructure (Fankhauser *et al.*, 2013; Du *et al.*, 2019). Studies conducted by Ahmad *et al.* (2021) demonstrate that eco-innovation in ASEAN countries promotes sustainability, but it has a less significant effect on emissions reduction. This could be attributed to the underdeveloped regulatory systems, reliance on fossil fuels, and limited policy support (Nguyen *et al.*, 2023; Yu, 2022). China's Gao *et al.* (2022) found that green innovation and industrial upgrades boost outcomes, but that impacts differ by innovation type (Wang & Dong, 2022).

Green technology innovation holds potential for lowering carbon emissions in growing Asian countries, but its impact differs due to disparities in governance, energy dependency, and economic structures (Bhuiyan *et al.*, 2022; Nguyen *et al.*, 2023). Although green technology innovation has been effective in reducing carbon emissions in developed countries with robust institutions and infrastructure, its impact is restricted in emergent Asian economies due to the unique challenges they encounter (Fankhauser *et al.*, 2013; Du *et al.*, 2019). There is a lack of study on the factors that influence green innovation results in these nations (Nguyen *et al.*, 2023; Yu, 2022). Unlike established countries, emerging Asian countries are undergoing fast industrialization and urbanization, which results in increased emissions and an urgent need for specific green solutions. It is imperative to concentrate research and policy on these economies due to their distinct sectoral dynamics, institutional capacities, and financial constraints, which necessitate context-specific approaches. By filling in these gaps, green technology may be fully utilized to promote sustainable development and mitigate climate threats, prioritizing it over just imitating models from developed countries that might not be applicable to local conditions.

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## Conflict of Interest Statement

The authors declare that there is no conflict of interest regarding the publication of this study.

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