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Assessing the Carbon Footprints of Income Growth, Green Finance, Institutional Quality and Renewable Energy Consumption in Emerging Asian Economies

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Abstract: Research Question: What is the applicability of the Environmental Kuznets Curve (EKC) hypothesis in emerging East and South Asian countries? Do institutional quality, trade openness, renewable energy consumption, green finance, financial development, and their interaction influence carbon emissions? **Motivation:** A new assessment of green finance, institutional quality, financial development, and other relevant variables in shaping the EKC hypothesis is required. **Idea:** In the context of emerging Asian countries, it requires consideration of cross-sectional dependence (CSD) due to the high economic integration among East and South Asian countries. They shared residual interdependency and cross-sectional exposure to common shocks, such as oil shocks, global financial shocks, and supply chain disruptions; hence, a more nuanced and multidisciplinary approach is needed. **Data:** A panel dataset that ranges from 2000 to 2019 is employed for ten developing East and South Asian economies, including China, India, Pakistan, Bangladesh, Sri Lanka, Indonesia, Malaysia, Thailand, Vietnam, and the Philippines. **Method/Tools:** A series of panel analyses, including the CSD test, slope heterogeneity test, the 2nd generation panel unit root and cointegration tests, and CS-ARDL modelling, have been employed to address heterogeneity and cross-sectional dependence issues. Robustness tests using the Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG) estimators corroborate the findings, reinforcing the study's credibility and policy implications. **Findings:** Both the short- and long-run results consistently confirm the income-environmental degradation link, but the U-type EKC effect is absent. While green finance, trade openness, and financial development have insignificant impacts on carbon emissions, institutional quality and renewable energy consumption exhibit negative effects, highlighting their importance in curbing environmental degradation. More policy efforts are needed to promote investment in environmental financing, upgrade clean production technology, and enhance the decarbonization process. This study also identifies heterogeneity and cross-sectional dependence on environmental policies among these nations. **Contributions:** Green finance and R&D investments in green technologies are inadequate. Efforts to promote carbon neutrality by redirecting financing towards the sustainable and renewable energy sectors are needed. These findings underscore the need for greater collaborative efforts among emerging

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Asian nations, particularly China, to safeguard the environment and achieve sustainable development.

Keywords: EKC, environmental degradation, income growth, green finance, institutional quality, renewable energy consumption.
JEL Classification: Q50, Q58, C33, G18

1. Introduction

The impacts of globalization and international trade on the environment in emerging East and South Asia have been significant, complex, and multifaceted. The growth of these economies has been based on an export-oriented manufacturing model, which has led to increased industrialization and intensification of resource extraction and use (Scheidel *et al.*, 2018). This has resulted in greenhouse gas emissions, land-use changes, and pollution, causing significant environmental and social consequences (Scheidel *et al.*, 2018). The emergence of global value chains has also led to the relocation of production processes to emerging Asian countries with weaker environmental regulations, resulting in a race to the bottom in environmental standards (Baldwin, 2016; Gerrefi and Fernandez-stark, 2016).

Environmental losses are evident following the expansion of industrial supply chains, particularly in manufacturing and construction, which are both energy- and resource-intensive (Chen and Ngniatedema, 2018). For example, China has become the world's largest producer of steel, cement, and chemicals, and its manufacturing sector accounts for over 60% of the country's energy consumption and more than 70% of its carbon emissions (Guan *et al.*, 2018). Similarly, the Indian manufacturing sector is growing rapidly, with the government aiming to increase its contribution to the economy from the current level of 16% to 25% by 2025 (Rijesh, 2019). However, this growth has come at a cost to the environment, with air and water pollution becoming major issues in India and other South Asian nations. Being the major players in manufacturing and global supply chains, ASEAN countries also exposes to severe air and water pollution, waste generation, and greenhouse gas emissions (Sovacool *et al.*, 2020a). Moreover, Malaysia and Indonesia – the world's largest producers of palm oil, rubber, and other commodities – are facing widespread deforestation, land degradation, and biodiversity loss in the region (ADB, 2019). The emerging Asian nations, while facing the challenge of harmonizing economic growth and environmental degradation, have made commitments of carbon reduction under the Kyoto Protocol and the Paris Agreement (2016). Table 1 depicts the overview of environmental commitments among the Asian, in the mitigation of climate change impacts and to achieve sustainable development:

Following the seminal works by Grossman and Krueger (1991) and Shafik (1994), the so-called Environmental Kuznets Curve (EKC) hypothesis has become the dominant approach for modelling ambient pollution concentrations and aggregate emissions. The EKC underlines the pollution trajectory between the periods and income. In line with the growing literature, there has been increasing interest in the potential role of financial advances in addressing environmental challenges associated with economic development. Nevertheless, the limited empirical evidence on emerging economies is mixed. Pande and Debnath (2020) and Alam *et al.* (2018) did not support the EKC hypothesis such that financial development in ASEAN has not able to reduce environmental degradation. Mainly, there is a lack of institutional capacity to enforce environmental regulations (Pande and Debnath, 2020) while investment in renewable energy is still low (World Bank, 2020), especially for ASEAN and South Asian like Bangladesh and Pakistan. Others have claimed that the positive effects of financial development on the environment may be offset by other factors, such as political will, regulatory oversight, and structural changes in the economy (see Yadav *et al.*, 2020; Srivastava and Chakraborty, 2020; for the case of India). Additionally, there may be a trade-off between short-term growth and long-term environmental sustainability, which can be exacerbated by financial development. For instance, China's focus on short-term economic growth coupled with a lack of regulatory oversight and enforcement has contributed to environmental problems (Deng *et al.*, 2021).

Table 1: Environmental commitments among the emerging Asian

Country	Kyoto Protocol[1]	Paris Agreement (2016)
China	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	world's largest emitter of greenhouse gases, pledged to peak its carbon dioxide emissions before 2030 and achieve carbon neutrality by 2060.
Indonesia	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Indonesia's NDC aims to reduce greenhouse gas emissions by 29% by 2030 compared to business-as-usual levels, with the potential to increase the reduction to 41% with international support.
Malaysia	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Malaysia's NDC targets a 35% reduction in greenhouse gas emissions by 2030 compared to business-as-usual levels, contingent on financial and technical support.
Philippines	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	The Philippines' NDC aims for a 70% reduction in greenhouse gas emissions by 2030 compared to business-as-usual levels.
Thailand	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Thailand's NDC aims to reduce greenhouse gas emissions by 20-25% by 2030 compared to business-as-usual levels.
Vietnam	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Vietnam's NDC aims to reduce greenhouse gas emissions by 8% by 2030 compared to business-as-usual levels, and up to 25% with international support.
India	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	India's NDC aims to reduce the carbon intensity of its GDP by 33-35% by 2030 compared to 2005 levels and increasing non-fossil fuel capacity to 40% of total power capacity by 2030. India also aims for carbon neutrality by 2070.
Pakistan	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Pakistan's NDC aims to reduce greenhouse gas emissions by 20% by 2030 compared to business-as-usual levels.
Bangladesh	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Bangladesh's NDC aims to reduce greenhouse gas emissions by 5% by 2030 compared to business-as-usual levels, with the potential to increase the reduction to 15% with international support.
Sri Lanka	Classified as developing country, not bound by mandatory emission reduction targets. Actively participated in the CDM projects.	Sri Lanka's NDC outlines actions to achieve a low-carbon and climate-resilient development pathway, including efforts to increase renewable energy capacity and enhance energy efficiency.

Notes: CDM - Clean Development Mechanism, NDC - Nationally Determined Contribution.

[1]Kyoto Protocol was adopted on 11 December 1997 and enforced on 16 February 2005. Under the Kyoto Protocol, developing countries like China, ASEAN nations, and South Asian countries were not subject to binding emission reduction targets. Instead, they had the opportunity to participate in the CDM by hosting projects that generated emission reduction credits. These credits could be sold to developed countries looking to meet their targets. This mechanism aimed to facilitate technology transfer, investment, and sustainable development in these countries while contributing to global emission reduction efforts.

Overall, although there have been significant advances in our understanding of the relationship between economic development, globalization, and environmental degradation, there are still important gaps and inconsistencies in the literature. Among these, the financial development-decarbonization nexus has been increasingly examined but inconsistently reported. Green finance has started to grow in China and emerging Asia, providing new business opportunities as well as policy options for market correction of environmental degradation. However, the problem statement has been well-documented. First, EKC curve may not hold for emerging countries because of differences in institutional quality, technological capabilities, and environmental regulations (Kanbur *et al.*, 2021). The effectiveness of green finance may be hindered by institutional barriers such as weak regulatory frameworks and a lack of financial infrastructure (Li *et al.*, 2020). Second, the drivers of environmental degradation differ between the developed and emerging economies. In developed economies, the main drivers of environmental degradation often associated with consumption patterns such as energy use and transportation (Galeotti *et al.*, 2020). However, in emerging economies, the main drivers of environmental degradation often associated with production processes such as industrialization and urbanization (Li *et al.*, 2020). Third, policy responses in developed economies often focus on market-based mechanisms such as carbon pricing and emissions trading systems (Stern, 2017). But in emerging economies, policy responses often focus on command-and-control measures such as pollution regulations and environmental taxes (Kanbur *et al.*, 2021).

Based on the preceding discussions, our study contributes significantly to three key areas. First, it emphasizes the role of green finance in achieving a harmonious balance between economic growth and environmental quality, as supported by relevant studies (Razzaq *et al.*, 2021; Mngumi *et al.*, 2022). Green finance facilitates the efficient allocation of funds from surplus economic sectors to eco-friendly and sustainable projects, as evidenced by Ibrahim *et al.* (2022). Additionally, instruments such as green bonds, carbon market tools, and fintech contribute to the realization of sustainable development goals (Sachs *et al.*, 2019). Crucially, green finances play a vital role in the transition to green energy sources and are essential for promoting environmental sustainability (Iqbal *et al.* 2021). Notably, amidst recent global shocks, such as the Covid-19 pandemic, green finances have made significant contributions to green projects (Rasoulinezhad and Taghizadeh-Hesary, 2022). These findings underscore the importance of green finance in shaping the environmental outcomes of emerging economies in South and East Asia, thereby enriching the empirical literature on this subject.

Second, our study underscores the increasing relevance of financial development in the context of environmental considerations, particularly within the green finance framework (Ibrahim *et al.*, 2022). Recent research highlights the crucial role of robust financial systems in facilitating green financial investments, thereby contributing to environmental goals (Li *et al.*, 2021). Consequently, a resilient financial system is imperative for the effective allocation of funds to environmentally friendly projects, thereby enhancing their overall efficiency. Recognizing the pivotal role of the financial system in the success of green finance, we incorporated financial development into our estimation model to explore the combined impact of green finance and financial development on carbon emissions in emerging Asian economies.

Third, the effective utilization of green finance to achieve sustainable environmental goals requires a sound institutional environment. Green finance integrates environmental considerations into financial decisions, demanding a robust institutional framework to realize its objectives (UN Environment Program, 2018). Fu *et al.* (2023) underscore the role of a robust regulatory framework in the success of green finance, while Çitil *et al.* (2023) find that both green finance and institutional quality significantly influence air quality in G-

20 countries. Consequently, green finance requires a robust institutional environment and a regulatory framework to achieve its objectives. Therefore, we include institutional quality alongside green finance, financial development, energy consumption, and economic growth in our examination of their impact on carbon emissions in emerging Asian economies.

A new assessment of green finance, institutional quality, financial development, and other relevant variables in shaping the EKC hypothesis is required for new academic and policy insights. In the context of emerging Asian, it requires consideration of cross-sectional dependence (CSD) due to high economic integration among East and South Asian countries. CSD arises from residual interdependency and cross-sections exposure to common shocks, such as the oil shocks, global financial shocks, the Covid-19 pandemic, and supply-chain disruptions, etc (Tao *et al.*, 2021; Zhao *et al.*, 2022). The presence of CSD biases the analysis of the relationship between EC, GDP, and CO2, and should not be disregarded (Munir *et al.*, 2019; Salim *et al.*, 2017). Addressing these gaps will require a more nuanced and multidisciplinary approach that considers the complex interactions between economic, social, and environmental systems, and the need for more effective governance and regulation of global trade and finance. This study has employed a series of panel analysis that consider slope heterogeneity and CSD in the analysis. These include the Pesaran's (2015) CSD test, the Pesaran and Yamagata (2008)'s slope heterogeneity test, 2nd generation panel unit root tests (Pesaran, 2007; Pesaran *et al.*, 2009), Panel cointegration tests (Westerlund and Edgerton, 2008; Pedroni, 2004), as well as the CS-ARDL modelling of long- and short-run dynamics of EKC framework. The CS-ARDL was conceptualized by Pesaran and Smith (1995) and further enriched by Chudik and Pesaran (2015).

However, based on latest dataset, our findings reveal that green finance, financial development, and trade openness among the emerging Asian have limited roles in environmental improvement and capital efficiency enhancement, which yet to improve the energy structure of the economy significantly. On the other hand, institutional quality and renewable energy consumption exhibited negative impacts on carbon emissions. More policy efforts needed to help companies invest in environmental financing, upgrade clean production technology, and enhance the decarbonization process. In the ASEAN and South Asian region, environmental performance has deteriorated owing to massive energy imports and consumption, and foreign direct investment in energy based industry. Therefore, the government must provide financial support for energy-efficient and environmentally beneficial initiatives (Anwar *et al.*, 2021; Fu and Irfan 2022). Policies for industrial structure customization in countries with high regional heterogeneity, such as China, are crucial for achieving effective green financing (Guo *et al.*, 2022; Lee *et al.*, 2023). This study recognizes the differences in the drivers of environmental degradation and policy responses between developed and emerging economies to devise effective policies to mitigate environmental issues and achieve sustainable development.

The remainder of this paper is organized as follows. The next section reviews the recent literature, focusing on the dynamic roles of green finance and financial development in shaping the EKC hypothesis. The third section presents the data and the methodology used. A detailed description of the heterogenous panel tests and the CS-ARDL method is provided. The penultimate section discusses the empirical results, while the final section summarizes the key findings with the support of policy implications.

2. Literature Review

Kuznets (1955) first hypothesized an inverse U-shaped relationship between economic development and income inequality that income inequality first rises and then falls as economic development proceeds. Grossman and Krueger (1991) and Shafik (1994) have advocated the Environmental Kuznets Curve (EKC) hypothesis for modelling ambient pollution concentrations and aggregate emissions. The EKC underlines the pollution trajectory between the periods and income growth. The EKC is generally divided into three phases: the early stage of economic development, the turning point, and the later stage (Stern, 2018). In the first phase, there is vast use of resources and a prompt increase in environmental degradation. The second phase, namely, the turning point, is achieved when a certain level of income has been reached, which causes a shift in the pollution trajectory. This further led to the third phase, which was characterized by mitigating environmental. However, when the phase reaches the turning point, the income level begins to be inseparable from emissions and environmental degradation, which eventually leads to the next phase of economic growth, where the deployment of clean technology and innovation begins to emerge (Leal and Marques, 2022). Numerous studies have tested the form of the EKC and produced various verification results. In addition to inverted U-shaped curves, studies have shown the presence of linear shapes: U-positive, N-inverted, and positive N-shaped (e.g., Chen and Ngniatedema, 2018; Kallis and Bliss, 2019; Nepal and Nirash, 2019; Shahbaz *et al.*, 2021; Kanbur *et al.*, 2021). These results have gradually emerged as research continues to improve. However, sustainable development is necessary to reach this turning point when economic growth is achieved without destroying the economic capital base, leading to low carbon emissions, the efficient use of natural resources, and social inclusion.

The relationship between economic development and environmental degradation is complex, with the costs of environmental degradation often borne by low-income and marginalized communities. While some studies have suggested that the EKC hypothesis provides a useful framework for understanding the relationship between economic growth and environmental degradation (Chen and Ngniatedema, 2018), others have argued that this framework is overly simplistic and overlooks important factors, such as the distribution of environmental costs and the role of institutions and governance in shaping environmental outcomes (Kallis and Bliss, 2019).

Indeed, the heterogeneity of the EKC relationship across different countries and regions is an important gap in the literature that needs to be addressed. In developed economies, the EKC curve often takes an inverted-U shape, where environmental degradation initially increases with economic growth, but then decreases after a certain income threshold (Stern, 2017). However, in emerging economies, the EKC curve may take a different shape, owing to differences in institutional quality, technological capabilities, and environmental regulations (Kanbur *et al.*, 2021). Recent studies on the EKC relationship in China and Southeast Asia have revealed that economic growth is accompanied by a decline in some types of environmental pollution (Chen and Ngniatedema, 2018; Kallis and Bliss, 2019). However, Ding *et al.* (2020) found evidence of an N-shaped EKC curve in China, in which environmental degradation initially increased with economic growth, then decreased, and finally increased again at higher income levels. In contrast, Shahbaz *et al.* (2021) found evidence of an inverted U-shaped EKC curve in India. Other studies have found little or no evidence of an EKC relationship in sub-Saharan Africa or South Asia, where economic growth is associated with increased environmental degradation (Nepal and Nirash, 2019).

This heterogeneity suggests that the relationship between economic development and environmental degradation is shaped by a wide range of contextual factors such as differences in natural resource endowments, governance structures, and cultural attitudes towards the environment. For example, countries that are rich in natural resources, such as oil or minerals, may be more likely to experience a resource curse where economic growth is accompanied by environmental degradation and social conflict (Yin and Zhao, 2019). Similarly, countries with weak governance structures or inadequate environmental regulations are more likely to experience environmental degradation due to economic growth (Kallis and Bliss, 2019). These contextual factors are likely to be particularly important for emerging economies in Asia, such as China, India, and ASEAN countries, which have experienced rapid economic growth but environmental losses in recent decades. While some of these countries have made progress in addressing environmental challenges, such as air pollution in China or water pollution in some parts of ASEAN, they also face significant environmental risks and challenges, such as climate change, deforestation, and biodiversity loss (ADB, 2020). Addressing these challenges will require a better understanding of the complex interactions among economic development, globalization, and the environment, as well as more effective governance and regulation of trade and finance.

Financial development has been explored in justifying the EKC hypothesis, in addition to globalization, trade openness, technology advances, institutional capacity, and so on. However, the support for the EKC-financial development nexus is at best mixed and varies across countries and sectors due to differences in institutional quality, technological capabilities, environmental regulations, political will, and structural changes (Kanbur *et al.*, 2021; Li *et al.*, 2020; Yadav *et al.*, 2020). More of recent, new studies suggest that green finance and its interaction effect with financial development facilitates environmental sustainability through technical innovation, capital support, financial assistance, and resource allocation. It stimulates economic activity while maintaining environmental quality by supporting the financing of renewable energy projects, energy infrastructure, and green energy for decarbonization (Sachs *et al.*, 2019). Through technological innovation, firms engaged in green technological innovation typically receive external credit, thereby supporting their research and development (R&D) activities, contributing to the improvement of energy efficiency utilization, facilitating the rapid growth of the green industry, and mitigating environmental pollution and ecological damage. Li *et al.* (2018) argue that government subsidies in green loans and green production innovation can reduce the financial burden on businesses and encourage the introduction and adoption of technological innovations. However, Lin (2022) revealed that strong urbanization and R&D investment must support the role of green finance. Developing a special mechanism to increase R&D investment is crucial to promote green finance through technological innovation. Such criteria remain a significant challenge for emerging nations in South and East Asia.

In the capital support channel, green finance supports firms with low energy intensity and carbon and pollution emissions, thereby discouraging them from engaging in high-emission and high-pollution business activities. For instance, van Veelen (2021) posited that the inclusion of green credit terms in China significantly affects corporate financing costs. Companies with high pollution and emissions face higher funding costs, whereas environmentally friendly businesses have lower funding costs. Supporting green upgrading of corporations improves ecological integrity both economically and environmentally, demonstrating how green credit policies can affect a company's lending performance (Zhang *et al.*, 2021). In addition, loan issuance for the accomplishment of green projects can reduce pollution, which leads to a better atmosphere, natural resources, and health, thereby reducing the risk of covid-19 (Biduri and Proyogi, 2021).

From the perspective of resource allocation channels, green finance may help enhance capital utilization efficiency through direct capital flows from industries with high emissions and poor efficiency to those with low emissions and high efficiency. Briefly, based on the explanation above, the three channels share certain similarities; by means, both are associated with the external financial support provided to environmentally friendly businesses. In this regard, developed financial systems make substantial contributions through the mobilization and allocation of idle resources to reduce financing costs and the financial burden borne by firms engaging in environmentally friendly and green behaviors (Kim *et al.*, 2020). A rampant study proved that green finance has a significant impact on decarbonization (Mamun *et al.*, 2022; Lan *et al.*, 2023; Fu and Irfan, 2022; Lee *et al.*, 2023a; Guo *et al.*, 2022; Alharbi *et al.*, 2023), improving the performance of sustainable development (Geng *et al.*, 2023; Jinru *et al.*, 2022; Lee *et al.*, 2023), and improving the quality of health during the Covid-19 outbreak (Chien *et al.*, 2021a; Chien *et al.*, 2021b; Biduri and Proyogi, 2021).

Nevertheless, the effectiveness of green finance varies across countries, with developed countries with high levels of credit markets, innovation, and climate change exposure benefiting the most. Investments in the green finance sphere are known to have low risk and high rates of return for investors (Schopohl *et al.*, 2021; Lee *et al.*, 2023). Yet, the weak financial foundation of the government, high costs and risks, and reluctance of the banking industry to fund green investments limit the private sector's interest in green technologies. Although the direction of government policy and national development in various countries play a crucial role in attracting investors, green investments are still considered highly risky by the banking industry (Saydaliev and Chin, 2022). Khan *et al.* (2021) and Hunjra *et al.* (2023) emphasize the importance of financial institution quality and financial development in decarbonization. Poor quality of financial institutions in several countries results in a decrease in environmental quality, whereas strong financial institutions tend to improve environmental quality. Their study inferred that green finance could drive decarbonization through positive signals of economic growth and financial development.

In recent years, numerous studies have focused on the intersection between green finance and the environment. However, most of these investigations have concentrated on individual countries, notably China (e.g., Zhou *et al.*, 2020; Chen and Chen, 2021). Conversely, some studies embrace a multi-country approach, primarily focusing on developed nations (De Haas and Popov, 2019; Meo and Karim, 2022). The literature reveals conflicting evidence concerning the impact of green finance on carbon emissions, with some studies suggesting a positive influence (e.g., Meo and Karim, 2022), while others indicate a negative impact (e.g., Wang and Ma, 2022). Notably, when investigating the impact of green finance on carbon emissions, Khan *et al.* (2021) and Hunjra *et al.* (2023) underscored the critical role of institutional quality and financial development.

Diverse studies have explored the relationship between financial development and carbon emissions, yielding mixed findings. Some studies indicate a negative relationship between financial development and carbon emissions (Sadorsky, 2010) and emission intensity (Tao *et al.*, 2023), whereas others report a positive impact (Ren *et al.*, 2023; Yang *et al.*, 2023). Recent research emphasizes the inclusion of financial development along with green finance, highlighting its pivotal role in the effective allocation of funds, particularly climate funds, to eco-friendly and green projects (Li *et al.*, 2021; Çitil *et al.*, 2023). Beyond financial development, the effective utilization of green finance for decarbonization necessitates a robust institutional environment. Green finance, which integrates environmental considerations into financial decisions, demands supportive institutional frameworks to achieve its objectives (UN Environment Program 2018). Fu *et al.* (2023) underscored the crucial role of a robust regulatory framework in the success of green finance, while Çitil *et al.* (2023) demonstrated the significant influence of both green finance and institutional quality on air quality. Consequently, achieving efficiency in green finance requires concurrent development in both the financial and institutional realms.

In summary, support for the Environmental Kuznets Curve and green finance is characterized by mixed and varied findings across countries and sectors, contingent on disparities in institutional quality, technological capabilities, environmental regulations, political will, and structural changes (Kanbur *et al.*, 2021; Li *et al.*, 2020; Yadav *et al.*, 2020). The substantial differences in the institutional environment, encompassing legal, financial, and regulatory aspects, between developed and emerging countries underscore the need for in-depth investigation. Surprisingly, there is a scarcity of studies exploring the combined impact of green finance, financial development, and institutional development in emerging Asian economies. In light of these gaps, our study aims to fill them by examining the impact of green finance, financial development, institutional quality, energy consumption, and economic growth on carbon emissions in N-10 emerging Asian economies.

3. Methodology

Using the EKC framework, this study examines the impact of green finance (GFin), financial development (FD), trade openness (TO), institutional quality (IQ), and renewable energy consumption (REN) on pollution emissions in ten developing East and South Asian economies. These countries include China, India, Pakistan, Bangladesh, Sri Lanka, Indonesia, Malaysia, Thailand, Vietnam, and the Philippines. A panel dataset that ranges from 2000 to 2019 is employed for analysis of two specified models. We limit our analysis until 2019 because consistent green finance data for all our sample countries were not yet available when we started our study in early 2022. Model 1 assesses the EKC hypothesis via economic growth, GFin, IQ, and FD, renewable energy consumption (REN), and trade openness (TO). In the Model 2, an interaction term between green finance and financial development (GFD) is included. The dependent variable was carbon emissions (CO2), measured in millions of metric tons of CO2 equivalent and sourced from the United Nation.

Among the independent variables, the green finance (GFin) can be defined as financial expenditures with environmental goals and benefits. GFin aims to tackle environmental and sustainability issues by providing funds for enabling technologies to reduce pollutant emissions, save energy, and efficiently use natural resources (Zhang *et al.*, 2022). Following previous studies (Wang *et al.*, 2022; Bakry *et al.*, 2023), we capture GFin using the natural logarithm of international financial support for R&D in clean energy and renewable energy production, including hybrid systems (constant at 2016, US$ millions). The GFin data is sourced from Our World in Data database. Next, the IMF financial development index that incorporates both financial institutions' development and financial market development is taken as proxy for financial development.

To capture institutional quality (IQ), we used 12-point index of "international Country Risk Guide (ICRG)". The index includes "bureaucratic quality, government stability, law and order, corruption, socio-economic conditions, investment profile, demographic accountability, ethnic tensions, religious tensions, internal conflict, external conflict, and military in politics" (PRS Group, 2020). Similar to past studies like Calderón *et al.* (2016), Asif and Majid (2018), and Hussain and Dogan (2021), we used a single ICRG's index for IQ by taking the average of all indices. For the EKC hypothesis, we include real gross domestic product per capita (constant at 2015, US$ millions) and square of it. Both data are extracted from the world development indicators from World Bank. Table 2 presents detailed measurements of the variables and data sources.

Before the empirical estimation, all data are log-transformed to avoid outliers (Stabilizing Variance) and reduce skewness, as well as for elasticities discussion of the coefficients. Because the linear and quadratic series are part of the same equation, mean centering of the series is performed to reduce the high values of the variance inflation factor and tackle the issue of multicollinearity.

Table 2: Variables description

Variable	Description	Source
Carbon emissions per capita (COP)	Annual carbon emissions in Million metric tons of CO_2 equivalent per capita	United Nations Framework Convention on Climate Change (UNFCCC) -(https://di.unfccc.int/detailed_data_by_party)
GDP	Gross Domestic Product per capita (constant 2015 US$)	WDI-World Bank- (https://data.worldbank.org/indicator/NY.GDP.PCAP.KD)
Green finance (GFin)	International financial flows to developing countries in support of clean energy R&D and renewable energy production, including the hybrid systems (US$ millions at constant value)	Our World in Data- (https://ourworldindata.org/grapher/international-finance-clean-energy)
Financial development (FD)	Financial Development Index	IMF-(data.imf.org/?sk=F8032E80-B36C-43B1-AC26-493C5B1CD33B&ref=mondato-insight)
Institutional quality (IQ)	Institutional Quality Composite Index	International Country Risk Guide- The PRS Group Incorporation
Renewable energy consumption (REN)	Renewable energy consumption (% of total final energy consumption)	WDI-World Bank (https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS)
Trade openness (TO)	Trade (percentage of GDP)	WDI-World Bank (https://data.worldbank.org/indicator/NE.TRD.GNFS.ZS)

3.1 Model Specification

The Environmental Kuznets Curve (EKC) postulates a nonlinear relationship between income and pollution. As discussed earlier, a positive association exists between income and environmental degradation during the early growth stages. However, constant economic expansion augments technological development and increases the proportion of total output devoted to the service sector compared to the production sector. In response to these adjustments, the overall ecosystem improves and the relationship between pollution and income becomes negative (Dinda, 2004). For this study, we introduce two new model specifications based on the baseline model that employed by previous studies (e.g., Zhao *et al.*, 2022; Han and Jun, 2023). For Model 1 that specified by Eq. (1), lnCOP denotes carbon emissions per capita, lnGDP and lnGDP^2 are the real GDP per capita and its square, respectively. The rest are green finance ($\text{lnGFin}_{\text{it}}$), financial development (FD), institutional quality (IQ), trade openness (TO), and renewable energy consumptions (REN).

$$lnCOP_{it} = \alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 lnGDP_{it}^2 + \alpha_3 lnGFin_{it} + \alpha_4 lnFD_{it} + \alpha_5 lnIQ_{it} + \alpha_6 lnREN_{it} + \alpha_7 lnTO_{it} + \mu_{it} \quad (1)$$

In equation (1), the subscripts represent the cross-sectional (i) and time (t) elements of the variables. $\alpha_1 - \alpha_3$ are coefficient estimates, α_0 constant term, and μ_{it} is the white-noise term. The relationship between GDP and COP can take various forms, where if, α_1=α_2= 0, (no relationship), α_1> 0, α_2= 0 (positive monotonic relationship), α_1< 0, α_2= 0 (negative monotonic relationship), α_1> 0, α_2< 0, (inverted U-shape relationship), and α_1< 0, α_2> 0 (U-shape relationship). More Specifically, the positive and significant α_1; and negative and significant α_2, justifies the validity of EKC hypothesis. Next, the negative and significant coefficients attached to α_3, α_4, α_5, and α_6 implies that GFin, FD, IQ, and REN, respectively, can help reduce COP. Finally, the positive significant coefficient associated to α_7 suggests that trade openness can potentially increase COP.

For Model 2 that specified by Eq. (2), an interacting effect of financial development and green finance (FD*GFIN) is introduced. We expect negative and significant coefficient α_5, which implies that financial markets and institutions development captured by financial development index can facilitate green finance to play a more prominent role in reducing carbon emissions among the East and South Asian economies. The new specification of Model 2 is as follows:

$$lnCOP_{it} = \alpha_0 + \alpha_1 lnGDP_{it} + \alpha_2 lnGDP_{it}^2 + \alpha_3 lnGFin_{it} + \alpha_4 lnFD_{it} + \alpha_5 ln(FD * GFIN)_{it} + \alpha_6 lnIQ_{it} + \alpha_7 lnREN_{it} + \alpha_8 lnTO_{it} + \mu_{it} \quad (2)$$

We analyse two models due to two main reasons. First, in the empirical literature, some studies used green finance and financial development as separate variables and others investigated the interacting effect of green finance and financial development on carbon emissions (Lv *et al.*, 2022; Ping and Shah, 2023). Second, when we included both green finance and financial development as separate predictors in Model 1, we noticed their insignificant impacts on carbon emissions. Therefore, in the second model, we included their interaction terms, but still we found insignificant impact of green finance and financial development on carbon emissions.

3.2 Econometric Methods

3.2.1 Cross-sectional Dependency

It is believed that due to globalization, financial market integration, and economic interdependence among countries and regions, various macroeconomic and financial variables' impact on one country may extend to others (Tao *et al.*, 2021; Zhao *et al.*, 2022). This interdependence in the data across cross-sectional units is called cross-sectional dependency (CSD). The presence of CSD leads to omitted variables bias (Salim *et al.*, 2017) and inefficient estimation (Zhao *et al.*, 2022). When data suffers from CSD, it requires the application of cross-sectionally augmented panel data estimators. CSD arises from residual interdependency and cross-sections exposure to common shocks. Commodity prices in international markets, global market uncertainty, the Covid-19 pandemic, and supply-chain disruptions are some examples of common shocks, which simultaneously affect various countries. In this way, higher connectivity and exposure to common shocks among the East and South Asian countries may lead to cross-sectional interdependence in the data. Therefore, we use Pesaran's (2015) to determine CSD among the units. Given Eq. (3) denotes Pesaran's CSD test:

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{j=i+1}^{N} \gamma_{ji}\right) \quad (3)$$

where cross-sectional units (*N*), time (*T*), *i* and *j* represent error correlation among the sample countries.

3.2.2 Slope Heterogeneity

In the presence of CSD, Pesaran and Yamagata (2008) established a random regression model to observe heterogeneity in slope parameters in panel data analysis. The inability to accommodate slope heterogeneity can lead to unreliable coefficients (see, Li *et al.*, 2022). Therefore, we observe slope heterogeneity through Pesaran and Yamagata (2008), where the null hypothesis assumes slope homogeneity.

3.2.3 Stationarity Testing

An important procedure before the cointegration and error correction modelling is to examine the variables' stationarity properties. When panel data suffers from issues like CSD and heterogeneity, we can only apply second-generation panel unit root tests to tackle these panel data issues. Therefore, to observe unit root we use second-generation panel unit root tests CIPS and Pesaran's CADF (PSCASDF) of Pesaran *et al.* (2009) and Pesaran (2007), respectively. These tests perform well in the presence of structural breaks, CSD, and slope heterogeneity (Moon and Perron, 2012).

3.2.4 Panel Cointegration

The next step is to establish a cointegrating relationship between the studied variables across all sample countries. For this matter, we are using Westerlund and Edgerton's (2008) test for panel cointegration. This test efficiently adjusts to cross-sectional structural breaks, CSD, slope parameters heterogeneity, and autocorrelated standard errors (Tao *et al.*, 2021). Next, due to the long panel (*T*>*N*) in the current study, we also use Pedroni's (2004) panel cointegration test which better performs in long panels (see, Neal, 2014).

3.2.5 Cross-sectionally Augmented Autoregressive Distributed Lag (CS-ARDL)

Once we established cointegration and determined slope heterogeneity and CSD in the data, CS-ARDL is the most suitable model to study both short- and long-term dynamic relationships. This model was originally conceptualized by Pesaran and Smith (1995) and further enriched by Chudik and Pesaran (2015). Previous studies have advocated (see, Yao *et al.*, 2019; Ahmed, 2020) that CS-ARDL addresses slope heterogeneity, cross-country error dependency, and helps estimate dynamic common correlation effects. Further, this method is credited to dealing with endogeneity problems (Chudik and Pesaran, 2015). Although one of the study limitations is small sample size (*T*-20; *N*=10). However, with a similar sample sizes CS-ARDL method has been applied in the literature (see, Tao *et al.*, 2021; Zhao *et al.*, 2022). Besides, CS-ARDL has been argued to infer accurate results even with small sample size (Hao *et al.*, 2021; Zhao *et al.*, 2022). Specifically, the CS-ARDL model becomes more relevant when *T*>*N* (Erülgen *et al.*, 2020), such is the case in this work. Due to these strong assumptions and the data properties, we apply the CS-ARDL method, which specifications are given in equation (4) as:

$$Z_{i,t} = \sum_{i=0}^{Pu} \theta_{i,t} W_{i,t-1} + \sum_{i=0}^{Pv} \rho_{i,t} X_{i,t-1} + \varepsilon_{i,t} \tag{4}$$

Next, we extend Eq. (4) into Eq. (5) by including the cross-section averages of the dependent and independent variables.

$$Z_{i,t} = \sum_{i=0}^{Pu} \theta_{i,t} Z_{i,t-1} + \sum_{i=0}^{Pv} \rho_{i,t} X_{i,t-1} + \sum_{i=0}^{Pw} \alpha_i \bar{X}_{t-1} + \varepsilon_{i,t} \tag{5}$$

where the symbol Z is the dependent variable depicting carbon emissions of country i at time t. The parameter $W_{i,t-1}$ denotes all the regressors LGDP, LGDP^2, LGFin, FD, IQ, TO, REN and LGFD. Moreover, $\bar{X}_{t-1}$ shows cross-sectional averages of all variables to alleviate the CSD problem due to the common spillover effect. Lastly, the titles Pu, Pv, and Pw illustrate the lagged effects of each of the variables. Now we present the mean group estimator and the long-run effects with the help of Eq. (6) and Eq. (7), respectively.

$$\hat{\lambda}CD - ARDL_i = \frac{\sum_{i=0}^{pv} \widehat{\gamma_{li}}}{1 = \sum_{i=0}} \hat{\Omega}_{l,t} \tag{6}$$

$$\bar{\hat{\lambda}}_{MG} = \frac{1}{N} \sum_{i=1}^{N} \hat{\lambda}_i \tag{7}$$

In the current study, the short-term coefficients are estimated as follows:

$$\Delta Z_{it} = \theta_i\left[Z_{i,t-1} - \delta_i X_{i,t-1}\right] - \sum_{i=0}^{Pu-1} \theta_{i,t}\Delta_i Z_{i,t-1} + \sum_{i=0}^{Pv} \rho_{i,t}\Delta_i X_{i,t-1} + \sum_{i=0}^{Pw} \alpha_i \bar{X}_t + \varepsilon_{i,t} \quad (8)$$

where in the above equation:

$$\Delta_i = \mathrm{t} - (\mathrm{t} - 1)$$

$$\hat{\lambda} = -\left(1 - \sum_{i=0}^{Pu-1} \hat{\Omega}_{i,t}\right) \quad (9)$$

$$\hat{\lambda}_i = \frac{\sum_{i=0}^{pv} \hat{\gamma}_{i,t}}{\hat{\tau}_i} \quad (10)$$

$$\bar{\hat{\lambda}}_{MG} = \frac{1}{N}\sum_{i=1}^{N} \hat{\lambda}_i \quad (11)$$

3.2.6 Robustness Checks (AMG and CCEMG)

For robustness checks of the CS-ARDL results, we applied the Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG) estimators of Eberhardt and Teal (2010) and Pesaran (2006). These methods are consistent, reliable, and offer efficient estimates that allow for group-specific regressions and cross-group average coefficients. Specifically, these estimators deal well with slope heterogeneity, CSD, and structural breaks (Li *et al.*, 2021). In addition, AMG is credited with performing well in the presence of endogeneity problems and non-stationarity (Eberhardt, 2012). CCEMG is also a common dynamic process that induces CSD, time-variant factors, and slope heterogeneity effect with identification issues (Eberhardt and Teal, 2010).

4. Findings and Discussion

4.1 Empirical Results and Discussion

This section begins with the data properties evaluation. The descriptive statistics are presented in Table 3, followed by correlation analysis in Table 4, Variance Inflation Factor (VIF) analysis in Table 5, CSD test of cross-sectional dependence in Table 6, slope heterogeneity test in Table 7, and the second-generation panel unit root tests in Table 8. The reported descriptive statistics include mean, standard deviation, minimum and maximum to ensure data consistency and reliability. In addition, the skewness and kurtosis statistics, and Adj. $\chi 2$ are estimated to gauge the normal distribution of our sample data. However, like many time series studies, the data are generally non-normally distributed.

Table 3: Descriptive statistics

Variable	N	Mean	Std. dev.	Min	Max	Pr(Skew)	Pr(Kurt.)	Adj. χ^2
LCOP	200	0.448	0.943	-1.583	2.109	0.319	0.000	15.780***
LGDP	200	7.832	0.727	6.471	9.316	0.319	0.000	18.160***
LGDP^2	200	4.316	0.954	0.000	5.298	0.000	0.000	54.130***
LGFin	193	4.194	0.940	0.000	5.187	0.000	0.000	48.900***
FD	200	0.391	0.150	0.135	0.735	0.002	0.006	14.710***
IQ	200	4.960	0.652	3.458	6.375	0.871	0.015	5.850**
LGFD	193	1.622	0.738	0.000	3.618	0.000	0.329	14.710***
TO	200	76.970	48.080	24.700	220.410	0.000	0.794	21.380***
REN	200	33.307	16.333	1.960	64.160	0.286	0.002	9.260**

Notes: *** and ** indicate significance at the 1% and 5% level, respectively. Pr (Skew) and Pr (Kurt.) are p-values for skewness and kurtosis, whereas Adj. χ^2 is the adjusted chi-square. Together, these three tests check for the data distribution and normality. Data transformation into natural logarithm includes the variables of Carbon emissions (LCOP), GDP (LGDP), GDP^2 (LGDP^2), Green Finance (LGFin) and the interaction variable (LGFD). As for the percentage, scale and ratio data, natural logarithm is not taken, such as the Financial development (FD), Institutional Quality (IQ), Trade openness (TO), and Renewable energy consumption (REN).

From the correlation analysis in Table 4, we found different degree of correlations among variables, ranging from -0.049 to 0.856. In what follows, we rely on the VIF and 1/VIF statistics that reported in Table 5, as diagnostic tools to identify multicollinearity. For Model 1, VIF ranges from 1.15 to 3.18, while for Model 2, VIF statistics are well below 3. At the same time, 0 < 1/VIF < 1 for both Model 1 and 2. Both VIF and 1/VIF statistics indicate moderate multicollinearity. In other words, there is some correlation between the variables and other independent variables, but it is not severe enough to cause significant issues in the analysis, that unstable and unreliable regression coefficient estimates are unlikely.

Table 4: Correlation analysis

Variables	LCOP	LGDP	LGDP^2	LGF	FD	IQ	LGFD	TO	REN
LCOP	1.000								
LGDP	0.856*	1.000							
LGDP^2	0.228*	0.316*	1.000						
LGFin	-0.049	-0.033	0.056	1.000					
FD	0.881*	0.748*	0.183*	-0.030	1.000				
IQ	0.622*	0.562*	0.245*	-0.067	0.570*	1.000			
LGFD	0.716*	0.604*	0.163*	0.486*	0.838*	0.421*	1.000		
TO	0.555*	0.554*	0.228*	-0.064	0.575*	0.657*	0.439*	1.000	
REN	-0.861*	-0.739*	-0.188*	0.049	-0.787*	-0.629*	-0.627*	-0.536*	1.000

Notes: * indicates significance at the 5% level. Definition of variables refers to Table 3.

Table 5: Variance Inflation Factor (VIF)

DV: LCOP	Model 1		Model 2	
	VIF	1/VIF	VIF	1/VIF
LGDP	2.740	0.364	2.490	0.402
LGDP^2	1.150	0.872	1.190	0.844
LGFin	1.990	0.501	1.010	0.988
FD	3.230	0.310	2.900	0.345
IQ	2.070	0.482	2.040	0.491
TO	1.900	0.528	1.720	0.582
REN	3.180	0.315	2.780	0.360
LGFD	-	-	1.990	0.503
Mean VIF	2.180		2.140	

Notes: Definition of variables refers to Table 4.1. VIF = 1: No multicollinearity; VIF > 1 and < 5: Moderate multicollinearity; VIF >= 5: High multicollinearity. 1/VIF = 1: No multicollinearity; 0 < 1/VIF < 1: Moderate multicollinearity; 1/VIF = 0: High multicollinearity.

Next, we checked cross-sectional dependence using Pesaran (2015)'s CSD test reported in Table 6. Despite the Institutional quality (IQ) that fail to reject the null hypothesis of no cross-sectional dependence, all other variables are reported significant at 10%, 5% and 1% level. This result implies that a shock in any of the East and South Asian is highly spill over to other economies in the region. It can be due to supply-chain integration, commodity price linkage, interconnectivity in the financial system, and various environmental protocols like the Kyoto Protocol and Paris Agreement. In brief, LCOP, LGDP, $LGDP^2$, LGFin, FD, IQ, TO, REN and LGFD are dependent among the emerging East and South Asian countries.

Table 6: Output of Pesaran's (2015) CSD test

Variable	CSD-test	p-value
LCOP	25.140***	0.000
LGDP	29.620***	0.000
$LGDP^2$	-1.660*	0.097
LGFin	1.910*	0.056
FD	8.750***	0.000
IQ	0.590	0.554
TO	4.460***	0.000
REN	8.950***	0.000
LGFD	2.460**	0.014

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. CSD = cross-sectional dependence. H0: Cross-sectional Independence.

In the next step, we check whether the slope parameters are heterogenous or homogenous through the test advocated by Pesaran and Yamagata (2008). Using this method, we estimated the delta (Δ) and adjusted delta (Adjusted Δ) to evaluate the alternate hypothesis of slope heterogeneity against the null hypothesis of slope homogeneity. At 5% significance level, slope homogenous have been rejected for Model 1 and 2. Table 7 confirms the supports for slope heterogeneity, which suggests that slope parameters vary across the cross-sectional units represented by developing East and South Asian economies.

Table 7: Slope heterogeneity (Pesaran and Yamagata, 2008)

DV: LCOP	Model 1	Model 2
Δ tilde	5.420**	4.389**
Δ tilde Adjusted	7.419**	6.322**

Notes: ** denotes significance at 5% level. H_0: slope coefficients are homogeneous.

Given the issues of CSD and slope heterogeneity in the data, we must proceed with the second-generation panel unit root tests that accommodate the panel data issues. For this matter, we applied CIPS and Pesaran's CADF (PSCADF) tests of Pesaran *et al.* (2009) and Pesaran (2007) panel unit root tests, respectively. From the results in Table 8, both the CIPS and PSCADF tests imply a $I(1)$ process among variables after the first-differencing. It implies that the mean and variance of the variables used in the models varies over time.

Now we aim to establish the cointegrating relationship between the studied variables. For this matter, we apply Westerlund and Edgerton's (2008) and Pedroni's (2004) cointegration tests. In Table 9, the results overwhelmingly accept the alternate hypothesis of a stable and long-term cointegrating relationship among the studied variables presented in both Model 1 and 2.

Table 8: Results of panel unit root tests

Variables	Level			
	CIPS		CIPS-M	
	Constant	Constant and trend	Constant	Constant and trend
LCOP	-1.908	-1.959	-1.908	-1.959
LGDP	-1.665	-1.249	-2.027	-1.197
$LGDP^2$	-1.604	-1.762	-1.604	-1.762
LGFin	-2.616	-2.617	-2.197	-2.195
FD	-2.207	-2.756	-2.280	-2.822
IQ	-2.224	-2.601	-2.321	-2.695
TO	-1.001	-1.045	-1.098	-1.045
REN	-1.273	-1.36	-1.426	-1.481
LGFD	-1.918	-1.992	-2.002	-1.826

Variables	First Difference				Order
	CIPS		CIPS-M		
	Constant	Constant and trend	Constant	Constant and trend	
LCOP	-3.726***	-4.114***	-3.726***	-4.142***	*I*(1)
LGDP	-2.473***	-2.939**	-2.473**	-2.939**	*I*(1)
$LGDP^2$	-3.686***	-3.814***	-3.686***	-3.814***	*I*(1)
LGFin	-5.956***	-6.062***	-5.551***	-5.638***	*I*(1)
FD	-4.286***	-4.192***	-4.265***	-4.246***	*I*(1)
IQ	-4.392***	-4.401***	-4.392***	-4.401***	*I*(1)
TO	-3.424***	-3.838***	-3.085***	-3.362***	*I*(1)
REN	-3.085***	-3.362***	-3.424***	-3.989***	*I*(1)
LGFD	-5.676***	-5.656***	-5.139***	-5.252***	*I*(1)

Notes: *** and ** and * indicate significance at the 1%, 5% and 10% level, respectively.

Table 9: Models panel cointegration tests

Cointegration tests	Model 1 (t-statistic)	Model 2 (t-statistic)
Westerlund and Edgerton test		
Variance ratio	-2.129**	-1.615**
Pedroni test		
Modified Phillips–Perron t	3.663***	3.934***
Phillips–Perron t	-5.873***	-4.282***
Augmented Dickey–Fuller t	-5.403***	-4.198***

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

After establishing the cointegration relationship, we proceed with the CS-ARDL estimation reported at Table 10, to assess the dynamic long- and short-run impacts of the examined variables on carbon emissions. The significant long-run economic coefficient, represented by GDP per capita (LGDP), was reported as 0.425 (Model 1) and 0.465 (Model 2). The positive relationship between LCOP and LGDP indicates that economic development in emerging Asian countries comes at the cost of increased carbon emissions, leading to environmental degradation in the long run. Many Asian countries have focused on energy-intensive production and industrial sectors over the past three decades, resulting in higher carbon emissions. Among others, Indonesia and Malaysia have faced deforestation due to palm oil plantations and rubber estates. Interestingly, the quadratic term of GDP ($LGDP^2$) showed negative but insignificant impacts on carbon emissions with respective coefficients of -0.033 (Model 1) and -0.043 (Model 2). These results do not support the inverted-U shaped Environmental Kuznets Curve (EKC) hypothesis, which suggests that beyond a certain level of economic development, environmental degradation starts to decline, and environmental quality improves. This finding serves as an early warning signal regarding the environmental consequences of ongoing economic growth.

Table 10: Long-run estimates and short-run dynamics (CS-ARDL)

	Model 1		Model 2	
DV: LCOP	Coefficient	Std. Err.	Coefficient	Std. Err.
Long-run estimates				
LGDP	0.425***	0.179	0.465**	0.221
$LGDP^2$	-0.033	0.041	-0.043	0.065
LGFin	-0.001	0.003	0.117	0.120
FD	-0.090	0.546	1.070	2.029
IQ	-0.061**	0.028	-0.072***	0.026
TO	-0.001	0.002	-0.001	0.002
REN	-0.033***	0.009	-0.035***	0.010
LGFD (interaction)	-	-	-0.294	0.360
CSD-Statistic	-0.570	-	-0.640	-
Short-run dynamics				
$\Delta LCOP_{t-1}$	0.007**	0.149	0.033	0.129
ΔLGDP	0.427***	0.174	0.446**	0.198
$\Delta LGDP^2$	-0.021	0.031	-0.032	0.050
ΔLGFin	0.001	0.003	0.043	0.061
ΔFD	-0.340	0.355	-0.195	1.065
ΔIQ	-0.059**	0.029	-0.062**	0.025
ΔTO	-0.001	0.001	0.000	0.001
ΔREN	-0.029***	0.008	-0.029***	0.008
ΔLGFD (interaction)	-	-	-0.061	0.186
ECT_{t-1}	-0.993***	0.148	-0.9669***	0.128

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Definition of variables refers to Table 3. Δ indicates the changes of variables, CSD denotes Cross-sectional dependence, and ECT denotes Error Correction Term.

When assessing institutional quality (IQ) and renewable energy consumption (REN), both coefficients are significant and have the expected signs in both Model 1 and Model 2. In Table 10, the long-run estimates for IQ are reported as -0.061 and -0.072, and for REN as -0.033 and -0.035, with and without considering the interaction effect of green finance. The negative signs indicate that both IQ and REN contribute to environmental quality improvements by reducing carbon emissions. An enhancement of IQ by 1% reduce the CO_2 by 0.061%-0.072%, whereas an increasing of REN reduce the CO_2 by 0.033%-0.035%. This finding aligns with previous studies such as Ibrahim and Law (2016) and Lau *et al.* (2018), which highlight institutional quality as a significant yet often overlooked factor influencing environmental sustainability. Likewise, the significant outcome of REN on CO_2 corresponds with the findings of Spiegel-Feld *et al.* (2016) and Khan *et al.* (2020), who established that renewable energy consumption improves environmental quality.

However, the other macro variable, trade openness (TO), did not show a significant impact on carbon emissions. In addition, green finance, financial development, and the interaction between these variables were all found to be insignificant in supporting the Environmental Kuznets Curve (EKC) hypothesis. These results contradict the findings of Bhatti (2020) and Othman (2020) but are consistent with the research by Nasreen (2015), who observed that financial development reduces environmental degradation in high-income countries but increases it in middle- and low-income countries. The ineffectiveness of green finance in our study may be attributed to institutional barriers, such as weak regulatory frameworks and a lack of financial infrastructure among the emerging Asian countries, as noted by Li *et al.* (2020).

Table 10 also presents the short-run findings, which are consistent with the long-run effects at different magnitudes. First, ΔLGDP shows a positive and significant effect on carbon emissions in Model 1 and 2, indicating an increase in non-sustainable economic development among the emerging Asian countries. Second, ΔIQ and ΔREN exhibit significant and negative impacts on per capita carbon emissions in East and South Asian economies. Both institutional quality and renewable energy consumption mimic the pattern of carbon mitigation effect, and when used together, they produce the same effect in both short and long-run periods. Moreover, the lag effect attached to carbon emissions changes ($\Delta LCOP_{t-1}$) is highly significant and positive, suggesting a lag effect of carbon emissions. In other words, emissions in the previous period significantly and positively affect emissions in the current period.

Third, the error correction terms (ECT_{t-1}) are negative and significant in both Model 1 and 2, which illustrates significant adjustments towards the long-term equilibrium. These ECT coefficients show fast convergence towards steady-state equilibrium with a 99.3% (Model 1) and 96.7% (Model 2) annual adjustment rate, respectively. In other words, the error corrections in response to external shocks require 1-1.1 years of adjustment for Model 1 and Model 2.

Table 11: Robustness results from AMG and CCEMG

Variables DV=LCOP	Augmented Mean Group (AMG)			
	Model 1		Model 2	
	Coefficient	Std.Err.	Coefficient	Std.Err.
LGDP	0.757***	0.204	2.408**	1.269
$LGDP^2$	-0.017	0.019	-0.071	0.049
LGFin	-0.001	0.002	-0.034	0.080
FD	-0.137	0.357	-0.990	0.913
IQ	-0.037**	0.023	-0.216**	0.117
TO	0.000	0.001	0.000	0.003
REN	-0.030***	0.009	-0.094**	0.041
LGfd	-	-	-0.093	0.159
Wald test	49.720***		70.980***	
CSD	-1.980**		-1.113	
Variables DV=LCOP	**Common Correlated Affects Mean Group (CCEMG)**			
	Model 1		Model 2	
	Coef.	Std. Err.	Coefficient	Std.Err.
LGDP	1.183***	0.511	0.868**	0.432
$LGDP^2$	-0.094	0.078	-0.127	0.131
LGFin	-0.006	0.010	-0.054	0.068
FD	0.578	0.805	-0.132	0.221
IQ	-0.136**	0.057	-0.331**	0.132
TO	0.000	0.003	0.255	0.265
REN	-0.021***	0.001	-0.522***	0.232
LGfd	-	-	-0.176	0.205
Wald test	81.840***		55.200***	
CSD	-0.213		-1.799*	

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively. Definition of variables refers to Table 3. Δ indicates the changes of variables, CSD denotes Cross-sectional dependence.

Next, we conducted robustness checks using the Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG) estimators. The findings are consistent with those reported in Table 10 previously. For instance, Table 11 shows that LGDP has a positive and significant coefficient, while $LGDP^2$ has a negative but insignificant coefficient, thus not supporting the U-shaped EKC hypothesis in both AMG and CCEMG estimators. Additionally, the results from both estimators suggest the important role of institutional quality (IQ) and renewable energy consumption (REN) in reducing carbon emissions in developing South and East Asian economies. However, LGfin, FD, TQ, and the interaction term (LGfd) are again insignificant in curbing carbon emissions among the ten emerging Asian economies. In short, the results from the AMG and CCEMG estimators are consistent with those of the CS-ARDL results. The regression adequacy results presented in Table 11 are acceptable. The Wald tests are all highly significant for all our models. The CSD tests are rather mixed for Model 1 and 2.

4.2 Market Mechanism and Policy Implications

The positive relationship observed between income growth and CO_2 emissions in the East and South Asian countries in our sample is primarily driven by rapid globalization and industrialization, which have come at the cost of the environment in these economies. For instance, the ASEAN region is a major producer of palm oil, rubber, and other commodities, leading to widespread deforestation, land degradation, and biodiversity loss (ADB, 2019). Moreover, countries like China, India, and ASEAN have become key centres for manufacturing and global supply chains, resulting in significant air and water pollution, waste generation, and greenhouse gas emissions (Sovacool *et al.*, 2020b). Based on World bank data base, the ten emerging Asian being studied accounted for half of the world manufacturing output and CO_2 emissions in 2021. The combination of rapid industrial growth and transportation, coupled with inadequate environmental regulations and enforcement, has led to high levels of carbon emissions in these emerging East and South Asian economies.

From Table 9, we observe that the impact coefficients of green finance (LGFin), trade openness (TO), and financial development (FD) on carbon emissions (COP) are negative but statistically insignificant, both with and without the green finance interactions. This finding contradicts the results of studies such as Al-Mulali *et al.* (2015), which found that financial development reduces environmental degradation in 129 sample countries, both in the short-term and long-term. Similarly, it is inconsistent with the findings of Zhao *et al.* (2021), which revealed a significant negative relationship between financial development and carbon emissions in China.

We interpret this result as an indication that the domestic financial markets and financial institutions' development, while stimulating manufacturing exports and attracting foreign direct and portfolio inflows, have not adequately promoted R&D investment that lead to potentially higher technological capabilities and energy-related efficiencies. Most of the financing and investment have been directed toward assembly and production activities that have not effectively reduced carbon emissions. Similarly, the development of commercial banking and credit markets has not sufficiently supported the renewable energy sector. This inefficiency in policy implementation requires urgent attention from policymakers, and further efforts are needed to achieve the goal of carbon neutrality. Literature has already highlighted that the financial sector plays a key role in reducing CO_2 emissions by improving the technological capability of the energy sector (Abbasi and Riaz, 2016). The renewable energy sector's higher dependency on debt and equity financing leads to faster growth in countries with robust financial markets (Kim and Park, 2016). In addition, green finance can also encourage companies to upgrade clean production technology, which will ultimately reduce industrial pollution emissions (Alharbi *et al.*, 2023; Lan *et al.*, 2023).

Recent studies have also revealed the inconsistent support for the EKC hypothesis and financial development, mainly due to factors such as institutional quality, technological capabilities, environmental regulations, political will, and structural changes (Kanbur *et al.*, 2021; Li *et al.*, 2020; Yadav *et al.*, 2020). However, these studies may have overlooked the role of unequal distribution of benefits. Financial development may not equally benefit all segments of the population, especially in many developing Asian countries where financial markets are dominated by a few large players, and access to finance is limited for smaller businesses and households. As a result, the benefits of financial development may not be distributed evenly across society, and environmental degradation may persist or even worsen.

On the other hand, our analysis uncovers that the renewable energy consumption exerts a negative impact on CO_2 emissions. From the viewpoint of climate change, the utilization of renewable energy sources has been considered to have a significant influence on environmental sustainability by decreasing the level of greenhouse gas pollution in the atmosphere (Bhattacharya *et al.*, 2017). This was supported by OECD (2013) that investment in green energy sources is usually considered less carbon-intensive than conventional energy. At present, China is the world's largest producer and consumer of renewable energy, with significant investments in renewable energy infrastructure and capacity. Hydroelectric power is the dominant renewable energy source in China, followed by wind and solar power. South Asian countries, including India, Pakistan, Bangladesh, Sri Lanka, and others, have also been increasing their focus on renewable energy projects such hydroelectric power and wind energy. India, in particular, has made significant strides in renewable energy development, with a strong emphasis on solar power. As for ASEAN, Thailand and the Philippines have been actively promoting renewable energy, including solar and wind power. Indonesia has significant geothermal resources, making geothermal energy a potential source of renewable power. Malaysia and Vietnam are also making progress in incorporating renewable energy into their energy mix, but the development is relatively slow. While the renew energy sectors are increasing receiving positive attention in the region, a few concerns are on the rise. First, the renewable energy landscape in these countries is constantly evolving due to changing policies, technological advancements, and investments in the renewable energy sector. Second, renewable energy market is more labour-intensive than the non-renewable energy sector (Blazejczak *et al.*, 2014) and the economic added values are relatively lower.

In addition, our analysis reveals the crucial role of institutional quality (IQ) in mitigating environmental degradation through effective environmental governance and regulation among emerging Asian economies, even though the Environmental Kuznets Curve (EKC) hypothesis is not supported. This finding aligns with Lau (2018), who emphasizes the importance of institutional quality and good governance in reducing CO_2 emissions, and Wu (2022), who emphasizes the significance of appropriate commercial laws to translate the benefits of foreign direct investment into environmentally sustainable development. Strong institutions play a vital role in promoting sustainable resource management practices, including policies that encourage responsible extraction of natural resources, reforestation, conservation of biodiversity, and protection of ecosystems, thus reducing environmental degradation. Additionally, as countries undergo development, citizens become more aware of environmental issues and demand better environmental protection. Strong institutions are better equipped to respond to these demands, leading to improvements in environmental policies and regulations. Transparent governance empowers citizens and stakeholders to participate in decision-making processes, advocate for environmental issues, and hold authorities accountable for their actions or lack of action regarding environmental challenges.

Among the emerging Asian economies, the status of institutional quality has shown improvements, but it still varies, and this has implications for environmental regulations across the region. The Chinese government has acknowledged the importance of addressing environmental challenges and has made efforts to strengthen environmental regulations and enforcement. However, the effectiveness of these regulations can be influenced by bureaucratic inefficiencies and corruption, particularly at the local governance level. In India, there exists a well-defined legal framework and environmental laws aimed at protecting the environment. Nevertheless, concerns persist regarding administrative efficiency and transparency. Other South Asian countries, such as Pakistan, Bangladesh, and Sri Lanka, have made progress in strengthening environmental governance and regulations. However, challenges persist, including corruption, bureaucratic hurdles, and limited resources for monitoring and enforcement. In ASEAN countries, some have made significant strides in addressing environmental challenges and promoting sustainable practices, while others face challenges related to institutional capacity, corruption, and coordination among various agencies involved in environmental governance. Overall, effective institutional quality is essential for achieving environmental sustainability and addressing environmental challenges in emerging Asian economies. Continuous improvements in institutional quality and enhanced regional cooperation on issues such as institutional capacity, transparency, and accountability are crucial for improving environmental regulations and compliance in the region.

5. Concluding Remarks

While the literature has confirmed the interconnections of globalization, manufacturing and decarbonization, the conventional EKC hypothesis has failed to address the pollution trajectory between the periods and income growth among emerging Asian nations. This study reassesses the EKC hypothesis for 10 emerging East and South Asian countries. In addition to institutional quality, renewable energy consumption and trade openness, the paper introduces green finance and its interaction with financial development to curb carbon emission. Possible biases due to slope heterogeneity and cross-sectional dependence (CSD) among the highly integrated East and South Asian countries are being tackled using a series of panel analyses on panel series during 2000-2019, e.g., the CSD test, slope heterogeneity test, the 2nd generation panel unit root tests, panel cointegration tests, and CS-ARDL modelling, as well as robustness tests.

The results are summarized as follows. First, the long- and short run coefficients of income per capita significantly linked to the carbon emissions but the income square ($LGDP^2$) was insignificant. This implies that the rapid economic growth of emerging Asian countries has come at a cost to the environment, with increased greenhouse gas emissions, water and air pollution, and deforestation. However, the U-typed EKC hypothesis was not supported as the insignificant $LGDP^2$ fail to a shift the pollution trajectory that followed by mitigation of environmental degradation. Second, green finance and trade openness are also insignificant in both long- and short-run to uphold the EKC and fail to facilitate financial development to reduce carbon emissions. The analysis suggests that the development of domestic financial markets and institutions in emerging Asian economies has not adequately promoted R&D investment and green technologies, resulting in limited progress in reducing carbon emissions. Policymakers need to address this inefficiency and increase efforts to achieve carbon neutrality by redirecting financing towards sustainable and renewable energy sectors.

Third, institutions quality (IQ) and renewable energy consumption (REN) are both consistently significant with negative impacts on the carbon emissions. This show that the continuous improvement of institutional quality that prioritize transparency and accountability in decision-making are more responsive to public concerns about environmental protection, among the emerging Asian. With higher education and awareness, societies may prioritize environmental quality and be more willing to invest in the renewable energy sectors. Effective institutions can also promote sustainable practices and investments in eco-friendly practices and green technologies, making it economically viable for industries to adopt cleaner production methods.

Finally, our study acknowledges the presence of heterogeneity and cross-sectional dependence issues among China, India, ASEAN, and South Asia concerning environmental policies and efforts. Although the EKC hypothesis is not supported, our analysis demonstrates that institutional quality and renewable energy consumption play crucial roles in mitigating environmental degradation. While progress has been made in reducing environmental degradation through these policies and efforts, achieving sustainable development and environmental protection remains a significant challenge. Among emerging Asian countries, China has shown notable advancements in renewable energy investment and implementing stricter environmental regulations, followed by ASEAN members. However, South Asian countries still grapple with macroeconomic imbalances and inadequate financial development. Balancing short-term growth and long-term environmental sustainability poses a critical dilemma, underscoring the importance of regional collaborations in strengthening environmental regulations and fostering sustainable development in the region.

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