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Racing Towards Carbon Neutrality: Synergy Between Environmental Poverty, Environmental Regulations, Financial Constraints and Political Instability

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Abstract

The main objective of this study is to analyse the impact of environmental poverty (*EP*), environmental regulation (*ENVR*), financial constraints (*FNC*) and political instability (*PIST*) on carbon dioxide emissions (abbr. CO_2e), with other variables including international collaboration in green technology development (*ICGTD*), hybrid electric vehicle technology (*HEVT*) and gross domestic product per capita (*GDPPC*). The augmented mean group estimator approach is chosen to gauge the long-term coefficients. The findings indicate that strengthening *ENVR* in Asian countries can reduce CO_2e effectively, highlighting the importance of policy-driven ecological interventions. In contrast, *EP*, *PIST* and *FNC* might worsen CO_2e, emphasizing the significance of political and economic stability for the region's environmental sustainability. The results also show that an increased *ICGTD* and *HEVT* contribute directly to the reduction of CO_2e in Asian countries. Even though economic growth is a sign of development, rising *GDPPC* in these economies is linked to higher CO_2e, demonstrating that the current association between economic growth and achieving carbon neutrality could be better.

Keywords: Environmental regulation, environmental poverty, political instability, financial constraints, carbon emissions, Asian economies

JEL Classification: Q58; H23; O13

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1. Introduction

The global ecosystem, characterized by complex interconnections, has a proven capacity for self-regulation over an extended period, enabling the successful adaptation and flourishing of life forms (Liguo *et al*., 2023). Nevertheless, human activity has considerably affected the natural systems, specifically urbanization, industrialization, deforestation and pollution (Fan *et al*., 2023). Once regarded as the Earth's primary respiratory system, forests play a crucial role in carbon dioxide (CO_2e) absorption and oxygen release, offering vital functions such as water filtration and soil enrichment (You *et al*., 2023). Nevertheless, deforestation, driven by the need for timber, agricultural expansion and urbanization, has resulted in substantial depletion of forests, damage to habitats, extinction of species and disruption of ecosystem services (Xin *et al*., 2022). Wetlands, commonly called the Earth's renal organs, perform the vital functions of purifying contaminants, controlling hydrological patterns and providing suitable environments for various plant and animal species. Coral reefs, often called the rainforests of the oceans, play a crucial role in supporting around 25% of the total marine species population (Xin *et al*., 2022). These ecosystems are of utmost importance due to their significant contributions to coastal protection, fisheries and tourism. Anthropogenic factors, including excessive fishing, pollution and ocean acidification resulting from climate change, have imposed significant pressures on these vulnerable ecosystems, resulting in extensive occurrences of coral bleaching and destruction of reefs (Khattak and Ahmad, 2022). The potential degradation of these crucial ecosystems poses a significant risk to the biodiversity they sustain and their indispensable benefits to human society, encompassing sustenance, access to clean water, climate moderation and recreational opportunities (You *et al*., 2022).

CO_2 is an essential component of the Earth's climate system, as it effectively retains heat that would otherwise dissipate into the atmosphere, resulting in the Earth's surface warming (Khan *et al*., 2022). Nevertheless, the equilibrium of this phenomenon has been perturbed by the swift escalation in CO_2e levels resulting from anthropogenic actions (Lorenz, 2010). The combustion of fossil fuels, including coal, oil and natural gas, constitutes a significant factor in the escalation of atmospheric CO_2e levels (Gilbert and Sovacool, 2017). The issue of deforestation is compounded by its contribution to the CO_2e problem, as forests play a crucial role as substantial carbon sinks by absorbing CO_2 through photosynthesis. Deforestation results in the liberation of carbon formerly sequestered within forests, diminishing their ability to sequester future carbon dioxide emissions effectively (Joshi and Singh, 2020). The consequences associated with increased concentrations of CO_2e encompass the phenomenon of global warming, which in turn triggers the process of polar ice caps and glaciers melting, resulting in the elevation of sea levels (Nema *et al*., 2012).

Consequently, this poses a significant risk to coastal towns at lower altitudes and island countries (Neumann *et al*., 2015). The disruption of conventional weather patterns has resulted in lengthy periods of drought and extraordinary occurrences of floods, which have placed significant strain on agricultural systems and have had a detrimental impact on food supply. The increase in CO_2 levels significantly affects the world's oceans. When CO_2 combines with seawater, it undergoes a chemical reaction and forms carbonic acid (Voormeij and Simandl, 2004). This process threatens marine life and can potentially disrupt marine ecosystems' overall health and equilibrium (Andrady, 2011).

The combustion of fossil fuels for energy generation and transportation represents the predominant source of worldwide CO_2e (Liguo *et al*., 2022). The advent of the Industrial Revolution brought about a notable transformation characterized by the swift expansion of industrial sectors, gross domestic product per capita (*GDPPC*) and the widespread adoption of fossil fuels (Demir *et al*., 2020). Industrial activities, such as cement and steel production, result in CO_2e as a secondary product. Deforestation and land-use changes, including the conversion of natural ecosystems into agricultural lands, influence the alteration of carbon dynamics on a global scale. Forests function as carbon reservoirs, sequestering and retaining CO_2e (Grimston *et al*., 2001). However, the disappearance of forests results in the depletion of this capacity for carbon storage, leading to the subsequent release of carbon into the atmosphere (Hudiburg *et al*., 2011). Land conversion for agricultural purposes results in emissions of methane, a greenhouse gas with a higher potency than CO_2. The rapid economic growth experienced in Asia has significantly increased energy consumption, particularly in Asian countries that primarily depend on coal-fired power plants (Clark *et al*., 2020). Urbanization, a consequence of industrialization, has led to the emergence of megacities, which frequently depend on fossil fuels as their primary energy source, leading to significant emissions. As civilizations undergo the modernization process, there is a noticeable transformation in consumption patterns (Friedmann, 2006). This shift is characterized by the emergence of an expanding middle class, a rise in aspirational spending and improved accessibility of a wide range of commodities. Consequently, this evolution in consumption habits has increased the production, transportation and consumption of various items (Kurz *et al*., 2015). Each of these activities is accompanied by a carbon footprint, which together contributes to the overall CO_2e generated by society (Dwyer *et al*., 2010).

The prevalence of environmental poverty (*EP*) in Asian countries presents considerable obstacles to achieving environmentally friendly development (Pandey and Asif, 2022). *EP* is a multifaceted phenomenon arising from the convergence of ecological deterioration and human adversity (Liu, 2012). Individuals residing in regions characterized by depleted resources, such as deforested terrains or contaminated bodies of water, frequently have restricted options that inadvertently perpetuate environmental degradation (Duraiappah, 1996). These particular habits, which have emerged as a result of need, have the potential to result in heightened levels of carbon emissions. Gaining a comprehensive understanding of this complex interconnection can provide valuable insights into the broader complexities associated with sustainable development and the pressing issue of climate change (Duraiappah, 1998). CO_2e, which are a significant factor in the phenomenon of global warming, originate from diverse sources. However, the relationship between these emissions and environmental poverty is frequently disregarded. Communities residing in environmentally disadvantaged regions may be compelled to depend on energy sources (Reardon and Vosti, 1995) that are both inefficient and environmentally detrimental (Jehan and Umana, 2003). As an illustration, in the absence of contemporary cooking fuels, many individuals turn to the combustion of biomass such as wood, resulting in substantial CO_2e. This behaviour is not motivated by a lack of concern for the environment but by decisions to ensure immediate survival (Reardon and Vosti, 1995).

In addition, habitats that have undergone degradation, such as that caused by deforestation or soil erosion, experience a decline in their capacity to function as “carbon sinks”. Healthy forests can absorb and retain substantial quantities of CO_2e (Kumar *et al*., 2022). However, the loss of these forests not only diminishes their ability to store carbon but also releases previously stored carbon into the atmosphere through deforestation. This dual impact further aggravates the issue of CO2e, resulting in significant consequences for global climate patterns (Vijayavenkataraman *et al*., 2012).

Political stability is essential for planning for the future and sustainable development because it provides a foundation for the composition, execution and supervision of consistent policies (Sohail *et al*., 2022). Nevertheless, the compromise of political stability can give rise to environmental sustainability challenges. Complex political climates can discourage investments in areas necessitating sustained engagement, such as renewable energy and green technologies (Asfew *et al*., 2023; Dai et al., 2024). The above risk has an upward trajectory, resulting in potential setbacks or hindered progress in developing renewable energy infrastructure, clean transportation and other environmentally friendly technologies (Shahsavari and Akbari, 2018).

Political instability (*PIST*) can create inconsistencies in environmental policy, as governments may retract, amend or postpone previously established environmental targets (Sohail *et al*., 2022). This might result in a protracted dependence on energy sources with a high carbon footprint. Moreover, regulatory entities may need more support in their authority or alterations in their focal points, resulting in unregulated industrial emissions, inadequate waste management and increased unsustainable behaviour (Sinclair, 1997). In heightened severity, overt conflicts can result in direct environmental consequences, including the devastation of infrastructure and the overutilization of natural resources (Pinstrup-Andersen and Pandya-Lorch, 1998). *PIST* is a significant catalyst for migration, wherein displaced communities frequently establish provisional settlements or camps (Agbola and Acupan, 2010). This phenomenon subsequently contributes to deforestation, land degradation and heightened CO_2e. Furthermore, *PIST* has the potential to initiate a chain reaction that negatively affects international partnerships and agreements, impeding collective global endeavours aimed at mitigating the escalating levels of CO_2e (Safi *et al*., 2021).

The presence of financial constraints (*FNC*) in Asian countries presents considerable obstacles in their endeavour to achieve sustainable development (Palit and Chaurey, 2011). The prioritization of economic development frequently results in using fossil fuels, namely coal, due to its perceived cost-effectiveness. Limited financial resources also affect the capacities for research and development, leading countries to depend on outmoded, inefficient and carbon-intensive technology for extended durations (Xin, 2023). The complexity of accessing foreign funding arises from bureaucratic procedures, rigorous eligibility criteria and the necessity of securing co-financing. Private investment plays a vital role in addressing the financial shortfall for sustainable enterprises (van Kleef and Roome, 2007). However, potential investors may be dissuaded by the perceived dangers of investing in environmentally friendly technologies inside emerging economies. The decision-making process regarding the trade-off between environmental sustainability and economic growth may be challenging, given that governments may prioritize immediate remedies over enduring and sustainable solutions (Schaafsma *et al*., 2021; Dai & Azhar, 2024). Nevertheless, a simple dichotomy only sometimes characterizes the trade-off between the economy and the environment. The dependence on environmentally harmful sources can lead to enduring expenses, including environmental deterioration, biodiversity loss, pollution-related health complications and prospective expenditures related to climate change-induced disasters (Hassan *et al*., 2021).

Environmental regulations (*ENVR*) are of utmost importance in influencing a country's carbon footprint since they establish a well-defined structure and instructions for various industries and sectors (Li *et al*., 2021). A fair playing field is established by implementing environmental criteria that are uniformly applied across all sectors, eliminating any potential competitive advantages. Imposing penalties on high-emitting entities is a deterrent, creating economic disincentives for firms that ignore environmental regulations (Santos *et al*., 2010). Tax incentives and subsidies can potentially enhance the attractiveness of adopting green technologies, particularly in Asian economies characterized by a fragile equilibrium between economic growth and sustainability (Altenburg and Lütkenhorst, 2015).

Nevertheless, implementing these norms may present challenges given the heterogeneous nature of the Asian region, characterized by differing administrative capabilities, levels of political commitment and degrees of industrial development (García-Canal and Guillén, 2008). Certain countries may need to improve their infrastructure or knowledge to oversee and implement regulations adequately. In contrast, others may encounter challenges due to the influence exerted by industrial interest groups. The formulation of these regulations necessitates a comprehensive understanding of the specific regional circumstances, given that the efficacy of measures implemented in one Asian economy may not be transferable to another (Wu *et al.*, 2020). Despite the above obstacles, some Asian countries have effectively included green laws in their policy frameworks, resulting in measurable decreases in CO_2e and other harmful substances (Knoepfel, 2007). This underscores the significant impact that carefully designed regulations can have in bringing about transformative changes (Thelen, 2004).

Numerous scholarly investigations have examined distinct Asian countries. However, a shortage of comprehensive analyses exists that systematically juxtaposes the effects of environmental legislation, financial restrictions and political instability on CO_2e across diverse Asian economies. A comparative analysis has the potential to shed light on distinct obstacles and achievements, enhancing comprehension of the subject matter. Most previous research has concentrated on a single isolated component, such as environmental rules, financial limits or political instability. The complex interaction among these variables and their cumulative influence on CO_2e has yet to be thoroughly investigated. The scholarly examination of the enduring ramifications of financial limitations and political instability on the efficacy and implementation of environmental policies in Asian economies remains very limited. A prospective analysis may offer helpful insights into prospective future scenarios and issues.

This study aims to comprehensively understand the collective impacts of environmental restrictions, financial limitations and political instability on CO_2e. The present study provides a comprehensive perspective by simultaneously examining these aspects, thereby addressing a significant void in the current body of knowledge. By examining specific situations within the varied Asian economies, this research provides insights into common difficulties and distinctive characteristics unique to each country. The comprehensive nature of this method renders it a significant asset for politicians and environmental advocates. Including quantitative methodologies for assessing the relative influence of each component on CO_2e will enhance the robustness of our outcomes. This empirical contribution has the potential to enhance comprehension of the quantity and significance of each aspect, bolstering our outcomes.

Comprehending the intricate interplay among many aspects can assist policymakers in formulating environmental policies that are more productive and customized. By acknowledging the impact of financial limitations and political volatility, policymakers can enhance the efficacy of their strategies in addressing these obstacles. This report offers valuable insights into the environmental sustainability landscape of Asian economies, which might interest investors, enterprises and international organizations. This knowledge can guide decision-making processes, guaranteeing that investments and activities are by sustainable objectives. The report serves as a fundamental resource for future sustainability planning by examining the present obstacles and achievements in the domain of CO_2e in Asian economies. The findings can be utilized by stakeholders at both local and global levels to develop policies and foster collaborations that promote a harmonious coexistence between economic growth and the preservation of the environment.

2. Literature Review

2.1 Nexus between environmental regulations and CO_2e

Chen *et al*. (2019) examined the nexus between environmental laws and CO_2e in China. Their findings indicate that implementing environmental rules and alterations in the industrial structure can decrease CO_2e. Nevertheless, areas characterized by inadequate optimization of their industrial structure may encounter a rise in CO_2e due to their failure to conform to regulatory measures effectively. The Kuznets curve hypothesis posits that there exists a nonlinear association, like an inverted U-shape, between the level of economic development and the extent of environmental degradation. This link is believed to be affected by the specific industrial composition within a given locality. To foster economic growth, the authors suggested that policymakers must consider the distinct characteristics and developmental phases of the industrial framework in each location while formulating rules.

Chang *et al*. (2023) investigated the correlation between environmental legislation, green innovation and the mitigation of CO_2e in China. The study used analytical models derived from data collected across 30 provinces to examine the impact of regulations on green knowledge and process innovation. The findings suggest that rules have a greater propensity to improve the positive benefits of green knowledge innovation, while their influence on green process innovation is comparatively less pronounced. The study revealed that investment-based regulation had the most significant impact on enhancing the connection between green innovation and emission reduction, with command-and-control-based regulation ranking second in influence. Nevertheless, it has been seen that the implementation of expenditure-based regulation has resulted in the promotion of short-term thinking within enterprises. The research also identified a spatial spillover phenomenon, wherein the introduction of environmentally friendly technical advancements in a particular region influences the levels of CO_2e in surrounding places.

Chen *et al*. (2019) analysed the association between environmental regulations and their consequent influence on the levels of regional CO_2e in China. The investigation, spanning from 2003 to 2019, unveiled notable discrepancies in the effects of different environmental regulations on CO_2e, suggesting the presence of regional diversity. The authors argued that the convergence of environmental regulations significantly affects CO_2e. The impact of environmental regulation on CO_2e reductions in China's eastern region was found to be substantial. In contrast, command and economic environmental regulations were identified as critical factors the central region.

Zhang *et al*. (2021) revealed a decline of 10.15% in carbon emission efficiency in China's transportation infrastructure between 2001 and 2017. This decline suggests that the higher emissions can be attributed to the country's fast urbanization and infrastructure expansion. The study also unveiled regional discrepancies in the Central and Eastern European (CEE) region, where certain provinces have successfully implemented efficient systems, resulting in reduced carbon footprints. The research employed Hansen's panel threshold model to detect the threshold effects of environmental legislation on CEE. Additionally, the research presented different approaches for assessing CEE and proposed theoretical frameworks to facilitate the dynamic measurement of this construct. These findings offer valuable contributions to scholars working in related disciplines.

Liu *et al*. (2022) inspected the effects of environmental regulation and local government rivalry on carbon emissions in the manufacturing sector in 30 Chinese provinces between 2007 and 2019. The researchers employed the spatial Durbin model for their analysis. The study revealed that implementing environmental regulations has a mitigating effect on CO_2e from local manufacturing activities. However, it also observed that rivalry among local governments has a counterproductive impact, increasing these emissions. Nevertheless, local governments appear to participate in high-level competition when faced with environmental constraints. Implementing environmental regulations exhibits a spatial spillover phenomenon, where favourable impacts are observed within 600 kilometres. In comparison, adverse consequences are discernible up to 1,600 kilometres. The variation in the effects of environmental legislation and local competition is noteworthy among the seven distinct manufacturing industries, emphasizing the necessity for customized green development plans within this sector.

Using fixed-effects and spatial spillover models, Song *et al*. (2022) investigated the association between carbon emission environmental control and its influence on regional spillovers. Their findings indicated that environmental regulation exerts a notable detrimental impact on carbon emissions, leading to a reduction in carbon dioxide emissions. Additionally, environmental regulation demonstrates a significant inhibitory effect on carbon emissions at the local level while simultaneously resulting in an increase in carbon emissions in adjacent areas. Hence, to effectively reduce carbon emissions, it is imperative to adopt suitable environmental regulatory laws. These regulations would facilitate enhanced cooperation in managing the carbon emission dynamics across various regions. In environmental conservation, it is imperative to acknowledge the significant role that environmental regulation assumes in safeguarding the natural environment. To enhance environmental governance and facilitate the harmonized advancement of regional carbon emission reduction efforts, it is imperative to establish a comprehensive framework for environmental regulation and a market-driven system for environmental regulation.

2. Nexus between political instability and CO_2e

Halkos and Tzeremes (2013) used nonparametric estimators to study the link between CO_2e and government in the twenty largest economies. The research indicated a non-linear association between a country's CO_2e and governance measures. The CO_2e levels of each country were influenced by governance issues to varying degrees, reflecting the unique regional and developmental settings of these countries. Notably, improving governance quality does not consistently result in decreased CO_2e.

Khan *et al*. (2023) explored the relationship between income inequality and CO_2e, focusing on the role of political stability in developing countries, high-income countries and the Belt Road Initiative (BRI) countries. The findings indicate that CO_2e and political stability are positively associated with income disparity, whereas economic growth negatively affects income inequality. In high-income countries, political stability and lower CO_2e are associated with reduced economic inequality. Conversely, the advancement of financial development tends to worsen income inequality. Notably, within countries participating in the BRI, a discernible correlation exists between political stability, economic growth, CO_2e and the reduction of income disparity.

Kartal *et al*. (2022) investigated the impact of political stability on CO_2e in Finland. Their key findings indicate a significant and enduring relationship between CO_2e, political stability and other factors. The study revealed a substantial correlation between positive changes in political stability and CO_2e. Still, adverse shifts in political stability do not have any statistically significant impact on CO_2e. It is noteworthy that positive changes in political stability and economic progress have the effect of increasing emissions.

Zhang and Chiu (2020) examined the non-linear effects of country risks on CO_2e in a panel of 111 countries. By employing the panel smooth transition regression model, the study examined the varying effects of real income, energy use and national risks on emissions, mainly when country risks are used as thresholds. A curvilinear relationship exists between economic risk and CO_2e, characterized by an inverted U-shape. Conversely, both financial and political risks have a consistent positive association with emissions, indicating a gradual and continuous impact. As the hazards associated with a country lessen, there is a noticeable initial impact of real income and energy consumption on emissions, which gradually diminishes over time. Interestingly, there is a correlation between the volatility of country risks and the increased susceptibility of lower-income countries to the impact of CO_2e.

Wang *et al*. (2022) examined the relationship between geopolitical risk and CO_2e using the geopolitical risk and a bootstrap Granger rolling-window analysis. Analysing several subsamples consistently demonstrates a reciprocal relationship between the two variables. The impact of geopolitical risk on CO_2e is closely influenced by various elements such as trade disputes, military actions and energy concerns. On the other hand, CO_2e influences geopolitical risk by affecting the development of international cooperation and geopolitical systems.

Khan *et al*. (2022) used the dynamic autoregressive distributed lag (ARDL) simulation model to investigate the nexus between CO_2e and governance in Morocco. Their findings demonstrate that effective governance has a substantial role in mitigating CO_2e. The Granger causality test was employed to investigate the causal relationships among the variables under consideration. The consequences of these findings have long-term significance for Morocco's policies in reducing CO_2e and addressing the challenges posed by climate change.

3. Model Specification and Data Sources

Following Hao *et al*. (2022), Aydin *et al*. (2023) and Hove and Tursoy (2019), this study uses the environmental Kuznets curve formula to examine the link between economic indicators and CO_2e:

$$CO_2e_{it} = \alpha_0 + \alpha_1 GDPPC_{it} + \alpha_2 GDPPC_{it}^2 + \varepsilon_{it} \tag{1}$$

Equation (1) can be extended by including *EP*, *PIST*, *ENVR*, *FNC*, international collaboration in green technology development (*ICGTD*) and hybrid-electric vehicle technology (*HEVT*):

$$\begin{aligned} CO_2e_{it} &= \alpha_0 + \alpha_1 GDPPC_{it} + \alpha_2 GDPPC_{it}^2 + \alpha_3 PIST_{it} + \alpha_4 ENVR_{it} + \alpha_5 FNC_{it} + \\ &+ \alpha_6 ICGTD_{it} + \alpha_7 HEVT_{it} + \alpha_8 EP_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

The additional variables are added due to the following reasons. Firstly, the transportation industry plays a substantial role in the generation of CO_2e, especially within thriving Asian countries. The ongoing advancements in *HEVT* offer a viable means to mitigate CO_2e associated with transportation. The incorporation of this variable offers an analytical perspective on the rates of acceptance, technological progress and market saturation of cleaner vehicle technologies within the Asian region. It is beneficial to gain insight into the technical evolution of the transportation sector and its broader implications for emissions. Secondly, cooperative efforts among countries, particularly in technological advancement, can significantly shape a country's environmental trajectory in the contemporary globalized era. The economies of Asian countries, a significant number of which are currently undergoing rapid industrialization, have the potential to derive substantial advantages from engaging in *ICGTD*, which prioritizes the development and implementation of environmentally sustainable technologies. Collaborative efforts of this nature have the potential to yield economies of scale, facilitate the transfer of technology and foster the exchange of standard best practices. Incorporating *ICGTD* enables the model to consider the broader range of international dynamics that affect domestic emission strategies. Thirdly, the influence of *PIST* on CO_2e and policy implementation is significant. During periods characterized by *PIST*, the prioritization of current issues may overshadow the implementation of long-term environmental initiatives. On the other hand, political systems characterized by stability may cultivate a conducive atmosphere for implementing consistent policies that promote environmentally friendly methods. By incorporating *PIST* as a variable, this study can address the frequently unforeseeable character of policy continuity and its consequences on CO_2e.

Fourthly, the ability of a country to undertake and sustain environmentally friendly measures can be severely affected by *FNC*. The economies of Asian countries, characterized by their diversity, frequently face the challenge of reconciling the pursuit of economic expansion with the imperative of environmental sustainability. By incorporating *FNC* as a variable, a more comprehensive understanding of how economic limitations might serve as obstacles or incentives in the context of reducing CO_2e is facilitated. Lastly, implementing *ENVR* significantly influences a country's strategy towards managing CO_2e. The laws in Asian economies can exhibit significant variation, encompassing harsh policies and more lenient guidelines. Through a careful analysis of these fluctuations, valuable insights can be derived regarding the effectiveness of diverse regulatory measures and their direct and indirect influence on emissions. In addition, gaining a comprehensive awareness of the intricacies of *ENVR* in various Asian countries can facilitate a comparative examination, offering insights into optimal approaches and potential areas for enhancement.

The World Bank database was used to obtain data on *GDPPC*, unemployment rate, total urban population, *PIST* and domestic credit to the private sector (% of GDP). In contrast, the OECD Statistics database was used to collect data on patents on hybrid electrical vehicle-related technologies, patents on green technologies (percentage within country co-inventions), CO_2e and environmental policy stringency from 1990 to 2019. Japan, Korea, China and India were selected as the four most innovative Asian countries based on the Global Innovation Index 2022. Table 1 offers a comprehensive overview of the data.

This study uses patents on green technologies (percentage of country co-inventions), environmental policy stringency and patents on hybrid electrical vehicle-related technologies as proxies for *ICGTD*, *ENVR* and *HEVT*, respectively.

Given the unavailability of direct data on environmental poverty, we employ the subsequent formula to approximate its values:

$$EP_{it} = \alpha \times E_{it} + \beta \times S_{it} \tag{3}$$

$$E_{it} = \gamma \times CO_2 e_{it} \tag{4}$$

$$S_{it} = \delta \times UNER_{it} + \eta \times GDPPC_{it} + \zeta \times URB_{it} \tag{5}$$

where S_{it} depicts the socio-economic status component, $UNER_{it}$ signifies the unemployment rate, URB_{it}stands for urbanization and α and β, γ, δ, η and ζ represent the weights assigned to these factors to correspond with their perceived importance.

Table 1: Summary of data

Variables	Notation	Description	Source of data
International collaboration in green technology development	*ICGTD*	Patents on green technologies (percent within country co-inventions)	OECD (2021c)
Urbanization	*URB*	Total urban population	World Bank (2021)
Gross domestic product per capita	*GDPPC*	Constant US$	World Bank (2021)
Unemployment rate	*UNPR*	Percentage of total labour force	World Bank (2021)
Carbon dioxide emissions	*CO2e*	Millions of tonnes	OECD (2021a)
Political instability	*PIST*	PIST	World Bank (2023)
Financial constraints	*FNC*	Domestic credit to private sector (% of GDP)	World Bank (2021)
Hybrid electrical vehicle technology	*HEVT*	Patents on hybrid electrical vehicle-related technologies	OECD (2021b)
Environmental regulation	*ENVR*	Environmental policy stringency	OECD (2020)

Source: Authors' own elaboration

4. Econometric Methodology

4.1 Cross-sectional dependency (CSD)

Economic interconnection among middle-income countries (MICs) gives rise to the possibility of correlations within the panel being examined. This implies that unanticipated occurrences or progressions in one entity have the potential to affect other entities negatively. Dogan *et al.* (2017) argued that the recognition and management of CSD are crucial to prevent the occurrence of biased and inconsistent estimators. Therefore, we employ the tests proposed by Friedman (1937) and Breusch and Pagan (1980), as well as Pesaran's (2015) CSD test and Pesaran's (2004) scaled LM test, to examine the presence of conditional dependence in the dataset. The typical equation for representing panel data is as follows:

$$Y_{it} = a_i + X_{it}\beta + u_{it} \tag{6}$$

where $\mu_{i,t}$ denotes the error term, α_i is a time-invariant computation, $X_{i,t}$ indicates a $K \times 1$ transmitter of input variables and $\beta_{i,t}$ shows a $K \times 1$ transmitter of the invariable to be computed. CSD can be tested using the hypothesis.

$$H_0 : \rho_{ij} = \rho_{ji} = cor\left(\mu_{it},\ \mu_{jt}\right) = 0 \ for\ j \neq i \tag{7}$$

$$H_A : \rho_{ij} = \rho_{ji} = cor\left(\mu_{it},\ \mu_{jt}\right) \neq 0 \ for\ j \neq i \tag{8}$$

where:

$$\rho_{ij} = \rho_{ji} = \frac{\sum_{t=1}^{T} \mu_{it}, \mu_{jt}}{\left(\sum_{t=1}^{T} \mu_{it}\right)^{1/2} \left(\sum_{t=1}^{T} \mu_{jt}\right)^{1/2}} \tag{9}$$

The Breusch and Pagan (1980) test includes the estimation of the following equations:

$$LM_{BP} = T \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \hat{\rho}_{ij}^2 \tag{10}$$

$$CD_{LM} = \sqrt{\frac{1}{n(n-1)}} \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \left(TP_{ij}^2 - 1\right) \tag{11}$$

Pesaran (2015) proposed the following equations for testing CSD:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \tag{12}$$

$$\hat{\rho}_{ij} = \frac{\sum_{t-1}^{T} \hat{\mu}_{i,t} \hat{\rho}_{i,t}}{\left(\sum_{t=1}^{T} \hat{\mu}_{it}\right)^{1/2} \left(\sum_{t=1}^{T} \hat{\mu}_{jt}\right)^{1/2}} \tag{13}$$

Friedman's (1937) CSD test is based on the following statistics:

$$r_{ij} = r_{ji} = \frac{\sum_{t=1}^{T} \left(r_{ij} - \left(T + \frac{1}{2}\right)\right)\left(r_{ij} - \left(T + \frac{1}{2}\right)\right)}{\sum_{t=1}^{T} \left(r_{ij} - \left(\left(T + \frac{1}{2}\right)\right)\right)^2} \tag{14}$$

$$R_{AVE} = \frac{2}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{r}_{ij} \tag{15}$$

where R_{AVE} reflects the presence of non-zero cross-sectional associations and indicates the model estimation of the residual grade connection coefficient.

4.2 Slope heterogeneity test (SHT)

The main objective of the SHT is to assess whether there is homogeneity in the slope of a regression line across different groups (Musah *et al.*, 2021). A SHT suggests that the relationship between the independent and dependent variables exhibits variation among these distinct groups (Murshed *et al.*, 2022). The use of this assessment is commonly observed in the context of interaction terms in regression models. Generating an interaction term involves multiplying an independent variable by a categorical variable representing discrete groups (Cheng and Yao, 2021). When the interaction term exhibits statistical significance, it suggests the presence of a variation in slope between the groups (Dong *et al.*, 2018). If the statistical test does not provide proof of heterogeneity in the slope, it suggests that the relationship between the two variables remains constant across all groups (Khan and Bin, 2020). Evidence of heterogeneity in the slope suggests that the relationship between the independent variable and the dependent variable changes among different groups (Dogan and Inglesi-Lotz, 2017). The study applied Pesaran and Yamagata's (2008) SHT methodology. The calculations are derived from the estimation of the equations below.

$$\tilde{\Delta} = N^{\frac{1}{2}} (2k)^{-\frac{1}{2}} \left(N^{-1}\tilde{S} - k\right) \tag{16}$$

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1}\tilde{S} - E\left(\tilde{Z}_{it}\right)}{\sqrt{var\left(\tilde{Z}_{iT}\right)}} \right) \tag{17}$$

4.3 Panel unit root test

The stationarity of the variables is determined using a cross-sectional augmented Dickey–Fuller test (CADFT). This test is a modified version of the conventional Dickey–Fuller test (DFT) developed to be tailored to panel data analysis (Baltagi, 2015). The CADFT is employed to ascertain the existence of unit roots in panel data, a critical aspect in comprehending the stationary characteristics of the variables within the panel (Lee and Chang, 2008). The application of the CADFT has been found to enhance the statistical power of unit root tests compared to the individual application of the DFT. This phenomenon occurs due to the simultaneous use of information from all entities within the panel. The CADFT statistic, akin to the conventional DFT, indicates the stationarity of the series when it is statistically significant (Dogan *et al*., 2017). On the other hand, a test statistic that is not statistically significant indicates the existence of a unit root, which implies non-stationarity (Abdul Rashid *et al*., 2017).

4.4 Cointegration test

This study uses the Westerlund (2007) cointegration test (WCT) to examine the long-term relationship between *ENVR*, *PIST*, *FNC*, *ICGTD*, *HEVT* and *GDPPC* on CO_2e. The primary objective of the WCT test is to ascertain the presence of cointegration, which refers to a sustained link across time among variables in panel data contexts (Rasheed *et al*., 2022). The significance of this issue resides in the observation that when variables exhibit cointegration, they demonstrate a common stochastic tendency. According to Sharif *et al*. (2019), any deviation from this state of equilibrium is temporary when considering the long-term perspective. The Engle-Granger and Johansen tests are widely used cointegration tests designed to analyse time series data about a single entity (Mehmood, 2022).

On the other hand, the WCT is tailored explicitly for analysing panel data, making it a more suitable choice for datasets that include both cross-sectional and time dimensions (Kasman and Duman, 2015). One of the main challenges encountered in analysing panel data is the existence of CSD, which denotes the correlation between observations across distinct entities (Danish, Baloch and Wang, 2019). The interdependence is taken into consideration by the WCT, resulting in more reliable outcomes (Sheng and Guo, 2016). When the test statistic obtained from the WCT reaches a level of significance, it suggests that the variables within the panel display cointegration, thereby demonstrating a long-term link (Nathaniel and Iheonu, 2019). In contrast, a test statistic that does not demonstrate statistical significance suggests an absence of cointegration (Ali and Seraj, 2022).

4.5 Estimation of long-run coefficients

The augmented mean group estimator (AMGE), a panel data technique, calculates the long-run coefficients. According to Nathaniel and Iheonu (2019), the AMGE offers dependable and efficient estimates of coefficient values in panel data models, mainly when there is heterogeneity among cross-sectional units (Dogru *et al*., 2020). One main challenge in analysing panel data is incorporating heterogeneity (Mania, 2020). Traditional panel data approaches, such as fixed-effects or random-effects models, may not fully capture the intrinsic heterogeneity present in the dataset (Karaduman, 2022). The AMGE has been specifically designed to address this specific challenge. The AMGE demonstrates proficient use of the temporal and geographical dimensions inherent in the dataset (Dong *et al*., 2019). The methodology entails estimating the model for each unit within the cross-sectional dataset and calculating the average coefficients over all units (Khattak and Ahmad, 2021).

The term "augmented", as used in the context of AMGE, refers to including additional variables in the model to mitigate potential concerns associated with cross-sectional dependence and endogeneity (Tenaw and Hawitibo, 2021). This augmentation ensures the estimator constancy even in the presence of such obstacles. The AMGE expands on the existing mean group estimator (MGE). The MGE, which entails straightforward averaging of coefficients over cross-sectional units, is further refined by the AMGE by including supplementary model specifications to address potential econometric issues (Ahmad and Zheng, 2021). The AMGE estimator provides a middle ground between assuming perfect homogeneity, as demonstrated in pooled ordinary least squares, and assuming complete heterogeneity, as observed in unit-by-unit estimation. This methodology allows for flexibility in relationships while providing a succinct means of summarizing the average influence across entities (Tenaw and Hawitibo, 2021). We employ a joint correlated mean group (CCMG) approach as a supplementary technique to assess the validity, robustness, consistency and precision of the findings.

5. Results and Discussion

Table 2 presents the results of the CSD. With a significance threshold of 1%, the null hypothesis – which contends that there is no CSD among the series – is categorically rejected. Economically speaking, this implies that if one of these countries experiences a shock in a particular series, it will likely affect the same variable in the other countries in the panel. Considering these countries' geographic and economic connectivity, this result aligns with our expectations.

Table 2: Results of CSD

Test method	Statistics	Probability
Friedman test	57.601	0
Pesaran scaled LM test	8.845	0
Pesaran CD test	–5.571	0
Breusch–Pagan LM test	41.266	0

Source: Authors' own elaboration

The HST results are shown in Table 3. At the 1% significance level, the alternative hypothesis of variable slopes between panels is accepted. The fact that the null hypothesis is rejected in the HST suggests that the impact of the variables *EP*, *ENVR*, *PIST*, *FNC*, *ICGTD*, *HEVT* and *GDPPC* on CO_2e varies across the Asian economies. This suggests that these economies cannot execute a consistent strategy for managing carbon. Nevertheless, governments must adapt their environmental and economic strategies to their specific situation while considering how these factors interact within their area of responsibility. Through the *ICGTD*, the delicate balancing act between economic growth and environmental protection or assessment of the environmental effects of their digital transitions, these countries must show their ability to adapt to achieve long-term prosperity and maintain the environment.

Table 3: HST results

Test	Value	Probability
$\tilde{\Delta}$	6.056	0
$\tilde{\Delta}_{adj}$	7.748	0

Source: Authors' own elaboration

Table 4 summarizes the outcomes of the panel unit root. At the first difference, all the variables – *ENVR*, *EP*, *PIST*, *FNC*, *ICGTD*, *HEVT*, *GDPPC* and CO_2e – are stationary. The findings imply that Asian economies predominantly address short-term variations in these variables. Given that changes in *ENVR*, *EP*, *PIST*, *FNC* and *GDPPC* can instantly influence CO_2e, this emphasizes the necessity for quick and flexible policy responses. The findings also point to the potential for long-term equilibrium relationships, underscoring the need for countries to adopt a proactive strategy and routinely monitor these factors. The main emphasis is on how important it is for progressive countries to be adaptable, quickly changing policies in light of new information to balance economic growth and environmental sustainability.

Table 4: CADF test results

At level		At first difference		Results
Variable	***t*-bar**	**Variable**	***t*-bar**	
CO_2e	–1.721	***CO_2e***	4.748***	I(1)
ENVR	–1.738	***ENVR***	4.167***	I(1)
FNC	–1.945	***FNC***	3.630***	I(1)
EP	–1.104	***EP***	–6.112	I(1)
PIST	–1.954	***PIST***	3.450***	I(1)
ICGTD	–2.846	***ICGTD***	3.195***	I(1)
HEVT	–2.221	***HEVT***	4.198***	I(1)
GDPPC	–1.359	***GDPPC***	3.153***	I(1)

Source: Authors' own elaboration

The results of the WCT are presented in Table 5. The findings confirm the long-run association between *ENVR*, *EP*, *PIST*, *FNC*, *ICGTD*, *HEVT*, *GDPPC* and CO_2e. The results highlight the interdependence of economic, technological, ecological and policy factors. Within the framework of countries known for their inventive capabilities, there is a need for formulating comprehensive and forward-looking policies. These policies should consider the long-term and linked ramifications of decisions made within a particular domain on the broader system.

Table 5: WCT results

Statistics	*Z*-value	*p*-value
G_t	−7.217***	0
G_a	−8.519***	0
P_t	−87.005***	0
P_a	−25.381***	0

Source: Authors' own elaboration

The findings of AMG are depicted in Table 6. Firstly, the results show that increasing *EP* leads to higher CO_2e. The findings indicate that several Asian economies have seen significant urbanization and industrialization in recent decades. China and India, characterized by substantial population sizes, have experienced a notable upswing in urban populations, resulting in a heightened need for housing, infrastructure and transportation. The expansion frequently entails compromising of environmental factors. Due to constraints on available resources for investment in sustainable and clean technology, these countries may opt for more cost-effective alternatives with a higher environmental impact. Coal, despite its adverse environmental impacts, continues to serve as a predominant energy source for most Asian economies owing to its abundant availability and cost-effectiveness. In the present context, environmental poverty can be understood as the deterioration of natural resources and ecosystems on which communities depend for sustenance. Deforestation is widespread in some areas of Asia, where extensive rainforests are systematically destroyed to establish palm oil plantations or for timber extraction. The forests, previously serving as carbon sinks, have now transitioned into CO_2e sources. The communities that formerly depended on these woods for their existence are currently compelled to seek alternative sources of livelihood, frequently in metropolitan regions, exacerbating the issue of urbanization.

Moreover, the agricultural industry in numerous Asian economies predominantly adheres to conventional methods and primarily depends on practices that may lack environmental efficiency. The depletion of natural resources may prompt farmers to apply excessive quantities of fertilizers and pesticides or even transition to crops with a higher carbon footprint, resulting in elevated levels of CO_2e. The nexus between environmental poverty and carbon emissions can also be observed via the lens of waste management. Efficient waste management systems are found to be insufficient in numerous burgeoning Asian urban areas. Consequently, considerable waste is deposited in landfills, whereby organic waste emits methane, a highly potent greenhouse gas. Furthermore, the absence of recycling infrastructure results in suboptimal utilization of resources, exacerbating the carbon footprint associated with manufacturing fresh materials.

Secondly, the findings indicate that implementing *ENVR* helps Asian economies with CO_2e. From an economic standpoint, it is commonly assumed that rules and regulations can impede corporate operations, leading to slow economic growth. Nevertheless, it is imperative to take into account the potential long-term advantages. The potential reduction in carbon footprint could enhance the appeal of these economies among investors and customers who prioritize environmental sustainability. This transition has the potential to stimulate the expansion of environmentally friendly industries, leading to the emergence of novel employment opportunities and fostering innovation. Over time, Asian economies have the potential to emerge as leaders in sustainable technology and practices. This contributes to their economic resilience, safeguarding them against obsolete industries due to the global emphasis on sustainability. The health ramifications are also substantial. Numerous urban areas in Asia experience elevated levels of air pollution, adversely affecting residents' well-being and physical health. The potential for significant improvements in public health exists through the implementation and strict adherence to rigorous *ENVR*. Reduced carbon emissions typically result in a drop in airborne pollutants, which in turn leads to a reduction in respiratory ailments, a decrease in hospital admissions and, eventually, a lowering of healthcare expenses.

The examination of the geopolitical dimension is also worthy of consideration. As the global imperative to address climate change intensifies, countries that adopt proactive measures can utilize their dedication to environmental stewardship as a strategic advantage in international deliberations and accords. This can bolster their international reputation, foster closer diplomatic ties with countries that promote sustainable practices and potentially result in collaborative initiatives or advantageous trade accords.

Moreover, from a sociocultural perspective, implementing these policies can initiate a more extensive cultural transformation towards sustainability inside these economic systems. As individuals observe the concrete advantages of decreased pollution and encounter an enhanced quality of life, there is a potential for heightened involvement in additional environmentally conscious endeavours throughout the general populace. This phenomenon has the potential to result in a rise in sustainability initiatives driven by the community, a shift towards more sustainable purchasing behaviour and an increased public inclination to demand corporate responsibility for their ecological footprint.

Table 6: Results of AMG

Variables	Coefficients	Std. error	*t*-statistic	Prob.
ENVR	−0.167***	0.041	−4.033	0
FNC	0.351***	0.083	4.250	0
EP	0.220***	0.049	4.523	0
PIST	0.046***	0.013	3.648	0
ICGTD	−0.390***	0.086	−4.530	0
HEVT	−0.060***	0.018	−3.419	0
GDPPC	0.724***	0.165	4.385	0
GDPPC^2	−0.310***	0.068	−4.582	0
Constant	−1.475***	0.299	−4.940	0

Source: Authors' own elaboration

Thirdly, the results indicate an upward trend between the rise in financial constraints and increased CO_2e. From an economic standpoint, businesses frequently face financial limitations that compel them to favour short-term gains above long-term viability. Companies, particularly smaller ones, may choose to employ cost-effective manufacturing methods with a higher carbon footprint rather than allocating funds towards adopting environmentally friendly technologies in constrained financial resources. The trend above may have a detrimental impact on the competitiveness of these economies within the global economy. In light of the global trend towards ecological sustainability, enterprises that encounter financial limitations and lack innovation may face marginalization.

From a policy standpoint, this tendency highlights the significance of financial forces in shaping environmental results. To promote the adoption of environmentally sustainable practices, it may be necessary for governments in Asian economies to intervene through the provision of incentives or subsidies, even in cases where budgetary constraints exist. Potential strategies to incentivize environmentally friendly practices include offering direct cash incentives, providing tax benefits or easing access to green financing choices. These actions are necessary for corporations' immediate financial challenges to result in enduring environmental and economic consequences. The significance of health implications should be considered. Growth in carbon emissions further intensifies air pollution, which is already a significant cause for alarm in numerous urban areas across Asia. An increase in pollutants has the potential to give rise to many public health issues, encompassing respiratory disorders and cardiovascular diseases. The economic ramifications of this phenomenon are twofold, encompassing both direct costs associated with healthcare expenditures and secondary costs attributable to diminished production resulting from a workforce with compromised health conditions.

Furthermore, the nexus between financial limitations and increased emissions has the potential to result in social unrest. As societal awareness regarding environmental concerns increases, there is the possibility of discontent towards governmental bodies or corporate entities that prioritize immediate financial profits at the expense of public well-being and ecological integrity. This phenomenon may present itself in diverse forms, ranging from organized demonstrations to shifts in consumer behaviour that prioritize sustainable enterprises. Within the broader context of global geopolitics, Asian economies that are perceived to be increasing their carbon emissions due to financial limitations could encounter several obstacles. In international forums, countries and blocs that prioritize environmental sustainability may criticize them, potentially leading to imposition of penalties or trade obstacles.

Next, the findings confirm the positive relationship between *PIST* and CO_2e. The link between political instability and heightened CO_2e in Asian countries entails various complex ramifications. The primary focus lies in the immediate environmental consequences. Political turmoil or changes can result in a relaxation of the enforcement of environmental legislation or a diminished dedication to green policies. In turn, this increases emissions, directly contributing to global climate change. Consequently, such circumstances might yield significant ramifications for the natural environment, exemplified by rising sea levels. This phenomenon poses an especially formidable challenge for numerous regions in Asia that are situated along coastlines or at lower elevations.

Another implication is the economic prospects of these Asian economies. Elevated levels of CO_2e frequently indicate a dependence on antiquated businesses and energy sources that exhibit lower levels of efficiency. These economies may be sacrificing the potential long-term economic advantages of shifting to cleaner and more sustainable technologies. In a progressively globalized economy, countries with antiquated models characterized by high emissions may encounter a notable competitive disadvantage, mainly due to international pressure to shift towards low-carbon alternatives. The association between political instability and increased emissions poses a potential threat to global cooperation. The success of numerous international climate projects hinges on countries' collaborative efforts in achieving their emission reduction objectives. The potential impact of political instability in Asian economies on implementing or adopting environmental pledges may challenge international relations and impair collective efforts to address climate change.

Moreover, the outcome poses a dual risk for the inhabitants of these economies. Political instability is frequently associated with unpredictable outcomes, degraded provision of public services and the possibility of societal upheaval. When combined with the growing environmental risks posed by heightened carbon emissions, such as degraded air quality and intensified natural disasters, there is a substantial potential for a reduction in the quality of life and general well-being of individuals residing in affected areas.

Next, the results suggest that an increase in *ICGTD* is inversely related to carbon emissions. Green collaboration could expedite the pace of invention. As Asian economies actively collaborate with foreign partners, they can expand their access to a broader range of research, knowledge and best practices. This implies that the resolution of technological challenges, which formerly required a significant amount of time to overcome within a country's borders, can now be accomplished more expeditiously and effectively. The rapid integration of newer, cleaner means of production, transportation and energy generation into these economies, driven by the accelerated speed of technical breakthroughs, significantly reduces CO_2e. International cooperation can potentially realign Asian economies within the global economy strategically. These countries can become centres for exporting clean technologies due to their increased ability to develop and implement environmentally friendly technologies. In addition to enhancing the diversification of their economic portfolios, this strategy has the potential to attract international investments specifically targeted at green technology ventures. Over time, there is potential for a transformation in the global economic landscape. Asian economies may establish themselves as prominent manufacturing powerhouses and emerge as frontrunners in green technology solutions.

This development indicates a noteworthy alteration in global dynamics. Through active engagement in collaborative efforts focused on green technologies, Asian economies can influence global environmental policies and standards. Engaging proactively in international forums can enhance their standing, assuring the adequate representation of their interests and perspectives while formulating global environmental agreements and protocols. Establishing international cooperation in green technology can effectively mitigate reliance on imported fossil fuels, reducing dependency on such resources. Asian economies have the potential to gradually shift away from conventional energy sources by embracing and advancing renewable energy technology. The transition described mitigates emissions and decreases vulnerability to swings in global oil prices, establishing a more stable energy framework. These results validate the previous studies conducted for South Korea (Jiang and Khattak, 2023), knowledge-based economies (Fan *et al*., 2023), China (You *et al*., 2023), the United States (Xin *et al*., 2022) and G7 countries (Aghabalayev and Ahmad, 2022).

Next, the findings indicate that increased *HEVT* is environmentally advantageous for Asian economies. Adopting hybrid electric vehicles (HEVs) has experienced a notable increase in Asian economies, leading to a consequential reduction in carbon emissions. This trend indicates a significant transformation in the transportation paradigm within these regions. From an economic standpoint, adopting HEVs presents a dual advantage. On the one hand, there exists the possibility of a decrease in the reliance on fossil fuels, which have historically been a substantial import for most Asian countries. Reducing fuel consumption for the expanding vehicle fleet can yield significant benefits in terms of foreign exchange savings and enhancing the balance of payments.

Concurrently, the emergence of HEVs presents opportunities for developing novel industrial sectors and innovation clusters across Asia. With the increasing demand for hybrid technology, there is a potential for the establishment and growth of local companies focused on manufacturing HEVs, production of batteries and related technologies. This phenomenon can result in a surge in job opportunities, heightened investments and the possibility of Asian countries assuming a prominent position as frontrunners in hybrid vehicle technology. Consequently, these economies could embrace this domain globally. A shift towards HEVs can potentially affect the energy policy dynamics in Asian countries significantly. The conventional dynamics, frequently influenced by partnerships centred on oil imports, could transform if the significance of oil decreases. This phenomenon has the potential to result in a realignment of diplomatic and trade connections, enabling Asian economies to establish alliances centred on technology cooperation rather than solely relying on energy trading. The emergence of HEVs calls for reconsidering urban planning and transportation networks from an infrastructure perspective. The requirement for charging infrastructure presents an opportunity to rejuvenate metropolitan areas, include intelligent grid solutions and engage private sector collaborations in the realm of public utilities. This finding is consistent with the recent study conducted for knowledge-based economies by Aghabalayev and Ahmad (2022).

Lastly, the study results confirm the validity of the environmental Kuznets curve (EKC) hypothesis in Asian economies. The validation of the EKC hypothesis in Asian countries has significant consequences for comprehending the association between economic growth and pollution and forecasting future environmental conditions in the region. The EKC hypothesis posits that as an economy grows, there is an initial rise in environmental degradation, followed by a subsequent decline once a specific revenue threshold is attained. Within the framework of Asian countries, the verification of this hypothesis implies that the early phases of economic development in numerous countries within this region were linked to increased environmental degradation. The observed phenomenon can be ascribed to the swift process of industrialization, urbanization and the prevailing emphasis on economic advancement at the expense of environmental considerations during the initial stages of development. During these stages, regulatory measures were less stringent and the adoption and affordability of technological solutions to mitigate environmental impacts may have needed improvement.

Nevertheless, as these countries advanced and experienced economic growth, the declining trajectory of the curve suggests that they have begun to place greater emphasis on and allocate resources towards cleaner technologies, more stringent laws and sustainable practices. A threshold is attained when additional economic growth ceases to yield further degradation but instead fosters environmental enhancements. This phenomenon may be attributed to the positive correlation between higher national income levels and improved education, heightened public awareness regarding environmental concerns and an increased demand for environmental cleanliness.

It is imperative to consider the ramifications of validating the EKC for the broader global community. Asian countries have consistently played a substantial role in driving worldwide economic expansion, a trend that persists today. If these countries adhere to the EKC trajectory, it could imply that as their development progresses, it is possible to stabilize or even reduce global environmental pressures, provided that the critical turning points are attained earlier rather than later. This study validates the previous studies conducted for Asian economies (Apergis and Ozturk, 2015), Vietnam (Al-Mulai *et al*., 2015), Kenya (Sarkodie and Ozturk, 2020), Portugal (Shahbaz *et al*., 2015), EU-8 states (Boubellouta and Kusch-Brandt, 2020), African states (Lin *et al*., 2016) and the USA (Atasoy, 2017).

6. Conclusion and Policy Implications

This study investigated the impact of *ENVR*, *PIST*, *FNC*, *ICGTD*, *HEVT* and *GDPPC* on South Asian economies' CO_2e. The present study employed various econometric methodologies: CSD tests, HST, CADFT, WCT and AMG estimator. The CSD tests confirmed that the economic conditions of other countries in the region could influence economic shocks in one country within Asian economies. The CADFT validated the stationarity of all the variables in the presence of CSD. The WCT showed a long-run link between *ENVR*, *PIST*, *FNC*, *ICGTD*, *HEVT*, *GDPPC* and CO_2e. The outcomes of AMG indicated that *ENVR* has a significant and negative association with CO_2e. This finding highlights the significance of dedication to ecologically conscious policies and its possible benefits for local and global environmentally friendly efforts. In addition, the study also indicated that the *PIST*, *FNC* and *GDPPC* have a positive connection with CO_2e, whereas *ICGTD* and *HEVT* have a negative association.

The study findings may have significant implications for policymakers. Firstly, the intricate relationship between environmental deprivation and heightened carbon emissions inside Asian countries necessitates implementing comprehensive policy solutions. Key aspects include sustainable urbanization, development of clean energy systems, a reform of agricultural practices, conservation of forests and implementation of effective waste management strategies. Urban green areas, renewable energy sources and farmer training are vital to contemporary society. Sustainable management of forests is crucial to mitigate carbon emissions and preserve water resources. Efforts aimed at waste reduction and promotion of recycling are of paramount importance. Implementing rigorous environmental standards and active participation of local populations in decision-making processes is vital. Economic mechanisms such as tax incentives and subsidies can potentially incentivize enterprises to embrace sustainable practices. Regional collaboration can also serve as a means to effectively tackle environmental concerns that are shared throughout multiple regions. The importance of innovation cannot be overstated, as evidenced by the significant investments made by governments in clean technology and sustainable waste management solutions. These efforts aim to foster a more sustainable and mutually beneficial relationship with the natural environment.

Secondly, Asian governments must perceive environmental rules as effective instruments for tackling climate change rather than as hindrances or impediments to economic growth. Enhancing current norms and standards can effectively mitigate emissions by implementing more stringent carbon emissions thresholds, allocating resources towards monitoring and enforcement methods and promoting sustainable practices through incentives. For countries in their early stages of development, exploiting the expertise of adjacent countries helps expedite the implementation of programmes. Regional cooperation, exemplified by organizations such as ASEAN and SAARC, can align standards and promote knowledge exchange. Transition strategies, encompassing training and reskilling initiatives, financial assistance and sustainable technological advancements, can facilitate the transformation of organizations towards more sustainable operational frameworks. Market-based mechanisms, such as the implementation of carbon pricing, have the potential to produce financial resources that can be allocated towards the development and implementation of renewable energy initiatives. To achieve a sustainable future, it is imperative to prioritize transparent communication and active stakeholder involvement.

Thirdly, improving and broadening bilateral and international alliances with a specific emphasis on advancing green and HEV technologies is crucial. It is recommended that Asian governments develop collaboration partnerships with advanced countries to enable the sharing of knowledge, joint research efforts and technology transfer. Regional centres of excellence or innovation hubs have the potential to attract both worldwide expertise and local talent, expediting the progress of technical developments. Creating a suitable environment for foreign direct investment in certain areas has the potential to attract sophisticated technology and techniques. Implementing standardized legislation and standards on green and HEV technologies throughout the region can facilitate collaboration and improve access to regional markets. Implementing educational programmes and training efforts prioritizing capacity building can effectively equip the local workforce with the essential skills required for their respective roles. Finally, incorporating environmentally friendly and HEV technologies into community infrastructure initiatives can guarantee extensive and enduring advantages.

Lastly, political instability (*PIST*) is essential for long-term sustainability initiatives, as it promotes consistent policymaking and environmental programme implementation. Countries characterized by *PIST* are more inclined to actively participate in and provide resources towards sustainable initiatives, forming bipartisan climate committees or implementing enduring sustainability agreements. There is a pressing need for inventive financial strategies to tackle CO_2e effectively. These strategies encompass the implementation of green financing structures, fostering partnerships with international financial institutions and providing tax incentives to encourage private sector investments in green technologies. The observed correlation between *GDPPC* and CO_2e implies that economic development frequently occurs at the expense of environmental welfare. It is imperative for policymakers to actively promote a green growth paradigm that effectively integrates economic expansion and environmental sustainability. This entails fostering financially viable industries prioritizing ecological considerations, implementing sustainable agricultural practices and promoting sustainable eco-tourism development. As the *GDPPC* experiences growth, there is a corresponding increase in consumption and emissions.

Consequently, it becomes imperative to implement strategies aimed at discouraging wasteful expenditure. These strategies include implementation of progressive taxation on luxury products with a high carbon footprint and promotion of a circular economy. Integrating environmental education into school curricula can contribute to developing future generations' ability to make sustainable decisions.

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