Qamruzzaman, Md; Farzana, Nusrat; Mindia, Piana Monsur

Article

Unveiling the path to environmental sustainability through energy efficiency, environmental innovation, and institutional quality in Southeast Asian Countries

International Journal of Energy Economics and Policy

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(6), 322-343.

Unveiling the Path to Environmental Sustainability through Energy Efficiency, Environmental Innovation, and Institutional Quality in Southeast Asian Countries

Md Qamruzzaman*, Nusrat Farzana, Piana Monsur Mindia

School of Business and Economics, United International University, Dhaka-1212, Bangladesh.
*Email: qamruzzaman@bus.uiu.ac.bd

Received: 11 August 2024 **Accepted:** 13 October 2024 **DOI:** https://doi.org/10.32479/ijefi.17191

ABSTRACT

This study examines the correlation between environmental innovation (EI), energy efficiency (EE), institutional quality (IQ), and environmental sustainability (ES) in the Southeast Asian economy from 1980 to 2019. The analysis employs both symmetric and asymmetric frameworks to provide a comprehensive understanding of the topic. The preliminary evaluation employing SHT, CSDT, and PURT indicates that the research variables demonstrate heterogeneity properties, cross-sectional dependence, and stationarity following the first difference. Moreover, the cointegration test results confirm a sustained relationship between the variables being explained and the explanatory variables in the long term. Utilizing the CS-ARDL methodology for symmetric analysis, this study reveals a positive and statistically significant correlation between the explanatory variables and environmental sustainability. This proposition posits that promoting EI, EE, and IQ can contribute to attaining the overarching objective of environmental protection. The study investigates long-term and short-run asymmetric relationships utilizing the standard Wald test, presenting definitive evidence. The presence of asymmetric coefficients reveals that positive and negative shocks in EI, EE, and IQ negatively influence environmental sustainability indicators, specifically CO_2 emissions and ecological footprint. This statement suggests that the implementation of environmentally-focused innovation, the integration of clean energy, and the establishment of effective governance have the potential to bolster environmental quality through the reduction of CO_2 emissions and the enhancement of ecological conditions. Regarding directional causality, the feedback hypothesis explores the causal connection between EE, IQ, and ES. The study's findings offer valuable insights for formulating policies that will effectively guide future development endeavors in the region. In conclusion, this research highlights the importance of fostering environmental innovation, promoting energy efficiency, and enhancing institutional quality as essential measures for achieving environmental sustainability in the Southeast Asian economy.

Keywords: Environmental Innovation, Energy Efficiency, Institutional Quality, Environmental Sustainability, ARDL, CS-ARDL, NARDL
JEL Classifications: Q12, M10, O32, J35

1. INTRODUCTION

Over the previous few decades, academics, researchers, scientists, and economists have paid a great deal of attention to the degradation of the environment due to the significant economic problem it presents. Many countries are now coping with the severe consequences of global warming because of the continuing rise in CO_2 and the resulting threats to human health and the integrity of the natural environment (Lanouar et al., 2016; Alola et al., 2022). In light of the hope for environmental sustainability brought on by a decrease in the harmful effects brought on by greenhouse gas (GHG) emissions into the atmosphere, scholars have accentuated the significance of studying the essential traits that aid in mitigating the current state of climate change (Ali et al., 2023). Due to a greater dependence on fossil fuels than renewable energy (RE, hereafter), significant CO_2 is produced during the economic boom when widespread industrialization and household aggregation occur. In addition, the administration has missed the bigger picture by prioritizing economic growth above everything else. There have been recent revelations about the causes of environmental deterioration. Governments are responding by trying to discover answers to the issues that are lowering environmental standards. CO_2 emissions are a contributor to climate change and global warming. The adverse impacts of ED, such as climate change and global warming, have been apparent globally, prompting governments to seek a collective solution to counteract these effects. Current scientific consensus suggests a three-pronged strategy is necessary to improve environmental quality: (1) a macro-fundamental contribution; (2) energy policies focused on the integration of renewable energy rather than fossil fuel (Jahanger et al.,); and (3) an individual's contribution (Cardenas et al., 2016). Although incorporating clean energy helps to manage the number of carbon emissions, which improves EQ. Apergis et al. (2010) discovered that severe energy laws impair economic growth. Therefore, policymakers have been compelled by the dilemma of conservative energy policy and economic growth to verbalize environmental strategy to reconcile EQ and economic growth via the management of energy amalgamation, preferably using RE sources. Because of this, leaders now have no choice but to create an environmental policy.

This study well-thought-out environmental innovation (EI, here after), energy efficiency (EE, hereafter), and Good Governance (GG, hereafter) in the equation of environmental sustainability (ES, hereafter). As a determinant of EE, the stud of Sun et al. (2019) documents green innovation, and the study of Brännlund et al. (2007) expose TI. In addition, the pace of technical innovation in environmental development has placed a greater emphasis on gradual and dramatic changes in technological advances in environmental and climatic changes, as well as on diffusion and adaptation in industrial growth. Environmentally innovative movement is at the core of the regulatory-adoption (Pata et al., 2023) of additional regulation is likely reflected in advanced innovation. Innovative movement leads to higher standardization (Carrión-Flores and Innes, 2010). There is an apparent connection between this phenomenon and corporations' adoption of previously developed environmental technology (Popp, 2005; Popp et al., 2010). Increasing the stringency of regulations makes it easier to implement the most advanced technology, achieving a higher level of uniformity. Literature has posited an institutional role in managing environmental protection by effectively implementing environmental policies and suggesting governmental initiatives to promote environmental quality through controlling inefficient energy inclusion, renewable technology integration, and waste management (Welsch, 2004). The government may impact the current and future state of the environment. The rule of law is one of the most valued aspects of a government. It is a sign of a solid and effective constitutional system. Along with protecting individuals from the adverse effects of market failures, a robust rule of law may help prevent future damage. Bernauer and Koubi (2009) pointed out that for market actors to cooperate appropriately, the government may need to provide both capable and impartial institutions. This is why it is essential to consider sustainable options while upholding the law. Since stringent enforcement is essential, businesses will not hesitate to comply once CO_2 control measures are in place. But suppose the institutions are not very good. In that case, companies will ignore CO_2 management strategies without considering how their actions will hurt the environment and slow growth (Issa).

The study's objective is to examine the contribution of environmental innovation, energy efficiency, and institutional quality to the effective management of environmental sustainability in the economies of Southeast Asia from 1990 to 2022. Among the econometric techniques used in this investigation are a cross-sectional dependency test, long-run cointegration through an error correction model, baseline estimation with random effects and fixed effects models, and ARDL for detecting the elasticity of explanatory variables on environmental sustainability. Also included are discussions of CS-ARDL, nonlinear ARDL, and directional causality to flesh out the picture. The research shows that negative impacts have flowed from explanatory factors to environmental sustainability, as shown by the rendered coefficients of explanatory variables using the specified regression. Dropping carbon emissions and safeguarding the ecological stability shows that EI, EE, and IQ all help with EQ management. Furthermore, a nonlinear ARDL analysis has shown an uneven connection between environmental sustainability explanation factors and environmental sustainability explanation factors. The research concludes that if effective environmental policies are developed and implemented with an well-organized institutional incidence in the economy, the existing status of environmental development in Southeast Asian nations may be better-quality by eliminating ecological inequity.

As a case study, the present study has considered a panel of 05 (five) Southeast Asian nations (Bangladesh, India, Pakistan, Sri Lanka, and Nepal) in exploring the effects of EI, EE, and EQ on ES, which is measured by carbon emissions and ecological footprint. Several facts have guided the selection of the sample. First, Environmental security has always been critical for the Southeast Asian economy because environmental instability adversely causes agricultural production and degrades long-term economic prospects. Environmental erratic behavior decreases the targeted agricultural output, intensifying the society's economic disequilibrium. Furthermore, natural catastrophes, irregular rain, and extreme environmental changes negatively cause the ordinary course of life. Second, Southeast Asia is one of the areas most likely to be severely impacted by climate change with negative environmental consequences. Climate change's negative effect on regional affairs adds another policy problem for the region's nations, many of which are already struggling to find solutions to increasing national populations while simultaneously battling chronic poverty. Third, South Asian countries have partly succeeded in eradicating poverty via fast industrialization, facilitated by liberal economic reforms (Onafowora and Owoye, 1998; Afzal et al., 2018). Many southeast Asian nations are currently in a transition characterized by increasing urbanization and industrialization, with increased greenhouse gas emissions and environmental damage. Regional players like Bangladesh and India have partly embraced growth strategies centered on heavy industry expansion, resulting in increased industrial production and environmental damage. Degradation exacerbates resource shortages, reduces agricultural output, and exacerbates severe weather (Zakaria and Bibi, 2019; Ascenso et al., 2021; Muhammad et al., 2022), and poor populations are disproportionately affected by global warming and environmental degradation (Gang et al., 2014). Liberalization and industrialization have increased South Asia's vulnerability to environmental deterioration and associated hazards (Joof et al., 2023).

In terms of existing research, the following fields benefit from the findings of the present study: First, according to the current body of literature about ED and sustainability, researchers and academics have spent time and effort discovering ways of reducing environmental adversity with the lodging of green energy and the execution of legislation. The importance of EI, EE, and GG in managing environmental variety for sustainability has been the subject of increasing study in recent years. These experts have considered either country-specifics or aggregated information from a variety of nations using both quantitative and qualitative methods. Despite the importance of environmental sustainability to South Asian economies, very little empirical research has been undertaken. The following is an example of such a study: (Hasnat et al., 2018; Murshed et al., 2021). We believe this study to be the first empirical investigation to examine the interplay of ES, EI, EE, and IQ as they pertain to the Southeast Asian economy. The study's findings point to a window of opportunity for developing and enacting environmental policy as part of environmental sustainability management. Second, there are competing views on how to quantify environmental sustainability. Some researchers have looked at carbon emissions as an indicator of environmental health (Kirikkaleli and Adebayo, 2021; Ahmed et al., 2021; Xia et al., 2022), while others have looked at a recently proposed proxy (Meo et al., 2021; Nathaniel, 2021a); in this study, we looked at both proxies to show that the substantial evidence supporting the predetermined connection.

The remaining article structure is as follows: Section I provides background information. Section II presents a literature review and hypothesis development. Section III describes the study's data, variables, and definitions, as well as its methodology. The structure is as follows: The empirical model estimate is shown in Section IV, the results are discussed in Section V, and the paper's conclusion and policy suggestions are provided in Section VI.

2. LITERATURE REVIEW

Regardless of the gathering state, environmental sustainability in the face of unnecessary carbon emissions into the ecosystem has climbed to the top of the debate table. Researchers, scholars, and politicians have spent much time and energy clarifying the macro principles of ecologically sustainable behaviors for the past few decades. However, there is not yet a broad consensus on the result. Industrial diversification, international integration, and the structure of the economy all necessitate the formation of direct and indirect interconnections between macro actors.; however, empirical findings combined with policy recommendations have uncovered effective ways to stop environmental degradation and achieve environmental sustainability.

2.1. Energy Efficiency and Environmental Sustainability

The beneficial role of efficient energy inclusion in expediting environmental development has been revealed in literature (Akram et al., 2020), Hanley et al. (2009), Sarkodie and Strezov (2019). Literature postulated that clean energy in the industrial production process lessens CO_2 emission, which can be avail with renewable technologies adoption. Furthermore, the reliance on fossil fuel demand transit into clean energy and technological advancement has substantially contributed to EQ improvement (Chi et al., 2021). Globally, scholars are concerned about the greenhouse effect, carbon emissions, and other forms of environmental deterioration. They are working on renewable energy and energy efficiency to achieve ES. Researches are looking for a way out of this critical situation (Ibrahim and Alola, 2020; Md, 2022; Sorrell, 2010; Vance et al., 2015). Reducing carbon dioxide emissions is one-way technological advancements in the energy sector help to better the environment. A study (JinRu and Qamruzzaman, 2022) suggested that lowering energy intensity and, consequently, carbon emissions is one way in which the use of energy-efficient technologies helps to ensure environmental sustainability. Energy safety and ecological sustainability have become essential priorities as the international community reforms its approaches to economic growth to guarantee a steady energy supply and protect the planet. (Murshed, 2020). Ibrahim and Alola (2020) analyzed the effects of nonrenewable on GDP growth, the Quality of the environment, and the cost of using natural resources using Data Envelopment Analysis (DEA) and the Autoregressive Distributed Lag (ARDL) & Pooled Mean Group (PMG) method. Research on the MENA region from 2006 to 2016 identified that the conventional energy efficiency rules MENA countries practiced were detrimental to the environment and did not contribute to ES. Applying the same econometrics model (Md, 2022) demonstrated that RE sources and EI improve long-term ES. According to the study, EI, EE, and IQ have helped endeavors to reduce carbon emissions and boost ecological growth. Carbon emissions and climate change are two of the most pressing concerns of our time, and according to the research of (Ponce and Khan, 2021), sustainable energy can help cut down on air pollution, therefore, could help fix the environment. This paper examines the link between some indicators measuring energy efficacy and asset rights in nine industrialized nations from 1995 to 2019. Developed European countries are shown to be in an equilibrium situation in the long term. However, the scenario is different for non-European developed countries. The primary findings reveal a regressive connection between RE, energy competence, and carbon dioxide emissions. The paper concludes with some policy recommendations for achieving environmental sustainability.

Five interconnected points concerning the association between energy use, fiscal growth, and environmental sustainability were presented in the paper (Sorrell, 2010). The analysis concludes that an advanced level of energy productivity than the current level is a must for a sustainable economy. The research from (Vance et al., 2015) reveals that we must cut our energy consumption to ensure long-term sustainability. Population growth, environmental effect, gross domestic product, and energy efficiency may all be analyzed to determine energy efficiency or sustainability. In order to make progress toward a more sustainable energy future, new technologies must be widely adopted, and practical policy frameworks must be developed (Vance et al., 2015).

2.2. Environmental Innovation and Environmental Sustainability

Greener industrial technology seems to significantly influence environmental performance without affecting economic growth (Arbolino et al., 2018). Sustainability in the natural world necessitates using cleaner energy sources, and environmental innovation is one of the most effective replacement options. Environmental sustainability is connected to EI, which is why Zhang et al. (2022) use the system generalized method of moments (SGMM) approach to examine the impact of EI on China's carbon emissions from 2000 to 2013. According to the research, most EI-related factors considerably impact effective carbon emission reductions. Using cross-sectional dependence (CD) and cross-sectional augmented Im-Pesaran-Shin (CIPS) tests, Paramati et al. (2021) examine the effect of GDP per capita, FDI, green technology, TO, and financial deepening on carbon emissions in a panel of 25 OECD countries from 1991 to 2016. According to the results, carbon emissions may be reduced by deploying green technology, attracting FDI, and expanding trade prospects.

On the other hand, economic development and higher personal wealth are related to increased carbon emissions. From 2001 to 2010, Lee and Min (2015) investigated the effects of green R&D investment for eco-innovation on the environmental and financial performance of Japanese manufacturing firms from a resource-based and natural resource-based perspective. Green R&D, as shown by the research, decreases greenhouse gas emissions. Furthermore, as Shahbaz et al. (2018) demonstrate, energy innovation enhances environmental quality by cutting carbon emissions. Environmental Technology Innovation, henceforth denoted as "environmental innovation," is the most effective method for long-term ecological protection. This is especially true when the significance of environmental preservation increases. Over the last several years, ecological innovation has become the utmost effective method for addressing environmental challenges and dangers. (Choi and Han, 2018) Proactive environmental management may pave the way for green/environmental innovation, which can spur developments in product/service design, manufacturing techniques, and market distribution. In contrast, innovation may spur the development of an enterprise's environmental management, increasing the enterprise's environmental proactivity. Thus, there are two-way causal links between environmental management and revolution (Dias Angelo et al., 2012).

In a study Li (2014), this query enquired how egocentric firms should respond to the current environmental crisis. If firms take measures to lessen their environmental impact, doing so may raise their operating expenses. If not, they run the possibility of being expelled from the industry. As a result, businesses have been pushed to reconsider their production processes in response to community and government concerns. The exploratory study by Sezen and Çankaya (2013) investigated how eco-innovation and green production impact the bottom line (economic, environmental, and social). A questionnaire was distributed to 53 firms in Turkey's automotive, chemical, and electronics industries. Researchers used regression analysis to analyze the empirical model to verify the hypothesized connections. Findings from this research suggest that there is a considerable beneficial effect on environmental and social outcomes from using green manufacturing practices.

Furthermore, an autoregressive distributed-lag model was used in the study conducted by (Mongo et al., 2021). This model was used to investigate the impact that environmental progress, utilization of renewable energy foundations, GDP per capita, and economic openness had on CO_2 releases in 15 countries from Europe over 23 years. According to their findings, advances in protecting the environment often result in lower CO_2 emissions over time. However, they have the opposite effect in the near term. This suggests that there might be a rebound effect. The researchers in a study (Chen et al., 2020) set out to learn how various technological and ecological innovation indices impacted carbon dioxide emissions from China's transportation sector. What this research adds is broken down into three sections: Using the double logarithmic model and the SGMM (system generalized method moment), the influence of technical and eco-friendly modernization on China's transport sector CO_2 releases will be explored, and multi-regional comparisons of emission drivers will be done.

In a separate study (Carrión-Flores and Innes, 2010), bidirectional connections were discovered between hazardous pollutant emissions and environmental innovation. Effective R&D decreases pollution, while stricter pollution targets encourage new R&D. From 1989 to 2004, they evaluated 127 industrial enterprises to assess research and pollution consequences. This study demonstrates a significant and unfavorable relationship between emissions and environmental patents. This approach is consistent with government programs and "private politics." In each case, innovation can reduce the costs associated with meeting stricter government, consumer, or NGO pollution goals, exceeding government or private environmental performance expectations. Tighter pollution limits improve the cost-saving benefits of environmental research and development, hence fostering innovation. This research demonstrated that a linear feedback model effectively captures the dynamic connections between environmental policy and innovation.

2.3. Good Governance and Environmental Sustainability

Most development institutes consider "good governance" one of the most critical factors, and they work tirelessly to promote it. However, this is even though the term has a wide range of meanings depending on the organization and the individual's role (Gisselquist, 2012). Implementing programs according to "good governance" requires systematic performance evaluation. Good governance has many principles, which vary across the literature. Few studies have quantified program success using these principles. The eight tenets of good governance are- inclusion, fairness, transparency, accountability, legitimacy, direction, performance, and capability, which form the basis of a scale for evaluating the success of a program (Pomeranz and Stedman, 2020). The quality of institutions, such as the rule of law, the efficiency of bureaucracy, and the prevalence of corruption, is typically underestimated, even though they may impact environmental quality (Yang et al., 2022). However, if institutions fail, ecosystems may suffer. Even though a country has a low GDP, it may be possible to enhance the environment by putting in place strong institutions. Abid (2017) emphasizing the significance of strong institutions in ensuring environmental sustainability. According to the report, high-quality institutions indirectly impact economic development and environmental quality in EU nations by increasing the efficiency of public investment, bolstering financial growth, and increasing the attractiveness of FDI. Lau et al. (2018) advocated robust institutions to minimize the impact of economic development on atmospheric carbon dioxide levels. Granger causality testing also validates the importance of institutional frameworks in lowering CO_2 emissions. They all have similar perspectives, but Bhattacharya et al. (2017) state that political stability, democracy, government efficacy, and corruption control negatively influence CO_2 emissions. In contrast, the rule of law and high-quality legislation reduce CO_2 emissions.

In the study of (Lin and Qamruzzaman, 2023; JinRu et al., 2023; Qamruzzaman and Kler, 2023) demonstrates that solid institutions and enterprises may help promote environmental sustainability. The findings demonstrate that institutional transformation in this manner actively promotes environmental excellence. Open trade may be hazardous to the environment. However, this impact is more evident in countries with poor institutions and less pronounced in those with solid institutions. Sarpong and Bein (2020) employed the generalized moment (GMM) approach to investigate the association between CO_2 and good governance in 38 Sub-Saharan African governments, both oil-producing and non-oil-producing, between 2005 and 2014. Researchers found that severe carbon emission regulations are required for a healthy Earth. Countries may get government support for lowering CO_2 emissions. Government efficiency and carbon dioxide emissions are favorably connected in oil-producing countries but negatively correlated in non-oil-producing countries. Better political, economic, and institutional management, according to Liu et al. (2020), considerably lower CO_2 emissions and pollution. Also, research shows that places that need to cut CO_2 emissions are where the government works well (Dadgara and Nazari, 2017).

Tamazian and Bhaskara Rao (2010) examine the relationship between GDP growth, environmental quality, financial development, and institutional quality in 24 transition economies from 1993 to 2004 using the GMM approach. The outcomes of this research confirm the EKC hypothesis and provide credence to the concept that better institutional practices and economic development are essential for enhancing environmental performance. The study's authors warn that financial liberalization might hurt environmental conditions if advances in environmental quality are not implemented within a sound institutional framework. Solarin et al. (2021) analyze the pollution haven hypothesis (PHH) for Ghana between 1980 and 2012, using the nation's carbon dioxide (CO_2) emissions as a proxy for air pollution. Other Variables Include urbanization, foreign direct investment, institutional quality, trade openness, renewable and fossil fuel energy use, and others. According to the research, economic development, foreign direct investment, international trade, financial growth, and urbanization contribute to reducing CO_2 emissions.

To demonstrate the relationship between corporate governance and environmental sustainability, Hussain et al. (2018) conducted a triple-bottom-line performance analysis through agency and stakeholder theory. The authors discovered a link between EN SUST (Environmental sustainability) and BINDP (Board Independence). The second relevant governance variable was discovered to be negative CEOD (CEO Duality). The significance of the role of the sustainability committee was also emphasized (CSRCOM). There is a positive correlation between the variable in question. Because CEO duality may influence board independence, the authors include an interaction variable (INDCEO) and examine its effects on the dependent variable. Negative and statistically significant coefficients indicate that a dual CEO outweighs efforts to increase board independence. The coefficient, however, is two orders of magnitude lower than CEOD. As a result, an independent board mitigates the negative consequences of a dual CEO. They are unable to find a link between the environmental SP variable and the variables BSIZE (Board Size), WOB (Women on Board), and BMTNG (Board Activity). Only profitability has been determined to be a valid control variable for environmental sustainability performance. In a sample of environmentally conscious businesses, environmental governance mechanisms are primarily symbolic and have little impact on organizations. Environmental governance mechanisms do not correlate with regulatory compliance, pollution prevention, or environmental capital expenditures. Environmental incentives reduce pollution (Rodrigue et al., 2013). The study by Rupley et al. (2012) investigates how governance, media attention, and voluntary environmental disclosure are related (VED). The empirical paper reveals a correlation between VED quality and factors like board independence, diversity, expertise, and adverse environmental media. Additional studies show that institutional investors affect environmental reporting decisions only when there is negative environmental media coverage. Furthermore, studies that track the same topic over time show that environmental disclosure gets better as time goes on.

2.4. Research Gap, Conceptual Model, and Hypothesis Development

Temperature spikes, twisters, and dry spells are just some of the extreme weather phenomena that climate change is responsible for. Climate change is the long-term trend of heightened or reduced severe weather occurrences caused by human activity or natural phenomena. Changes in South Asia's climate are primarily due to rising levels of greenhouse gases (GHGs). Because of increased industrialization and other human activities, carbon dioxide (CO_2), an essential greenhouse gas, has increased over much of South Asia. Both India and Pakistan contribute significantly to regional carbon dioxide emissions. Researchers and scholars have spent over a decade pinpointing the essential macro aspects that may aid environmental adversity management to improve the existing scenario. Renewable energy, technological advancement, strong institutions, and other similar factors have all been cited as essential for managing environmental quality. This study examines some factors contributing to environmental sustainability in the South Asian economy and the following hypothesis to be tested (Figure 1).

3. DATA AND METHODOLOGY OF THE STUDY

3.1. Model Specification

This study aims to determine whether or not the explanatory variables (such as EI, EI, and IQ) enhance or diminish ES by using data from the South Asian economies of Bangladesh, India, Pakistan, Sri Lanka, and Nepal from 1980 to 2019. Only the availability of data and the sample period dictate sample selection. The current study builds on previous research by Hanley et al. (2009), Ingrao et al. (2018) by including two additional variables—environmental innovation and institutional quality—to demonstrate a link between energy efficiency and environmental sustainability. The generalized model is as follows:

$$ES_{(CO2|\,EF)}\,|EE, EI, IQ \quad (1)$$

ES, EI, IQ, and EE stand for environmental sustainably, environmental innovaton, institutional quality, and energy efficiency.

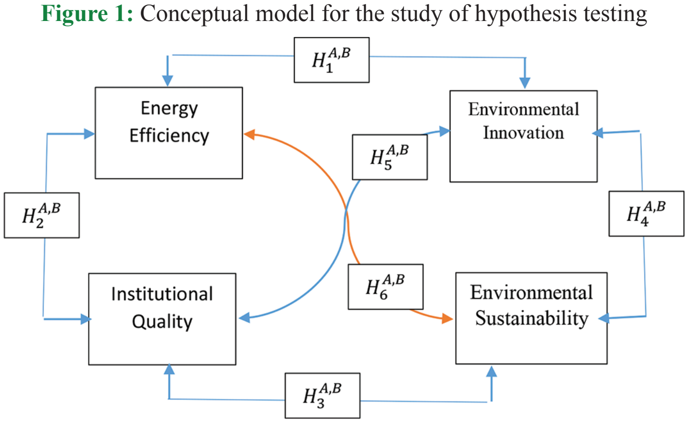
All the variables have been transformed into natural logarithms to ensure empirical robustness and efficient estimation. After transformation, the above equation (1) reproduces in the following regression form coefficients extraction.

$$ES\,(co2) = \alpha_0 + \beta_1\, EE_{it} + \beta_2\, EI_{it} + \beta_3\, IQ_{it} + \beta_4\, TO_{it} + \beta_5\, FDI_{it} + \varepsilon_{i,t} \quad (2)$$

$$ES(EF) = \alpha_0 + \gamma_1\, EE_{it} + \gamma_2\, EI_{it} + \gamma_3\, IQ_{it} + \gamma_4\, TO_{it} + \gamma_5\, FDI_{it} + \varepsilon_{i,} \quad (3)$$

Where environmental sustainability (ES) is measured by carbon emission (CO_2) and ecological footprint (EF), EE, EI, and IQ, TO, and FDI stands for energy efficiency, environmental innovation, institutional quality, trade openness, and inflows of foreign direct investment, the coefficients of $\beta_1 \ldots\ldots \beta_5$; $\gamma_1 \ldots \gamma_5$ explain the elasticity of explanatory variables and control variables on ED.

Figure 1: Conceptual model for the study of hypothesis testing



3.2. Variables Definition and Data Sources

The variables, proxies, and data sources are displayed in Table 1

The institutional quality is measured by constructing the index through the PCA, and their results are displayed in Table 2.

3.3. Estimation Strategy

3.3.1. Correctional dependency

In order to document the research variable's cross-sectional dependency, the study implemented the CSDT following the procedure offered by (Breusch and Pagan, 1980; Pesaran, 2004; Pesaran, 2006; and Pesaran et al., 2008) and test statistics extracted by executing the following equation.

$$y_{it} = \alpha_i + \beta_i\, x_{it} + u_{it} \;\; i = 1\ldots.N,\; t = 1\ldots.T \quad (4)$$

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{IJ} \underset{d}{\rightarrow} X^2 N(N+1)2 \quad (5)$$

$$CD_{lm} = \sqrt{\frac{N}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(T\hat{\rho}_{ij}-1\right) \quad (6)$$

$$CD_{lm} = \sqrt{\frac{2T}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\hat{\rho}_{ij}\right) \quad (7)$$

$$CD_{lm} = \sqrt{\frac{2}{N(N-1)}}\sum_{I=1}^{N-1}\sum_{J=i+1}^{N}\left(\frac{(T-K)\hat{\rho}_{ij}^2 - u_{Tij}}{\upsilon_{Tij}^2}\right)\vec{d}\,(N,0) \quad (8)$$

Table 1: Variable definition and sources

Variable	Definition	Units	Sources
Environmental sustainability	CO_2 emissions per capital		WDI, World Bank (2022)
	Ecological footprint (total GHA)		Global Footprint Network (2021)
Environmental innovation	Environment-related patents number	n	OECD (2020)
	No patent application	n	WDI, World Bank (2022)
Energy efficiency	The ratio of renewable energy to fossil fuel consumption	%	Authors construction
Institutional quality index	Institutional composite indexed constructed by employing PCA	Index	Authors construction
Control variables			
Financial development	Domestic credit to the private sector (% of GDP)	%	WDI, World Bank (2022)
TO	Trade as a percentage of GDP	%	
FDI	FDI net inflow as a percentage of GDP	%	
RE	Renewable energy consumption		

PCA: Principal components analysis, WDI: World development indicator, OECD: Organization for economic co-operation and development

Table 2: Principal components analysis

Eigenvalues: (Sum=6, Average=1)						
Number	**Value**	**Difference**	**Por**	**CV**	**CP**	
V	2.030832	0.836007	0.3385	2.030832	0.3385	
PS	1.194825	0.138544	0.1991	3.225657	0.5376	
GE	1.056281	0.266011	0.1760	4.281938	0.7137	
RQ	0.790270	0.095811	0.1317	5.072208	0.8454	
L	0.694459	0.461127	0.1157	5.766667	0.9611	
CC	0.233333	–	0.0389	6.000000	1.0000	
Eigenvectors (loadings)						
Variable	**V**	**PS**	**GE**	**RQ**	**L**	**CC**
V	0.606065	−0.104628	0.331622	−0.081171	−0.061121	−0.708125
ps	0.184381	0.655866	−0.121268	−0.652833	0.303590	0.052737
GE	−0.208214	0.345969	0.693959	0.375948	0.462467	0.012654
RQ	0.213111	0.640245	−0.203720	0.510641	−0.491784	−0.023693
L	0.602363	−0.137879	0.329633	−0.027345	−0.117311	0.703549
CC	0.383509	−0.101359	−0.493539	0.405440	0.659249	0.008704
Ordinary correlations						
Variables	**V**	**PS**	**GE**	**RQ**	**L**	**CC**
V	1.000000					
PS	0.122746	1.000000				
GE	−0.102276	0.007962	1.000000			
RQ	0.102934	0.240197	0.018915	1.000000		
L	0.764587	0.073313	−0.113800	0.109432	1.000000	
CC	0.256391	0.057318	−0.233628	0.133061	0.252961	1.000000

CC: Control of corruption, GE: Government effectiveness, PS: Political stability and absence of violence/terrorism, RQ: Regulatory quality, V: Voice and accountability, L: Legal environmental

3.3.2. Panel unit root test

The study relied on second-generation unit root tests familiarized by Pesaran (2007), commonly known as CADF and CIPS. The following equation is implemented in extracting the test statistics for stationary tests.

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \vartheta_i \bar{y}_t + \tau_{it} \tag{9}$$

$$\Delta Y_{it} = \mu_i + \theta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{k=1}^{p} \gamma_{ik} \Delta y_{i,k-1} + \sum_{k=0}^{p} \gamma_{ik} \overline{\Delta y}_{i,k-0} + \tau_{it} \tag{10}$$

$$CIPS = N^{-1} \sum_{i-1}^{N} \partial_i (N,T) \tag{11}$$

$$CIPS = N^{-1} \sum_{i-1}^{N} CADF \tag{12}$$

3.3.3. Westerlund cointegration test

The panel cointegration test following the error correction base has been implemented to assess the long-run association between ED, EE.

$$\Delta Z_{it} = \partial_i' d_i + \varnothing_i \left(Z_{i,t-1} - \delta_i' W_{i,t-1} \right) + \sum_{r=1}^{p} \varnothing_{i,r} \Delta Z_{i,t-r} + \sum_{r=0}^{p} \gamma_{i,j} \Delta W_{i,t-r} + \varepsilon_{i,t} \tag{13}$$

The results of group test statistics can be derived with equations 14 and 15.

$$G_T = \frac{1}{N} \sum_{i-1}^{N} \frac{\varphi_i}{SE\varphi_i} \tag{14}$$

$$G_a = \frac{1}{N} \sum_{i-1}^{N} \frac{T\varphi_i}{\varphi_i(1)} \tag{15}$$

$$P_T = \frac{\varphi_i}{SE\varphi_i} \tag{16}$$

$$P_a = T\varphi_i \tag{17}$$

3.3.4. Panel autoregressive distributed lag (PARDL)

The long-run and short-run equation as follows: ARDL (p, q ….n) as an empirical structure:

$$ES_{it} = \varepsilon_{it} + \sum_{j=1}^{p} \beta_{ij} ES_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij} EE_{i,t-j} + \sum_{j=0}^{q} \rho_{ij} EI_{i,t-j} + \sum_{j=0}^{q} \pi_{ij} IQ_{i,t-j} + \varepsilon_{it} \tag{18}$$

Where,

$$\varepsilon_{it} = \omega_t' G_t + \varepsilon_{it} \tag{19}$$

$$Q_{i,t-j} = \alpha_i + \beta_{ij} REC_{i,t-j} + \omega_t^{'} G_t + \mu_{it} \quad (20)$$

$$\Delta ES_{it} = \alpha_i + \xi_i \left(ES_{it-1} - \omega_t^{'} Q_{it-1} \right) + \sum_{J=1}^{M-1} \gamma_{iJ} \Delta ES_{it-J} + \sum_{J=0}^{N-1} \beta_{ij} \Delta Q_{it-J} + \mu_{it} \quad (21)$$

Where $\xi_i = -1\left(1 - \sum_{j-1}^{M} \gamma_{iJ}\right)$, $\omega_t^{'} = \xi_i^{-1} \sum_{j=0}^{N} \beta_{ij}$,

$\gamma_{i,j}^{*} = -\sum_{I=J+1}^{M} \gamma_{il}$ *for J=1, 2.,M-l, and* $\beta_{i,j}^{*} = -\sum_{I=J+1}^{N} \beta_{il}$

For J=1, 2. N-l. $\left(Q_{it-1} - \omega_t^{'} X_{it-1} \right)$.

3.3.5. CS-ARDL

Considering the results of CSDT and PURT, the present study extends the empirical investigation by including the proposed novel framework. Chudik and Pesaran (2015) can address the issue of CSD among research units. Therefore, when averaging equations (16) and (17) across *time,* we obtain

$$\overline{ES}_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}_t^{'} G_t + \bar{\varepsilon}_{it} \quad (22)$$

Where, $\bar{\alpha}_{it} = \dfrac{\sum_{i-1}^{N} \alpha_i}{N}$

$$\overline{ES}_{t-j} = \frac{\sum_i^N ES_{i,,t-j}}{N}, \quad \bar{\beta}_j = \frac{\sum_i^N \beta_{i,j}}{N} \qquad j = 0,1,2 \quad p$$

$$\bar{Q}_{t-j} = \frac{\sum_i^N Q_{i,,t-j}}{N}, \quad \bar{\Upsilon}_j = \frac{\sum_i^N \Upsilon_{i,j}}{N}, \qquad J = 0,1,2 \;\; q$$

$$\bar{\bar{\omega}}_j = \frac{\sum_{i=1}^{N} \omega_i}{N}, \bar{\varepsilon}_t = \frac{\sum_i^N \varepsilon_{i,t}}{N}$$

$$ES = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}_t^{'} G_t$$

$$\bar{\omega}_t^{'} G_t = \overline{ES}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j}$$

$$G_t = \frac{\overline{ES}_{it} - \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j}}{\bar{\omega}_t^{'}} \quad (23)$$

$$\overline{ES}_{it} = \varepsilon_{it} + \sum_{j=1}^{p} \beta_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij} \bar{Q}_{i,t-j} + \sum_{j=0}^{p} \bar{\partial}_{tj}^{'} \bar{Z}_{i,t-j} + \varepsilon_{it} \quad (24)$$

Where $\bar{Z} = (\overline{EE}, \overline{EI}, \overline{IQ},)$ and $S_{\bar{Z}}$ in the number of lagged cross-sectional averages. Furthermore, Equation (24) can be reparametrized to the effects of the ECM presentation of Panel CS-ARDL as follows:

$$\Delta ES_{it} = \alpha_i + \xi_i \left(ES_{it-1} - \omega_t^{'} Q_{it-1} \right) + \sum_{J=1}^{M-1} \gamma_{iJ} \Delta ES_{it-J} + \sum_{J=0}^{N-1} \beta_{ij} \Delta Q_{it-J} + \sum_{j=1}^{p} \lambda_j \overline{\Delta ES}_{i,t-j} + \sum_{j=0}^{q} \delta_j \overline{\Delta Q}_{i,t-j} + \sum_{j=0}^{S_{\bar{Z}}} \bar{\partial}_{ij}^{'} \bar{Z}_{i,t-j} + \mu_{it} \quad (25)$$

Where $\overline{\Delta ES}_{t-j} = \dfrac{\sum_i^N \Delta ES_{i,,t-j}}{N}$, $\overline{\Delta Q}_{t-j} = \dfrac{\sum_i^N \Delta Q_{i,,t-j}}{N}$

3.3.6. Nonlinear panel ARDL

Following Shin et al. (2014), the nonlinear equation as follows.

$$\Delta ES_{it} = \beta_{0i} + \beta_{1i} ES_{it-1} + \beta_{2i}^{+} EE_{t-1}^{+} + \beta_{2i}^{-} EE_{t-1}^{-} + \beta_{3t}^{+} EI_{t-1}^{+} + \beta_{3t}^{-} EI_{t-1}^{-} + \beta_{4t}^{+} IQ_{t-1}^{+} + \beta_{4t}^{-} IQ_{t-1}^{-} + \sum_{J=1}^{M-1} \gamma_{iJ} \Delta ES_{i,t-J} + \sum_{J=0}^{N-1} \left(\gamma_{ij}^{+} \Delta EE_{i,t-j}^{+} + \gamma_{ij}^{-} \Delta EE_{i,t-j}^{-} \right) + \sum_{J=0}^{O-1} \left(\left(\delta_{ij}^{+} \Delta EI_{i,t-j}^{+} + \delta_{ij}^{-} \Delta EI_{i,t-j}^{-} \right) \right) + \sum_{J=0}^{P-1} \left(\mu_{ij}^{+} \Delta IQ_{i,t-j}^{+} + \mu_{ij}^{-} \Delta IQ_{i,t-j}^{-} \right) + \varepsilon_{it} \quad (26)$$

The positive and negative shocks of explanatory variables as follows.

$$\begin{cases} EE_i^{+} = \sum_{k=1}^{t} \Delta EE_{ik}^{+} = \sum_{K=1}^{T} MAX\left(\Delta EE_{ik}, 0\right) \\ EE_i^{-} = \sum_{k=1}^{t} \Delta EE_{ik}^{-} = \sum_{K=1}^{T} MIN\left(\Delta EE_{ik}, 0\right) \end{cases} \quad (27)$$

$$\begin{cases} EI_i^{+} = \sum_{k=1}^{t} \Delta EI_{ik}^{+} = \sum_{K=1}^{T} MAX\left(\Delta EI_{ik}, 0\right) \\ EI_i^{-} = \sum_{k=1}^{t} \Delta EI_{ik}^{-} = \sum_{K=1}^{T} MIN\left(\Delta EI_{ik}, 0\right) \end{cases} \quad (28)$$

$$\begin{cases} IQ_t^{+} = \sum_{k=1}^{t} \Delta IQ_{ik}^{+} = \sum_{K=1}^{T} MAX\left(\Delta IQ_{ik}, 0\right) \\ IQ_t^{-} = \sum_{k=1}^{t} \Delta IQ_{ik}^{-} = \sum_{K=1}^{T} MIN\left(\Delta IQ_{ik}, 0\right) \end{cases} \quad (29)$$

The error correction version of equation 26 is as follows:

$$\Delta ES_{it} = \tau_{1i}\xi_{it-1} + \sum_{J=1}^{M-1}\gamma_{iJ}\Delta ES_{i,t-J} + \sum_{J=0}^{N-1}\left(\gamma_{ij}^{+}\Delta EE_{i,t-j}^{+} + \gamma_{ij}^{-}\Delta EE_{i,t-j}^{-}\right)$$
$$+\sum_{J=0}^{O-1}\left(\left(\delta_{ij}^{+}\Delta EI_{i,t-j}^{+} + \delta_{ij}^{-}\Delta EI_{i,t-j}^{-}\right)\right) + \sum_{J=0}^{P-1}\left(\mu_{ij}^{+}\Delta IQ_{i,t-j}^{+} + \mu_{ij}^{-}\Delta IQ_{i,t-j}^{-}\right)$$
$$+\varepsilon_{it} \tag{30}$$

The study implements the granger causality test following the procedure initiated by Dumitrescu and Hurlin (2012), the following equations are executed for test statistics.

$$Y_{it} = \alpha_i + \sum_{K-1}^{P}\gamma_{ik}Y_{i,t-k} + \sum_{K-1}^{P}\beta_{ik}X_{i,t-k} + \mu_{it} \tag{31}$$

$$W_{NT}^{Hnc} = N^{-1}\sum_{i-1}^{N}W_{i,t} \tag{32}$$

$$Z = \sqrt{\frac{N}{2P}\times\frac{T-2P-5}{T-P-3}}\times\left[\frac{T-2P-3}{T-2P-1}\bar{W} - P\right] \tag{33}$$

4. EMPIRICAL MODEL ESTIMATION AND INTERPRETATION

4.1. CSDT and SHT Results

Assessing research variables' properties is essential in selecting and implementing the appropriate econometrical techniques for exploring the target relations. The study implemented CSDT and SHT before reaching the target model estimation; the results are displayed in Table 3. Referring to the test statistics derived from CSDT, it is evident that all the variables share particular typical dynamics, which confirms their interdependence. Moreover, the test statistics of SHT revealed the heterogeneity attributes by nullifying the null hypothesis of independency.

Instead of the standard IPS, LLC, and Bretting tests, the CIPS and CADF panel unit root tests were used for exposing the stationary properties. Because of Pesaran's efforts (2007), these exams gained prominence. According to Dogan, Seker, and Bulbul (2017), standard panel unit root tests have limitations for cross-sectional data analysis. When cross-sectional independence is present, the CADF and the CIPS unit root tests produce accurate findings. The results of a test for the unit root of a panel are shown in Table 4.

Panel cointegration tests (*Pedroni, 2004; Pedroni, 2001)* and error correction-based panel cointegration test *Westerlund (2007)* were used to investigate the long-run relationships between EI, EE, IQ, and ES, as shown in Table 5. Most Pedroni cointegration test findings are statistically significant at 1%, indicating that the null hypothesis of no cointegration should be rejected. It establishes a time link between the variables. Furthermore, the ADF test findings indicated that the null hypothesis was incorrect, showing the existence of a long-term association. Researchers employed error correction-based cointegration to improve the accuracy and robustness of their findings. Sustainability, energy efficiency, innovations in the environment, and the quality of institutions have all been studied for a long time in South Asian countries.

4.2. Hausman Test Results

The H-test statistics displayed in Tables 6-8 are derived from the Hausman test. The study revealed that all the test statistics are statistically insignificant; that is, the P-value of each test statistic is higher than the cut-off value, which is 0.005., indicating the present random effects in the equation.

4.3. Baseline Estimation with Random and Fixed Effects Regression

Before estimating the goal model using the more advanced econometric model, the research assessed the baseline model with random and fixed effects in panel OLS. This step was taken before the desired model was calculated. Table 6 presents the outcomes of these baseline estimates, with Panel-A displaying the outcomes of carbon emission models and Panel-B displaying the outcomes of ecological footprint analyses. There is a statistically significant inverse relationship between energy efficiency and environmental sustainability, as shown by both models. Environmental sustainability is ensured, and the rate of environmental degradation is delayed when green technology is used. This finding corroborated the study of both models, which had shown that ecological output lessens environmental impacts. Institutional excellence has been found to have beneficial (negative) consequences on environmental sustainability, measured by a company's carbon emissions (ecological footprint).

Table 3: Cross-sectional dependency and homogeneity test

Variables	Panel-A: Cross-sectional dependency test				Panel-B: Slop of homogeneity	
	LM_{BP} (Breusch and Pagan, 1980)	LM_{PS} Pesaran (2004)	CD_{PS} Pesaran (2006)	LM_{adj}	Δ	Adj.Δ
ES1	2905.823***	35.668***	36.951***	32.168***	17.875***	2905.823***
ES2	1599.362***	8.729***	2.9742***	5.229***	45.178***	1599.362***
EE	2736.745***	32.182***	40.649***	28.682***	32.81***	2736.745***
EI_1	3470.07***	47.302***	35.958***	43.802***	61.814***	3470.07***
EI_2	341.1624***	74.051***	18.372***	73.999***	95.391***	341.1624***
IQ	417.2093***	91.054***	20.399***	91.002***	41.24***	417.2093***
FDI	257.5122***	55.345***	7.8477***	55.293***	89.679***	257.5122***
FD	255.6662***	54.932***	7.1211***	54.884***	18.08***	255.6662***

***The superscript denotes the 1% level of significance. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

Table 4: Panel unit root test results

Panel-A: Conventional unit root test						
Variables	LLC t		IPS W-stat		ADF - Fisher Chi-square	
	t	T and c	t	T and c	t	T and c
Panel-A: Al level						
ES1	−3.122**	−0.1	−1.366	−1.483	32.604	38.315
ES2	−1.705	−2.879*	−0.276	−1.874	51.759*	37.164
EE	−1.062	−0.096	−0.098	−0.553	42.788	44.449
EI1	−0.873	−3.015**	−3.222**	−2.416	48.793	60.986*
EI2	−2.963	−3.229**	−1.057	−2.676	51.808*	52.005*
IQ	−1.644	−2.874*	−3.087**	−0.617	30.033	37.083
FDI	−2.01	−0.489	−3.102**	−2.486	52.281*	41.707
FD	−0.705	−1.761	−3.627**	−2.921*	51.089*	34.588
Panel-B: After the first difference						
ES1	−9.517***	−13.565***	−18.144***	−9.614***	196.794***	145.822***
ES2	−11.479***	−15.752***	−13.565***	−5.409***	199.27***	184.079***
EE	−10.626***	−22.95***	−11.408***	−9.618***	182.298***	149.765***
EI1	−10.481***	−9.885***	−5.792***	−6.402***	308.483***	102.75***
EI2	−11.376***	−19.945***	−11.006***	−7.379***	205.832***	156.491***
IQ	−10.009***	−21.954***	−7.882***	−5.859***	231.782***	199.737***
FDI	−11.313***	−5.89***	−20.997***	−5.582***	121.764***	141.889***
FD	−12.818***	−20.022***	−8.146***	−8.477***	182.392***	155.879***

Panel-B: Unit root test with CSD				
Variables	CIPS		CADF	
	At level	Δ	At level	Δ
ES1	−1.259	−5.878***	−0.834	−4.656***
ES2	−3.281***	−5.519***	−2.953***	−4.495***
EE	−3.131***	−6.105***	−2.968***	−5.252***
EI_1	−5.008***	−6.190***	−3.601***	−6.190***
EI_2	−2.449***	−5.657***	−2.393***	−4.442***
IQ	−2.410***	−5.965***	−2.292**	−4.655***
FDI	−2.286***	−5.892***	−2.359**	−4.732***
FD	−3.452***	−5.912***	−2.895 ***	−4.622***

The superscript ***/**/*denotes the 1%/5%/10% level of significance, respectively. IPS: Im-Pesaran-Shin, CIPS: Cross-sectional augmented IPS, EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

Table 5: Results of panel cointegration test

Model - 1: Environmental sustainability measured by carbon emissions				
Panel-A: PCT				
Test	1	2	3	4
Panel v-statistic	2.795**	2.888**	2.436**	2.89**
Panel rho-statistic	−4.839**	−5.305***	−5.814***	−5.442***
Panel PP-statistic	−9.357***	−9.976***	−9.441***	−10.148***
Panel ADF-statistic	−4.844**	−3.67*	−3.483*	−6.859***
Group rho-statistic	−0.497	−0.152	−1.473	−1.765
Group PP-statistic	−6.177***	−6.022***	−7.847***	−10.789***
Group ADF-statistic	−9.086***	−8.384***	−10.302***	−8.486***
Panel v-statistic	−8.696***	−8.757***	−7.131***	−7.242***
Panel rho-statistic	−11.026***	−11.839***	−8.788***	−7.908***
Panel PP-statistic	−9.163***	−11.907***	−9.752***	−7.568***
Panel ADF-statistic	−2.245	−3.576	−4.624	−2.054
Panel-B: KCT				
ADF	−2.9726***	−1.5814***	−2.8971***	−5.8228***
Panel-C: ECBCT				
Gt	Ga	Pt	Pa	
−13.915***	−12.029***	−14.904***	−13.577***	

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively

4.4. Long-run ad Short-run Coefficients: AEDL and CS-ARDL

Using ARDL and CS-ARDL, with carbon emissions as a stand-in for environmental sustainability, the research analyzed the interplay between EE, EI, and IQ and their impact on long-term ES. Table 7 shows the estimated model findings, with the long-run coefficient in panel A and the short-run coefficient in panel B.

The study found a negative and statistically significant relationship between EE and ES, with a coefficient of −0.0949 (−0.1358).

Table 6: Baseline estimation with FF and RE

Variable	Random effects	Fixed effects	Random effects	Fixed effects
	Panel-A: ES measured by Carbon emissions			
Variable	**[1]**	**[2]**	**[3]**	**[4]**
EE	−0.7959** (0.4049) [−1.9657]	−0.7776** (0.3475) [−2.2379]	0.0556*** (0.0061) [9.0898]	0.6887*** (0.1386) [4.9657]
EI_1	−0.0405*** (0.0068) [−5.9456]		0.1411** (0.0553) [2.5505]	-
EI_2		−0.0551*** (0.0069) [−7.9119]		0.0712* (0.0545) [1.3065]
IQ	−0.0320** (0.0156) [−2.0514]	0.4086** (0.1971) [2.0735]	0.6803** (0.2891) [2.3526]	0.1632* (0.0947) [1.7218]
FDI	−0.1154* (0.0773) [−1.6f993]	−0.2179** (0.1030) [−2.1156]	−0.0243* (0.0165) [−1.7695]	−0.0435* (0.0218) [−1.994]
FD	−0.0139*** (0.0042) [−3.3014]	−0.0037 (0.0053) [−0.7111]	−0.0627* (0.0469) [−1.3359]	0.1868 (0.172) [1.0864]
C	−2.3629*** (0.3731) [−6.3321]	−1.12635*** (0.3091) [−3.6432]	−1.0636*** (0.1389) [−7.6568]	1.6614*** (0.278) [5.976]
H-test	0.541		0.671	
	Panel –B: ES measured by ecological footprint			
Variable	**[5]**	**[6]**	**[7]**	**[8]**
EE	−0.0859*** (0.0152) [−5.6513]	−0.0587*** (0.0089) [−6.5955]	0.3682** (0.1706) [2.1582]	0.937* (0.7365) [1.2722]
EI_1	−0.207***0.0144) [−13.888]		−0.1013* (0.0572) [−1.7692]	
EI_2		−0.1049*** (0.0113) [−9.2831]		−0.0839* (0.0662) [−1.2673]
IQ	−0.1213*** (0.0134) [−9.0522]	−0.0862*** (0.0079) [−10.9114]	0.8067 (0.206) [3.9149]	0.6614** (0.278) [2.3791]
FDI	0.0844*** (0.0145) [5.8206]	0.1131*** (0.0083) [13.6265]	−0.0002* (0.0001) [−1.8661]	−0.1799** (0.0816) [−2.2046]
FD	0.0803*** (0.0122) [6.5819]	0.0634*** (0.0117) [5.4188]	0.1476* (0.1119) [1.3185]	−0.2636* (0.1389) [−1.8977]
C	0.111*** (0.0174) [6.3793]	0.1127*** (0.0091) [12.3846]	−1.2779** (0.6273) [−2.037]	1.2515* (0.848) [1.4758]
H-test	15.942***		25.6148***	

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively the value in () represents standard effort, and in [] denotes t-statistics. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

This implies that environmental challenges can be overcome by establishing energy efficiency and incorporating clean energy into the economy, thus achieving environmental sustainability. Here, we are discussing the ARDL-derived long-run coefficient (CS-ARDL). To be more precise, a decrease in current carbon emissions in the Southeast Asian economy of 0.949% to 1.358% may occur as a consequence of an increase in energy efficiency of 10% points. These results are consistent with those of other studies. Please think about the following: Several studies have been conducted on this subject, including (Shu Xu et al., 2021; Rosenfeld, 1999; Clarke et al., 2008). Energy efficiency and carbon emissions are positively (or negatively) correlated in the near term, with a value of 0.0152. This connection goes against common sense (−0.0264). The study found that changes in energy use have a more significant effect on the environment in the long run than in the short run.

Using ARDL (CS-ARDL) to investigate the relationship between environmental innovation (EI) and environmental sustainability (ES). The research found a negative statistically significant tie with a coefficient of −0.0579 (−0.0888), suggesting that development in EI helps reduce environmental adversity via incorporating environmentally friendly technology in industrial output, lowering the economy's carbon intensity. Concerning the interim evaluation, the negative and statistically significant association coefficient was −0.0253 in both models (−0.0544). Environment-friendly technologies are suitable for environmental well-being, as shown by studies such as those conducted by (Spiller et al., 2017; Többelmann and Wendler, 2020; and Iqbal et al., 2021). Hodson et al. (2018) institute that environmental innovation increases the success of energy integration by decreasing the cost of energy and the time it takes to transition to a cleaner energy source. It also leads to better EQ by lowering carbon emissions. Cagno et al. (2015) around that EI encourage businesses to switch to renewable energy sources, which cuts down on carbon emissions.

The ARDL (CS-ARDL) examination of the link between institutional quality and environmental sustainability indicated a statistically significant negative impact. For instance, a 10% increase in IQ will result in a −0.857% (−2.217%) improvement in environmental sustainability, indicating that the effective and efficient role of domestic institutions plays a key role in enhancing environmental advancement by lowering economic carbon emissions. In other words, a catalyst's ability to reduce carbon emissions in the economy benefits the environment. A 0.857% (2.217%) improvement in environmental quality may be related to

Table 7: Environmental sustainability measured by CO_2 emissions

Variable	ARDL	CS-ARDL	ARDL	CS-ARDL
EE	−0.0949*** (0.0134) [−7.0494]	−0.1358** (0.0385) [−3.5222]	−0.1724** (0.1129) [−1.526]	−0.1303** (0.0571) [−2.2815]
EI_1	−0.0579*** (0.0108) [−5.3250]	−0.0888*** (0.0154) [−5.7366]		
EI_2			−0.162*** (0.0236) [−6.8615]	0.1291** (0.0563) [2.2909]
IQ	−0.0857** (0.0294) [−2.9158]	−0.2217*** (0.0378) [−5.8659]	0.0828*** (0.0235) [3.5255]	0.1526*** (0.0221) [6.8903]
FDI	−0.0412*** (0.0052) [−7.8330]	−0.0155** (0.0049) [−3.1693]	−0.1309*** (0.0191) [−6.8355]	0.0747*** (0.0155) [4.7976]
FD	0.0671** (0.0153) [4.3756]	0.1682* (0.1548) [1.0865]	0.1274** (0.079) [1.6129]	0.1396 (0.1583) [0.8816]
ΔEE	0.0152*** (0.0055) [2.7624]	−0.0264** (0.0151) [−1.7534]	−0.1134*** (0.0274) [−4.1376]	−0.0171 (0.7144) [−0.024]
ΔEI	−0.0253 (0.0231) [[−1.0947]		−0.0351*** (0.0069) [−5.0766]	
ΔEI		−0.0544*** (0.0071) [−7.6484]		−0.036** (0.0153) [−2.3433]
ΔIQ	0.0372* (0.0243) [1.5257]	−0.0091** (0.0044) [−2.0552]	0.0909*** (0.0295) [3.0808]	0.074*** (0.0101) [7.2882]
ΔFDI	0.0073 (0.0086) [0.8541]	0.0201 (0.0071) [2.81556]	−0.0791*** (0.011) [−7.1454]	−0.0396 (0.028) [−1.4127]
ΔFD	0.0181*** (0.0033) [5.4313]	−0.0472 (0.0366) [−1.2894]	0.1336* (0.0692) [1.9296]	0.0343 (0.0811) [0.423]
ECT (−1)	−0.2055 (0.0421) [−4.8798]	−0.1641*** (0.0379) [−4.3217]	−0.1801*** (0.685) [−0.263]	−0.294*** (0.0499) [−5.8854]
H−test	0.5541	0.6371	0.5521	0.2274

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively. The value in () represents standard effort, and in [] denotes t-statistics. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

a 10% increase in institutional quality in the South Asian economy. Our findings are comparable with those of Khan et al. (2021), and Tang et al. (2021). Lau et al. (2014) examine the long-term link between CO_2 emissions, exports, institutional quality, and economic development in a separate study. Using an autoregressive distributed lag (ARDL) bounds testing technique and Granger causality tests, and they additionally evaluate the causal link between these variables in Malaysia from 1984 to 2008. This was conducted to examine the connection between these factors and economic development. According to the study results, there is a relationship between all of the traits throughout time. CO_2 emissions must be controlled throughout the economic development process, necessitating high institutional quality levels (Bhattacharya et al., 2017).

According to the research findings, foreign direct investment inflows into the economy boost green energy integration and operational efficiency, thereby mitigating the harmful effects of environmental degradation. This was brought up concerning the influence of FDI on ES. To be more exact, a 10% increase in foreign direct investment into the economy might speed up environmental gains by reducing carbon emissions in the atmosphere by 0.0412% to 0.0155%. Tang et al. (2021) and Zafar et al. (2021) have previously confirmed our results.

The next research stage will include substituting the proxy measures of environmental sustainability with ecological footprints to undertake an empirical evaluation. Table 8 displays the empirical estimate findings comprising four unique model outputs. The empirical model findings in columns [1-4] illustrate that higher environmental efficiency leads to higher environmental quality. One explanation for this is that a smaller ecological footprint results from improved environmental efficiency, reducing deterioration's negative consequences. The model's coefficients show that a 10% increase in EE might enhance ES by reestablishing ecological equilibrium between 0.6055 and 1.584%. The study's findings suggest that reducing the adverse effects of unnecessary CO_2 on the ecosystem can positively affect the growth of EQ through the effective integration of energy in macroeconomic aggregation and industrial progress that relies on renewable energy rather than fossil fuel for production. Usman and Hammar (2021) discovered a statistically significant negative relationship between RE use and EF, implying that shifting to renewable energy sources will benefit the environment. There is statistical evidence that employing RE sources has a detrimental impact on the environment. Nathaniel (2021b), on the other hand, established a positive association between excessive fossil fuel consumption and environmental damage in his research. This

Table 8: Dependent variable ecological footprint as a proxy for environmental sustainability

Variable	[1]	[2]	[3]	[4]
	ARDL (PGM)	CS-ARDL	ARDL (PGM)	CS-ARDL
	Panel-A: long-run coefficient			
EE	−0.0827***(0.0175) [−4.706]	−0.0743***(0.0168) [−4.4053]	−0.0605*(0.0382) [−1.5819]	−0.1584***(0.0279) [−5.6627]
EI	−0.0518*(0.0288) [−1.8012]	−0.0876***(0.0114) [−7.6299]		
EI			−0.0774***(0.019) [−4.0634]	−0.0813***(0.0155) [−5.2258]
IQ	−0.0322* (0.0199) [−1.6036]	−0.1736***(0.0421) [−4.1217]	−0.2341**(0.0905) [−2.5863]	−0.2877**(0.1172) [−2.4546]
FDI	−0.0956*** (0.0243) [−3.9804]	−0.0794***(0.0231) [−3.4253]	0.0151 (0.012) [1.2551]	−0.0324 (0.0299) [−1.0818]
FD	0.0411** (0.0151) [2.7279]	0.0766***(0.0186) [4.1016]	0.0356 (0.0898) [0.3969]	0.0556**(0.0209) [2.6604]
	Panel-B: for short-run coefficients			
ΔEE	−0.0332* (0.019929) [−1.6679]	0.0462*** (0.0103) [4.4687]	0.0673 (1.0378) [0.0649]	0.1215** (0.0529) [2.2964]
ΔEI	−0.0841*** (0.01749) [−4.8128]	0.0292* (0.0186) [1.5703]	−0.1201 (0.2227) [−0.5393]	0.0376 (0.0418) [0.8983]
ΔIQ	−0.0719*** (0.0163) [4.4107]	−0.0299*** (0.0041) [7.1783]	−0.01816*** (0.0052) [3.4505]	−0.01869 (0.0148) [1.2625]
ΔFDI	0.0456 (0.384066) [0.1189]	0.06714 (0.0169) [3.9610]	0.0023 (0.0075) [0.3165]	−0.012* (0.0081) [−1.4767]
ΔFD	0.0035*** (0.00035) [9.7493]	−0.02336 (0.0135) [−1.7189]	0.0725 (0.0874) [0.829]	0.0642*** (0.0143) [4.4727]
ECT(−1)	−0.3260*** (0.0316) [−10.3006]	−0.1805 (0.0320) [−5.6346]	−0.2731*** (0.0587) [−4.6508]	−0.1959*** (0.0593) [−3.2998]
H-test	0.8451	0.512	0.482	0.224

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively. The value in () represents standard effort, and in [] denotes t-statistics. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

shows that the use of fossil fuels has had unforeseen repercussions that have aggravated the ecological imbalance.

Columns [1] and [2] use the overall number of patents as a proxy for environmental innovation, whereas columns [3] and [4] use patents specifically relevant to the environment as proxies in each evaluation of the impact of EI on ES. Statistically, more giant ecological footprints are associated with lower levels of economic success, as shown by the coefficient's negative sign. Thus, it is clear that innovations in processing development and environmental improvement are essential for reducing ecological imbalance and enhancing environmental sustainability. The ARDL (CS-ARD) estimates that using total patents as a proxy, a 10% increase in environmental innovation might boost ES by 0.518% (0.876%). Moreover, ARDL (CS-ARDL) shows that an increase of 10% in environmental-related innovation accounts for a 0.744% (0.813%) improvement in ES. Recent studies suggest that technologies prioritizing EF might hasten the transition toward ES by reducing synthetic versions of dangerous compounds already prevalent in the environment. More efficient energy usage and the development of carbon dioxide emission-cutting technologies are examples of innovations Hodson et al. (2018) suggest contributing to reducing carbon emissions. Similar findings were observed in research by Cagno et al. (2015), demonstrating that technical progress may reduce pollution by improving energy efficiency and lowering dependence on nonrenewable energy sources. Loredo et al. (2019) examined the relationships between GDP growth, technological advancement, and CO_2 emissions. They believe new ideas are crucial to the economy's shift toward renewable energy and environmentally friendly production methods.

The study discovered a negative and statistically significant association between the coefficients of IQ and ES. This indicates that better institutions improve EQ by reducing carbon emissions and negative EF. Our results have been supported by previous studies carried out by a variety of writers, including (Ibrahim and Law, 2016; Nguyen and Dinh Su, 2021; Ahmad et al., 2021). According to Abid et al. (2022) improvements in EQ may be attributed to several factors, including increasing public investment, domestic trade liberalization, foreign ownership, and financial efficiency. In addition, Salman et al. (2019) revealed that domestic institution policies establishing legal and cultural norms within which economic and social interactions occur are frequently cited as significant contributors to a nation's overall institutional quality. This is because domestic institution policies establish the framework within which economic and social interactions can take place (Asoni, 2008). Long-run convergence due to short-term disequilibrium has been demonstrated to occur faster when the short-term error correction coefficient is negative and statistically significant at the 1% level. Since the ECT coefficient suggests that disequilibrium caused by short-run shocks can be fixed at 18.09% to 32.60% per period, we can say that complete equilibrium can be restored within a horizon of 4 years.

4.5. Nonlinear Estimation

The study utilizes the asymmetric framework to discover the potential for EE, EI, and IQ to have asymmetric effects on ES in the economies of Southeast Asia. These implications might be positive or negative. The results of the asymmetric assessment are shown in Table 9, which includes the long-run asymmetric coefficient in Panel-A and the short-run asymmetric coefficient in Panel -B.

Using the conventional Wald test for long-run symmetry, we looked at the asymmetry between EE, EI, IQ, and ES. Statistics from a Wald test and the corresponding P-value indicate that the long-run symmetry null hypothesis could be rejected. Demonstrates an asymmetry between the explanatory factors and long-term environmental viability. Then, we will look at how these unequal impacts will limit the ability of future generations to protect Earth's natural wonders. According to the theory of asymmetric shocks, a positive (negative) variance in energy efficiency is inversely related to environmental sustainability. The resulting correlation coefficient is −0.0899 (−0.0641), indicating a negative relationship. The study suggests Southeast Asia may achieve green economic growth by switching from traditional fossil fuels to renewable energy sources. The rate at which ES increases (or decreases) is 0.899% (0.641%) for every 10% gain in EE. The ecological footprint was shown to be a negative and statistically significant association between positive and negative fluctuations in energy efficiency and environmental sustainability. This finding relates to asymmetric energy efficiency shocks' impact on the planet's carbon footprint (−0.0548). According to the authors, using RE instead of fossil fuels enhanced EQ in Southeast Asian economies and restore ecological balance. For instance, the environmental impact of a 10% boost in energy efficiency would be 0.424% (0.548%)

Table 9: Long-run and short-run asymmetric coefficients

Variable	DIV: CO_2 as environmental sustainability			DIV: Ecological footprint as environmental sustainability		
	Coefficient	SE	t-statistic	Coefficient	SE	t-statistic
Panel –A: long-run coefficients						
EE	−0.0899***	0.0231	−3.8853	−0.0424***	0.0037	−11.2328
EE	−0.0641***	0.0258	−2.4877	−0.0548***	0.0084	−6.8199
EE	−0.0841***	0.0141	−5.9645	−0.0933***	0.0211	−4.4222
EE	−0.0722***	0.0154	−4.6883	−0.0877***	0.0421	−2.0849
EI	−0.2354***	0.0694	−3.3883	−0.0899***	0.0231	−3.8853
EI	−0.1561**	0.1444	−1.0807	−0.0641***	0.0258	−2.4877
IQ	−0.0416***	0.0037	−10.5979	−0.1354**	0.0694	−1.9494
IQ	−0.0148**	0.0081	−1.8454	−0.0561***	0.0144	−3.8846
FDI	0.4374***	0.1344	3.2546	0.13747***	0.0344	3.2546
FDI	−0.055***	0.0141	−3.5835	−0.1505***	0.04108	−3.5835
Long-run symmetry test						
W_{LR}^{EE1}	11.137***			13.484***		
W_{LR}^{EE2}	12.931***			13.571***		
W_{LR}^{EI}	11.416***			9.198***		
W_{LR}^{IQ}	8.874***			8.983***		
Panel –B: short-run coefficients						
EE	−0.0068***	0.0022	−2.9817	−0.0108**	0.0031	−2.0839
EE	−0.0057***	0.0021	−2.7581	−0.0536***	0.0211	−2.5883
EI	−0.0112	0.0190	−0.5898	0.0444***	0.0058	7.6148
EI	0.0267**	0.0166	1.6085	0.0347***	0.0071	4.8797
IQ	0.0221***	0.0024	8.8822	−0.0169	0.0484	−0.35027
IQ	−0.0316***	0.0025	−12.402	0.0337**	0.0096	2.4215
FDI	−0.0655***	0.0086	−7.5304	−0.0859***	0.0244	−3.9261
FDI	0.0018**	0.0009	1.96402	−0.0131	0.0755	−0.1744
C	0.1244**	0.0676	1.8393	5.5888***	0.0130	2.7762
ECT(−1)	−0.1739***	0.0231	−7.5029	−0.1190***	0.0565	−2.10303
Short-run symmetry test						
W_{SR}^{EE1}	8.865			13.584***		
W_{SR}^{EE2}	9.759			13.69***		
W_{SR}^{EI}	11.866			12.358***		
W_{SR}^{IQ}	13.154			12.941***		
Hausman test	2.34 (0.983)			1.795 (0.558)		
Number of Obs	215			215		
Likelihood	2030.143			1754.62		

The superscripts of *** indicate the significance level at a1% . EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality , SE: Standard error lower. Statistically substantial negative correlations between positive (negative) shocks and ES are known as asymmetric impacts of EI. For example, investing only 10% in environmental innovation might lead to a 2.35% drop in carbon emissions and a rebalancing of the ecological footprint. This requires reevaluating the ecological footprint. Reduced environmental innovation of 10% over the same period would lead to an increase in carbon emissions of 1.561% and a worsening ecological imbalance of 0.64%. Research suggests that environmentally favorable deviations from the status quo may have far-reaching implications. It squared with the data showing disparate elasticity coefficients. As can be seen from the data, there is a negative and statistically significant correlation between IQ and ES. A 10% increase in IQ resulted in a 0.416% reduction in carbon emissions and a 1.356% reduction in ecological imbalance. With a 10% decline in IQ, the environment would suffer an additional 0.148% rise in carbon emissions and a 0.561% decrease in the natural ecosystem.

The results of the conventional Wald test statistics and the corresponding P-value imply that the short-run symmetry null hypothesis cannot be supported. On the other hand, it demonstrates that over the short run, there is an unbalanced relationship between the explanatory factors and environmental sustainability. There is a negative and statistically significant association between environmental sustainability and a coefficient of −0.0068, referred to as a positive (negative) variance in energy efficiency. These shocks' asymmetry causes an increase (or decrease) in energy efficiency (−0.0057). According to the study, transitioning from traditional fossil fuels to RE sources would benefit the local economy and nature. For every 10% increase in EE, ES would improve (worsen) by 0.068% (−0.057%). The study also discovered a statistically significant negative correlation between positive and negative fluctuations in EE and ES, which has implications for the asymmetric shocks that energy efficiency has on EF. The link was assessed using the ecological footprint. More specifically, a 10% increase in energy efficiency would increase (decrease) the rate of environmental sustainability improvement by 0.108% (−0.536%). The relationship between positive and negative shocks and ES has been positive and statistically significant, particularly for EF. However, only adverse shocks of EI have been demonstrated to be positive and statistically significant, establishing a positive correlation with a value of 0.067. This conclusion could be because environmental innovations have different effects on long-term sustainability.

Tables 10 and 11 display the causality test results following the D-H causality framework. According to obtained results, the study revealed feedback hypothesisi available between energy efficiency, institutional quality, and environmental sustainability [ES←→EE; ES←→IQ]. Moreover, the unidirectional causality runs from environmental sustainably to FDI and environmental innovation [ES→FDI; ES→EI].

The directional causalities with environmental innovation are shown in Table 11. These causalities refer to causalities in the panel -A (B). The feedback hypothesis is valid in explaining the causal relationship between energy efficiency, environmental innovation, and ecological footprint. Furthermore, the unidirectional association was documented for EE→ES and IQ→ES.

In the following the study assess the robustness of empirical estimation through the execution of FGLS, PCSE, and FMOLS and their results displayed in Table 12 including two pane of output representation that is panel-A of CO_2 as a proxy for ES and ecological footprint as a proxy for ES, respectively. Referring to coefficient and associated sig, study confirmed the similar line of linkage toward ES which was revealed in the earlier estimation. Thus confirm the robustness in model construction and efficient in estimation.

5. DISCUSSION

Ecological discord, environmental challenges, and environmental sustainability are now the driving force behind global efforts to promote long-term economic growth. The pollution haven hypothesis infers that developed nations feel the environment should suffer for economic progress. In contrast, the effects of unchecked carbon emissions on the environment, the growth of poverty, the reduction of foreign capital inflows, and the Pollution haul hypothesis were intolerable. However, this research aimed to show how energy efficiency, environmental innovation, and institutional quality all play a part in managing environmental concerns in the Southeast Asian economy.

EE is a crucial indicator for ensuring the environment grows sustainably. The burning issues of today's world are the greenhouse effect, carbon emission, and environmental pollution, which are hindrances to ensuring ES. The study looked at the environmental impacts of energy efficiency and found that integrating clean energy into aggregated economic output via the industrialization process improves environmental quality by decreasing carbon emissions and ecological footprints. It is expected that if we successfully integrate energy into macroeconomic aggregates and establish industrial development based on RE rather than fossil fuels, we may accidentally alleviate the negative environmental implications of excessive carbon emissions. According to Usman and Makhdum (2021), renewable energy consumption has a statistically significant negative link with environmental effects. This demonstrates that transitioning to renewable energy would be beneficial since it would have a more negligible environmental effect. Alternative energy sources have been discovered to have a significant and detrimental impact on the surrounding biosphere. On the other hand, Nathaniel (2021a) discovered that high energy usage in the form of fossil fuels was positively related to environmental deterioration, demonstrating that this kind of energy consumption has harmed the ecological balance throughout time.

The growing demand for energy in manufacturing, driven by nonrenewable energy sources, harms global environmental quality (Banerjee and Solomon, 2003; De la Cruz-Lovera et al., 2017; Mikučionienė et al., 2014). Based on our findings, we may infer that utilizing fossil fuels to create electricity damages the environment and degrades the quality of the surrounding environment, while using renewable energy sources improves environmental conditions. According to our findings, utilizing

Table 10: Results of causality test: EI measured by the total number of patent

Variable	ES	EE	EI	IQ	FDI	FD
Panel –A: Environmental sustainability measured by CO_2						
ES	-	(5.9503)***	(3.0124)	(4.0641)**	(2.8098)	(2.4394)
		[3.8889]	[0.9198]	[1.9679]	[0.7151]	[0.3407]
EE	(10.2756)***	-	(4.3209)***	(5.3537)***	(2.6453)	(3.0286)
	[8.2614]		[2.2493]	[3.2697]	[0.5498]	[0.9374]
EI	(3.5263)*	(2.7387)	-	(2.1062)	(5.9128)***	(2.1568)
	[1.4392]	[0.6469]		[0.0063]	[3.8325]	[0.051]
IQ	(7.6467)***	(5.8023)***	(7.7091)***	-	(4.6846)***	(1.4839)
	[5.5706]	[3.7212]	[5.641]		[2.6178]	[-0.6265]
FDI	(6.8604)***	(5.1292)***	(5.029)***	(10.4969)***	-	(2.5408)
	[4.8087]	[3.0681]	[2.9665]	[8.4476]		[0.4441]
FD	(3.8716)**	(2.1303)	(2.9513)	(1.393)	(5.3326)***	-
	[1.7882]	[0.029]	[0.8592]	[-0.7179]	[3.2672]	
Panel –B: environmental Sustainability measured by Ecological footprint						
ES		(6.0057)***	(3.012)	(4.3222)**	(2.5295)	(3.0627)
		[3.9398]	[0.9175]	[2.2241]	[0.4303]	[0.9686]
EE	(9.9637)***		(4.3209)***	(5.3537)***	(5.1292)***	(4.6846)**
	[7.9357]		[2.2493]	[3.2697]	[3.0681]	[2.6178]
EI	(3.836)**	(2.7387)		(2.1303)	(5.9128)***	(1.4839)
	[1.7493]	[0.6469]		[0.029]	[3.8325]	[-0.6265]
IQ	(7.1701)***	(5.8023)***	(7.7091)***		(3.0286)	(2.1568)
	[5.0851]	[3.7212]	[5.641]		[0.9374]	[0.051]
FDI	(3.9035)**	(2.6453)	(2.9513)	(1.393)		(5.3326)***
	[1.8174]	[0.5498]	[0.8592]	[-0.7179]		[3.2672]
FD	(6.7139)***	(2.1062)	(5.029)***	(10.4969)***	(2.5408)	
	[4.6547]	[0.0063]	[2.9665]	[8.4476]	[0.4441]	

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

Table 11: Results of causality test: EI measured by Environment-related patents Number

Variable	ES	EE	EI	IQ	FDI	FD
Panel –A: Environmental sustainability measured by CO_2						
ES		(2.1064)**	(3.1147)	(2.8626)	(4.0052)**	(4.6226)***
		[2.0271]	[1.0201]	[0.7569]	[1.9186]	[2.5416]
EE	(5.2419)***		(4.3209)***	(5.3537)***	(5.1292)***	(4.6846)***
	[3.1666		[2.2493]	[3.2697]	[3.0681]	[2.6178]
EI	(4.0468)**	(2.7387)		(2.1303)	(5.9128)***	(1.4839)
	[1.9607	[0.6469]		[0.029]	[3.8325]	[−0.6265]
IQ	(7.9785)***	(5.8023)***	(7.7091)***		(3.0286)	(2.1568)
	[5.8937	[3.7212]	[5.641]		[0.9374]	[0.051]
FDI	(4.9079)***	(2.6453)	(2.9513)	(1.393)		(5.3326)***
	[2.8295]	[0.5498]	[0.8592]	[−0.7179]		[3.2672]
FD	(7.6364)***	(2.1062)	(5.029)***	(10.4969)***	(2.5408)	
	[5.5827]	[0.0063]	[2.9665]	[8.4476]	[0.4441]	
Panel –B: environmental Sustainability measured by Ecological footprint						
ES		(2.1568)	(5.4974)***	(7.0572)***	(7.081)***	(4.5601)**
		[0.051]	[3.4143]	[4.9687]	[5.0086]	[2.4917]
EE	(10.4969)***		(7.4584)***	(5.1446)***	(2.8877)	(4.6846)**
	[8.4476]		[5.4032]	[3.0836]	[0.7978]	[2.6178]
EI	(6.4519)***	(4.2053)**		(2.5867)	(2.2101)	(1.4839)
	[4.3752]	[2.1206]		[0.4872]	[0.1072]	[−0.6265]
IQ	(3.4933)	(3.6755)	(2.8267)		(3.0286)	(2.1568)
	[1.3902]	[1.5957]	[0.7295]		[0.9374]	[0.051]
FDI	(6.9393)***	(1.9414)	(2.9513)	(1.393)		(5.3326)***
	[4.866]	[−0.1638]	[0.8592]	[−0.7179]		[3.2672]
FD	(7.2453)***	(6.9586)***	(5.029)***	(10.4969)***	(2.5408)	
	[5.2113]	[4.9208]	[2.9665]	[8.4476]	[0.4441]	

The superscript ***/**/* denotes the 1%/5%/10% level of significance, respectively. EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality

renewable energy sources is better for the environment than nonrenewable energy sources since the former emits fewer greenhouse gases and pollutes the environment while the latter devastates ecosystems. Long-term advantages of switching to renewable energy sources include decreased reliance on oil-producing nations, the replacement of polluting and fossil-fuel energy sources with clean energy sources, and the introduction of clean energy sources. This illustrates that renewable energy

Table 12: Results of robustness test

Variable	FGLS			PCSE			FMOLS		
	Coefficien	SE	t-stat	Coefficient	SE	t-stat	Coefficien	SE	t-stat
Panel –A: ES measured by CO_2									
EE	−0.0984	0.0191	−5.1518	−0.1022	0.035	−2.92	−0.1497	0.0204	−7.3382
EI	−0.1486	0.0425	−3.4964	−0.1263	0.014	−9.0214	−0.1286	0.0354	−3.6327
IQ	−0.1744	0.0378	−4.6137	−0.087	0.0375	−2.32	−0.1475	0.0192	−7.6822
FDI	−0.1049	0.0461	−2.2754	−0.1316	0.0313	−4.2044	−0.1169	0.0268	−4.3619
FD	0.0768	0.0356	2.1573	0.0748	0.0189	3.9576	0.0501	0.0414	1.2101
r^2					0.547			0.528	
Adj R^2								0.46	
Wald χ^2		16,413.14301			17,860.03192				
P		0			0			0	
Panel –B: ES measured by EF									
EE	−0.1573	0.0138	−11.3985	−0.1118	0.0246	−4.5447	−0.1662	0.0149	−11.1543
EI	−0.1442	0.0269	−5.3605	−0.0883	0.031	−2.8483	−0.1701	0.0306	−5.5588
IQ	−0.1526	0.0403	−3.7866	−0.1242	0.0242	−5.1322	−0.1506	0.0446	−3.3766
FDI	−0.1822	0.0239	−7.6234	−0.1701	0.0241	−7.058	−0.1528	0.0203	−7.527
FD	0.0524	0.0233	2.2489	0.0598	0.029	2.062	0.0559	0.0245	2.2816
r^2					0.542			0.698	
Adj R^2								0.413	
Wald χ^2		22,408.24088			19,647.55565				
P		0			0			0	

EE: Energy efficiency, EI: Environmental innovation, IQ: Institutional quality, SE: Standard error

can be produced domestically, meaning that our dependency on non-domestic energy sources like petroleum may be minimized. However, given the ease with which renewable energy sources may be produced, there may be a causal link between these energy sources and long-term development. The economy, health, and the way social and environmental concerns are addressed improve (Pan et al., 2022).

Sustainability is a burning issue that must be followed in every business, civilization, and ecosystem element. The environmental crisis on a worldwide scale is affecting everything from agriculture to energy to forests, and it is being made worse through challenges such as climate change, the oil crisis, and rapidly growing populations. Technology integration into the production process to control the excessive use of conventional energy and enhance energy efficiency has been linked to environmental improvement investments in one country (Truffer and Coenen, 2012). In addition, innovative environmental protection measures reduce the need for traditional energy sources, signaling the start of the energy shift away from fossil fuels and toward renewables. (Ma and Qamruzzaman, 2022; Sánchez-Medina et al., 2011; Shi and Qamruzzaman, 2022). Environmental innovation refers to the efforts of organizations (including enterprises, labor unions, and private individuals) to create and apply creative solutions to environmental challenges and attain ecological sustainability. These initiatives are known as "green innovation." As a result, it is an efficient strategy for promoting sustainable development, which benefits both the economy and the environment. When the goals of economic growth and protecting the environment are at odds, the "public good" status of environmental improvements may make businesses less likely to participate in them (López-Menéndez et al., 2014).

Our research leads us to believe that companies have reduced their reliance on carbon-intensive operational processes in places with solid governance because of the predominance of institutions such as good governance, the rule of law, and human rights protection. In addition, our results demonstrate that the governments of the nations on the panel are taking enough precautions to protect the environment from harm. Free markets and a commitment to individual liberty, which is represented in more vital institutions, are two factors that contribute to an improvement in the quality of the environment (Hunjra et al., 2020; Lau et al., 2018). The practical implementation of energy laws and regulations, as well as the development of alternative energy sources, are both facilitated by well-established organizations. Levels of corruption may decrease with the assistance of solid institutions, which would then improve the rule of law (Riti et al., 2021). In order to maintain a high level of life and maintain the health of ecosystems, all appropriate agencies are tasked with enforcing environmental legislation. In light of the facts presented here, it is abundantly apparent that the quality of institutions directly impacts environmental policy. This influence may assist developing nations in lowering pollution levels and raising funds. Quality institutions can foster the technology spillover that might result from foreign direct investment (FDI) by controlling aspects like service quality, human rights, corruption, politics, and accountability. They are also essential for enhancing environmental governance and making the most available resources. Our research provides substantial empirical evidence in favor of the theoretical underpinnings of the institutional quality hypothesis. Benefits can be gained from anything if they govern openly, accountable, and fair way. Compliance with the laws and regulations ensure by good governance. Humans have used the environment for so long without good upkeep or rules, so the prospect of a livable environment has grown increasingly remote. Humans have altered every part of Earth with their actions, which they made for short-term gain without considering the long-term consequences. Both wealthy and developing nations suffer significant environmental damage due to this. The public and the government are currently trying to recoup the damage by enacting various measures to guarantee environmental sustainability, including raising public awareness of renewable, green, and clean energy sources and cutting carbon emissions. Furthermore, the objective cannot accomplish without effective leadership. A practical regulatory framework, pollution control, and environmental capital expenditure organization can significantly cut pollution levels. Suppose a company does not take measures to ensure the environment's longevity. In that case, it might expect a hit to its bottom line and credibility. A company with good corporate governance should employ a moral philosophy to achieve environmental sustainability and gain positive market acceptability from the complaint body and customers.

6. CONCLUSION AND POLICY RECOMMENDATION

This research will evaluate energy efficiency, environmental innovation, and institutional quality in the Southeast Asian economy's pursuit of environmental sustainability from 1980 to 2019. The observed association and significant conclusions of the research were assessed using a variety of econometric approaches, some of which are as follows:

First, the test statistics of cross-sectional dependency have revealed statistically significant, suggesting the rejection of the null hypothesis of cross-sectional independence. Thus it is inferential that those research units share certain typical dynamism. Moreover, the slope of the homogeneity test has suggested that heterogeneous properties can find in the selected research variables. Second, the variable's order of integration discloses with the panel unit root test implementation. The conventional unit root test has established that variables are integrated in mixed order, implying that variables are stationary either at a level or after the first difference, not after the second difference. Furthermore, the study applied a unit root test with cross-sectional properties. The documented variables were stationary after the first difference. Third, the long-run cointegration between energy efficiency, environmental innovation, institutional quality, and environmental sustainability evaluate through a panel cointegration test following Pesaran et al. (1996), Kao (1999), and Westerlund (2007). Refers to the panel cointegration test statistics, the long-run association in the empirical relationship is documented and valid for all three cointegration tests. Fourth refers to the target variables' magnitudes on environmental sustainability. Reducing carbon emissions and enhancing environmental quality have been bolstered by innovations in energy efficiency, institutional quality, and environmental protection, according to the report. The results of this study point to the fact that energy-efficient technology is the end result of joint innovation development and environmental sustainability.

By taking account of the findings from empirical estimation, the study documented that the inclusion of energy efficiency in energy consumption that relies on renewable energy integration in economic growth can boost the environmental development in South Asian countries by lowering carbon emissions. Study findings further postulated that energy development and inclusion strategies in the South Asian economy must reconstruct with the extended capacity to absorb renewable energy sources in the industrial output. The impact of environmental innovation on environmental sustainability has documented positive linkage, suggesting that technological development, primarily focusing on the environment, should preferably boost ecological stability with a balanced ecosystem. According to the research's conclusions, improving environmental quality is significantly influenced by the quality of institutions. It demonstrates how government involvement in the effective implementation of environmental measures may significantly impact how long environmental conditions last. Moreover, the panel economy should pay close attention to ensuring good governance, protecting public rights, laws, and regulations, keeping political stability, and systematizing management. All of these things will help the environment develop in the long run.

Based on the empirical findings, the study came up with the following policy suggestions for future development in environmental protection. First, replacing conventional energy with renewable sources is essential to bolster environmental sustainability and foster ecological balance. The study advocated formulation and effective implementation of energy policies focusing on renewable energy development and inclusion instead of fossil fuel consumption. Second, innovation in environmental protection has revealed a way of environmental improvement; thus study suggests that governments should concentrate on formulating environmental policies to foster environmental innovation. Third, in today's contemporary cultures, maintaining a natural environment free from pollution is considered one of the essential factors in elevating human living standards. The government and regulatory agencies actively invest in managing natural resources to ensure the ecosystem's health. Therefore, the study suggested that a solid and well-functioned government should be ensured environmental development through the effective implementation of environmental policies.

Our study considers a panel data estimation focusing on the Southeast Asian economy with a panel of 05 countries. Thus, future studies can initiate by focusing on country-specific assessments with a more significant period of data. Furthermore, in the future study, the panel data estimation can be applied to a panel of developed and developing nations, and countries can group into account for income level. The study considered energy efficiency as measured by the ratio of renewable energy to fossil fuel consumption. The future study can extend by incorporating more proxies for energy efficiency, such as per capita renewable energy consumption from different sources. The inclusion of diversified measures for energy efficiency will open an alternative avenue for formulating energy-efficient strategies for the economy. Regarding addressing the impact of institutional quality on environmental sustainability, the study used an aggregated proxy indexed. In the future, the effects of each proxy of institutional quality can be considered and exacted to have output diversifications, leading to greater scope for policy implication. The future study can establish by incorporating the interactive term of institutional quality and foreign direct investment, technological innovation, and FDI.

6. FUNDING

This study was supported by the institute of Advanced Research (IAR), United International University. Ref: IAR-2024-PUB-0059.

REFERENCES

Abid, A., Mehmood, U., Tariq, S., Ul Haq, Z. (2022), The effect of technological innovation, FDI, and financial development on CO_2 emission: Evidence from the G8 countries. Environmental Science and Pollution Research, 29, 11654-11662.

Abid, M. (2017), Does economic, financial and institutional developments matter for environmental quality? A comparative analysis of EU and MEA countries. Journal of Environmental Management, 188, 183-194.

Afzal, M.N.I., Mansur, K., Manni, U.H. (2018), Entrepreneurial Capability (EC) environment in ASEAN-05 emerging economies. Asia Pacific Journal of Innovation and Entrepreneurship, 12, 206-221.

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., Sinha, A. (2021), Financial development and environmental degradation: Do human capital and institutional quality make a difference? Gondwana Research, 105, 299-310.

Ahmed, Z., Cary, M., Ali, S., Murshed, M., Ullah, H., Mahmood, H. (2021), Moving toward a green revolution in Japan: Symmetric and asymmetric relationships among clean energy technology development investments, economic growth, and CO_2 emissions. Energy and Environment, 33, 1417-1440.

Akram, R., Chen, F., Khalid, F., Ye, Z., Majeed, M.T. (2020), Heterogeneous effects of energy efficiency and renewable energy on carbon emissions: Evidence from developing countries. Journal of Cleaner Production, 247, 119122.

Ali, S., Yan, Q., Dilanchiev, A., Fahad, S. (2023), Modeling the economic viability and performance of solar home systems: A roadmap towards clean energy for environmental sustainability. Environmental Science and Pollution Research, 30, 30612-30631.

Alola, A.A., Alola, U.V., Akdag, S., Yildirim, H. (2022), The role of economic freedom and clean energy in environmental sustainability: Implication for the G-20 economies. Environmental Science and Pollution Research, 29, 36608-36615.

Apergis, N., Payne, J.E., Menyah, K., Wolde-Rufael, Y. (2010), On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecological Economics, 69, 2255-2260.

Arbolino, R., Carlucci, F., De Simone, L., Ioppolo, G., Yigitcanlar, Y. (2018), The policy diffusion of environmental performance in the European countries. Ecological Indicators, 89, 130-138.

Ascenso, A., Augusto, B., Silveira, C., Rafael, S., Coelho, S., Monteiro, A., Ferreira, J., Menezes, I., Roebeling, P., Miranda, A.I. (2021), Impacts of nature-based solutions on the urban atmospheric environment: A case study for Eindhoven, The Netherlands. Urban Forestry and Urban Greening, 57, 126870.

Asoni, A. (2008), Protection of property rights and growth as political equilibria. Journal of Economic Surveys, 22, 953-987.

Banerjee, A., Solomon, B.D. (2003), Eco-labeling for energy efficiency and sustainability: A meta-evaluation of US programs. Energy Policy, 31, 109-123.

Bernauer, T., Koubi, V. (2009), Effects of political institutions on air quality. Ecological Economics, 68, 1355-1365.

Bhattacharya, M., Awaworyi Churchill S., Paramati, S.R. (2017), The dynamic impact of renewable energy and institutions on economic output and CO_2 emissions across regions. Renewable Energy, 111, 157-167.

Brännlund, R., Ghalwash, T., Nordström, J. (2007), Increased energy efficiency and the rebound effect: Effects on consumption and emissions. Energy Economics, 29, 1-17.

Breusch, T.S., Pagan, A.R. (1980), The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies, 47, 239-253.

Cagno, E., Ramirez-Portilla, A., Trianni, A. (2015), Linking energy efficiency and innovation practices: Empirical evidence from the foundry sector. Energy Policy, 83, 240-256.

Cardenas, L.M., Franco, C.J., Dyner, I. (2016), Assessing emissions-mitigation energy policy under integrated supply and demand analysis: The Colombian case. Journal of Cleaner Production, 112, 3759-3773.

Carrión-Flores, C.E., Innes, R. (2010), Environmental innovation and environmental performance. Journal of Environmental Economics and Management, 59, 27-42.

Chen, F., Zhao, T., Liao, Z. (2020), The impact of technology-environmental innovation on CO_2 emissions in China's transportation sector. Environmental Science and Pollution Research, 27, 29485-29501.

Chi, M., Muhammad, S., Khan, Z., Ali, S., Li, R.Y.M. (2021), Is centralization killing innovation? The success story of technological innovation in fiscally decentralized countries. Technological Forecasting and Social Change, 168, 120731.

Choi, J., Han, D. (2018), The links between environmental innovation and environmental performance: Evidence for high-and middle-income Countries. Sustainability, 10, 2157.

Chudik, A., Pesaran, M.H. (2015), Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. Journal of Econometrics, 188, 393-420.

Clarke, J.A., Johnstone, C.M., Kelly, N.J., Strachan, P.A., Tuohy, P. (2008), The role of built environment energy efficiency in a sustainable UK energy economy. Energy Policy, 36, 4605-4609.

Dadgara, Y., Nazari, R. (2017), The impact of good governance on environmental pollution in South West Asian Countries. Iranian Journal of Economic Studies, 5, 49-63.

De la Cruz-Lovera, C., Perea-Moreno, A.J., De la Cruz-Fernández, J.L., Alvarez-Bermejo, J.A., Manzano-Agugliaro, F. (2017), Worldwide research on energy efficiency and sustainability in public buildings. Sustainability, 9, 1294.

Dias Angelo, F., Ahmed, A., Jose Chiappetta Jabbour, C., Vasconcellos Galina, S.(2012), Environmental innovation: In search of a meaning. World Journal of Entrepreneurship, Management and Sustainable Development, 8, 113-121.

Dumitrescu, E.I., Hurlin, C. (2012), Testing for Granger non-causality in heterogeneous panels. Economic Modelling, 29, 1450-1460.

Gang, C., Zhou, W., Chen, Y., Chen, Y., Wang, Z., Sun, Z., Li, J., Qi, J., Odeh, I. (2014), Quantitative assessment of the contributions of climate change and human activities on global Grassland degradation. Environmental Earth Sciences, 72, 4273-4282.

Gisselquist, R.M. (2012), Good Governance As a Concept, and why this Matters for Development Policy. WIDER Working Paper 2012/30.

Global Footprint Network. (2021), Global Footprint Network.

Hanley, N., McGregor, P.G., Swales, J.K., Turner, K. (2009), Do increases in energy efficiency improve environmental quality and sustainability? Ecological Economics, 68, 692-709.

Hasnat, G.N.T., Kabir, M.A., Hossain, M.A. (2018), Major environmental issues and problems of South Asia, particularly Bangladesh. In: Hussain, C.M., editor. Handbook of Environmental Materials Management. Cham: Springer International Publishing. p1-40.

Hodson, E.L., Brown, M., Cohen, S., Showalter, S., Wise, M., Wood, F., Caron, J., Feijoo, F., Iyer, G., Cleary, K. (2018), U.S. Energy sector impacts of technology innovation, fuel price, and electric sector CO_2 policy: Results from the EMF 32 model intercomparison study. Energy Economics, 73, 352-370.

Hunjra, A.I., Tayachi, T., Chani, M.I., Verhoeven, P., Mehmood, A. (2020), The moderating effect of institutional quality on the financial development and environmental quality nexus. Sustainability, 12, 3805.

Hussain, N., Rigoni, U., Orij, R.P. (2018), Corporate governance and sustainability performance: Analysis of triple bottom line performance. Journal of Business Ethics, 149, 411-432.

Ibrahim, M.D., Alola, A.A. (2020), Integrated analysis of energy-economic development-environmental sustainability nexus: Case study of MENA countries. Science of the Total Environment, 737, 139768.

Ibrahim, M.H., Law, S.H. (2016), Institutional quality and CO_2 emission-trade relations: Evidence from Sub-Saharan Africa. South African Journal of Economics, 84, 323-340.

Ingrao, C., Messineo, A., Beltramo, R., Yigitcanlar, T., Ioppolo, G. (2018), How can life cycle thinking support sustainability of buildings? Investigating life cycle assessment applications for energy efficiency and environmental performance. Journal of Cleaner Production, 201, 556-569.

Iqbal, N., Abbasi, K.R., Shinwari, R., Guangcai, W., Ahmad, M., Tang, K. (2021), Does exports diversification and environmental innovation achieve carbon neutrality target of OECD economies? Journal of Environmental Management, 291, 112648.

Issa, A. (2023), Shaping a sustainable future: The impact of board gender diversity on clean energy use and the moderating role of environmental, social and governance controversies. Corporate Social Responsibility and Environmental Management, 30(6), 2731-2746.

Jahanger, A., Balsalobre-Lorente, D., Ali, M., Samour, A., Abbas, S., Tursoy, T., Joof, F. (2023), Going away or going green in ASEAN countries: Testing the impact of green financing and energy on environmental sustainability. Energy and Environment. Doi: 10.1177/0958305X231171346

JinRu, L., Qamruzzaman, M. (2022), Nexus between environmental innovation, energy efficiency, and environmental sustainability in G7: What is the role of institutional quality? Frontiers in Environmental Science, 10, 860244

JinRu, L., Qamruzzaman, M., Hangyu, W., Kler, R. (2023), An assessment of the symmetric and asymmetric impact of globalization, environmental sustainability on tourism development in BRICS nations: Mediating role of good governance. Frontiers in Environmental Science, 11, 190.

Joof, F., Samour, A., Ali, M., Tursoy, T., Haseeb, M., Hossain, M.E., Kamal, M. (2023), Symmetric and asymmetric effects of gold, and oil price on environment: The role of clean energy in China. Resources Policy, 81, 103443.

Kao, C. (1999), Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90, 1-44.

Khan, A., Chenggang, Y., Hussain, J., Kui, Z. (2021), Impact of technological innovation, financial development and foreign direct investment on renewable energy, non-renewable energy and the environment in belt & Road Initiative countries. Renewable Energy, 171, 479-491.

Kirikkaleli, D., Adebayo, T.S. (2021), Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. Sustainable Development, 29, 583-594.

Lanouar, C., Al-Malk, A.Y., Al Karbi, K. (2016), Air pollution in Qatar: Causes and challenges. White Paper, 1, 1-7.

Lau, L.S., Choong, C.K., Eng, Y.K. (2014), Carbon dioxide emission, institutional quality, and economic growth: Empirical evidence in Malaysia. Renewable Energy, 68, 276-281.

Lau, L.S., Choong, C.K., Ng, C.F. (2018), Role of institutional quality on environmental kuznets curve: A comparative study in developed and developing countries. In: Advances in Pacific Basin Business, Economics and Finance. United Kingdom: Emerald Publishing Limited. p223-247.

Lee, K.H., Min, B. (2015), Green R&D for eco-innovation and its impact on carbon emissions and firm performance. Journal of Cleaner Production, 108, 534-542.

Li, Y. (2014), Environmental innovation practices and performance: Moderating effect of resource commitment. Journal of Cleaner Production, 66, 450-458.

Lin, J., Qamruzzaman, M. (2023), The impact of environmental disclosure and the quality of financial disclosure quality, and IT adoption on firm performance: Does corporate governance ensure sustainability? Frontiers in Environmental Science, 11, 1002357.

Liu, X., Latif, K., Latif, Z., Li, N. (2020), Relationship between economic growth and CO_2 emissions: Does governance matter? Environmental Science and Pollution Research, 27, 17221-17228.

López-Menéndez, A.J., Pérez, R., Moreno, B. (2014), Environmental costs and renewable energy: Re-visiting the environmental Kuznets curve. Journal of Environmental Management, 145, 368-373.

Loredo, E., Lopez-Mielgo, N., Pineiro-Villaverde, G., García-Álvarez, M.T. (2019), Utilities: Innovation and sustainability. Sustainability, 11, 1085.

Ma, C., Qamruzzaman, M. (2022), An asymmetric nexus between urbanization and technological innovation and environmental sustainability in Ethiopia and Egypt: What is the role of renewable energy? Sustainability, 14, 7639.

Meo, M., Nathaniel, S., Shaikh, G., Kumar, A. (2021), Energy consumption, institutional quality and tourist arrival in Pakistan: Is the nexus (a)symmetric amidst structural breaks? Journal of Public Affairs, 21, e2213.

Mikučionienė, R., Martinaitis, V., Keras, E. (2014), Evaluation of energy efficiency measures sustainability by decision tree method. Energy and Buildings, 76, 64-71.

Mongo, M., Belaid, F., Ramdani, B. (2021), The effects of environmental innovations on CO_2 emissions: Empirical evidence from Europe. Environmental Science and Policy, 118, 1-9.

Muhammad, S., Pan, Y., Agha, M.H., Umar, M., Chen, S. (2022), Industrial structure, energy intensity and environmental efficiency across developed and developing economies: The intermediary role of primary, secondary and tertiary industry. Energy, 247, 123576.

Murshed, M. (2020), An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. Environmental Science and Pollution Research, 27, 36254-36281.

Murshed, M., Rahman, M.A., Alam, M.S., Ahmad, P., Dagar, V. (2021), The nexus between environmental regulations, economic growth, and environmental sustainability: Linking environmental patents to ecological footprint reduction in South Asia. Environmental Science and Pollution Research, 28, 49967-49988.

Nathaniel, S.P. (2021a), Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. GeoJournal, 86, 2057-2070.

Nathaniel, S.P. (2021b), Economic complexity versus ecological footprint in the era of globalization: Evidence from ASEAN countries. Environmental Science and Pollution Research, 28, 64871-64881.

Nguyen, C.P., Dinh Su, T. (2021), Tourism, institutional quality, and environmental sustainability. Sustainable Production and Consumption, 28, 786-801.

Onafowora, O.A., Owoye, O. (1998), Can trade liberalization stimulate economic growth in Africa? World Development, 26, 497-506.

Pan, Y., Chen, J., Yan, X., Lin, J., Ye, S., Xu, Y., Qi, X. (2022), Identifying the spatial-temporal patterns of vulnerability to re-poverty and its determinants in rural China. Applied Spatial Analysis and Policy, 15, 483-505.

Paramati, S.R., Mo, D., Huang, R. (2021), The role of financial deepening and green technology on carbon emissions: Evidence from major OECD economies. Finance Research Letters, 41, 101794.

Pata, U.K., Caglar, A.E., Kartal, M.T., Kılıç Depren, S. (2023), Evaluation of the role of clean energy technologies, human capital, urbanization, and income on the environmental quality in the United States. Journal of Cleaner Production, 402, 136802.

Pedroni, P. (2001), Purchasing power parity tests in cointegrated panels. Review of Economics and Statistics, 83, 727-731.

Pedroni, P. (2004), Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econometric Theory, 20, 597-625.

Pesaran, M.H. (2004), General Diagnostic Tests for Cross Section Dependence in Panels. CESifo Working Paper Series No. 1229, IZA Discussion Paper No. 1240.

Pesaran, M.H. (2006), Estimation and inference in large heterogeneous panels with a multifactor error structure. Econometrica, 74, 967-1012.

Pesaran, M.H. (2007), A simple panel unit root test in the presence of cross-section dependence. Journal of Applied Econometrics, 22, 265-312.

Pesaran, M.H., Shin, Y., Smith, R.J. (1996), Testing for the "Existence of a Long-run Relationship". Cambridge Working Papers in Economics 9622. Faculty of Economics, University of Cambridge.

Pesaran, M.H., Ullah, A., Yamagata, T. (2008), A bias-adjusted LM test of error cross-section independence. The Econometrics Journal, 11, 105-127.

Pomeranz, E.F., Stedman, R.C. (2020), Measuring good governance: Piloting an instrument for evaluating good governance principles. Journal of Environmental Policy and Planning, 22, 428-440.

Ponce, P., Khan, S.A.R. (2021), A causal link between renewable energy, energy efficiency, property rights, and CO_2 emissions in developed countries: A road map for environmental sustainability. Environmental Science and Pollution Research, 28, 37804-37817.

Popp, D. (2005), Lessons from patents: Using patents to measure technological change in environmental models. Ecological Economics, 54, 209-226.

Popp, D., Newell, R.G., Jaffe, A.B. (2010), Energy, the environment, and technological change. Handbook of the Economics of Innovation, 2, 873-937.

Qamruzzaman, Md. (2022), Nexus between environmental innovation, energy efficiency and environmental sustainability in the lower-income economy. GSC Advanced Research and Reviews, 12, 68-83.

Qamruzzaman, M., Kler, R. (2023), Do clean energy and financial innovation induce SME performance? Clarifying the nexus between financial innovation, technological innovation, clean energy, environmental degradation, and SMEs performance in Bangladesh. International Journal of Energy Economics and Policy, 13, 313-324.

Riti, J.S., Shu, Y., Kamah, M. (2021), Institutional quality and environmental sustainability: The role of freedom of press in most freedom of press countries. Environmental Impact Assessment Review, 91, 106656.

Rodrigue, M., Magnan, M., Cho, C.H. (2013), Is environmental governance substantive or symbolic? An empirical investigation. Journal of Business Ethics, 114, 107-129.

Rosenfeld, A.H. (1999), The art of energy efficiency: Protecting the environment with better technology. Annual Review of Energy and the Environment, 24, 33-82.

Rupley, K.H., Brown, D., Marshall, R.S. (2012), Governance, media and the quality of environmental disclosure. Journal of Accounting and Public Policy, 31, 610-640.

Salman, M., Long, X., Dauda, L., Mensah, C.N. (2019), The impact of institutional quality on economic growth and carbon emissions: Evidence from Indonesia, South Korea and Thailand. Journal of Cleaner Production, 241, 118331.

Sánchez-Medina, P.S., Corbett, J., Toledo-López, A. (2011), Environmental innovation and sustainability in small handicraft businesses in Mexico. Sustainability, 3, 984-1002.

Sarkodie, S.A., Strezov, V. (2019), Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Science of the Total Environment, 646, 862-871.

Sarpong, S.Y., Beinm, M.A. (2020), The relationship between good governance and CO_2 emissions in oil-and non-oil-producing countries: A dynamic panel study of sub-Saharan Africa. Environmental Science and Pollution Research, 27, 21986-22003.

Sezen, B., Çankaya, S.Y. (2013), Effects of green manufacturing and eco-innovation on sustainability performance. Procedia - Social and Behavioral Sciences, 99, 154-163.

Shahbaz, M., Nasir, M.A., Roubaud, D. (2018), Environmental degradation in France: The effects of FDI, financial development, and energy innovations. Energy Economics, 74, 843-857.

Shi, Z., Qamruzzaman, M. (2022), Re-visiting the role of education on poverty through the channel of financial inclusion: Evidence from lower-income and lower-middle-income countries. Frontiers in Environmental Science, 10, 873652.

Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014), Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Festschrift in Honor of Peter Schmidt. Berlin: Springer. p281-314.

Solarin, S.A., Nathaniel, S.P., Bekun, F.V., Okunola, A.M., Alhassan, A. (2021), Towards achieving environmental sustainability: Environmental quality versus economic growth in a developing economy on ecological footprint via dynamic simulations of ARDL. Environmental Science and Pollution Research, 28, 17942-17959.

Sorrell, S. (2010), Energy, economic growth and environmental sustainability: Five propositions. Sustainability, 2, 1784-1809.

Spiller, E., Sopher, P., Martin, N., Mirzatuny, M., Zhang, X. (2017), The environmental impacts of green technologies in TX. Energy Economics, 68, 199-214.

Sun, H., Edziah, B.K., Sun, C., Kporsu, A.K. (2019), Institutional quality, green innovation and energy efficiency. Energy Policy, 135, 111002.

Tamazian, A., Bhaskara Rao, B. (2010), Do economic, financial and institutional developments matter for environmental degradation? Evidence from transitional economies. Energy Economics, 32, 137-145.

Tang, C.F., Abosedra, S., Naghavi, N. (2021), Does the quality of institutions and education strengthen the quality of the environment? Evidence from a global perspective. Energy, 218, 119303.

Töbelmann, D., Wendler, T. (2020), The impact of environmental innovation on carbon dioxide emissions. Journal of Cleaner Production, 244, 118787.

Truffer, B., Coenen, L. (2012), Environmental innovation and sustainability transitions in regional studies. Regional Studies, 46, 1-21.

Usman, M., Hammar, N. (2021), Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: Fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. Environmental Science and Pollution Research, 28, 15519-15536.

Usman, M., Makhdum, M.S.A. (2021), What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. Renewable Energy, 179, 12-28.

Vance, L., Eason, T., Cabezas, H. (2015), Energy sustainability: Consumption, efficiency, and environmental impact. Clean Technologies and Environmental Policy, 17, 1781-1792.

Welsch, H. (2004), Corruption, growth, and the environment: A cross-country analysis. Environment and Development Economics, 9, 663-693.

Westerlund, J. (2007), Testing for error correction in panel data. Oxford Bulletin of Economics and statistics, 69, 709-748.

World Bank. (2022), World Development Indicators. Available from: https://data.worldbank.org/data-catalog/world-development-indicators

Xia, C., Qamruzzaman, M., Adow, A.H. (2022), An asymmetric nexus: Remittance-led human capital development in the top 10 remittance-receiving countries: Are FDI and gross capital formation critical for a road to sustainability? Sustainability, 14, 3703.

Xu, S., Qamruzzaman, M., Adow, A.H. (2021), Is financial innovation bestowed or a curse for economic sustainably: The mediating role of economic policy uncertainty. Sustainability, 13, 2391.

Yang, Y., Huang, S., Li, W., Li, W., Zhong, F., Lan, T. (2022), Does government efficiency mitigate the effect of natural disasters on tourist arrivals? Current Issues in Tourism, 25, 2177-2191.

Zafar, S.Z., Zhilin, Q., Malik, H., Abu-Rumman, A., Al Shraah, A., Al-Madi, F., Alfalah, T.F. (2021), Spatial spillover effects of technological innovation on total factor energy efficiency: Taking government environment regulations into account for three continents. Business Process Management Journal, 27, 1874-1891.

Zakaria, M., Bibi, S. (2019), Financial development and environment in South Asia: The role of institutional quality. Environmental Science and Pollution Research, 26, 7926-7937.

Zhang, D., Mohsin, M., Taghizadeh-Hesary, F. (2022), Does green finance counteract the climate change mitigation: Asymmetric effect of renewable energy investment and R&D. Energy Economics, 113, 106183.