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Nexus between environmental innovation, energy efficiency and environmental sustainability in the lower-income economy

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Abstract

Every major event on a national or global scale influences the environment, and scientists are always looking for new solutions to decrease ecological destruction. Throughout the preceding decade, professionals offered and executed policy ideas for energy adaptation and integration, such as the use of renewable energy. Between 1980 and 2021, the study looks at the relationship between environmental innovation, energy efficiency, and institutional quality in low-income nations. Autoregressive distributed lag (ARDL), cross-sectional ARDL, and Dumitrescu-hurling models were used to investigate the empirical connection. Following the identification of the initial difference, the stationary variables were combined due to commonalities in their dynamics. The panel counteraction test revealed that long-term relationships between variables exist. Including renewable energy sources and environmental innovation improves the long-term sustainability of low-income economies. The ARLD and CS-ARDL variable coefficients have a greater effect on environmental policy when their institutions are strong, ecologically aware, and resourceful. A well-established feedback loop connects renewable energy with environmental sustainability. Institutional excellence and environmental sustainability are inextricably linked. According to the report, governments and policymakers should increase the usage of renewable energy sources and invest in environmental innovation to attain environmental sustainability.

Keywords: Environmental Innovation; Energy Efficiency; Institutional Quality; Environmental Sustainability; ARDL; CS-ARDL

1. Introduction

During the phase of economic expansion, thorough industrialization and domestic aggregation cause substantial carbon emissions due to a heavy reliance on fossil fuels rather than renewable energy. In addition, the government has ignored the ultimate consequence by focusing solely on economic development. This is because fossil fuels are the primary energy source for most industrial processes. In recent years, several factors contributing to the deterioration of the environment have come to light, and governments are now trying to address issues connected to the environment's quality (1-3). There is a widespread consensus that climate change and global warming are at least partially caused by carbon dioxide emissions (CO2). The safety of the environment has always been of the utmost significance in South Asia; it impacts both the quantity of food produced by agriculture and the lives of millions of people daily (4-6)

Because the detrimental impacts of environmental degradation, such as climate change and global warming, have begun to show globally, countries are forced to look for a collective solution to this problem. Existing research on environmental quality reveals that increasing environmental quality involves two courses of action: a macro-fundamental contribution and energy policies focused on integrating renewable energy sources instead of fossil fuels

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(7, 8). According to Apergis and Payne (9), stringent energy rules impede economic development. This is the case even though the incorporation of clean energy reduces carbon emissions and, as a result, improves environmental quality. Therefore, the challenge of conservative energy policy and economic development has prompted policymakers to adopt an environmental policy that reconciles environmental quality and economic growth via the management of energy integration, preferably through renewable energy sources. This policy seeks to achieve this reconciliation through using renewable energy sources. In economics, the deterioration of the environment is an important problem that has received a great deal of attention from economists, academics, and researchers over the last few decades. There has been a steady increase in carbon emissions, and as a result, there have been dangers to both human health and the environment. As a result of these concerns, nations face significant implications due to global warming (10). Researchers have emphasized research into the key factors that contribute to mitigating the present climate change crisis to increase environmental sustainability by reducing the harmful effects of greenhouse gas (GHG) emissions into the atmosphere. This is done to achieve the goal of increasing environmental sustainability (11).

The present study contributes to the existing literature in the following ground. First, according to existing literature surrounding environmental degradation and sustainability, researchers and academicians have invested their time and efforts in unleashing the way of lessening the environmental adversity with the accommodation of green energy and policy implementation. In managing environmental diversification for sustainability, a growing number of researchers have examined the role of environmental innovation, energy efficiency and good governance by taking into account either country specifics or/and panel data (12-19). However, focusing on environmental Sustainability in Lower Income economies, very few studies have been performed in empirical assessment see, for instance (20)et al., 2021; Hasnat (21-23). With our best knowledge, for the first time, the nexus between environmental sustainability, environmental innovation, energy efficiency, and institutional quality in the Lower Income economy has been investigated.

This study examines the impact of environmental innovation, energy efficiency, and institutional quality on environmental sustainability management in the Lower Income economy between 1980 and 2020. A cross-sectional dependency test, long-run cointegration using an error correction model, baseline estimation with random effects and fixed effects model, explanatory variables magnitudes on environmental sustainability detected via ARDL and CS-ARDL, and directional causality was implemented in the Study. The Study's results demonstrated that research units shared a dynamic and heterogeneous nature. Variables stay unchanged after the first difference, but neither is exposed to the second difference, as is desirable for robust estimation.

The remaining stricture of the article is as follows: Section I deals with the background of the Study, and the literature review and hypothesis development are available in Section II. Section III reports the data, variables definition, and methodology of the Study. Section IV displays the empirical model estimation and discussion, and the conclusion and policy suggestions are finely exhibited.

2. Literature review

2.1. Environmental innovation and environmental sustainability

Using a technique known as the system generalized method of moments (SGMM), Zhang, Chevallier (24) investigated the impact that technological advancements in the field of environmental protection had on China's carbon emissions from 2000 to 2013. This research examines the relationship between technological advancement in environmental protection and long-term environmental preservation. As shown by the Study's conclusions, the bulk of the environmental innovation aspects reportedly applies a considerable effect to decreasing carbon emissions successfully. Paramati, Mo (25) Investigated the role of per capita income, foreign direct investment (FDI), green technology, trade openness, and financial deepening on carbon emissions in a panel of 25 OECD countries from 1991 to 2016. They use cross-sectional dependence (CD) and cross-sectional augmented Im-Pesaran-Shin (CIPS) tests. This inquiry focuses on the nations that are members of the OECD, covering the years 1991 to 2016. According to the Study's conclusions, there is a possibility that carbon emissions might be lowered by expanding the openness of commerce, the use of environmentally friendly technologies, and the flows of foreign direct investment.

On the other hand, a rise in both financial depth and income per capita leads to increased carbon emissions. This is the case regardless of the kind of growth. The resource-based and natural resource-based views were utilized in Lee, Min (26) Qamruzzaman (16) analyses to determine the impact of green research and development investment on eco-innovation on the environment and the financial performance of Japanese manufacturing firms from 2001 to 2010. This was done to determine the impact of green research and development investment for eco-innovation on Japanese manufacturing firms from 2001 to 2010. From 2001 till 2010, this was the period that was taken into account. The results of the Study indicate that there is a corrosive link between environmentally friendly research and development and carbon emissions. In addition, Shahbaz, Shahzad (27) offered evidence to support the claim that the development of new energy sources contributes favorably to decreasing CO2 emissions, which in turn serves to enhance the overall quality of the environment.

Kneifel (28) Urged incorporating energy-efficient technology to enhance environmental sustainability by reducing energy intensity and, eventually, carbon emissions. Using conventional energy efficiency technologies, the energy use/consumption of new commercial buildings can be lowered by an average of 20 to 30 percent, according to the Study. For some building types and environments, the decline might exceed 40 percent. These enhancements reduce a building's carbon footprint by an average of 16 percent while saving money and energy. According to Lantz and Feng (29), the relationship between technology and carbon dioxide is U-shaped. In addition, Akinsola, Awosusi (30) discovered an asymmetric link between technological innovation and environmental sustainability, with positive (negative) technological innovation shocks resulting in a decrease (increase) in Sweden's carbon emissions.

Adebayo, Oladipupo (31) Employed the Morlet wavelet technique to evaluate the link between renewable energy utilization, technological innovation, and carbon emissions in Portugal between 1980 and 2019. According to the Study's findings, the connection of indicators rises with time and frequency. In addition, this analysis reveals strong wavelet coherence and significant lead and lag linkages in the frequency domain but contradicting interactions between the variables in the time domain. Even though trade openness, technological innovation, and economic expansion contribute to CO2 emissions, Wavelet research shows that using renewable energy helps decrease CO2 emissions. Using wavelet analysis in Japan, Adebayo and Kirikkaleli, Ali (32) and Xia, Qamruzzaman (6) postulated that globalization, GDP growth, and technological innovation increase CO2 emissions in Japan, but that renewable energy consumption mitigates CO2 emissions in the short and medium future.

2.2. Energy efficiency and environmental sustainability

According to the Energy efficiency and environmental sustainability nexus, a growing number of research have shown a positive and statistically significant correlation between energy efficiency and environmental sustainability. See Akram, Majeed (33), Hanley, McGregor (34), Qamruzzaman (35). According to Sarkodie and Strezov (36) study, energy use significantly impact greenhouse gas emissions. Reducing greenhouse gas emissions requires increased energy efficiency, using clean and contemporary technologies such as renewable energy and nuclear power, and carbon capture and storage in fossil fuel and biomass energy-generating processes.

Balsalobre-Lorente, Shahbaz (37) examine the link between economic development, energy innovation, renewable power consumption, natural resource availability, trade openness, and carbon dioxide emissions in five nations between 1985 and 2016. (Germany, France, Italy, Spain, and the United Kingdom). The research shows that using renewable energy, energy innovation, and natural resources enhances environmental quality. Trade liberalization, on the other hand, and the link between economic development and renewable energy consumption positively impact carbon dioxide emissions. Boutabba (38) Used the Granger Causality Test to examine the long-term equilibrium as well as the presence and direction of a causal link between carbon emissions, energy consumption, financial development, trade openness, and economic growth in India from 1971 to 2008. The research found a long-term causal relationship between per capita carbon emissions and per capita energy usage. After controlling for several factors, Sun et al.(2019) showed that green innovation and institutional quality substantially affected energy efficiency improvement. Between 1980 and1997, Brännlund, Ghalwash (39) explore how external technical development in the form of increased energy efficiency affects the consumption decisions of Swedish households and, as a result, their carbon dioxide and sulfur emissions and nitrogen oxide. According to the research, a 20% improvement in energy efficiency would reduce CO2 emissions by 5%. Miao, Razzaq (40) Used the Method of Moments Quantile Regression on yearly data from 1990 to 2018 to study the relationship between renewable energy use, globalization, and ecological footprint in newly industrialized countries (NICs). (MMQR). The outcomes of this study demonstrate the favorable and statistically significant impact of financial globalization and renewable energy use on environmental quality improvement.

2.3. Institutional quality and environmental sustainability

Third, Abid (41) investigates the impact of institutional, financial, and economic changes on the rate of environmental degradation in 41 E.U. countries and 58 MEA countries between 1990 and 2011. Environmental sustainability and institutional quality are the topics that are covered in this research. According to this study's findings, robust institutions have both a direct and an indirect impact on economic growth and environmental quality in the countries that make up the E.U. They do this by enhancing the efficiency of public spending, fostering financial development, and encouraging direct investment from other countries. In a separate piece of research, Lau, Choong (42) used Granger causality tests and the autoregressive distributed lag (ARDL) limits testing technique to investigate the causative relationships between CO2 emissions, exports, and institutional quality, and economic development in Malaysia from 1984 to 2008.

The period under investigation was from 1984 to 2008. The findings of the study point to the existence of a correlation sustained through time between the variables. One of the conclusions that can be drawn from this is that maintaining a high level of institutional quality is necessary to curb CO2 emissions and foster economic growth. Granger causality testing provides more data demonstrating the significance of institutional frameworks in reducing carbon dioxide emissions. In line with the findings that were uncovered via the investigation conducted by Bhattacharya, Awaworyi Churchill (43). According to Abid (44), factors like political stability, democracy, the effectiveness of the administration, and the avoidance of corruption all have a bearing on the amount of carbon dioxide released into the atmosphere. On the other hand, strong regulation and the rule of law positively impact the amount of carbon dioxide released into the atmosphere.

Ibrahim and Law (45) Investigate the roles of institutional quality, trade and their interactivity in explaining CO2 emissions for 40 Sub-Sahara African (SSA) countries for the period 2000 to 2010 by applying the system generalized method of moments (GMM). Study unveils trade and institutional quality is beneficial to environmental sustainability. The study also suggested that institutional reforms explicitly support excelling the environmental status. However, trade openness is detrimental to the environment in countries with poor institutional quality and helpful in those with high institutional quality. Sarpong and Bein (46) Apply the generalized moment (GMM) method in assessing the nexus between CO2 and good governance with a panel of 38 oil- and non-oil-producing nations in the Sub-Saharan Africa region from 2005 to 2014. The Study divulges that good governance is the bestow in manage carbon emissions in enduring Environmental Sustainability. Countries have a good governance structure that aids in controlling and reducing CO2 emissions. Furthermore, there is a positive correlation between government administration quality and CO2 emissions in oil-producing nations, but in non-oil-producing countries, the correlation is negative. Liu Liu, Ma (47) document that political, economic and institutional governance substantially negatively affect CO2 emissions, reducing pollution levels. Empirical results also reveal that government effectiveness is helpful in the reduction of CO2 emissions in high carbon-emitting nations.

3. Data and methodology of the Study

3.1. Model specification

Environmental sustainability has been a growing concern for everybody. Therefore, many researchers have invested their time in exploring the key determinants for managing environmental costs over the past decades. In the line of empirical investigation, researchers have documented several critical macro fundamentals in environmental protection; however, their role in environmental sustainability differs from geographical and economic structural changes. The motivation of the study is to gauge the role of energy efficiency, environmental innovation, and institutional quality in managing environmental sustainability, that is, do all the explanatory variables augment or degrade the environmental sustainability in the Lower Income economy. The generalized empirical model is as follows:

E.S. (CO2, E.F.) | E.E., E.I., I.Q ……………. (1)

Where E.S. stands for environmental Sustainability, E.E. explains energy efficiency, E.I. for environmental innovation, and I.Q. denotes institutional quality. The variables proxies and data sources are displayed in table -1

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

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

3.2. Variables and descriptive statistics

3.2.1. Environmental Sustainability

Environmental sustainability is concerned with developing strategies to guarantee that economic development is sustainable without degrading environmental quality since it is undesirable to encourage economic growth at the price of environmental degradation. In light of this, the challenge of environmental protection over the last several decades has been adopting clean energy in industrial production to reduce the number of carbon emissions in the atmosphere. Environmental sustainability was measured by ecological footprints and carbon emissions (Hongxing (48-51). We studied the current literature and assessed both proxies in measuring environmental sustainability to study the complete and comparative assessment.

3.2.2. Energy efficiency

Energy efficiency has recently emerged as a tool in the field of energy management for lowering carbon emissions via the use of renewable power sources. The shift from conventional to renewable energy sources affects the quality of the environment, environmentally friendly industrial output, and economic development. Large sums of money are needed to diversify the energy sector with renewables. Costly initial expenditures make it difficult to transition to renewable energy sources to power the economy rapidly. In the present literature, there is no mention of any metrics for evaluating energy efficiency. We offered the proportion of renewable energy to fossil fuel consumption after carefully evaluating the concept and motivation of energy efficiency. As the ratio rises, energy efficiency and carbon dioxide emissions decrease.

3.2.3. Environmental innovation

Environmental innovation includes adopting and using carbon emission reduction and renewable energy technology. When we talk about environmental innovation (E.I.), we are talking about the spread and adaption of cutting-edge technologies and practices related to the environment and the climate. Environmental innovation is at the root of the regulatory-adoption link; fear of greater regulation likely leads to more innovation. According to research conducted by Carrión-Flores and Innes (52), the adoption of environmental technology by businesses is linked to the level of innovation inside such businesses (53). In literature measuring the effects of environmental innovation on environmental sustainability or quality, two-line of research studies are available; first, a group of researchers measured environmental innovation by considering the number of patent applications extracted from the World development indicator (WDI) see Wang, Bui (54),Többelmann and Wendler (55).. Two surrogate measures examine the relationship between environmental innovation and environmental sustainability. It is hypothesized from the Study that there is a connection between high environmental quality and creative problem solving (56).

3.3. Estimation strategy

3.3.1. Anal Autoregressive Distributed Lagged (PARDL)

Pooled groped Mean hereafter PGM. PGM can estimate both long-run and short-run magnitude by addressing heterogeneity issues. The following ARDL (p, q ….n) as an empirical structure:

$$ES_{it} = \epsilon_{it} + \sum_{j=1}^{p} \beta_{ij} ES_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij} EE_{i,t-j} + \sum_{j=0}^{q} \rho_{ij} EI_{i,t-j} + \sum_{j=0}^{q} \pi_{ij} IQ_{i,t-j} + \epsilon_{it} \; \dots\dots\dots\dots\dots (3)$$

3.3.2. CS-ARDL

Note, nonetheless, that panel ARDL undertakes errors are cross-sectionally independent. Nevertheless, such perceived notions might produce spurious estimations in some situations and lead to badly predisposed estimates if the regressors' unobserved common factors are correlated (57-59). Chudik and Pesaran (60) Propose implementing Common Correlated Effects (CCE) approach in the context of panel ARDL models. Pesaran (61) Displays the average values used in the Equation to represent unobserved common factors as a proxy for dependent and independent variables. Therefore, when averaging equations (16) and (17) across *time,* we obtain

$$\overline{ES}_{it} = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij} \overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij} \bar{Q}_{i,t-j} + \bar{\omega}'_t G_t + \bar{\epsilon}_{it} \; \dots\dots\dots\dots\dots (4)$$

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

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

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

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

The error term, εi, in Eq. (6) is independently distributed across time and countries, mean congregates to zero (i.e., $\bar{\varepsilon}t$ = 0) in root mean square error as $N \to \infty$. Therefore, the linear effects of both dependent and independents can establish in the presence of cross-sectional dependence in μi,

$$ES = \bar{\alpha}_{it} + \sum_{j=1}^{p} \bar{\beta}_{ij}\overline{ES}_{i,t-j} + \sum_{j=0}^{q} \bar{\gamma}_{ij}\bar{Q}_{i,t-j} + \bar{\omega}_t' G_t \;\ldots\ldots\ldots\ldots\ldots (4)$$

$$\downarrow$$

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

$$\downarrow$$

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

Thus, the Panel CS-ARDL specification of Equation (2)

$$\overline{ES}_{it} = \epsilon_{it} + \sum_{j=1}^{p} \beta_{ij}\overline{ES}_{i,t-j} + \sum_{j=0}^{q} \gamma_{ij}\bar{Q}_{i,t-j} + \sum_{j=0}^{p} \bar{\partial}_{tj}' \bar{Z}_{i,t-j} + \epsilon_{it} \;\ldots\ldots\ldots\ldots\ldots (6)$$

Where $\bar{Z} = (\overline{EE}, \overline{EI, IQ,})$ and $S_{\bar{Z}}$ in the number of lagged cross-sectional average furthermore, Equation (6) can be reparametrized to the effects of ECM presentation of Panel CS-ARDL as follows:

$$\Delta ES_{it} = \alpha_i + \xi_i(ES_{it-1} - \omega_t' Q_{it-1}) + \sum_{J=1}^{M-1} \gamma_{ij}\Delta ES_{it-J} + \sum_{J=0}^{N-1} \beta_{ij}\Delta Q_{it-J} + \sum_{j=1}^{p} \lambda_j \overline{\Delta ES}_{i,t-j} + \sum_{j=0}^{q} \delta_j \overline{\Delta Q}_{i,t-j} + \sum_{j=0}^{S_{\bar{Z}}} \bar{\partial}_{tj}' \bar{Z}_{i,t-j} + \mu_{it} \; (7)$$

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

4. Empirical model estimation and interpretation

Before adopting the target model to explore the magnitudes of E.I., E.E., and I.Q. on E.S., the research did many econometrical tests, including slop of heterogeneity, cross-sectional dependence, unit root test, panel cointegration test, and baseline estimate. The slope of heterogeneity, cross-sectional dependence, panel cointegration test, and baseline estimation (62). Table 1 shows that all test statistics are significantly based on cross-sectional dependency. The study units have cross-sectional dependence. We may assume the research units have a common energy. Pesaran and Yamagata (63) Are credited for the homogeneity results, which are consistent with Table 3's null hypothesis of "homogeneity" (Panel B). Both the test and adjustment statistics are statistically significant, indicating study unit heterogeneity.

Table 1 Cross-sectional dependency and Homogeneity test

	Panel –A: Cross-sectional Dependency test				Panel-B: Slop of Homogeneity	
	LM_{BP}	LM_{PS}	CD_{PS}	LM_{adj}	Δ	Adj.Δ
ES1	212.283***	42.642***	121.195***	24.818***	16.474***	75.991***
ES2	180.713***	21.998***	250.834***	7.051***	89.632***	121.622***
EE	290.671***	30.501***	236.045***	22.269***	46.001***	110.785***
EI	359.981***	33.221***	194.783***	12.155***	79.585***	150.827***
IQ	251.129***	21.422***	166.605***	48.175***	46.748***	91.664***
FDI	191.3***	28.548***	105.48***	9.264***	39.496***	104.323***
FD	237.128***	26.115***	234.987***	53.86***	16.785***	151.623***

Following Gengenbach, Palm (64), we used a panel unit root test known as CIPS and a panel unit root test devised by Pesaran Pesaran (65) known as the Constrained Autocorrelation Dispersion Function (CADF) to assess the order of integration. According to Dogan and Aslan (66), conventional panel unit root tests have limitations owing to the absence of cross-sectional independence. When cross-sectional independence is present, the CADF and CIPS unit root tests provide correct results. Table 2 presents the test results for unit roots in a panel.

Table 2 Panel unit root test results

Panel –A: Conventional Unit root test						
	Levin, Lin & Chu t		Im, Pesaran and Shin W-stat		ADF - Fisher Chi-square	
	t	t&c	t	t&c	t	t&c
Panel –A: Al level						
ES1	-1.23	-0.77	-1.556	-0.422	34.238	36.59
ES2	-3.268	-0.668	-3.724	-1.204	56.318	30.566
EE	-1.619	-3.699	-3.774	-1.371	45.611	58.195
EI	-1.489	-1.931	-2.871	-0.937	40.833	37.785
IQ	-1.654	-1.469	-2.149	-0.835	37.452	57.268
FDI	-3.708	-1.395	-2.879	-2.823	51.925	42.403
FD	-0.878	-0.412	-1.753	-3.418	41.536	45.332
Panel –B: After the first difference						
ES1	-10.929***	-8.317***	-11.181***	-8.872***	275.902***	138.934***
ES2	-12.36***	-14.865***	-14.235***	-7.099***	301.722***	198.202***
EE	-5.065***	-7.889***	-8.679***	-5.337***	257.114***	111.375***
EI	-11.709***	-19.079***	-6.082***	-8.009***	153.176***	181.492***
IQ	-11.475***	-10.083***	-16.518***	-9.843***	281.364***	152.305***
FDI	-10.705***	-14.808***	-11.52***	-10.507***	166.385***	84.635***
FD	-10.376***	-22.569***	-7.76***	-5.348***	295.123***	193.026***

Panel –B: Unit root test with Cross-sectional dependency				
	CIPS		**CADF**	
	At level	**Δ**	**At level**	**Δ**
ES1	-1.448	-4.327***	-2.726	-6.666***
ES2	-1.106	-7.438***	-1.252	-6.586***
EE	-2.648	-4.546***	-2.409	-4.525***
EI_1	-1.963	-5.687***	-2.518	-4.946***
EI_2	-1.683	-3.271***	-2.969	-5.183***
IQ	-1.916	-5.264***	-2.145	-2.18***
FDI	-2.241	-7.144***	-2.799	-6.057***
FD	-1.448	-4.327***	-2.726	-6.666***

Table 3 Results of panel cointegration test

Model - 1: Environmental Sustainability measured by carbon emission				
Panel –A: Pedroni cointegration test				
	(1)	**(2)**	**(3)**	**(4)**
Panel v-Statistic	1.937	2.568	1.411	1.375
Panel rho-Statistic	-6.028	-6.418	-6.229	-5.798
Panel PP-Statistic	-9.955	-8.46	-9.763	-9.075
Panel ADF-Statistic	-6.274	-4.901	-6.526	-4.686
Group rho-Statistic	-1.633	-1.476	-0.976	-0.397
Group PP-Statistic	-10.465	-6.795	-8.576	-6.151
Group ADF-Statistic	-11.141	-9.427	-8.094	-7.586
Panel v-Statistic	-9.837	-8.059	-11.293	-6.538
Panel rho-Statistic	-11.246	-7.997	-7.296	-6.982
Panel PP-Statistic	-9.149	-10.697	-7.807	-7.164
Panel ADF-Statistic	-3.049	-3.918	-3.554	-3.547
Panel –B: Kao cointegration test				
ADF	-2.9726***	-1.5814***	-2.8971***	-5.8228***
Panel C: Error correction based panel cointegration test				
Gt	-10.556***	-13.234***	-11.829***	-13.039***
Ga	-9.742***	-13.542***	-10.085***	-8.08***
Pt	-12.187***	-8.692***	-9.098***	-6.793***
Pa	-8.542***	-10.213***	-6.767***	-6.898***

Note: the superscripts of *** explain the statistical significance at a 1% significance level.

The following study examined the long-run link between environmental sustainability, energy efficiency, environmental innovation, and institutional quality using classical (67, 68) and error correction-based panel cointegration tests (69).

Table 3 shows long-term cointegration. Most Padroni cointegration test data are statistically significant at a 1% level, suggesting rejection of the null hypothesis: "no-cointegration." Alternately, links analyze variables through time. ADF test statistics demonstrated a long-run link by rejecting the null hypothesis. The Study used error-correction-based cointegration to produce more accurate findings. The study found links between environmental sustainability, energy efficiency, environmental innovation, and institutional quality in Lower Income countries.

The Study evaluated the baseline model with random and fixed effects before estimating the target model using the more sophisticated econometric model. Baseline values for carbon emission and ecological footprint models are included in Table 4. According to Houseman test statistics, the fixed-effects model estimate is more efficient (70, 71). The Study indicated a negative link between energy efficiency and environmental sustainability for both model assessments. Green technology integration aids environmental sustainability, and environmental innovation decreases environmental degradation. Both model evaluations demonstrate that ecological output lowers harmful environmental consequences. When carbon emission (ecological footprint) is a dependent variable, institutional quality and environmental sustainability are favorably (negatively) associated.

Table 4 Baseline estimation with fixed effects and random effects

Variable	Random effects	Fixed effects	Random effects	Fixed effects
Panel-A: environmental sustainability measured by Carbon emission				
	[1]	**[2]**	**[3]**	**[4]**
EE	0.047(0.0049)[9.441]	0.617(0.0691)[8.917]	0.494(0.0467)[10.56]	0.673(0.0671)[10.022]
EI_1	0.098(0.0232)[4.208]	0.644(0.0937)[6.871]	-	-
EI_2	-	-	0.241(0.0498)[4.831]	-0.238(0.0372)[-6.393]
IQ	0.468(0.0431)[10.835]	0.072(0.0062)[11.596]	-0.189(0.0217)[-8.702]	0.545(0.1254)[4.343]
FDI	0.737(0.084)[8.769]	-0.007(0.0009)[-7.219]	0.317(0.0623)[5.085]	0.567(0.0456)[12.429]
FD	0.537(0.0668)[8.032]	0.403(0.0634)[6.347]	0.723(0.0799)[9.045]	-0.108(0.0097)[-11.128]
C	0.686(0.1455)[4.714]	0.245(0.0527)[4.645]	-0.208(0.0186)[-11.145]	0.214(0.0229)[9.326]
H-test	11.541		25.671	
Panel –B: environmental sustainability measured by ecological footprint				
	[5]	**[6]**	**[7]**	**[8]**
EE	0.658(0.0957)[6.875]	0.338(0.0419)[8.064]	0.562(0.0777)[7.229]	-0.03(0.0071)[-4.216]
EI_1	0.611(0.0694)[8.803]	0.249(0.0553)[4.498]	-	-
EI_2	-	-	0.204(0.0261)[7.799]	0.108(0.0208)[5.169]
IQ	0.178(0.0233)[7.61]	0.229(0.0295)[7.737]	0.299(0.0729)[4.097]	-0.034(0.0033)[-10.068]
FDI	0.71(0.1356)[5.234]	-0.075(0.0066)[-11.238]	0.369(0.0912)[4.046]	0.26(0.0333)[7.805]
FD	0.723(0.1604)[4.507]	0.144(0.0276)[5.214]	-0.118(0.0166)[-7.091]	0.032(0.0033)[9.659]
C	0.413(0.0578)[7.145]	0.165(0.0171)[9.644]	0.637(0.0705)[9.032]	0.56(0.1158)[4.833]
H-test	15.942		25.6148	

Note: the value in () represent standard effort and in [] denotes t-statistics.

With a coefficient of -0.1699(-0.0743), the study found a negative and statistically significant relationship between energy efficiency and environmental sustainability, suggesting that Lower Income nations can manage carbon emissions into the ecosystem by ensuring energy efficiency. This is because the energy transaction is from fossil fuel to renewable energy. More precisely, a 10% increase in energy efficiency can lower carbon emissions in the Lower Income economy by between 0.7439 and 1.699% of their present level. This is in line with what is known now, as shown by this research and others like it. In a nutshell, Sun and Parikh (72), Qamruzzaman (73) and Rosenfeld (74). According to the interim study results, there is a statistically significant and negative (positive) association between energy efficiency and carbon emission (coefficient = -0.0415). (0.0462). Researchers showed that although there might be some negative environmental consequences from using more efficient energy sources, the beneficial development benefits were far more pronounced.

The application of ARDL to environmental sustainability (CS-ARDL) (see Table 5) is at the crossroads of environmental innovation (E.I. hereafter). According to the coefficients from both estimations, the study revealed a negative and statistically significant tie with a coefficient of -0.1728 (-0.0876), implying that progress in environmental innovation aids in reducing the level of environmental adversity through the incorporation of environmentally friendly technology in industrial output, eventually decreasing carbon intensity in the economy. In terms of short-run evaluation, the study found a negative and statistically significant connection in both model estimations, with a value of -0.0361. (-0.0292). (-0.0292). Other scholars, like Zhang et al. (2017), Töbelmann and Wendler (55), Zhao and Qamruzzaman (75)and Iqbal, Abbasi (76) have found that environmental innovations are beneficial to environmental prosperity. In contrast to Khan, Weili (1) and Yang, Qamruzzaman (58). According to Hodson, Brown (77), environmental innovation promotes successful energy integration by reducing energy costs and transition and improving environmental quality by cutting carbon emissions. Furthermore, Cagno, Ramirez-Portilla (78) argued that environmental innovation supports the economy by shifting energy reliance away from fossil fuels and toward renewable energy for industrial output, cutting carbon emissions.

Table 5 Environmental sustainability measured by CO_2 emission

	ARDL	CS-ARDL	ARDL	CS-ARDL
	[1]	**[2]**	**[3]**	**[4]**
EE	-0.1699(0.0968)[-1.7548]	-0.0743(0.0168)[-4.4037]	0.1046(0.05)[2.0902]	0.1056(0.0162)[6.4901]
EI_1	-0.1728(0.0546)[-3.1629]	-0.0876(0.0114)[-7.6262]	-	-
EI_2	-	-	-0.0341(0.0101)[-3.3741]	-0.1566(0.0936)[-1.6731]
IQ	-0.1449(0.0265)[-5.4535]	-0.0794(0.0231)[-3.4253]	-0.0163(0.0018)[8.7263]	-0.0925(0.0435)[-2.126]
FDI	0.058(0.124)[0.4678]	0.0766(0.0186)[4.0978]	0.1574(0.0556)[2.8285]	0.1271(0.033)[3.8446]
FD	-0.0997(0.5558)[-0.1793]	-0.1062(0.0985)[-1.0784]	-0.0211(0.0058)[-3.633]	-0.1377(0.0963)[-1.4287]
ΔEE	-0.0415(0.3399)[-0.1223]	0.0462(0.0103)[4.4687]	-0.0523(0.0163)[-3.1979]	0.0533(0.052)[1.0238]
ΔEI	-0.0361(0.0912)[-0.3957]	-0.0292(0.0186)[-1.5703]	0.0468(0.0193)[2.4198]	0.0679(0.108)[0.6288]
ΔEI	0.0433(0.0068)[6.2981]	0.0299(0.0041)[7.1783]	-0.0063(0.0016)[-3.8157]	0.0076(0.0309)[0.2472]
ΔIQ	0.0975(0.0291)[3.3526]	0.0671(0.0169)[3.961]	0.0493(0.0236)[2.0828]	-0.0049(0.0301)[-0.1654]
ΔFDI	0.0322(0.0529)[0.6082]	-0.0233(0.0135)[-1.7189]	0.0518(0.0177)[2.9127]	0.019(0.0699)[0.2722]
ΔFD	-0.0846(0.0185)[-4.5581]	-0.1805(0.032)[-5.6346]	0.0211(0.012)[1.7612]	0.0023(0.002)[1.1529]
ECT(-1)	-0.3737(0.4373)[-0.8544]	-0.1846(0.0972)[-1.8982]	-0.0924(0.0466)[-1.9793]	-0.2616(0.7996)[-0.3272]
H-test	0.5541	0.6371	0.5521	0.2274

Note: the value in () represent standard effort and in [] denotes t-statistics.

ARDL (CS-ARDL) analysis found a negative and statistically significant relationship between institutional quality and environmental sustainability, with a value of -0.1449 indicating the strength of this relationship (-0.0794). This shows that competent and efficient domestic institutions play a catalytic role in enhancing environmental development by cutting carbon emissions in the economy. This would be an important step toward achieving the Sustainable Development Goals. It is possible that an improvement in environmental quality in south Asia of 1.449% would result from an increase in institutional quality of 0.794 %. Tang, Abosedra (79) & Abid (41) investigates the effect that economic, financial, and institutional shifts had on the state of the environment in 58 Middle Eastern and African countries and 41 European Union nations between the years 1990 and 2011. According to the Study's findings, the standard of institutions has both a direct and an indirect impact on economic growth and environmental quality in E.U. nations. This influence is manifested through the efficiency of public spending, the growth of the financial sector, and foreign direct investment.

Lau, Choong (42) explore the long-run link between CO2 emission, exports, institutional quality, and economic development in Malaysia from 1984 to 2008 using autoregressive distributed lag (ARDL) bounds testing and Granger causality tests. This was done to examine the causal link between these elements (80). The research indicates that there is a long-term connection between the components. In addition, a high level of institutional quality is essential if CO2 emissions are to be controlled throughout the economic development process. Furthermore, Granger causality studies demonstrate the significance of institutional frameworks in reducing CO2 emissions. In the same spirit as the findings provided in Bhattacharya, Awaworyi Churchill (43). According to Koshta, Bashir (81), political stability, democracy, administrative efficiency, and corruption control all negatively affect CO2 emissions. However, the quality of laws and the existence of the rule of law positively affect CO2 emissions (82).

Regarding the impact of foreign direct investment on environmental sustainability, it is obvious that FDI inflows encourage green energy integration and increase operational efficiency, mitigating environmental degradation's negative effects. In particular, an increase of 10 percent in FDI inflows may enhance environmental quality by reducing carbon emissions by 0.0412 to 0.0155 percent. Tang, Abosedra (79) and Zafar, Shahbaz (83) support our Study's findings.

Table 6 Results of causality test: E.I. measured by the total number of patent

	ES	EE	EI	IQ	FDI	FD
Panel –A: Environmental sustainability measured by CO2						
ES	-	(4.8618)*** [5.1243]	(6.1222)*** [6.4528]	1.543 [1.6263]	(5.0361)*** [5.308]	(3.6365)** [3.8329]
EE	(4.7959)*** [5.0549]	-	(6.017)*** [6.3419]	(4.1891)** [4.4153]	(5.5738)*** [5.8748]	(2.8671)** [3.0219]
EI	(2.4197)* [2.5504]	(4.1859)** [4.412]	-	(4.1987)** [4.4254]	1.8724 [1.9735]	(3.3889)** [3.5719]
IQ	(5.3623)*** [5.6519]	(3.5781)** [3.7713]	(3.272)** [3.4487]	-	(3.3921)** [3.5753]	(4.5387)** [4.7838]
FDI	(6.0541)*** [6.3811]	1.2306 [1.297]	(6.1615)*** [6.4942]	1.5589 [1.6431]	-	(6.1976)*** [6.5323]
FD	1.1976 [1.2623]	(3.0754)** [3.2415]	1.3039 [1.3743]	1.6014 [1.6879]	(2.8235)* [2.976]	-
Panel –B: environmental sustainability measured by Ecological footprint						
ES	-	(2.6068)* [2.7475]	(2.0106)* [2.1192]	(5.984)*** [6.3071]	0.8097 [0.8535]	(5.0116)*** [5.2823]
EE	1.3145 [1.3855]	-	(2.7619)* [2.9111]	(2.4112)* [2.5414]	(6.2614)*** [6.5995]	(3.1445)** [3.3143]
EI	0.8554 [0.9016]	(3.2146)** [3.3882]	-	(2.0648)* [2.1763]	(3.1445)** [3.3143]	(3.9362)** [4.1487]
IQ	1.0106 [1.0652]	1.1615 [1.2242]	(4.6121)** [4.8611]	-	(5.6896)*** [5.9969]	(4.4452)** [4.6853]
FDI	(5.2656)*** [5.55]	1.8682 [1.9691]	(3.7938)** [3.9987]	(3.7874)** [3.9919]	-	(5.7577)*** [6.0686]
FD	(3.0882)** [3.2549]	(2.6556)* [2.799]	1.8427 [1.9422]	(4.2242)** [4.4523]	(3.8065)** [4.0121]	-

Using the Panel Causality Tests developed by *Dumitrescu and Hurlin (84)*, the direction of the association between environmental sustainability, energy efficiency, environmental innovation, institutional quality, foreign direct investment, and financial development was investigated. The findings of the panel causality test for carbon emission as an indicator of environmental sustainability in Panel A and ecological footprint as an indicator of environmental sustainability in Panel B are shown in Table 6. We focused on causation from explanatory elements to environmental sustainability. Multiple directional causalities have been established amongst study units, and we have chosen to analyze the directional effects of independent variables on environmental sustainability. For panel A, the Study discovered a bidirectional causal link between environmental sustainability and energy efficiency, as well as between institutional quality and environmental sustainability.

Moreover, environmental innovation, foreign direct investment, and financial growth contribute in a unidirectional manner to environmental sustainability. The feedback theory explains the causal link between energy efficiency, environmental sustainability, and institutional quality. In addition, environmental sustainability supports environmental innovation, economic expansion, and foreign direct investment unidirectional.

5. Conclusion

This study examines the role of energy efficiency, environmental innovation, and institutional quality in attaining environmental sustainability in the Lower Income economy between 1980 and 2020. Several econometric techniques were used to examine the empirical relationship, and the following are the key findings of the Study:

- The statistical significance of the test's findings for cross-sectional dependence suggests that the null hypothesis of cross-sectional independence should be rejected. Consequently, it may be stated that these research units share vigor. In addition, the slope of the homogeneity test suggests that the variables chosen for the Study have distinct features.
- The sequence of variable integration has been exposed with the deployment of the panel unit root test. The conventional unit root test has shown that variables are integrated in mixed order, indicating that variables are stationary either at a level or after first differences but not after second differences. In addition, the research employs a unit root test with cross-sectional features, and recorded variables are stationary after the initial difference.
- Using a panel cointegration test, the long-run cointegration between energy efficiency, environmental innovation, institutional quality, and environmental sustainability was evaluated. Refers to the test statistics for panel cointegration, which demonstrate the empirical relationship's long-run connection. Long-term co-motion effects may be seen on both sides, with environmental quality enhancing energy efficiency and economic innovation. Any negative environmental innovation, improvement in energy efficiency, or institutional development may have environmental repercussions. Consequently, policymakers must address all interdependent aspects of environmental cost management.
- Refers to the magnitudes of Environmental Sustainability objective factors. Environmental innovation, energy efficiency, and institutional quality have boosted efforts to preserve ecological balance by reducing carbon emissions and supporting ecological development, according to the Study. Environmentally advanced technology growth in the economy helps manage environmental costs by lowering carbon emissions and ecological degradation, as demonstrated by the Study. Similar to the results of Zaidi, Wei (85), Mensah, Sun (86) & Andriamahery and Qamruzzaman (87). Clean energy integration enables industrial output with less ecological destruction, as evidenced by the correlation between energy efficiency and environmental development. This is because energy efficiency promotes environmental development by reducing ecological imbalance through reducing carbon emissions. Energy efficiency looks to be a particularly appealing option for decreasing energy-related environmental and health consequences. In principle, if we can maintain service levels while using less energy, we can lessen the impact on our infrastructure, our pockets, our health, and the environment.

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