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Does Environmental Innovation, Foreign Direct Investment and Renewable Energy Consumption Curb Environmental Quality Issues? Evidence from PMG-ARDL Approach

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ABSTRACT

One of the major concerns for environmental quality improvement is to reduce reliance on fossil energy consumption. However, there is a possibility that economic developments like foreign direct investment (FDI), urbanization, innovation and renewable energy consumption can mitigate carbon emission and curb environmental quality issues. Hence this examines the impact of innovation, FDI, renewable energy consumption and urbanization on the environmental quality of 46 countries for the period of 1990-2021. The study employed pooled mean group auto regressive distributed lag stationarity estimator for the empirical results. The study findings depict that in the long run, trade openness and innovation positively influence environmental quality, whereas FDI does not significantly affect environmental quality deterioration. Renewable energy consumption plays an important role in relying on fossil energy consumption and reducing carbon emissions. This study gives insights into necessary policy endorsements for the sustainability of environment through innovation.

Keywords: Energy Efficiency, Climate Change, Environmental Quality, Financial Market
JEL Classifications: Q5; Q01

1. INTRODUCTION

Innovation is the crucial driving force behind economic growth and many countries have proposed strategies that drive innovation brought by foreign direct investment (Zhou et al., 2020). In recent decades, FDI has played a key role in creating highly advanced high-tech products and significantly influenced technological innovations in the host countries (Sivalogathasan and Wu, 2014). FDI improves production processes in host countries but can have negative environmental impacts. While production activities bring economic benefits, the environmental costs can sometimes exceed the financial gains. Foreign Direct Investment (FDI) and other economic growth factors, such as trade openness, urbanization, and energy consumption, heavily rely on fossil fuels. This dependence on fossil fuels leads to higher CO_2 emissions, contributing significantly to environmental pollution (Li et al., 2020). Consequently, many countries recognize the ecological costs associated with production processes, especially those driven by foreign direct investment (Ali et al., 2022). Numerous researchers, such as (Hao et al., 2020; Khan et al., 2022), have identified FDI as a key driver of economic growth, highlighting its role as a significant source of employment and a channel for technology transfer to host economies. Conversely, researchers like (Demena and van Bergeijk, 2019; Hu et al., 2021) have noted the negative aspects of FDI, particularly its potentially harmful environmental effects.

In recent years, global warming has escalated, leading to more frequent and severe extreme weather events that inflict substantial damage on ecosystems worldwide. Consequently, mitigating greenhouse gas emissions and tackling global climate change have become imperative tasks for humanity (Song et al., 2019). Major

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cause of climate change and global warming are due to greenhouse gas emissions. Additionally, in recent years, environmental degradation has become a critical global issue, primarily due to the increase in carbon emissions. Furthermore, still the situation is unclear on how countries can simultaneously boost economic growth and protect environmental quality. Achieving environmental sustainability is a major concern for many countries, yet the discussion on the role of innovation and institutions in this area remains insufficient. Climate change, CO_2 emissions and globalization and the three major challenges that the global economy is facing currently. In recent decades, CO_2 emissions have been recognized widely in the literature as a crucial measure of environmental pollution (Tiba and Omri, 2017).

Green innovation has the potential to enhance environmental quality and promote a cleaner environment (Khan et al., 2022). It has been observed that the production technologies utilized by foreign companies are generally more environmentally protective compared to the domestic technologies used in developing countries (Al-Mulali et al., 2015). There is no doubt that economic growth puts pressure on environmental quality due to increased energy consumption, creating a potential conflict between economic and environmental objectives. Policymakers face the challenging task of balancing these competing goals. The relationship between economic growth, energy consumption, and environmental quality has been extensively studied in the field of energy economics (Apergis and Payne, 2010).

This study contributes to the existing knowledge on the economic and environmental dimensions that drive environmental quality. First, we contribute to the environmental literature by showing different roles of innovation to combat social issues and drive economy. The structure of the paper is organized as follows: Section 1 introduces the study, highlighting the significant gap and the research objectives. Section 2 reviews the literature and develops relevant hypothesis, covering innovation, economic factors such as urbanization and FDI, environmental factors like renewable energy consumption. Section 3 details the methodology of the research, including the model estimation, data screening, and data collection process. Section 4 discusses the descriptive statistical analysis and the regression analysis results. Section 5 concludes by addressing the study's contributions to the literature and offering recommendations for future research.

2. LITERATURE REVIEW

Innovation is an all-important factor that fosters economic growth and combats the social problems of a nation. Low- and Middle-income nations that are aspiring for rapid economic growth need to attract foreign direct investment through technological innovations. The rapid increase in the economic activity fostered by national innovation systems takes a toll on environmental sustainability by increasing the ecological footprint through high levels of resources extraction and energy use. There is also an increasing consensus among nations worldwide on combatting and addressing climate risk and achieving economic growth synchronously. So, one of our research questions will be an attempt to answer how far national-level innovation and FDI affect environmental quality.

The rising annual surface temperature over the past 30 years is much faster than the long-term trend, stated by the Sustainability report 2018. The earth's temperature has risen by an average of 0.11 per decade since 1850's and year 2023 is the warmest year ever since. Burning of fossil fuels which release CO_2, one of the prominent greenhouse gases that causes global warming. There has been extensive literature discussing the Environmental Kuznet Curve (EKC) proposed by Simon Kuznet examines the relationship between economic growth and carbon emissions. Though in recent times, factors such as foreign direct investment, technological advancements, trade, financial development, income inequality, deforestation, and tourism have been integrated into the EKC model including Renewable energy. RE is included as a major independent variable in carbon emission studies and has reported mixed results supporting the EKC hypothesis (Anwar et al., 2021; Jebli et al., 2020). In contrast to fossil fuels, REs is sustainable and, most importantly, far less harmful to the environment compared to non-renewable energy sources (non-REs) (Jafarinejad and Beckingham, 2023).

The net inflow of foreign direct investment is always considered crucial for collectively contributing to a more dynamic and resilient economy. FDI often brings new technologies and expertise, infrastructure development through capital inflow, human capital development and the like. However, FDI, and other economic growth variables like trade openness, urbanization, innovation consume high amount of fossil fuels and thus emit high levels of GHG and eventually affects the environmental quality. An attempt by (Safi et al., 2022) to study how FDI affects innovation in the host country identified a positive impact both the quantity and quality of innovation, including radical innovation, within the Chinese firms. These positive effects mainly result from increased competition rather than from knowledge spillovers, which are assessed through patent citations between local companies and foreign-invested enterprises. In the study performed by Walz (1997) stated that foreign direct investment promotes innovation in upstream industries via backward knowledge spillovers.

A study by Wang et al. (2023) highlights that OECD economies account for 35% of the world's CO_2 emission proportionately facing grave danger to their natural environment. The paper also talks about the extraordinary strides made by these nations in recent years in decreasing energy-related carbon emissions despite the increasing trend in economic expansion. The intense need for green innovation is the development of eco-friendly technologies and strategies for minimizing environmental losses by efficiently using energy. A similar study by Ganda (2019) in OECD countries reports that using RE and R&D can significantly reduce carbon emissions in these countries. The study emphasized that innovation and technological advancements still have potential to enhance environmental quality. The target of zero emissions can be achieved by integrating natural environmental standards into patents and enhancing green skills of research worldwide. Similar recommendations were proposed in a very recent study by Hoa et al. (2023) where they examined the intersection of FDI, innovation, RE consumption, and economic growth by applying granger causality tests. A bidirectional relationship between FDI and innovation and a mediating relationship between innovation and RE consumption were observed among the low, middle and high income-based countries as reported by this study. According to Wani et al. (2024) green energy can significantly contribute to FDI and economic growth of countries both in the long and short run. The study suggests that by incorporating exclusive policies that promote FDI in green technology and energy investments can foster environmental development and sustainability.

Another study by Sharif et al. (2023) examines the interdependencies between renewable energy supply, green energy investment, environmental tax, and economic growth in green technology innovation in 6 ASEAN countries. The empirical result of the study shows a positive impact of green energy and green technology innovation both in the short and long run, yet a stronger relationship in the long run. The findings of Phan (2024) in the same geographical zone infer that sustainable business practices through creating an association between ESG practices, clean energy, and green financing can strengthen green economic advancement. The need of the hour is that Governments, firms, economic activists, investors, and individuals must synergize together, develop, promote, and strive towards achieving a carbon-free environment.

Stressing the same point, Sun et al. (2023) examines the impact of environmental taxes, renewable energy, green innovation, and economic growth on green total factor productivity in China. They argue that achieving green productivity goals requires significant penalties on carbon emissions and some constraints on economic growth. The study suggests that developing nations should emulate China's approach by taxing carbon emissions and investing in renewable energy and green innovation to address ecological challenges and promote sustainable economic development. Similarly, Zhou et al. (2023) proposes a hypothetical economic system where green behavior by firms and households becomes a common form. The proposed system will encompass two development stages: green transformation and green innovation. This paper under the pattern of green development follows the endogenous growth model that considered green innovation and growth of the economy together with green initiatives in environmental aspects. Furthermore, the research findings will help to increase the knowledge on green innovation and its importance to the economic enculturation effect and the environmental enculturation effect in the economic system.

Table 1 provides some of the previous studies that focused on environmental quality issues as follows:

The research gap is identified in the current study. While there is existing research on environmental quality concerns in different regions, there is a need for studies that examine the impact of the latest environmental innovation on environmental quality (Li et al., 2021). Previous studies have explored renewable energy, environmental innovation, trade openness and quality institutions and their effect on environmental sustainability (Khan et al., 2022).

2.1. Factors Affecting Environmental Quality

2.1.1. Environmental innovation

Compared to traditional innovation, the academic study of green innovation is relatively new. However, interest among researchers in green innovation has significantly increased in recent years. Environmental innovations contribute to reduced energy consumption by utilizing cleaner technologies, which in turn help lower carbon emissions (Ridzuan et al., 2023). Previous studies have considered environmental degradation as a daunting challenge. Rising levels of CO2 emissions and the subsequent increase in temperatures have severe consequences for ecosystems and life on Earth (Baloch et al., 2021). Extreme weather events are driven by these alarming CO_2 levels and rising atmospheric pollutants (Safi et al., 2022). Consequently, climate change is viewed as a significant threat to human life, stemming from persistent pollution without regard for its harmful effects (Elbasiouny et al., 2021).

2.1.2. Trade openness

Free trade can have both negative and positive environmental impacts due to scale, technique, and composition effects (Antweiler et al., 2001). Additionally, trade influences the environment through its impact on economic growth. In this context, trade openness can support economic growth by leveraging comparative advantages for resource transfer among countries. However, its environmental impact varies depending on the mechanisms through which it operates (Mahmood et al., 2019). FDI and trade lead to increased energy consumption and global manufacturing, significantly impacting the global climate (Shakib et al., 2022). While FDI and trade openness contribute to higher CO_2 emissions, they also have the potential to mitigate these negative effects through the adoption of renewable energy sources (Pata et al., 2023).

2.1.3. FDI

Developing countries are facing various macroeconomic challenges due to lack of capital. To address these issues, countries often seek foreign loans or FDI. Developing nations may tighten environmental regulations and prioritize economic growth to attract FDI. However, there is a concern that "emerging countries could become pollution havens, where FDI might contribute to environmental degradation in these regions" (Gökmenoğlu and Taspinar, 2016). Furthermore, Guo et al. (2021) stated that "FDI enhances the environmental quality in host economies by introducing clean technology". Additionally, foreign direct investment boosts the capital resources and production capacity of the host countries. When FDI levels are low, the capacity for scientific and technological innovation tends to exacerbate environmental pollution. However, once FDI surpasses a certain threshold, it can enhance scientific and technological innovation, thereby improving environmental quality (Wang and Luo, 2020).

2.1.4. Renewable energy consumption

Globally, the focus on renewable energy is centered on solar and wind power to reduce CO_2 emissions and combat climate change. "The push for renewable energy is motivated by environmental concerns, the depletion of nonrenewable resources, and advancements in technology" (Hoa et al., 2024). Existing

Table 1: Empirical studies on environmental quality and other variables

Authors	Variables	Methodology	Time period	Outcomes
(Hoa et al., 2024)	Chemical Oxygen Demand (COD), FDI, GDP, Industrial Weights, Population density, Environmental regulations.	Spatial Lag Model Spatial Error Model	2000-2022	Technological Innovation reduce emission of sulfur dioxide but increases COD
Anwar et al., 2021	CO_2, GDP, RE consumption and non-RE consumption	Methods of Moments Quantile Regression FMOLS, DOLS, FE-OLS	1990-2018	Renewable energy consumption reduces CO2
Jebli et al., 2020	CO2, Economic growth, RE consumption, Industrial Value added (IVA) and Service Value Added (SVA)	Generalized Methods of Moments System Granger Causality Tests	1990-2015	CO2 have a negative impact on IVA and positive impact on SVA
Wang et al., 2023	CO2, Green Innovation, Carbon tax, RE, GDP	Quantile Regression Method	1990-2018	Eco-innovation and Environment related tax and RE reduces PCO2 emissions
Hoa et al., 2023	CO2, GDP, RE consumption, Innovation	Unrestricted Fixed Effects Regression	2000-2022	Innovation increases CO2and RE reduces CO2 emissions
Ganda 2019	CO2, Primary Energy Supply, R&D, Patents, GDP, FDI, Domestic credit, Labor force participation, Population and RE consumption.	Generalized Methods of Moments System	2000-2014	RE and R&D reduces CO2 emissions

Source: Compiled by the authors

literature indicates that renewable energy can help address energy security and climate change challenges (Wang et al., 2018). There is a general agreement that energy use policies should be revised to increase the share of renewable energy sources, thereby controlling environmental pollution (Zheng et al., 2015). There is a relationship between renewable energy consumption and environmental quality. Several studies have highlighted the role of renewable energy consumption towards improving environmental quality. For example, Zafar et al. (2020) explored the relationship between "renewable energy consumption and CO_2 emissions in presence of FDI, natural resource abundance and economic growth". Furthermore, Khan et al. (2019) revealed that "renewable energy production has significant long term effect on carbon emissions". Similarly, Caglar and Askin (2023) revealed that renewable energy consumption and human capital can be strong factor to environmental quality.

3. METHODOLOGY

3.1. Sample

The world's top 100 densely populated countries were initially selected for the present study. Accounting for the continuous and recent data availability from 1990 to 2021 the sample was reduced to 46 countries which includes countries from 6 continents. The study's independent variables are all sourced from the database of World Bank Data. Innovation is measured as the ratio of total number patents by residents and non-residents to total population. FDI shows the total net inflow of foreign direct investment measured as a percentage of the country's GDP. Renewable energy consumption is measured as the share of renewable energy in the selected countries' final energy consumption. Trade openness is the sum of exports and imports of goods and services measured as a percentage of a country's GDP. The study's dependent variable Environmental Quality is proxied with the carbon footprint which measures the carbon emission connected with fossil fuel consumption. In Ecological Footprint accounts, the amounts are converted into biologically productive areas required to absorb CO_2. The carbon footprint is part of the Ecological Footprint because it competes for bio productive space. Growing CO_2 concentrations in the atmosphere is seen as a build-up of ecological balance. Some carbon footprint measurements report results in tons of CO_2 released per year, without converting this measure into the area needed to cut off it. The Environmental Quality data was sourced from Global footprint network database.

3.2. Empirical Model

The environmental quality model in the functional form is provided as follows in the equation 1:

$$CO2_t = f(INN_t, TRADE_t, FDI_t, REC_t, URB_t) \quad (1)$$

Where,

CO_2 signifies environmental quality

INN signifies environmental innovation

TRADE signifies trade openness

REC signifies renewable energy consumption

URB signifies urbanization

The variables have been selected with the help of previous studies and their suggestions. Equation 2 provides variables to estimate short and long run elasticities.

$$CO2_t = \delta_t + a_1 INN_t + a_2 TRADE_t + a_3 REC_t + a_4 FDI_t + a_5 URB_t + \mu_t \quad (2)$$

Table 2 provides the sources of the data collected for the study and its descriptions.

This study employs Pooled Mean Group (PMG)-Autoregressive Distributed Lag (ARDL) analysis to examine the short and long-run relationship between FDI, Innovation, Renewable Energy consumption, and Environmental Quality. We considered PMG as the appropriate technique considering our dataset included heterogeneous panels including 46 countries which may exhibit diverse behaviors at different time periods.

4. RESULTS

In this part, the outcomes are shown following the regression analysis conducted in EViews 12, using the collected data. The equations described in the research methods section were employed for the regression, and the results will be displayed in the same sequence.

Table 3 displays the descriptive statistics of all variables included in our study from 1990 to 2021. We analyze the mean, standard deviation, minimum and maximum values, and the data's skewness and kurtosis. The mean value of CO_2 emissions, foreign direct investment, innovation, renewable energy consumption, trade openness and urbanization are 2.143 tons, 2.64 billion, 28 patents per 10000 population, 20.422%, 65% and 55103821 population. For standard deviation, the carbon emissions were relatively low compared to renewable energy consumption. Innovation had the highest deviation from the mean indicating that there is still a need to focus on innovation in the countries to improve carbon emissions.

After the initial descriptive statistics, the data were tested for heteroskedasticity using the Breusch-Pagan (BP) test and for autocorrelation using the Durbin-Watson (DW) test. A DW test value of 2.0 indicates no autocorrelation in the sample.

Table 2: Data sources

Variables	Descriptions	Sources
Carbon emissions	CO_2 emissions representing environmental quality measured in the form of metric tons per capita.	WDI
Innovation	Environmental patent divided by population	WDI
FDI	Foreign direct investment net inflows (% of GDP)	WDI
REC	Renewable energy consumption (metric tons per capita)	WDI
URB	Urbanization	WDI

Table 4 shows the unit root test results, where the augmented Dickey Fuller (ADF), Phillips-Pherron (PP) and Im, Pesaran and Shin (IPS) tests were employed. To examine the relationships between the dependent, explanatory, and control variables, it is essential to ensure their stationarity by integrating them at order one (Panigrahi, 2023). The results indicated that except for carbon emissions and trade openness, all other variables were significant at constant level. However, all the variables were found significant statistically at 1st difference and 2nd difference. The results of these tests indicate that the data comprises both stationary and non-stationary series. These unit root tests justify proceeding with the cointegration analysis using ARDL estimation.

Table 5 provides the correlation results that insight into the strength and direction of the linear relationship between the variables. The correlation between carbon emissions and FDI was 0.074 indicating a weak relationship between them. This suggests that if FDI increases there is a slight increase in carbon emissions. Similarly, carbon emissions have a weak relationship with innovation and trade openness by 0.128 and 0.112. However, the correlation coefficient between carbon emissions and renewable energy consumption was −0.50 with moderate negative relationship suggesting that as renewable energy consumption increases, carbon emissions decrease.

In the context of cointegration test results as shown in Table 6, panel statistics were used to determine the long run equilibrium relationship between the variables in the panel data. Panel v-statistics with the positive value of 1.376 indicated that there is evidence of cointegration. Similarly, panel rho-statistics of −2.171, panel PP-statistics of −14.670 and Panel ADF-statistics of −14.995 that was significantly <0, indicated strong evidence of cointegration.

The cointegration test results provide strong evidence for a long-term equilibrium relationship among the variables. The significant negative values of the Panel rho-statistics (−2.171), PP-statistics (−14.670), and ADF-statistics (−14.995), as well as the positive v-statistics (1.376), all support rejecting the null hypothesis of no cointegration.

Table 7 provides the long run regression estimation with the pooled mean group approach. Here, carbon emission was taken as dependent variable whereas; FDI, innovation, renewable energy consumption, trade openness, and urbanization were considered as independent variables. The regression coefficient between carbon emissions and FDI indicates that a one-unit increase in FDI is linked to a 0.0029 unit rise in the dependent

Table 3: Descriptive statistical results

Descriptives	CO_2	FDI	INN	REC	TRADE	URB
Mean	2.143	2.643	28.000	20.422	65.022	55103821
Median	1.928	1.930	7.780	15.800	57.447	23653235
Maximum	7.853	105.500	345.000	78.100	220.406	8.830008
Minimum	0.000	−40.080	0.000	0.000	13.753	2.821739
Std. Dev	1.534	5.539	52.280	17.191	34.180	1.050
Skewness	0.820	7.400	3.455	1.035	1.504	4.381
Kurtosis	3.307	117.380	16.690	2.452	5.658	25.822

CO_2: Carbon emissions; FDI: Foreign direct investment; INN: Innovation; REC: Renewable energy consumption; Trade: Trade openness; URB: Urbanization

Table 4: Unit root test results

Test for unit root	CARBON	INN	FDI	REC	TRADE	URB
Augmented dickey fuller						
Level	−1.12	−3.20	−12.54	4.62	1.02	18.23
1st Difference	−25.47*	−24.46	−29.50	−23.41	−24.90	−0.71
2nd Difference	−33.34*	−33.75	−34.43	−34.36	−33.41	−15.83
Phillips-Pherron						
Level	−1.125	−3.52	−12.27	5.10	1.78	16.58
1st Difference	−26.60	−25.34	−31.61	−23.87	−27.07	−1.55
2nd Difference	−29.27	−28.72	−28.19	−30.94	−30.23	−16.03
Im, Pesaran and Shin						
Level	−2.46	−1.19	−3.25	−0.83	−1.39	2.68
1st difference	−41.39	−34.19	−7.01	−5.20	−5.47	−1.65
2nd difference	−54.73	−59.34	−9.8	−8.94	−8.09	−4.03

*-significant at $P<0.05$

Table 5: Correlation results

Constructs	CARBON	FDI	INN	QREC	TRADE	URB
CARBON	1					
FDI	0.074	1				
INN	0.128	−0.031	1			
REC	−0.50	−0.046	−0.0451	1		
TRADE	0.112	0.255	−0.005	−0.101	1	
URB	−0.210	−0.045	−0.116	0.037	−0.283	1

Table 6: Cointegration results

Cointegration parameters	Statistics	Prob	Weighted statistics	Prob
Panel v-statistics	1.376	84.000	−3.871	0.999
Panel rho-statistics	−2.171	0.014	1.787	0.963
Panel PP-statistics	−14.670	0.000	−6.686	0.000
Panel ADF-statistics	−14.995	0.000	−9.159	0.000

Table 7: Long run regression estimation

Variables	Coefficients	Std error	t-statistics	Prob
FDI	0.0029	0.001	1.774	0.076*
INN	0.001	0.0004	2.545	0.011**
REC	−0.013	0.001	−11.77	0.000***
TRADE	0.0007	0.0004	1.787	0.074*
URB	−7.49	3.674	−2.044	0.041**

$P<0.1$*, $P<0.05$**, $P<0.001$***

variable. However, with a p-value of 0.076, this result is not statistically significant at the 5% level, though it is close to being significant. Similarly, the regression coefficient between carbon emissions and innovation suggests that a one-unit increase in INN results in a 0.001 unit increase in the dependent variable. This result is statistically significant at the 5% level, with a P = 0.011. Furthermore, the regression coefficient between carbon emissions and renewable energy consumption shows that a one-unit increase in REC leads to a decrease of 0.013 units in the dependent variable. This result is highly statistically significant, with a P = 0.000. The coefficient between carbon emissions and trade openness implies that a one-unit increase in TRADE is associated with a 0.0007 unit rise in the dependent variable. This result is not statistically significant at the 5% level, with a P = 0.074, but it is close to being significant. Finally, the coefficient between carbon emission and urbanization indicates that a one-unit increase in URB leads to a decrease of 7.49 units in the dependent variable. This result is statistically significant at the 5% level, with a P = 0.041.

Table 8: Short run regression estimation

Variables	Coefficients	Std error	t-statistics	Prob
FDI	0.0027	0.0037	0.752	0.452
INN	0.019	0.011	1.76	0.078*
REC	−0.074	0.0309	−2.39	0.017***
TRADE	0.009	0.002	3.31	0.0009***
URB	−1.69	−0.0022	−0.76	0.4423

$P<0.01$*, $P<0.05$**, $P<0.001$***

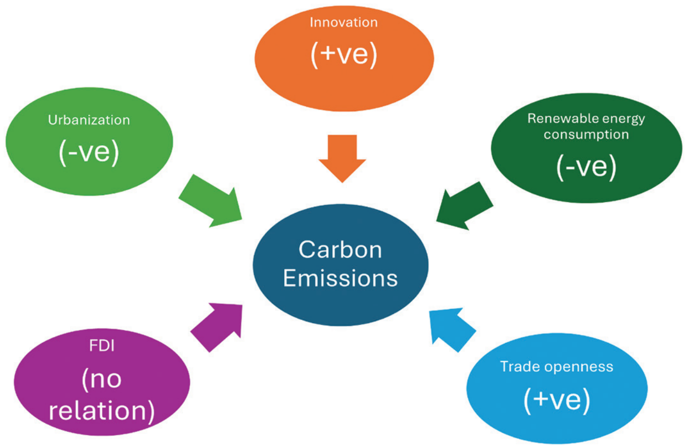
In summary, FDI, INN, and TRADE have a positive long run effect on carbon emissions, while REC and URB have a negative effect on the dependent variable.

Table 8 shows the short-run relationship between the constructs. The coefficients suggest there is no short-run impact of FDI and urbanization on carbon emissions, but renewable energy consumption and trade openness have a short-run impact on carbon emissions. Innovation has a P-value close to 0.05, suggesting a potential impact, but it is not significant statistically at the 5% level.

The world's heavy dependence on non-renewable resources has led to major global problems, including potential future oil shortages, instability in electricity supply, and environmental issues. The global economy faces the risk of rising energy consumption as it strives to sustain economic development and ensure long-term sustainability.

Figure 1 uncovers that innovation and trade openness has a positive impact on carbon emissions, whereas urbanization and renewable energy consumption has a negative impact on carbon emissions. Furthermore, FDI had no relationship with carbon emissions.

Figure 1: Long term impact of study variables to curb carbon emissions



5. CONCLUSIONS AND POLICY IMPLICATIONS

This study examined the association among innovation, trade openness, FDI, renewable energy consumption and urbanization and carbon emissions representing environmental quality. The study data range from 1990 to 2021, and the stationarity of the variables was confirmed from the unit root tests including ADF, PP and IPS. The PMG-ARDL technique was utilized to address the dynamic relationships among the variables. The results indicate that in the long run, trade openness, renewable energy consumption, and innovation positively influence environmental quality, whereas FDI does not significantly affect environmental quality deterioration. Additionally, the short-run findings also demonstrate that renewable energy consumption, trade openness, and innovation have a significant positive association with environmental quality.

Foreign investment, technological advancements, and effective governance are essential tools for meeting carbon emission reduction targets. Our empirical study emphasizes that the countries should actively enhance their ability by adopting eco-friendly policies to address current environmental challenges. Based on the empirical findings, policymakers should prioritize the adoption of technological advancements to promote sustainable energy development. It is suggested that countries should prioritize increased investment in education and the renewable energy sectors. Furthermore, there should be strategic planning for research and development in renewable energy to ensure environmental sustainability.

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