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Renewable Energy Consumption, Natural Resource, Urbanization and Environmental Sustainability in Pakistan

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Abstract

Energy is an indubitable imperative for economic development, yet it also generates CO2 emissions, which are the leading cause of climate change and environmental deterioration. Renewable energy can stimulate economic growth and can help to achieve economic and environmental sustainability. This paper seeks to investigate the impact of renewable energy consumption, total natural resource rent, urbanization and GDP, on CO2 emissions, ecological footprint (LEF), Methane (LCH4), Nitrogen dioxide (LN2O) and deforestation (LDF) in Pakistan over the period spanning from 1986 to 2021. The present paper employs the autoregressive distributed lag model (ARDL). The empirical evidence revealed that renewable energy and total natural resource rent show negative ramifications on environmental quality, while urbanization and GDP show positive impacts on CO2 emanations. Renewable energy is independent variable and displays different results with different dependent variables. Renewable energy shows a negative association with LEF and LN2O, yet it boosts LCH4 and LDF in the long run.

Keywords: Renewable energy consumption, urbanization, ecological footprint, carbon emissions, deforestation.

1. Introduction

Globally, to combat the problem of climate change, overcome pollution and ensure energy security, the economies have to shift low carbon economies (Miguel et al., 2019; Mitic et al., 2023).Devastating levels of pollution in the environment is the main hurdle for sustainable development; thus, the affiliation between GDP and the environment has captured great attention nowadays (Bakhsh et al., 2017; Awan & Azam, 2021). In the present era of development, environmental sustainability has become a hot debate and has monopolized political, social, health and economic issues; it's all because of the negative ramifications of global warming and climate changes on the environment (Ahmed et al., 2021; Iheonu et al., 2021). Climate change slows down economic activities, alters the natural environment and harms human life on the planet (Nathaniel & Iheonu, 2019; Iheonu et al., 2021). Human actions have been the major contributor to climatic shifts since the middle of the twentieth century; human activities accelerate the temperature, triggering a domino effect of catastrophes in the biosphere and atmosphere (Godil et al., 2021; Zhang et al., 2022). In order to accelerate their industrialization, developing countries are consuming enormous amounts of energy to generate an increasing quantity of commodities and services (Sadiq et al., 2022; Jahangir et al., 2023). After the 1990s, CO2 emissions from emerging industrialized countries have exceeded those from developed countries (Shan et al., 2021; Adebayo et al., 2022).

In the beginning, natural resources are mainly utilized without considering the environmental consequences. This massive utilization of natural resources in mining and agriculture disturbs the ecosystem, and upsurges the CO2 levels (Panayotou, 1993; Baloch et al., 2019; Isiksal et al., 2022). Use of fossil fuels for transport and energy is the primary human activity behind the CO2 emissions; even so, some other activities are still emitting CO2, for instance, production bustles and land use modification; overheating and weather change are influencing the planet in multidimensional ways including health, ecological, weather pattern, water system dispersion and sea level rise (He et al., 2021; Adebayo & Kirikkaleli, 2021). According to the international energy report (IEA, 2009), energy-related carbon discharge will get doubled by 2050 if mark able policies are not initiated; the energy security situation is expected to worsen as the need for oil continues to rise (IEA, 2009). Empirical results confirm that RNE utilization abates the CO2 emanations, yet non-renewable energy utilization boosts it up (Bekun et al., 2019; Ehigiamusoe & Dogan, 2022). The European Commission's joint research Centre claims that the burning of fossil fuels contributes almost 90% of total global CO2 emanations (Shayanmehr et al., 2020; Radmer et al., 2021).

Economic expansion and energy demand are the eminent factors behind CO2 discharge and environmental deterioration in many countries (Adebayo et al., 2021; Suhrab et al., 2023). Economic activities from different channels and industries are all responsible for pollution and CO2 emanations (Udemba, 2020; Suhrab et al., 2023). Economic growth has largely stimulated society's welfare while adversely impacting the environment and human life (Djellouli et al., 2022; Kirikkalleli et al., 2023).Recently, developed economies are focusing on measures to combat environmental issues, and each country's GDP is the prime desired goal for the economy (Raworth, 2017; Awan & Azam, 2022). Increasing capital is required to meet human needs, which needs more resources; increasing demand for more resources is the vital factor behind contaminants of used resources and, ultimately, environmental degradation; This inconsistency between GDP and the climate creates a huge hurdle to overcome the environmental problems (Albayark & Gokce, 2015; Basar & Tosun, 2021).

Urbanization is a migration of a large number of the labour force for the sack of better economic opportunities; on the other hand, this migration also exerts negative influences on the environment, human health, air, sanitation, deforestation and traffic problems (Madlener & Sunak, 2011; Nosheen et al., 2020). The urban population negatively impacts environmental quality by captivating abundant energy resources and electricity (Liddle & Lung, 2014: Abassi et al., 2020). Population growth, manufacturing and rapid metropolitan are the major influential contributors to CO2 emissions (Raihan & Tuspekova., 2023; Voumik et al., 2023). Urbanization not only adversely affects the CO2 emissions and human health (Asongu & Odhiambo, 2019; Danish & Hassan, 2023). However, urbanization is fruitful for job opportunities, higher standards of living, enhanced R&D activities and technological innovations (Khan et al., 2021; Danish & Hassan, 2023). IEA report claims that in 2010, 71% of global CO2 emissions are observed from urban areas, moreover, this population will grow as the urbanization process kept on (Haseeb et al., 2017; Zhu et al., 2018). Rapid urbanization causes severe threats to environmental quality, also responsible for more than 80% of CO2 emissions around the globe (Wang & Zhao, 2018; Salahuddin et al., 2019).

Economic growth spurs industrialization, which enhances the demand for natural resources; industrialization causes deforestation, mining, agriculture and extraction of natural resources, as a result this causes environmental worsening and ecological destruction (Baloch et al., 2019; Nathaniel & Bekun, 2020; Nathaniel, 2021). Natural resources can be regenerated by adopting sustainable practices in production and consumption activities (Nathaniel & Bekun, 2020; Nathaniel, 2021). Overpopulation is the root cause of natural resource depletion, as the people in developing countries are cleaning the land, accumulating the growing population's social and economic needs leading to resource depletion (Zhang et al., 2021; Zhang et al., 2022). High rise of GHGs, soil erosion, and damage of biodiversity are held by the dwindling of raw material; the exhaustion is the prime factor of global warming; high levels of drought and flooding are associated with poor environmental management in developing countries (Chopra et al., 2022; Zhang et al., 2022). Recent times have witnessed an extreme upsurge in demand for natural resources; the world has turned from NRE consumption to RNE utilization, which causes resource exploitation. Furthermore, many studies confirmed that natural resource utilization alters classical energy and hence lessens environmental contamination (Khan et al., 2021; Zahoor et al., 2022). Moreover, mineral deposits aplenty effectively minimize energy intensity and usage of hydrocarbons, thus reducing CO2 levels (Dogan & Ozturk, 2017; Bhat & Mishra, 2018; Iqbal et al., 2022).

Our study is unique from other studies in several ways to fill the gap in previous studies in different ways: (i) our study use the multiple measures of environment (CO_2 emission, ecological footprint, Methane, deforestation, N_2O) in spite of single proxy because it provides the robust findings in Pakistan. (ii) This study employed ARDL on different models that provided reliable results as compared to traditional methods. (iii) Our study is very useful for policymakers and government officials to formulate concerned policies.

The remaining segments are as following: the segment 2 reports the previous literature; segment 3 portraits methodology; segment 4 and 5 are about results and conclusion.

2. Literature Review

The connection between RNE and eco quality has been examined by a large number of authors. They consider some other features like GDP, and financial development. The relationship between these variables showed mixed results for different samples.

2.1 CO2 and Renewable Energy

Sahoo and Sahoo (2022) documented the affiliation between GDP, renewable energy sources, NRE sources, and carbon release via the ARDL methodology for India. Empirical evidence of the survey unveiled that hydro energy utilization exerted a positive but insignificant impact on CO_2 release, while nuclear energy negatively correlated with CO_2 outflow. GDP unfolded positive association with CO_2 ejection. Bouyghrissi et al. (2022) inspected the bond among renewable energy, economic boom, FD, FDI, and environment, using ARDL and FMOLS approaches. The research accumulated data from Morocco over the period from 1980 to 2017. The observed calculation of the survey proposed the positive interaction between FD, FDI, GDP, and CO_2 emanations; conversely, renewable energy utilization negatively associated with CO_2 release. Adebayo and Kirikkaleli (2021) documented the interconnection between GDP, RNE, globalization, and CO_2 discharge using a wavelet statistical tool. The research gathered data from Japan covering the years 1990 to 2015. The verifiable assessment of the paper disseminated that globalization, GDP, and technological innovation positively affected CO_2 outpouring; on the other hand, renewable energy negatively correlated with CO_2 outpouring. Adebayo (2022) inspected the affinity between GDP, renewable energy usage, trade globalization, political risk, and CO_2 outpouring by employing the dynamic ARDL method over the period 1990 to 2018 for Canada. The verifiable findings of the survey confirmed the negative correlation between RNE, GDP, political risk, and CO_2 release. Bilgli et al. (2016) scrutinized the affinity of GDP, RNE, GDP^2, and CO_2 release via FMOLS and DOLS methods. Research was conducted between 1997 and 2010 in 17 countries of the OECD. According to verifiable calculations, GDP square and renewable energy adversely affected CO_2 ejections; on the other hand, GDP positively correlated with CO_2 outflow. Charfeddine and Kahia (2019) scrutinized the alliance between gross capital formation, sustainable energy, FD, real GDP, labor force, and CO2 discharge by adopting PVAR for the MENA region for the time being 1980 to 2015.

According to empirical evidence, renewable energy adversely affected the environment; meanwhile, FD and GDP positively correlated with CO2 emanations. Bhat. (2018) probed the association between renewable energy utilization, non-renewable energy consumption, GDP, capital, per capita income, labor, and CO2 ejection via PMG and GMM techniques. The paper gathered facts from BRICS at that time frame from 1992 to 2016. The actual observation of the paper unfolded that per capita income, and NRE exhibited positive ramifications on CO2 emanations; yet, renewable energy exhibited an adverse influence on CO2 release. For E7 countries over the period 2001 to 2020, Chien et al. (2023) discovered the connectedness of RNE, urbanization, energy import, industrialization, and CO2 discharge. The estimated outcomes of the results unfold that RNE and electricity consumption lessen CO2 discharge; meanwhile, industrialization, energy import, and urbanization damage environmental quality. For 35 BRI countries employing the GMM, Khan et al. (2023) evaluated the tie between GDP, natural resources, RNE, and CO2 ejections. The confirmed outcomes of the research disseminated that GDP and natural resources accelerated CO2 discharge; in addition, RNE reduced CO2 secretion. The interconnection between energy structure, EPU, urbanization, TNNR, and CO2 discharge covering the period 1992 to 2020, for E7 economies by employing the FMOLS approach was investigated by Hussian et al. (2023). The empirical outcomes of the research disclosed that natural deposit, EPU, and urbanization harm EF, while energy structure enhanced environmental quality.

2.2 Total Natural Resource Rent and CO2

Zahoor et al. (2022) inspected the tie between total natural resource rent, cropland, manufacturing value-added, urbanization, and CO2 emanations by using GLM and GEE techniques. The study used Chinese data spanning the years 1970-2016. The estimated results of the research unfold the negative interconnection between total natural resource rent, permanent cropland, and CO2 ejections, while urbanizations and manufacturing value-added showed positive affiliation with CO2 emanation. Arsalan et al.(2022) demonstrated the affiliation between total natural resource rent, FD, merchandise trade, urban population, and CO2 emanations by making use of GMM and DOLS techniques. The poll collected information from China from 1970 until 2016. According to factual evidence, TNRR adversely affected CO2 release; meanwhile, trade, FD, merchandise and urban population growth showed constructive association with CO2 discharge. Hung (2022) probed the interconnection between total natural resource rent, globalization, FD, and CO2 discharge by adopting wavelet coherence and cross-wavelet techniques. The survey gathered data from Vietnam over the period 1990 to 2019. According to verifiable outcomes, FD, globalization, and TNRR exerted unfavorable consequences to CO2 outpouring. Isiksal et al. (2022) identified the affiliation between human capital, total natural resource rent, GDP, and CO2 emanations by adopting PMG and Dumitrescu-Hurlin techniques. The research obtained data from the Central Asian state during the period 1995 to 2018.

According to experimented evidence, human capital adversely affected the COs release; in contrast, total natural resource rent and GDP unfold positive ramifications on COs outflow. Zhang et al. (2022) probed the affinity between total natural resource rent, energy resources, education, tax revenue, GDP, and COs emanations by adopting CS-ARDL. The study piled up figures from 48 developing nations during the period 1990 to 2020. The verifiable assessment of the survey unveiled the positive relationship between TNRR, energy source excessive utilization, and GDP with COs emanation; on the other hand, tax revenue and education exerted an adverse impact on COs discharge. Nathaniel. (2021) unfolded the linkage between GDP per capita, human capital, TNRR, GDP per capita square, and ecological footprint by employing CADF, CIPS, and AMG techniques. The study accumulated information from Asian economies during 1990 to 2016. The verifiable calculations of the analysis displayed that GDP and TNRR exerted an adverse influence on the environment; but human capital showed a weak negative relationship with the environment. Jahangir et al. (2023) scrutinized the alliance between TNR, globalization, GDP, institutional quality, FDI, use of energy, and COS emanations through the Panel threshold technique. From 1990 through 2018, the survey collected information from 73 developing nations. The factual outcomes of the survey revealed that TNRR, INSQ, globalization, and human capital exerted adverse consequences on COs discharge; in contrast, FDI and energy utilization positively correlated with COs ejections.

2.3 Urbanization and CO2

Danish and Hassan (2023) scrutinized the correlation between urbanization, total natural rent, GDP, and COs ejection using dynamic ARDL techniques. Information from Pakistan was collected for this study spanning from 1971 to 2017. The actual calculations of the experiment revealed that TNRR and GDP exerted significantly positive ramifications on COs discharge; on the other hand, urbanization adversely influenced COs emanations. Siqin et al. (2022) conducted the affiliation between industrial structure, fossil fuel energy, GDP, and COs emanations by adopting a cross-sectional correlation test, and Granger causality test. From 2004 to 2019, the investigation gathered information from Northern China. The practical estimations of the survey confessed the positive correlation between industrial structure, fossil fuel energy, and COs release; in contrary, GDP and urbanization displayed an inverse impression on COs discharge. Kwakwa et al. (2023) inspected the affiliation between ICT development, FDI, urbanization, fertilizer utilization, GDP, GDP square, and COs emanations, employing the ARDL. The study utilized information of Ghana including the time frame 1971 to 2018. According to actual evidence, GDP and urbanization adversely affected COs release; meanwhile, FDI, ICT development, fertilization, and GDP square positively correlated with COs discharge.

From 1984 to 2016, Salahuddin et al. (2019) documented the nexus among GDP, urbanization, poverty, globalization, and COs release by adopting second generation such as MG, CCEMG, AMG, and Dumiterescu-Hurlin for African countries. The long-run estimations of PMG revealed that GDP, energy poverty, urbanization, and globalization have positive repercussions on COs emanations. Voumik et al. (2023) demonstrated the affinity between population, GDP, industry, TNRR, electricity utilization, and COs emanations by adopting CS-ARDL, STIRPAT, CSD, AMG, MG, and CCEMG techniques. The research acquired data from the South Asian region during the period 1972 to 2021. The verifiable consequences of the research disseminated the positive association between GDP, industrialization, urbanization, and COs outflow; in contrast, population growth, electricity utilization, and total natural resource rent displayed an unfavorable impact on COs outflow. For Chinese; Cheng and Hu (2023) found the interconnection between population size, urbanization, urban sprawl, affluence, technology, and COs emanation by using STIRPAT, QML, and GMM techniques. The verifiable outcomes of the research unveiled that urbanization population size, urban sprawl, and technology displayed positive ramifications on COs release.

2.4 Economic Growth and CO2

Raihan and Tuspekova (2022) investigated the affinity between GDP, fossil fuel energy use, renewable energy utilization forested area, international tourism, urbanization, and COs release via ARDL and FMOLS. The research piled up data from Brazil for 1990 to 2019. The verifiable calculations of the research demonstrated that GDP, fossil fuel energy utilization, urban clustering, tourist arrivals, and agricultural value-added exerted favorable ramifications on COs discharge, while renewable energy utilization and forested areas negatively influenced the COs outflow. The connection between GDP and COs outflow was evaluated by Hasanov et al. (2019) using Johansen, ARDL, DOLS, FMOLS. Information was collected from Kazakhstan over the years 1992 to 2013. The estimated outcomes of the study unfold that GDP enhanced CO2.

For Pakistan, Suhrab et al. (2023) reviewed the affiliation of urbanization, trade, FD, renewable energy, GDP, and CO2 outpouring via co-integration and Granger causality test. Information was collected from Pakistan between 1985 and 2018 for the purpose of the research. The estimated calculation of the research unfolded the positive affiliation between urbanization, FD, trade, and COs outflow; further, renewable energy utilization displayed a negative impact on CO2 discharge. The Granger causality test revealed one-way causality between GDP and COs release. Shabani et al. (2022) evaluated the union between GDP, energy, urbanization, GDP square, and COs ejections by employing FMOLS, two stages Engels-Granger, and Dumitrescu- Hurlin techniques. The paper obtained figures of ECO member countries during the period 1990 to 2014. The verifiable calculation of the survey proposed that significant positive interaction between GDP, energy utilization, urbanization, and COs discharge; in contrast, GDP squares exerted significant negative ramifications on COs release. Hanif (2018) unfolded the affiliation between GDP, fossil fuels utilization, solid fuel consumption, renewable energy, urbanization, and GDP square, by employing the GMM approach. The study collected data from 34 emerging economies covering the period 1995 to 2015.

According to experimented evidence, GDP, fossil fuel utilization, solid fuel, and urbanization positively connected with COs outflow; meanwhile, GDP square, renewable energy adversely correlated with COs release. Iheonu et al. (2021) scrutinized the interconnection between GDP, international trade, URB, RNE, and COs outflow by adopting quantile regression. The study accumulated information from African countries for the time frame 1990 to 2016. The actual observation of the paper revealed that GDP and URB exerted a favorable influence on COs discharge, since, renewable energy and international trade negatively influenced COs ejection. Mitic et al. (2023) identified the linkage between GDP, Gross available energy, employment, and COs emanations by adopting the panel co-integration test and VECM model. From 1995 to 2019, the study compiled information from South-Eastern European nations. The survey unfolded the two-way causality between GDP, gross available energy, employment, and COs release. Awan and Azam (2022) evaluated the affinity between GDP, FD, social globalization, technological progress, energy use, and COs ejection by using the Driscoll-Kraay technique. The research assembled data from G-20 economies during the period 1993 to 2017. The observed assessments of the paper unfold the positive affiliation between technological advancement, energy utilization, and COs emanation; conversely, FD, and social globalization displayed an adverse impact on COs release. GDP confirmed N-shaped EKC. The judgments of the panel causality approach showed two-way causality between GDP and COs release.

3. Methodology

The study scrutinized the affiliation between renewable energy, urbanization, TNRR, GDP, CO2 emissions, CH4, N2O, and deforestation in Pakistan for the period 1986 to 2021. The variables description is given below in table 1. The present study utilized the ARDL technique presented by Pesaran et al. (2001) to estimate the elasticities of short and long run for LCO2, LEF, LCH4, LN2O, and LDF in Pakistan. The ARDL technique has supremacy in many ways over other methods according the nature of data base utilized in this study. Issues of bias due to a small sample size are well handled by the ARDL (Odhiambo, 2009). ARDL can accommodate the problem of serial correlation by taking flexible lag, for each of the study variables (Malik et al. 2020). Different orders of co-integration among variables are allowed in the ARDL method (level and Ist difference are permitted; second difference is not), rather than being required (Ahmad & Du, 2017). ARDL approach can be used to estimate the short and long run results. ARDL models allow for the examination of both short-term and long-term relationships between variables. This makes it particularly useful for capturing the dynamics of economic processes that involve both immediate and lagged effects. ARDL is known for its robustness to small sample sizes. ARDL is specifically designed for cointegrated variables. Cointegration implies a long-term relationship between variables that may not be apparent when looking at individual non-stationary series. ARDL helps identify and model these cointegrating relationships. ARDL models can accommodate different lag structures for different variables, providing flexibility in modeling the lag dynamics of variables. ARDL models provide inference about the long-run relationships between variables, making them suitable for policy analysis and understanding the sustained effects of economic shocks.

Table 1: Variables Description

Variables	Symbol	Measurement	Data Source
Dependent variables			
Carbon emission	CO2	CO2 emissions (kt)	WDI
Ecological footprint	EF	Ecological Footprint (gha per person)	https://data.footprintnetwork.org
Methane	CH4	Methane emissions (kt of CO2 equivalent)	WDI
Nitrous oxide	N2O	Nitrous oxide emissions in energy sector (% of total)	WDI
Deforestation	DF	Forest area (% of land area)	WDI
Independent Variables			
Renewable energy	RNE	Renewable electricity output (% of total electricity output)	WDI
Urbanization	URBN	Urban population growth (annual %)	WDI
Total natural resources	TNRR	Total natural resources rents (% of GDP)	WDI
Economic growth	GDP	GDP (constant 2015 US$)	WDI

The following equation will be the Econometric Equation of the study;

$$LCO_{2t} = \varphi_0 + \varphi_1 LRNE_t + \varphi_2 LURBN_t + \varphi_3 LTNRR_t + \varphi_4 LGDP_t + \mu_t \text{ ...... (1)}$$

$$LEF_t = \varphi_0 + \varphi_1 LRNE_t + \varphi_2 LURBN_t + \varphi_3 LTNRR_t + \varphi_4 LGDP_t + \mu_t \text{ .... (2)}$$

$$LCH4_t = \varphi_0 + \varphi_1 LRNE_t + \varphi_2 LURBN_t + \varphi_3 LTNRR_t + \varphi_4 LGDP_t + \mu_t \text{ ...... (3)}$$

$$LN2O_t = \varphi_0 + \varphi_1 LRNE_t + \varphi_2 LURBN_t + \varphi_3 LTNRR_t + \varphi_4 LGDP_t + \mu_t \text{ ...... (4)}$$

$$LDF_t = \varphi_0 + \varphi_1 LRNE_t + \varphi_2 LURBN_t + \varphi_3 LTNRR_t + \varphi_4 LGDP_t + \mu_t \text{ .... (5)}$$

Where suffix "t" displays the period (1986 to 2021) and μ shows error term. The parameters φ_i (i=1…4) are the elasticity criterion to be estimated. The regressand variables LCO2, LEF, LCH4, LN2O, and LDF are natural logarithms of CO2, EF, CH4, N2O, and DF.

ECM model estimation is as follows :

$$\Delta LCO_{2t} = \varphi_0 + \sum_{i=1}^{l} \varphi_{1i} \Delta LCO_{2t-1} + \sum_{i=0}^{p} \varphi_{2i} \Delta LRNE_{t-i} + \sum_{i=0}^{q} \varphi_{3i} \Delta LURBN_{t-i} + \sum_{i=0}^{r} \varphi_{4i} \Delta LTNRR_{t-i} + \sum_{i=0}^{s} \varphi_{5i} \Delta LGDP_{t-i} + \lambda ECT - 1 + vt_t \quad (6)$$

$$\Delta LEF_t = \varphi_0 + \sum_{i=1}^{l} \varphi_{1i} \Delta LEF_{t-1} + \sum_{i=0}^{p} \varphi_{2i} \Delta LRNE_{t-i} + \sum_{i=0}^{q} \varphi_{3i} \Delta LURBN_{t-i} + \sum_{i=0}^{r} \varphi_{4i} \Delta LTNRR_{t-i} + \sum_{i=0}^{s} \varphi_{5i} \Delta LGDP_{t-i} + \lambda ECT - 1 + vt_t \quad (7)$$

$$\Delta LCH4_t = \varphi_0 + \sum_{i=1}^{l} \varphi_{1i} \Delta LCH4_{t-1} + \sum_{i=0}^{p} \varphi_{2i} \Delta LRNE_{t-i} + \sum_{i=0}^{q} \varphi_{3i} \Delta LURBN_{t-i} + \sum_{i=0}^{r} \varphi_{4i} \Delta LTNRR_{t-i} + \sum_{i=0}^{s} \varphi_{5i} \Delta LGDP_{t-i} + \lambda ECT - 1 + vt_t \quad (8)$$

$$\Delta LN2O_t = \varphi_0 + \sum_{i=1}^{l} \varphi_{1i} \Delta LN2O_{t-1} + \sum_{i=0}^{p} \varphi_{2i} \Delta LRNE_{t-i} + \sum_{i=0}^{q} \varphi_{3i} \Delta LURBN_{t-i} + \sum_{i=0}^{r} \varphi_{4i} \Delta LTNRR_{t-i} + \sum_{i=0}^{s} \varphi_{5i} \Delta LGDP_{t-i} + \lambda ECT - 1 + vt_t \quad (9)$$

$$\Delta LDF_t = \varphi_0 + \sum_{i=1}^{l} \varphi_{1i} \Delta LDF_{t-1} + \sum_{i=0}^{p} \varphi_{2i} \Delta LRNE_{t-i} + \sum_{i=0}^{q} \varphi_{3i} \Delta LURBN_{t-i} + \sum_{i=0}^{r} \varphi_{4i} \Delta LTNRR_{t-i} + \sum_{i=0}^{s} \varphi_{5i} \Delta LGDP_{t-i} + \lambda ECT - 1 + vt_t \quad (10)$$

The CO_2 emissions are measured in terms of kilo tons, LCH4, LN2O, LEF, and LDF are measured in term of Methane emissions (kt of CO2 equivalent), Nitrous oxide emissions in energy sector (% of total), Ecological Footprint (gha per person), and Forest area (% of land area) respectively. The independent variable LRNE indicates the natural logarithm of the RNE measured in Renewable electricity output (% of total electricity output), the variables LURBN, LTNRR and LGDP are the natural log of urbanization, total natural resource rent and real gross domestic product measured in Urban population growth (annual %), Total natural resources rents (% of GDP), GDP (constant 2015 US$), respectively. The data for all study variables is procured from world development indicators expect EF which is taken from Global footprint network.

4. Results and Discussion

The study used multiple stages of estimations. Firstly, the study analyzed descriptive statistics then the unit root test, co integration, F-bound test and auto regressive distributed lag model. Table 2 describes the description of data, its highs and lows and overall description of the required data. Diagnostic tests play an essential role in econometrics, particularly in the context of regression analysis and time series modeling, when analyzing statistical models and data. There are a number of benefits to using these tests to determine a model's validity, dependability, and appropriateness for use in research and economics. It is helpful in following ways Model Validation, Identification of Outliers, Assumption Testing, Heteroscedasticity Detection, Autocorrelation Testing, Multicollinearity Assessment, Goodness of Fit, Model Comparison, Robustness, Policy Implications.

Table 2: Descriptive Statistics

	CO2	EF	DF	N2O	CH4	RNE	URBN	TNRR	GDP
Mean	126696.3	0.770000	5.388011	1.339618	114974.7	48.82663	2.935333	1.742830	2.00E+11
Median	127076.5	0.770000	5.500033	1.313183	112062.4	47.94500	2.800542	1.671523	1.94E+11
Maximum	208022.7	0.850000	6.407271	1.626646	170505.4	58.09129	4.115170	2.891167	3.41E+11
Minimum	59026.00	0.710000	0.187759	1.005434	72877.19	41.49200	1.779757	0.965331	9.95E+10
Std. Dev.	44039.23	0.036016	1.062645	0.204668	30565.46	4.482369	0.692235	0.583957	7.33E+10
Skewness	0.253840	0.547061	-3.726739	-0.073335	0.262794	0.261569	0.035806	0.345490	0.408422
Kurtosis	1.994291	2.713850	19.21526	1.589876	1.773236	2.314839	1.832100	1.738414	1.948614
Jarque-Bera	1.692254	1.918479	424.6519	2.679950	2.374924	0.990824	1.825491	2.758736	2.363527
Probability	0.429074	0.383184	0.000000	0.261852	0.304994	0.609320	0.401421	0.251738	0.306737
Sum	4054282.	27.72000	172.4164	42.86777	3679191.	1562.452	93.93067	55.77055	6.39E+12
Sum Sq. Dev.	6.01E+10	0.045400	35.00563	1.298561	2.90E+10	622.8407	14.85487	10.57116	1.67E+23

To avert the problems of “Pseudo-regression”, it is necessary to test the stationarity of the data; different methods of stationarity may show different results.

Table 2: ADF and PP Test

Variable	ADF		PP	
	Level	**First Difference**	**Level**	**First Difference**
CO2	-1.129	-5.198***	-1.365	-5.429***
DF	-5.287***	-2.622	-3.4214***	-1.5117
CH4	0.577	-4.343***	1.294	-3.514***
N2O	0.006	-9.225***	2.979	-18.940***
EF	-0.159	-5.497***	-0.266	-5.497***
RNE	-0.618	-5.965***	-0.638	-5.959***
URB	-0.012	-7.316***	-0.136	-7.552***
TNRR	-2.659*	-6.329***	-2.658*	-8.567***
GDP	-2.433	-4.410***	-2.344	-4.393***

Note: *,**,***implies the significance level at 10%, 5% and 1%, respectively.

We have developed five models in current study. We evaluated the model 1, model 2, model 3, model 4, and model 5, with CO2 emissions, ecological footprint, LCH4, LN2O, and deforestation respectively and results show that co-integration exists in all cases.

Table 4: Bound Test Estimation

F-stat: 4.7097 **Model 1: LCO2**	**6.354** **Model. 2 LEF**	**5.6409** **Model. 3 LCH4**	**5.2357** **Model. 4 LN2O**	**10.9112** **Model. 5 LDF**
Range			Critical values	
			I(0) bound	I(1) bound
10%			2.45	3.52
5%			2.86	4.01
1%			3.74	5.06

After estimating the co-integration between variables, ARDL approach is utilized. We have developed five models in current study. We evaluated the model 1, model 2, model 3, model 4, and model 5, with CO2 emissions, ecological footprint, LCH4, LN2O, and deforestation respectively.

The long run and short measures are described in table number 5 and 6. Firstly we analyze the outcomes of model 1 specifically. The sign of LRNE is contentious and significant indicating that LRNE decrease CO2 emanation in the long run. In both time periods RNE causes a decrease in CO2 emission and positively affects the environmental quality.

Now proceeding towards the elasticities of co-efficient, the elasticity of LCO2 with reference to RNE is -0.23 which demonstrates that 1% upsurge in RNE will minimize CO2 emissions by 0.23%. The outcome concedes with Chien et al. (2023) for E7 countries, Khan et al. (2022) for BRI countries. The urbanization shows positive and significant alliance with CO2 emissions; Implies that urbanization enhances CO2. The results are similar to Voumik et al. (2023) for South Asian region, Cheng and Hu, (2022) for Chinese Provinces.

The elasticity of LCO2 with respect to urbanization is 0.152, which exhibits that 1% rise in urbanization will expand CO2 levels by 0.152% in long run. The co-efficient of LTNRR is inverse and insignificant both time spans denoting that TNRR decrease CO2 ejections. The LCO2 has elasticity 0.006 with respect to LTNRR, which mentions that 1% growth in LTNRR drops the CO2 by -0.006% and positively affect the environmental quality. The results are alike Zahoor et al. (2022) for China, Arslan et al. (2022) for China, Huang. (2022) for Vietnam. The co-efficient of LGPD is positive and significant in long run but positive and insignificant in short run. The positive co-efficient of LGDP intimate that GDP escalates CO2 emanation in short and long run. The elasticity of LCO2 is 0.049 with respect of GDP. It refers that 1% expansion in GDP will upturn CO2 emanations by 0.049% and 0.033% singly in both times. The results are similar with Raihan and Tuspekova, (2022) for Brazil, Suhrab et al. (2022) for Pakistan, Shabani et al. (2021) for ECO member countries.

Next, we investigate the results of model 2. CO2 is replaced by ecological footprint in model 2. The measures of all study variables in model 2 are persistent model 1. The coefficients of LRNE are significant negative denoting that 1% upturn in LRNE will decrease ecological footprint by -0.57% in long term. The co-efficient of LURBN is significantly positive, which entails that 1% upturn in LURBN will abate LEF by 7.965 in long and in short run by 8.204%, furthermore the sign of LTNRR is negative. The results infer that 1% upturn in LTNRR will decrease LEF by 0.045% in long run, but it will reduce by -0.001% in short run. The favorable and significant signs of GDP display the fact that 1% grow in GDP will surge EF by 2.32% in long run.

Now moving towards model 3, the results are same to model 1 and model 2. The co-efficient of LRNE and LTNRR are negative, which designate that 1% growth in LRNE will drop the N2O by -0.252% and 1% rise in LTNRR will decrease LN2O by 0.062%, while the signs of LGDP and LURB are positive refers that 1% expansion in LGDP and 1 % increase in LURB will upsurge the N2O by 0.031% and 0.071% respectively.

Table 5: Long Run Estimations

Model 1: LCO2			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
LRNE	-0.2326***	0.0406	-5.7302
LURBN	0.1522***	0.0357	4.253
LTNRR	-0.006	0.0145	-0.4713
LGDP	0.0499**	0.0234	2.1331
C	14.4939***	0.6691	21.6612
Model 2: LEF			
LRNE	-0.5727***	0.0796	-7.1879
LURBN	7.9635***	1.8653	4.2691
LTNRR	-0.0458	0.0298	- 1.5371
LGDP	2.3220***	0.5364	4.3286
C	86.5994***	19.9376	4.3435
Model 3: LN2O			
LRNE	-0.2526***	0.0323	-7.8153
LURBN	0.0310	0.0276	1.1244
LTNRR	-0.0626***	0.0130	-4.8069
LGDP	0.0718**	0.0330	2.1741
C	14.9507***	0.9837	15.1973
Model 4: LCH4			
LRNE	-0.0148***	0.0018	-7.9746
LURBN	0.1391**	0.0437	3.1829
LTNRR	-0.0085***	0.0015	-5.6445
LGDP	0.0330	0.0220	1.4936
C	1.8022***	0.1791	10.0585
Model 5: LDF			
LRNE	-0.9603***	0.3027	-3.1718
LURBN	0.6114**	0.2739	2.2317
LTNRR	-0.1749**	0.0850	-2.0573
LGDP	0.1118	0.0797	1.4036
C	5.2253***	0.7390	7.0705

Note: **& *** denotes significance level at 5% and 1%, respectively.

Our model 4 describes the impact of LRNE, LURBN, LTNRR, and LGDP on LCH4. LCH4 is taken as dependent variable in model 4. In model 4 LRNE has negative significant coefficient. The elasticity of LCH4 manifested that 1% growth in LRNE will be responsible for 0.014% decrease in LCH4 in long run while 1% rise in LRNE causes 0.009% decline in LCH4 in short run. The further two variables LGDP, and LURBN have positive co-efficient in long run, which are denoting that 1% escalation in LGDP, and LURBN will enlarge LCH4 by 0.033%, 0.139% and, respectively. LTNRR having negative coefficient entails that 1% expansion in LTNRR causes -0.008 decline in CH4 in long run.

Model 5 indicates the relationship between LRNE, LTNNR, LGDP, LURBN and deforestation. LRNE, and LTNRR have negative affiliation with deforestation while LGDP and LURB, shows positive sign in long run. The negative elasticities of LTNRR, and LRNE with respect to deforestation refer to the point that 1% upturn in LRNE, and LTNRR, expand the deforestation by 0.96%, 0.174%, correspondingly. Moreover, the coefficient of LGDP and LURBN are favorable which entails that 1% increase in LGDP and LURBN will upsurge deforestation by 0.111 and 0.611%.

Table 6: Short Run Estimations (ARDL)

Model. 1			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
D(LRNE)	-0.1579***	0.05312	-2.9732
D(LURBN)	0.1033***	0.0301	3.4242
D(LTNRR)	-0.0046	0.0097	-0.4774
D(LGDP)	0.0339	0.0210	1.6099
CointEq(-1)	-0.6788***	0.1594	-4.2565
Model. 2			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
D(LEF(-1))	-0.1752	0.14580	-1.2021
D(LEF(-2))	-0.3645**	0.1431	-2.5465
D(LRNE)	-0.0676	0.0402	-1.6817
D(LRNE(-1))	-0.1048**	0.0463	-2.2628
D(LURBN)	8.2048**	3.5726	2.2965
D(LURB(-1))	10.0151**	3.5035	2.8585
D(LTNRR)	-0.0010	0.0137	-0.0788
D(LTNRR(-1))	-0.0300**	0.0139	-2.1463
D(LGDP)	1.7597***	0.2588	6.7986
D(LGDP(-1))	-0.5139	0.3257	-1.5777
CointEq(-1)	-0.4968***	0.1331	-3.7303
Model. 3			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
D(LN2O(-1))	0.3790*	0.2142	1.7695

D(LRNE)	-0.0720*	0.0402	-1.7903
D(LRNE(-1))	-0.1250***	0.0417	-2.9941
D(LTNRR)	-0.0221**	0.0094	-2.3374
D(LURBN)	0.0592	0.0415	1.4259
D(LGDP)	0.0506	0.0295	1.7158
CointEq(-1)	-0.7059***	0.1855	-3.8053
Model. 4			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
D(LCH4(-1))	0.3879	0.2759	-1.4055
D(LRNE)	-0.00971	0.0764	- 0.1270
D(LTNRR)	-0.0297*	0.0163	- 1.8165
D(LGDP)	0.0098*	0.0098	-1.9384
D(LURBN)	0.3064 ***	0.0897	3.4159
CointEq(-1)	-0.1701**	0.0737	-2.3066
Model. 5			
Variables	**Coefficient**	**[S.E]**	**{t-ratio}**
D(LDF(-1))	-0.5342*	0.2625	-2.0346
D(LRNE)	-0.0036***	0.0008	-4.4898
D(LRNE(-1))	-0.0061***	0.0012	-4.8889
D(LRNE(-2))	-0.0028**	0.0011	-2.5515
D(LURBN)	0.0044	0.0581	0.0772
D(LURBN(-1))	0.5590***	0.1339	4.1723
D(LURBN(-2))	0.4129***	0.0735	5.6148
D(LTNRR)	-0.0006**	0.0003	-2.1621
D(LTNRR(-1))	-0.0025***	0.0005	-5.0594
D(LTNRR(-2))	0.0005	0.0003	1.4930
D(LGDP)	0.0201***	0.0054	3.7393
D(LGDP(-1))	0.0077	0.0077	0.9973
D(LGDP(-2))	-0.0228***	0.0058	-3.8902
CointEq(-1)	0.4943**	0.2156	2.2922

Note: **& *** denotes significance level at 5% and 1%, respectively.

When elasticities are predicted we run some diagnostic tests. To estimate the serial correlation problem among variables, we used the Breusch-Godfrey Lagrange multiplier (LM) test, then we applied Jarque-Bera test (Normality) to examine whether the residual is normal or not, additionally, we performed the Ramsey Reset test. At the end we examined the stability of elasticity parameters by CUSUM and CUSUMQ tests.

Diagnostic tests play an essential role in econometrics, particularly in the context of regression analysis and time series modeling, when analyzing statistical models and data. There are a number of benefits to using these tests to determine a model's validity, dependability, and appropriateness for use in research and economics. It is helpful in following ways Model validation, identification of outliers, assumption testing, heteroscedasticity detection, autocorrelation Testing, multicollinearity assessment, Goodness of fit, model comparison, robustness, policy implications.

Table 7: Diagnostic Test (ARDL)

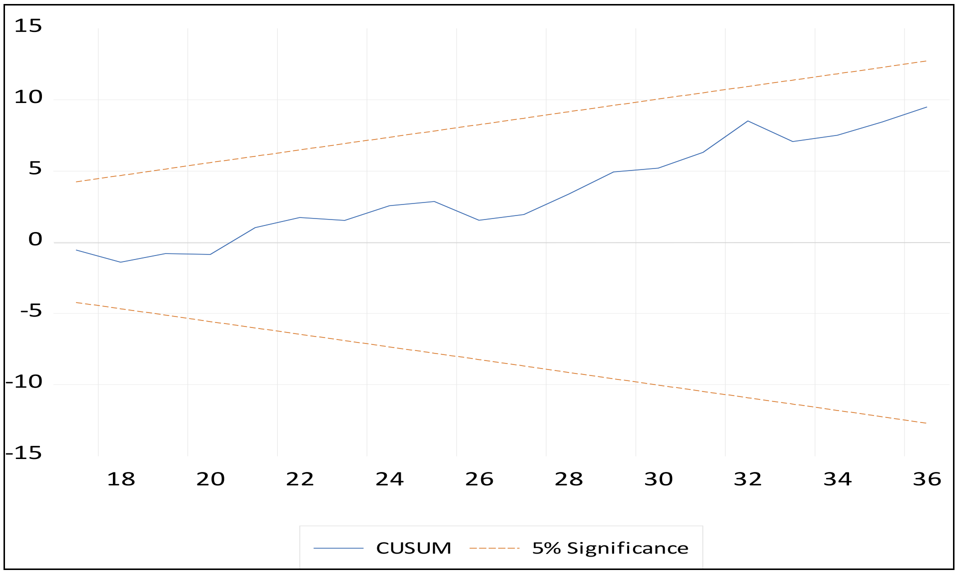
MODEL	**LCO2**	**LEF**	**LCH4**	**LN2O**	**LDF**
R^2	0.919	0.992	0.962	0.989	0.999
Adj R^2	0.903	0.984	0.941	0.985	0.999
Durbin-Watson	2.088	2.255	2.176	1.916	1.957
LM test	0.675 (0.519)	0.366 (0.702)	0.462 (0.505)	0.925 (0.416)	2.433(0.157)
Jarque-Bera	0.441 (0.802)	0.288 (0.865)	0.622 (0.732)	0.488 (0.783)	0.641(0.725)
Hetero	1.065 (0.404)	1.902 (0.133)	0.801 (0.629)	0.415 (0.896)	0.744(0.716)
Ramsey reset	1.390 (0.177)	2.428 (0.138)	3.468 (0.079)	2.491 (0.114)	2.942(0.172
CUSUM	Stable	Stable	Stable	Stable	Stable
CUSUMQ	Stable	Stable	Stable	Stable	Stable

Note: the values in (parenthesis) are p-values.

Following are the figures of CUSUM and CUSUMQ test for stability accordingly.

The CUSUM and CUSUMQ charts have following advantages. They excel in identifying changes and trends in data that take place over time. They are more responsive than typical control charts. They serve as an early warning system for changes in the process, enabling appropriate adjustments to be made.

Model 1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CUSUM
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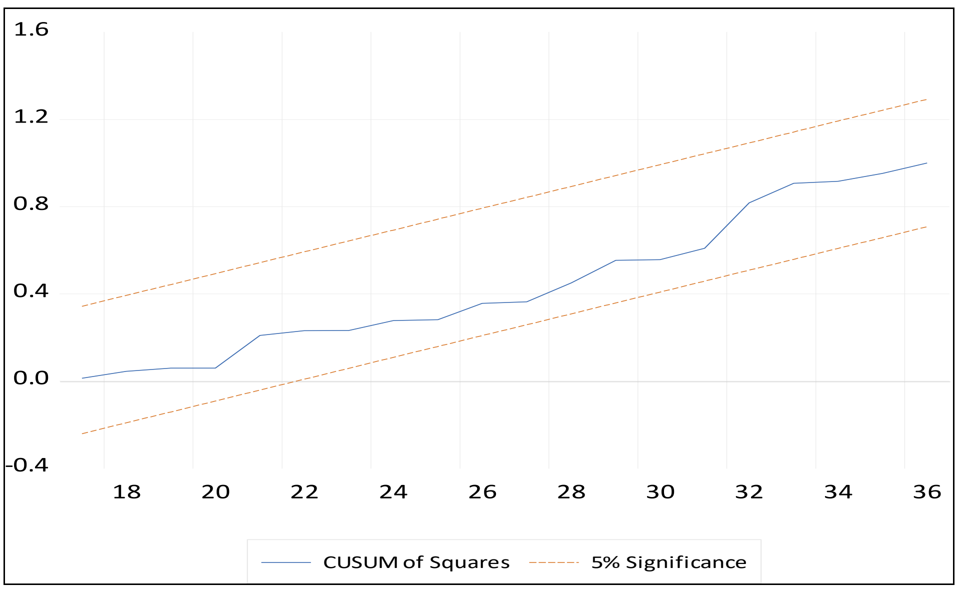
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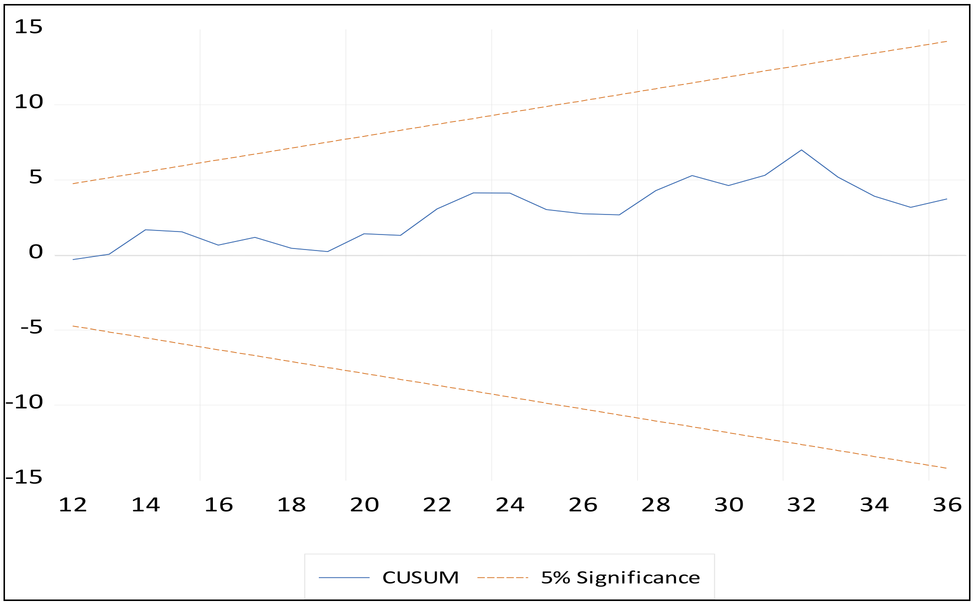
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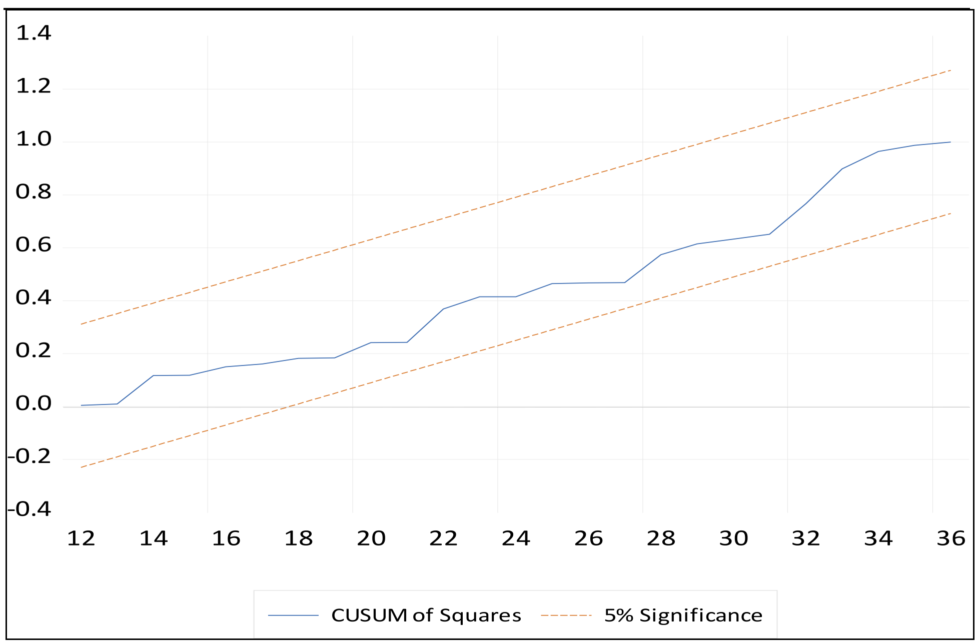
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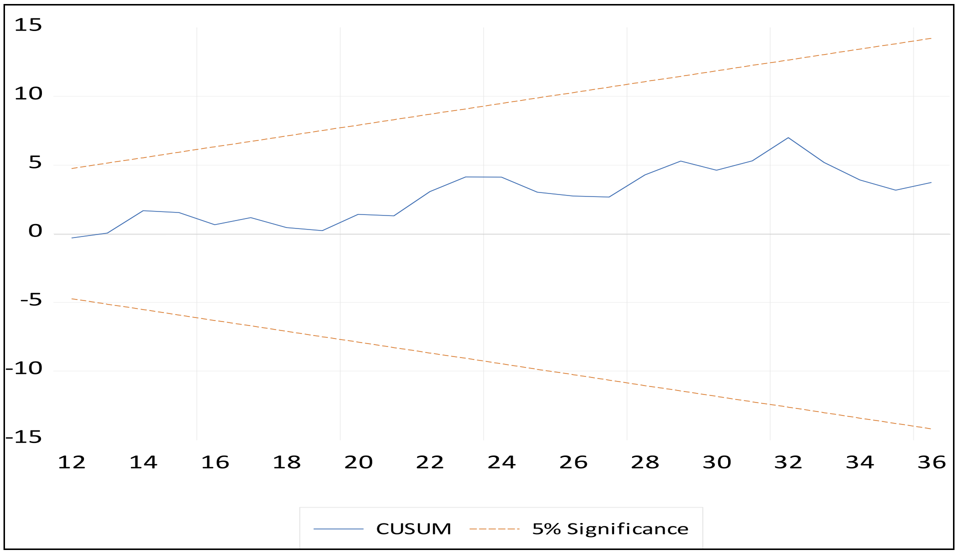
Model 3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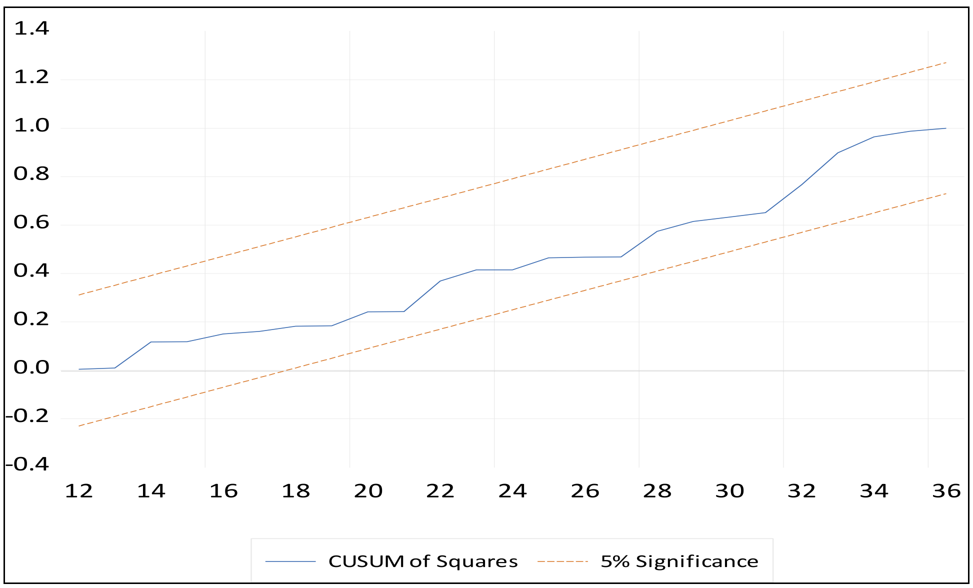
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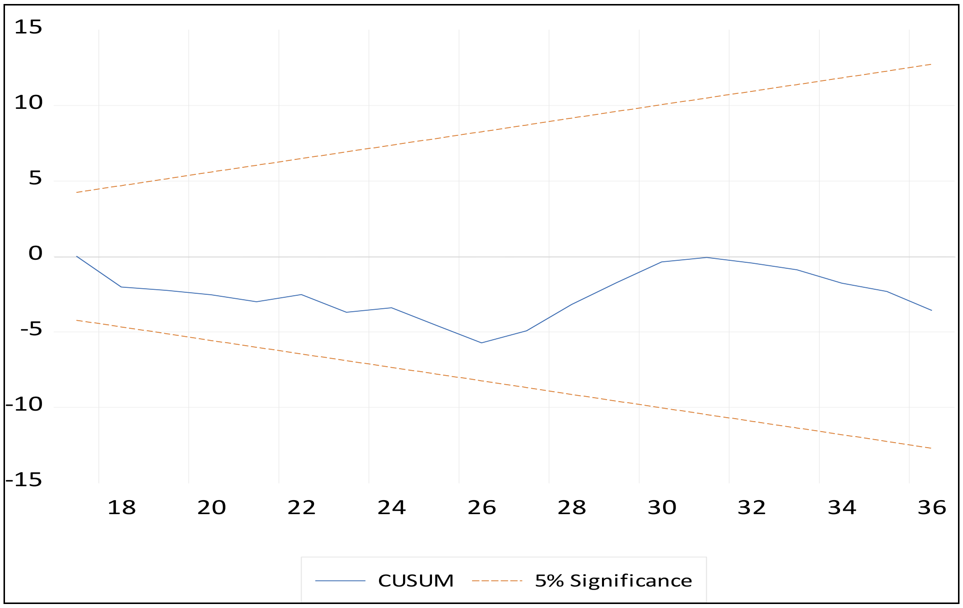
Model 4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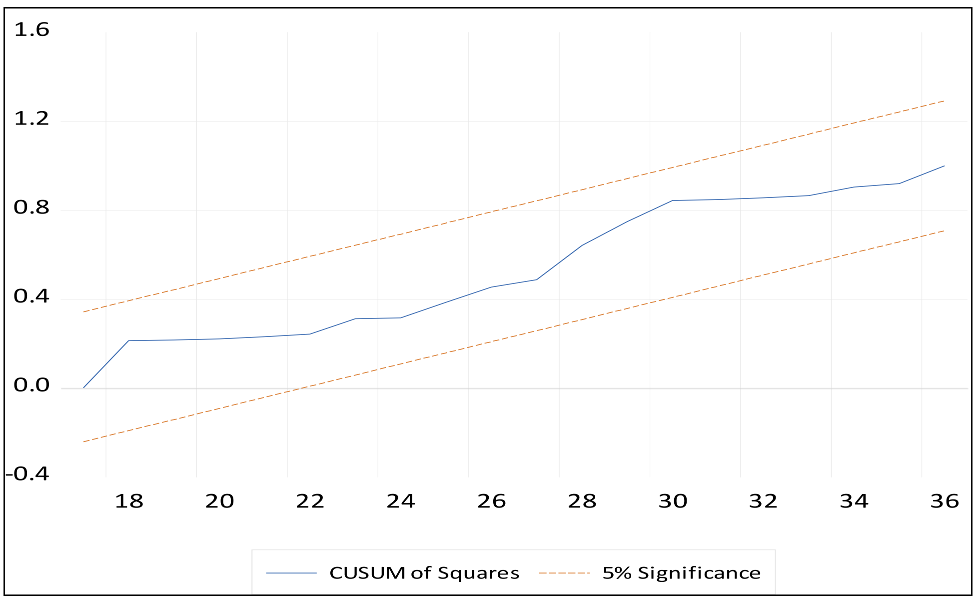
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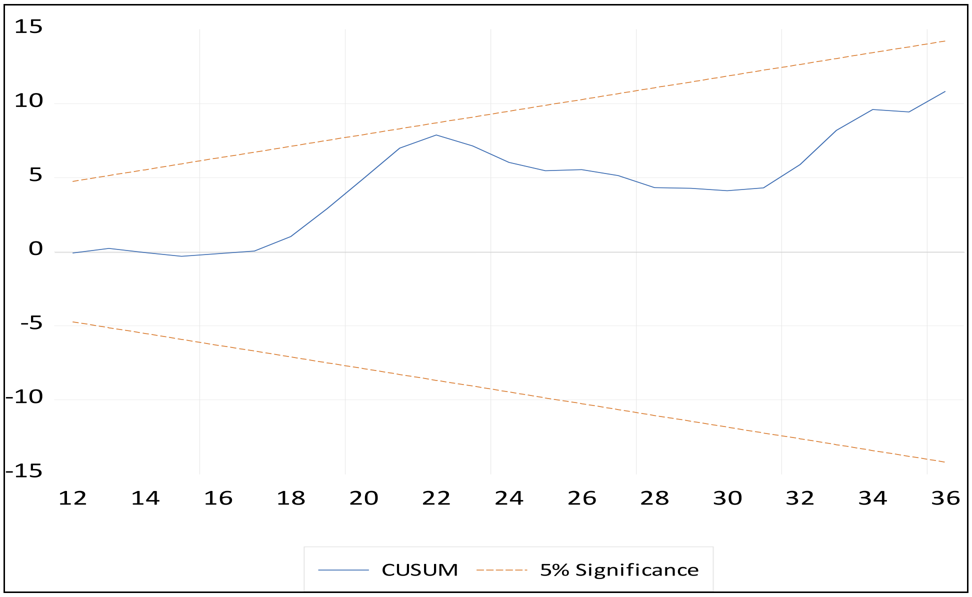
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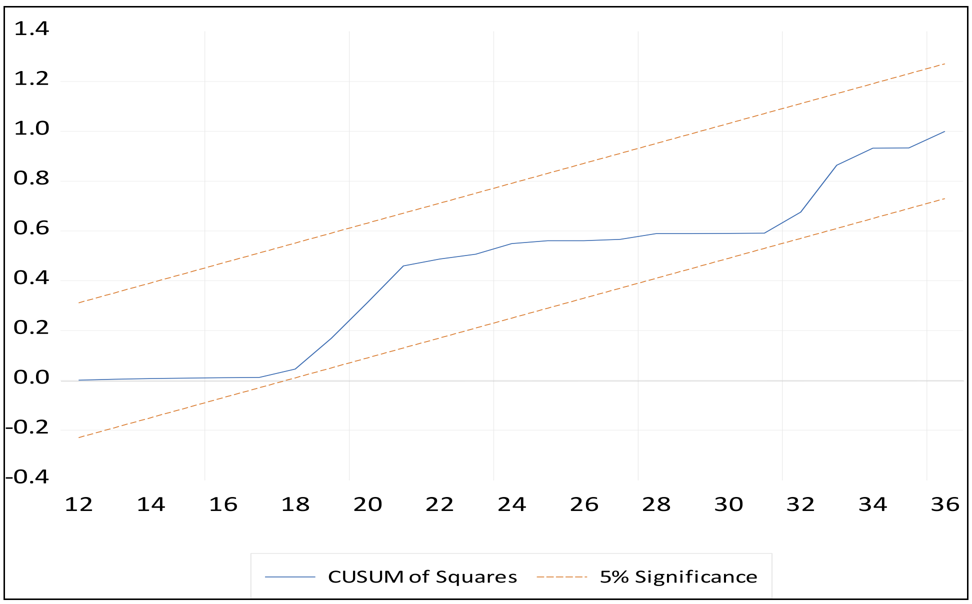
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5% Significance

5. Conclusion and Implications

This paper used the ARDL to determine the effect of LRNE, LURBN, LGDP, and LTNRR on LCO2 emanations, LCH4, LN2O, LEF, and LDEF for Pakistan covering the years 1986 to 2021. The findings of paper reveal different results for different models. The estimated calculations show the negative ramification of LRNE and LTNRR on CO2 emissions, yet LURBN and LGDP exert favorable effect on CO2 emissions in Pakistan in long term. The second model having ecological footprint as dependent variables shows that LRNE and LTNRR are contentiously linked with LEF, but LURBN and LGDP are favorably correlated with LEF. LRNE and LTNRR are negatively connected with N2O and LGDP and LURBN are positively affiliated with N2O. The results of model 4show a negative relation of LRNE and LTNRR with LCH4 but LURBN and LGDP exerts positive impact on LCH4. Deforestation shows different results for different variables. LURBN and LGDP infer positive effect on deforestation, at the same time LRNE, and LTNRR negatively influence deforestation.

5.1 Implications

Governments play a critical role in addressing and reducing CO2 discharge, which contribute to climate change. Here are some key actions governments can take to reduce CO2 release:

The results of this paper are helpful for policy formulation. LRNE decrease environmental damage. Our research indicates that LRNE plays vital role in abating CO2 emissions, LN2O and EF. The authorities should focus on use of RNE usage instead of conventional energy usage for environmental sustainability. The use of RNE also negatively impacted the deforestation and CH4. The government should make policies regarding the cut in household energy consumption by using energy efficient electric appliance and use of solar energy.

Urbanization boosts up CO2 release, ecological footprint, CH4, deforestation and LN2O. Massive urbanization demands more energy consumption which ultimately raises CO2emissions, moreover, the rise of urbanization require more land, which leads to cut in forestation and cause deforestation and upturn the level of N2O. The government should implement the policies to promote the eco-friendly economic activities and should also shift economy from high carbon economy to low carbon economy. Clean energy utilization in economic activities can also abate CO2 ejections. Specific measures should be taken by the government of Pakistan to mitigate the inverse effect of LGDP on environment. To avert the problem of deforestation, the government should introduce the smart city concept for sustainable urban progress. The concept of compact cities may also be helpful in reducing CO2 emissions. Economic growth shows positive relationship with CO2 emanations and ecological footprint and other study variables.

Encourage the use of LRNE sources through government incentives and mandates. Subsidies, tax credits, and R&D funding are all possibilities. Improve energy efficiency by enforcing policies and rules that promote the use of practices and technologies that reduce energy consumption across a wide range of industries, from construction to transportation to manufacturing. As a result, energy use and carbon dioxide emissions may both decrease. Promote public understanding and education: Governments can launch public awareness campaigns to inform people to lower carbon dioxide emissions and the part they can play in doing so. Governments around the world need to work together to combat climate change, which is why they should take part in international climate agreements. The goal is to help developing nations switch to cleaner energy sources by sharing best practices, transferring technology, and providing financial support.

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