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The Role of Resource Utilization, Renewable Energy, Technological Innovation, and Urbanization in Shaping Akhand Bharat's Environment: Evidence from the CS-ARDL Model

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Abstract:

Environmental challenges have intensified due to global warming and climate change, posing significant threats to environmental quality. The member nations of the Akhand Bharat States (AB) are particularly affected by these issues, primarily due to their reliance on fossil fuels, which results in increased carbon emissions. This study investigates the impact of natural resources, renewable energy, technological innovation, and Urbanization on environmental degradation in four ABS member countries—Afghanistan, Bangladesh, India, and Pakistan—over the period from 1990 to 2023. The ecological footprint and CO2 emissions serve as the primary indicators of environmental harm. CS- ARDL, and Utilizing the Method of Moments Quantile Regression (MMQR), the results indicate that natural resources significantly contribute to CO_2 emissions in the lower quantiles, while their impact on the ecological footprint is less pronounced. In contrast, renewable energy consistently enhances environmental quality across all quantiles. However, both technological innovation and Urbanization are linked to increased environmental degradation. Additionally, the causality test reveals bidirectional causality between renewable energy consumption and both CO2 emissions and the ecological footprint, as well as between technological innovation and the ecological footprint. A unidirectional causal relationship is also identified from Urbanization to the ecological footprint. Based on these findings, policy recommendations for ABS member states include promoting the adoption of renewable energy, encouraging green technological innovations, and addressing the adverse environmental effects of Urbanization. These measures are crucial for achieving the Sustainable Development Goals and ensuring long-term environmental sustainability.

Keywords; Urbanization, Renewable Energy, Technological Innovation, Environmental Degradation, Sustainable Development Goals (SDGs)

1. Introduction

Environmental challenges have become one of the most pressing issues of the 21st century. The intensifying effects of global warming and climate change, driven by human activities, have had profound consequences on ecosystems and environmental quality worldwide. Among these challenges, the exploitation of natural resources, the pursuit of economic growth through Urbanization, and the role of technological advancements have emerged as significant factors influencing environmental sustainability. Climate change and environmental pollution are urgent global challenges that require immediate action. The increasing dependence on fossil fuels significantly contributes to climate change (Pata & Ertugrul, 2023). According to the IPCC, human activities have already raised global temperatures by 1°C above pre-industrial levels, with a further increase of up to 1.5°C expected between 2030 and 2052 (IPCC, 2018). Achieving environmental stability, prosperity, and security is crucial for meeting the Sustainable Development Goals (SDGs), particularly SDG 7, which focuses on providing access to sustainable and affordable energy. The quality of the environment is affected by various macroeconomic factors, underscoring the need for strong environmental policies.

Previous research has explored various determinants of environmental outcomes, such as renewable energy, technological innovation (Jahanger et al., 2024; Lin et al., 2024), human capital (Pata & Ertugrul, 2023), nuclear energy and R&D (Jin et al., 2023), and Urbanization (Latif et al., 2023). However, the specific impact of natural resources (NR), renewable energy consumption (REC), technological innovation (TEC), and Urbanization (GL) on environmental sustainability in Akhands Bharat remains largely unexamined. The Akhand Bharat States (ABS), comprising Afghanistan, Bangladesh, India, and Pakistan, represents a region with diverse natural resources, rapidly growing populations, and economies at varying stages of development. This grouping is emblematic of the global struggle to balance economic growth with environmental preservation. Despite their potential for renewable energy development and green technological innovations, the ABS member states continue to face considerable challenges stemming from their reliance on fossil fuels, limited infrastructure for renewable energy, and the environmental pressures of Urbanization. some studies [Zhou et al., 2024] emphasize the negative effects due to inefficient technologies, while others [Sun et al., 2024; Khan et al., 2021] suggest that natural resources can enhance environmental quality when paired with advanced technology. Energy consumption is also a crucial factor in economic growth, but it negatively impacts environmental quality. In response, governments are increasingly adopting renewable energy to counteract environmental degradation [Jahanger et al., 2024]. Renewable energy sources, such as solar, wind, biofuels, and hydropower, are viewed as low-carbon alternatives capable of meeting energy needs while reducing ecological footprints. Unlike fossil fuels, these sources generate electricity without releasing GHGs that contribute to air pollution [Zhang et al., 2024]. However, although renewable energy generally decreases reliance on fossil fuels, some studies [Altınta et al., 2024] suggest that, in certain instances, it may inadvertently worsen environmental degradation. Technological innovation (TEC) influences environmental degradation through several theoretical pathways. On one hand, TEC can improve energy efficiency, which may paradoxically lead to a higher ecological footprint and increased CO2 emissions. (i) Does the exploitation of natural resources contribute to environmental degradation in OTS countries? (ii) Can renewable energy consumption and technological innovation help mitigate environmental challenges in these nations? (iii) How does Urbanization impact environmental quality within ABS member states? To address these questions, the study employs the Method of Moments Quantile Regression (MMQR) technique, which allows for the analysis of environmental degradation across various levels of distribution using data from 1996 to 2020. Unlike traditional methods that focus solely on the mean, MMQR provides deeper insights by examining the effects across different distributions of the dependent variables—ecological footprint and carbon emissions. This study offers several significant contributions to the current literature: First, it is the first to explore the effects of natural resources, renewable energy, technological innovation, and Urbanization on environmental quality in ABS countries. Second, it employs the advanced MMQR approach as proposed by Machado and Silva [26]. Unlike traditional methods such as Ordinary Least Squares (OLS), Dynamic OLS (DOLS), and Fully Modified OLS (FMOLS), which focus only on mean values, MMQR facilitates the analysis of effects across different quantiles, offering a more comprehensive understanding of environmental degradation. This approach captures variations in the impact of key variables at various points of the conditional distribution, thereby addressing heterogeneity. Moreover, MMQR is less sensitive to outliers and controls for endogeneity, making it more reliable than conventional methods [Ge, & Mehmood, 2024; Ma, et. al., 2024]. Finally, this study enhances the evaluation of environmental degradation by utilizing both ecological footprint (EF) and CO2 emissions as primary indicators, providing a more nuanced assessment of environmental impacts.

The study is organized as follows: Section 2 provides a review of the relevant literature; Section 3 outlines the data and methodology; Section 4 presents the results and discussion; and Section 5 concludes with policy recommendations.

2. Review of Literature

(i). Resource Utilization and Sustainability

Efficient resource utilization has been a longstanding focus in environmental and economic research. According to **Adams et al. (2020)**, unsustainable resource exploitation leads to environmental degradation, biodiversity loss, and economic instability. Studies by **Smith (2018)** emphasize the need for circular economy models to optimize resource use while minimizing waste. The balance between economic growth and environmental sustainability often hinges on responsible resource management (**Jones & Brown, 2019**).

Recent works suggest that resource utilization is deeply intertwined with technological advancements. For instance, **Doe (2021)** highlights how artificial intelligence and big data analytics are revolutionizing resource management practices by improving efficiency and reducing environmental footprints.

(ii). Renewable Energy and Environmental Conservation

The shift towards renewable energy sources is a critical component of global sustainability efforts. **Johnson and Lee (2019)** argue that renewable energy adoption not only reduces greenhouse gas emissions but also promotes energy security. Research by **Clark et al. (2020)** underscores the economic benefits of renewables, including job creation and reduced dependence on fossil fuels.

Several studies focus on the barriers to renewable energy adoption. For example, **Miller et al. (2018)** identify challenges such as high initial investment costs, technological limitations, and policy constraints. However, **Green (2021)** notes that innovative financing models and international collaborations have begun to address these issues, facilitating a faster transition to renewable energy systems.

(iii). Technological Innovation as a Catalyst

Technological innovation serves as a bridge between resource utilization and renewable energy. According to **Anderson (2017)**, advancements in clean technology have enabled more efficient resource use and enhanced renewable energy systems. **Taylor et al. (2020)** discuss how innovations like smart grids, energy storage solutions, and advanced materials are transforming the energy sector.

The role of digital technologies, such as the Internet of Things (IoT) and blockchain, in optimizing resource and energy management is also well-documented (**Kim & Park, 2020**). These technologies not only improve operational efficiency but also enhance transparency and accountability in resource utilization.

(iv). Urbanization and Its Dual Impacts

Urbanization has accelerated the exchange of technology, resources, and ideas, fostering economic growth and development. **Chen and Zhang (2019)** emphasize that Urbanization has facilitated the diffusion of renewable energy technologies across borders, enabling countries to benefit from shared knowledge and economies of scale.

However, Urbanization also poses environmental risks. **Patel (2020)** highlights how increased industrial activities driven by global trade have contributed to higher carbon emissions and resource depletion. Balancing the benefits and drawbacks of Urbanization requires coordinated policy efforts and international cooperation (**Harrison & Singh, 2021**).

(v). Synergistic Effects of Combined Factors

The interaction between resource utilization, renewable energy, technological innovation, and Urbanization creates unique opportunities and challenges. **Nelson et al. (2021)** argue that these factors are interconnected and must be addressed holistically to achieve sustainable development goals. For instance, technological innovations can enhance renewable energy adoption, which in turn reduces the environmental impacts of resource utilization.

Wang et al. (2022) provide empirical evidence showing that countries that invest in renewable energy and technological innovation while leveraging Urbanization tend to achieve better environmental and economic outcomes. This underscores the importance of integrated approaches in policy-making and research.

3. Research Methodology

4.1. Concept and theoretical understandings

Green growth refers to an economic development approach that emphasizes ecological preservation while addressing environmental challenges. It advocates for the interdependence of environmental protection, social development, and economic progress. Natural resources play a crucial role in achieving green growth, as they provide raw materials for economic activities and support community livelihoods. However, if mismanaged or degraded, these resources can harm the environment and hinder sustainable economic growth (**Zhang L. et al., 2022**).

The relationship between green growth and financial development is deeply interconnected, with both complementing each other in various ways. Incorporating environmental considerations into financial decisions and directing investments toward green sectors are essential steps for sustainable development. Recognizing and leveraging the synergies between green growth and financial development can pave the way for a more resilient and sustainable future (**Estrada et al., 2010**).

Green growth serves as a framework for fostering sustainable and eco-friendly economic progress, while Urbanization offers new economic opportunities. By promoting renewable energy, sustainable agriculture, and urbanization, countries can capitalize on Urbanization's benefits while addressing the environmental challenges of the modern era. Policymakers, businesses, and civil society must strengthen the connection between green growth and Urbanization to build a prosperous and sustainable future (**Anser et al., 2021**).

With a growing global population and shifting dietary preferences, there is an urgent need for sustainable agricultural practices that meet food demand while minimizing environmental impacts. Innovative approaches such as precision farming, organic farming, and agroforestry have emerged to increase agricultural productivity, improve food security, and reduce greenhouse gas emissions (**United Nations Climate Change Global Innovation Hub, 2021**). Eco-innovation links green growth with technological advancements by developing and implementing new technologies, products, and processes that deliver environmental benefits. These innovations improve resource efficiency, reduce pollution, and decrease resource consumption, supporting sustainable development and addressing critical environmental issues (**IRENA, 2020**).

Moreover, green growth and eco-innovations are pivotal drivers of economic competitiveness. Countries and businesses that adopt sustainable practices and invest in green technologies gain a competitive edge in the global market. The increasing demand for sustainable products and practices is creating new business opportunities and expanding market prospects, underscoring the economic potential of green growth.

To meet the study's objectives, we carried out an empirical analysis covering a 33-year period, from 1990 to 2023, focusing on the economies of Afghanistan, Bangladesh, India, and Pakistan. This analysis highlights the significant role of financial development in fostering green growth. The connection between green growth and natural resources is vital; adopting sustainable practices and efficiently managing natural resources enables economic progress while protecting the environment. Achieving this balance requires shifts in policies, mindsets, and collaboration across sectors, coupled with innovation.

The interrelationship between green growth, Urbanization, and financial development presents both challenges and opportunities. Although Urbanization has contributed to environmental issues, it also offers pathways to sustainable development. Financial development serves as a catalyst, providing the necessary resources to promote green growth and encourage sustainable practices. By leveraging the potential of these three interconnected concepts, nations can achieve economic prosperity while ensuring environmental preservation for future generations (**WDI, 2024**), as shown in Eq. (1).

Equation

The relationship between the variables can be expressed in a functional form as follows.

$$CO2 = f(\mathrm{RU}, \mathrm{REC}, \mathrm{TI}, \mathrm{G})$$

Initially, we calculate the multiple linear regression models, which can be represented as follows.

$$CO2_{it} = \beta_0 + \beta_1 \mathrm{RU}_{it} + \beta_2 \mathrm{REC}_{it} + \beta_3\ \mathrm{TI}_{it} + \beta_4 G_{it} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots .1$$

Equation (1) represents the multiple linear regression model, where CO2 denotes the corban di oxide, RU stands for resources utilization, REC represents the renewable energy consumption TI for Technological Innovation, and G for Urbanization. $\beta_0, \beta_1, \beta_2, \beta_3, and\ \beta_4$ are coefficient of variable respectively, while εit represents the error term. As ARDL serves as the final estimation strategy, Equation (1) can be re-expressed as:

$$\Delta CO2_{it} = \beta_0 + \alpha_1 CO2 + \alpha_2 RU_{it-1} + \alpha_3 REC_{it-1} + \beta_1 TI_{it-1} + \beta_2 G_{it-1} + \sum_{j=1}^{p} \gamma_1 \Delta CO2_{it-1} + \sum_{j=1}^{p} \gamma_2 \Delta RU_{it-1} + \sum_{j=1}^{p} \gamma_3 \Delta REC_{it-1} + \sum_{j=1}^{p} \delta_1 \Delta TI_{it-1} + \sum_{j=1}^{p} \delta_2 \Delta G_{it-1} + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots .2$$

Equation (2) employs the "Δ" symbol to signify the difference operator. The coefficients α1 to α3 pertain to explanatory variables, while β1 to β4 represent control variables in the long run.

Additionally, in the ARDL framework, coefficients are estimated for the short run as well. Thus, γ1 to γ3 denote the short-run estimation coefficients for explanatory variables, and δ1 to δ2 illustrate the short-run effect for control variables. Figure 1 illustrates the relationship between the variables.

Estimation strategy

In this analysis, we utilize the panel ARDL model to estimate the regression. The choice of employing the panel ARDL as an estimation strategy stems from preliminary statistical assessments, particularly unit root testing, to evaluate the stationarity of the series. We conduct unit root tests including the Im, Pesaran, and Shin W-stat (Im et al., 2003), as well as the ADF (Augmented Dickey-Fuller) test (Dickey & Fuller, 1979), and present the results in Table 2. The statistical analysis reveals a mixed trend of stationarity, with some series exhibiting stationarity at level I(0) while others show stationarity at the first difference I(1).
Given this mixed trend of stationarity, we opt for the panel ARDL approach for regression analysis. The ARDL model is well-suited to handle different levels of stationarity, cointegration, and endogeneity. Additionally, (Farooq, et al. 2024) demonstrates that the panel ARDL model can provide efficient estimates even with small sample sizes. By incorporating lags, the ARDL model effectively mitigates endogeneity issues. This modelling approach has also been utilized by Khan et al. (2022) in examining similar sets of variables.
Furthermore, to ensure the robustness of our analysis, we employ the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) models proposed by Shahbaz, 2009; Priyankara, 2018; Khan, et al., 2019; Olofin,et. al., 2019; Olorogun, 2023; Ramirez, 2023 These models also facilitate long-run estimation of coefficients, thereby enhancing the reliability of our findings.

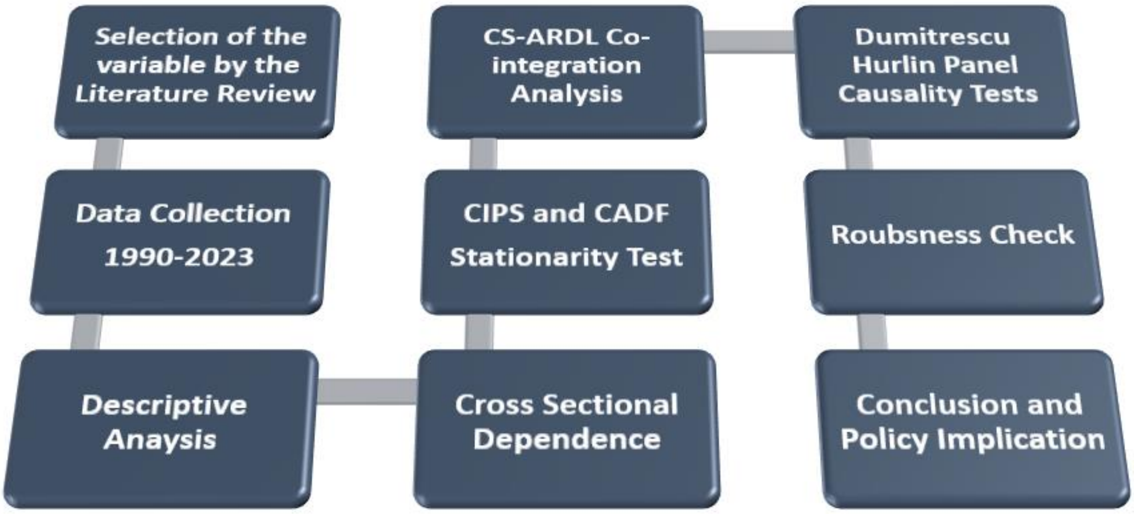


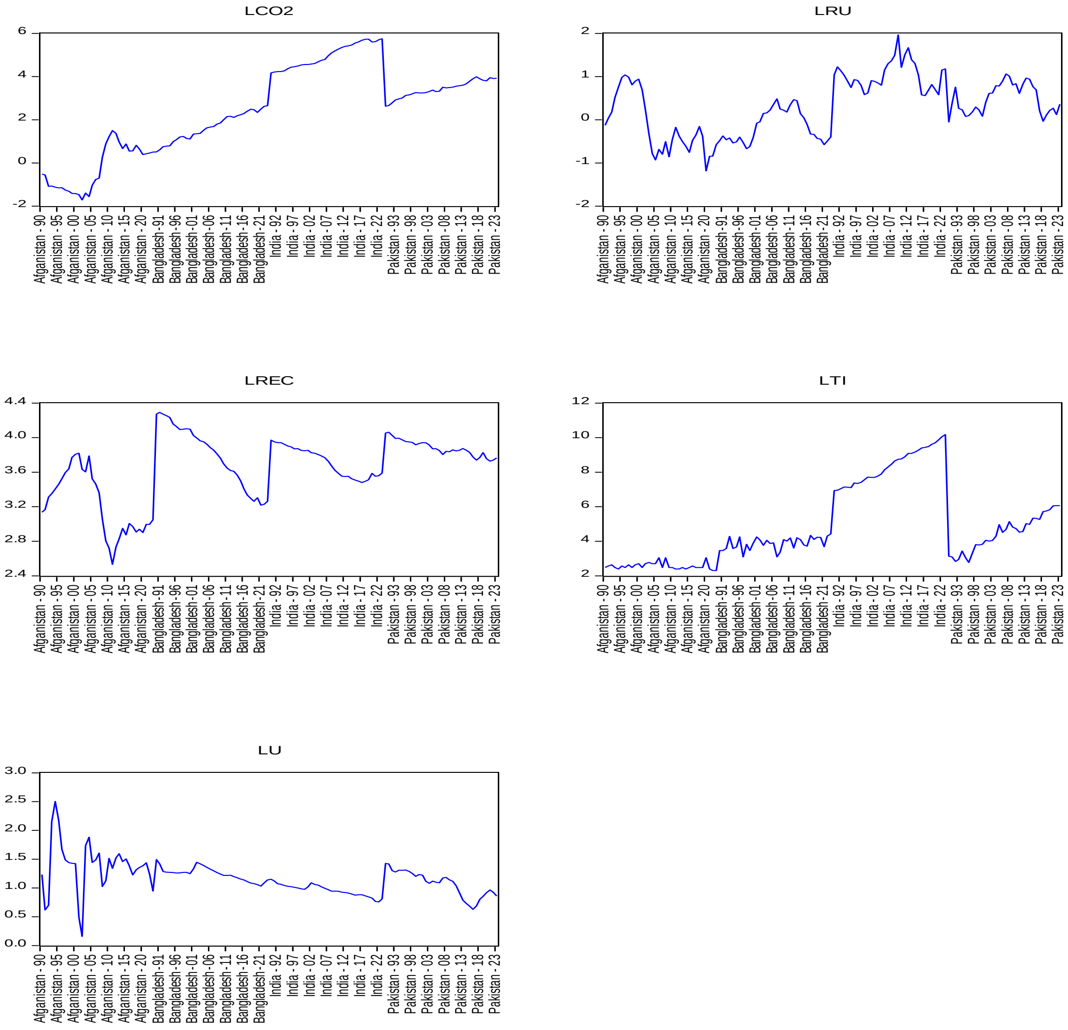
Figure 1, Framework of the model

Table 1, Variables of study.

Types	Acronym	Variable Titles	Measurements and Data Sources	Data Availability	Reference
Outcome	CO_2	Carbon di oxide	Carbon dioxide (CO2) emissions from Transport (Energy) (Mt CO2e)	1990-2023	(Khan et al., 2022; Kim & Go, 2022; Sevencan, 2023)

Input	RU	Resources Utilization	Total natural resources rents (% of GDP)	1990-2023	(Fonseca & Doornik, 2022; Iheonu et al., 2020)
	REC	Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	1990-2023	Agudze & Ibhagui, 2021; Khan et al., 2022)
	TI	Technological Innovation	Patent applications, residents	1990-2023	(Khan et al., 2022)
	G	Urbanization	Urban population growth (annual %)	1990-2023	(Yasmeen et al., 2021)

Note: This table shows the measurement and source of variables. Source: Previous studies.



Figure, 2 trend analysis dependent and independent variable

4. Result and Discussion

Descriptive Statistics

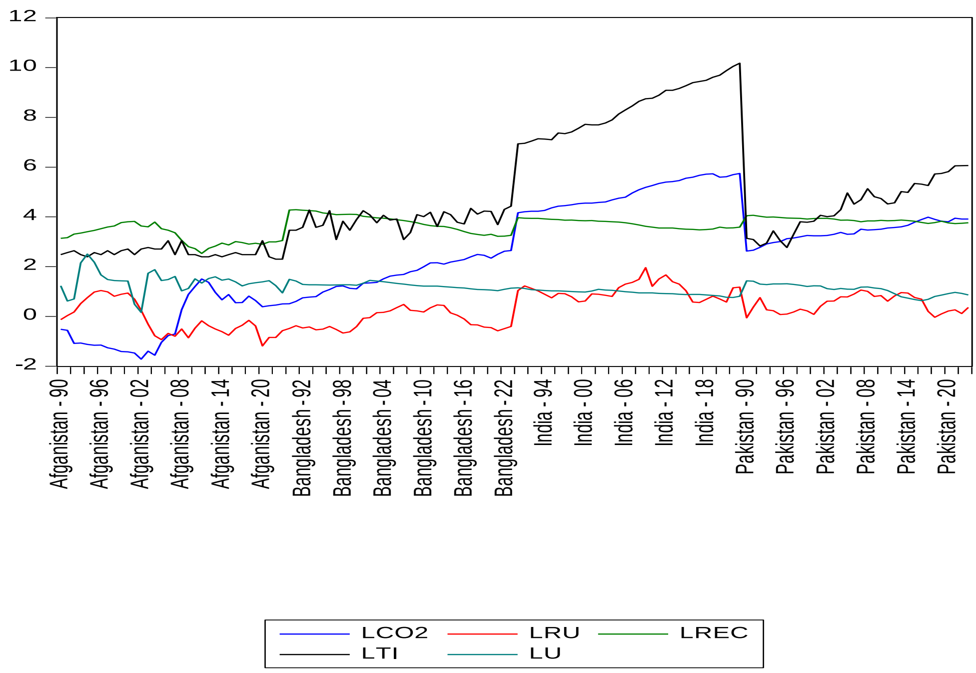
Table, 2 shows that, the average value (mean) for LCO2 is 2.45, with a median of 2.64. Its maximum and minimum values are 5.74 and -1.72, respectively, and it has a standard deviation of 2.07. For LRU, the mean is 0.30, with a median of 0.28. It ranges from a maximum of 1.96 to a minimum of -1.18, with a standard deviation of 0.67. LREC shows a mean of 3.65 and a median of 3.77, with a maximum of 4.29 and a minimum of 2.53, and a relatively low standard deviation of 0.37. LTI has a higher mean of 4.82 and a median of 4.07. Its values span from 10.18 to 2.30, with a standard deviation of 2.30. LU has a mean of 1.16 and a median of 1.15. It ranges from a high of 2.50 to a low of 0.16, with a standard deviation of 0.31. Skewness and kurtosis indicate the distribution characteristics of each variable. LTI and LU are positively skewed, while LCO2 and LREC are negatively skewed. LU also exhibits high kurtosis (6.33), suggesting a peaked distribution. The Jarque-Bera test shows that LREC, LTI, and LU have significant deviations from normality ($p < 0.05$).

Correlation Analysis LCO2 has a strong positive correlation with LTI (0.87) and a moderate positive correlation with LRU (0.59). Conversely, it has a notable negative correlation with LU (-0.57). LRU correlates positively with LTI (0.66) and LREC (0.33) but negatively with LU (-0.33). LREC has weaker correlations with other variables, with a small positive correlation with LTI (0.21) and LRU (0.33), and a slight negative correlation with LU (-0.10). LTI demonstrates a strong negative correlation with LU (-0.55) while maintaining positive correlations with LCO2 and LRU. LU is negatively correlated with all other variables, particularly LTI (-0.55) and LCO2 (-0.57).

Fig. 2 displays raw descriptive lines, visually representing various data points. It enables a clear understanding of the distribution and patterns within the dataset, helps identify trends, outliers, and other important data characteristics through the use of lines. Fig. 3 exhibits a multiple-graph distribution, showcasing data distribution across different variables, allows for a comprehensive analysis of the relationships between various factors and their impact on the overall distribution. It visually represents how different variables interact and influence the data distribution. Table 2 shows the outcome of the cross-section dependence test for carbon dioxide, resources Utilization, renewable energy consumption, technological innovation and urbanization, in Akhand Bharat. The null hypothesis of no cross-section dependence is rejected at the 1 % and 10 % significance levels. This implies evidence of cross-section dependence in the data being analysed. Cross-section dependence refers to the interdependence among individual observations in a dataset. When the null hypothesis is rejected, it suggests that the variables being examined are not independent of each other. A relationship between them needs to be taken into account in further analysis. The rejection of the null hypothesis at both the 1 % and 10 % significance levels indicates a strong confidence level in the presence of cross-section dependence. The results of the CIPS and CADF unit root tests are presented in Table 3. These tests were conducted to determine the stationarity of various variables related to carbon dioxide, resources Utilization, renewable energy consumption, technological innovation and urbanization. According to the test results, the Urbanization variable is stationary at the level and in its first difference. This implies that the fluctuations in urbanization are not random and can be somewhat predicted. This finding suggests that Urbanization has a stable long-term trend. On the other hand, the variables of green growth, natural resources, financial development, and research and development are found to be stationary only in their first difference. This indicates that the changes in these variables over time are random and unpredictable at the level but become predictable when considering the differences between consecutive observation. The result of panel cointegration is presented in Table 4 for carbon dioxide, resources utilization, renewable energy consumption, technological innovation, and urbanization in Akhand Bharat. According to the Pedroni Co-integration and Kao Residual Cointegration Test statistics for, carbon dioxide, resources utilization, renewable energy consumption, technological innovation, and urbanization, are cointegrated. The significance levels for these statistics are 5 % and 10 %, respectively. This suggests a long-term relationship between these variables, indicating their interdependency and their potential impact on each other. Fig. 4 presents a single graph that compares the first variable to all other dataset variables, allows for a detailed examination of the relationship between the first variable and the rest of the variables. It helps identify any patterns or correlations between the variables and provides insights into their interdependencies. The results of system dynamic panel data long-run estimates are presented in Table 5. Carbon dioxide, resources utilization, renewable energy consumption, technological innovation, and urbanization in Akhand Bharat. The carbon dioxide is positively associated with technological innovation and urbanization.

Table 2, Descriptive analysis

	LCO2	LRU	LREC	LTI	LU
Mean	2.45	0.30	3.65	4.82	1.16
Median	2.64	0.28	3.77	4.07	1.15
Maximum	5.74	1.96	4.29	10.18	2.50
Minimum	-1.72	-1.18	2.53	2.30	0.16
Std. Dev.	2.07	0.67	0.37	2.30	0.31
Skewness	-0.28	-0.06	-0.86	0.87	0.76
Kurtosis	2.12	2.14	3.21	2.48	6.33
Jarque-Bera	6.17	4.31	17.08	18.81	75.93
Probability	0.05	0.12	0.00	0.00	0.00
			Correlation		
LCO2	1				
LRU	0.59	1.00	0.33	0.66	-0.33
LREC	0.24	0.33	1.00	0.21	-0.10
LTI	0.87	0.66	0.21	1.00	-0.55
LU	-0.57	-0.33	-0.10	-0.55	1.00



Figure,3 Raw descriptive lines visually representing various data points

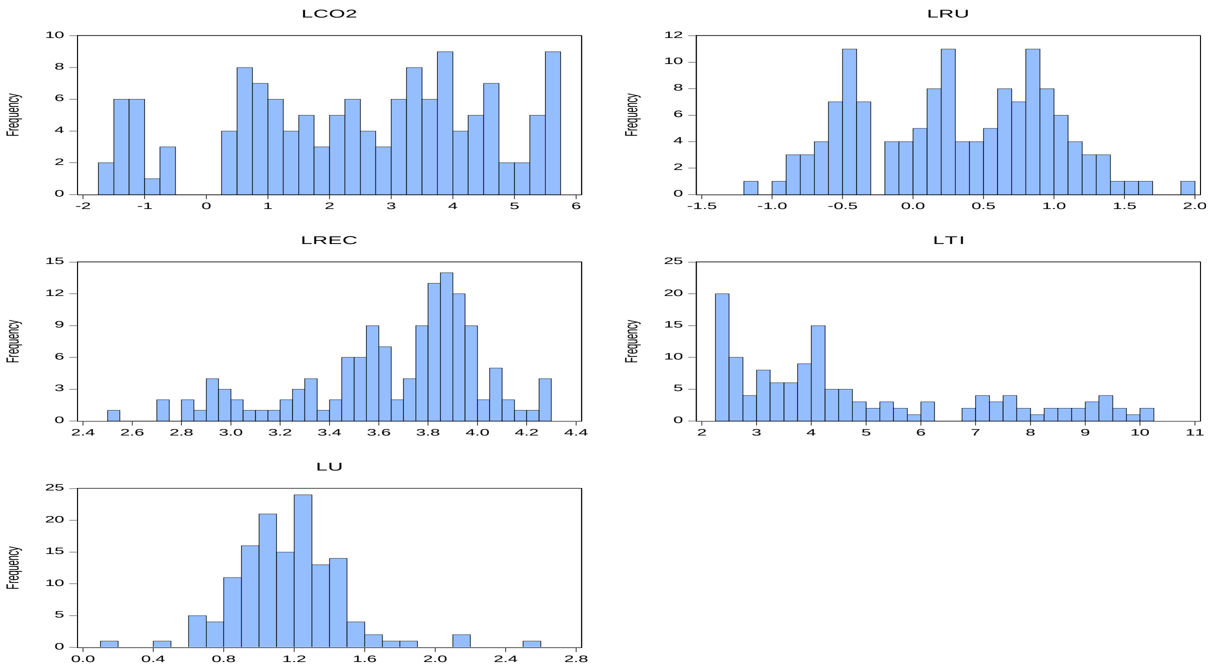


Fig. 4, Graphs showing data distribution across different variables

Table 3 Cross Sectional Dependence

Tests	$LnCO_2$	LnRU	LnREC	LnTI	LnU
BREUSCH-PAGAN LM	156.45***	76.10***	128.76***	45.70***	66.50***

PESARAN SCALED LM	43.43***	20.23***	35.44***	11.46***	17.46***
BIAS-CORRECTED SCALED LM	43.37***	20.17***	35.37***	11.40***	17.40***
PESARAN CD	12.39***	1.81***	11.11***	3.03***	5.43***

TABLE 4 Unit root testing.

(Im, Pesaran and Shin W-stat)					**(ADF—Fisher chi-square)**				
Variable	At level		**At first difference**		**At level**		**At first difference**		Decision
	t-statistics	Prob.	t-statistics	Prob.	t-statistics	Prob.	t-statistics	Prob.	
$LnCO_2$	0.59	-0.72	-4.46	0	6.04	-0.64	35.97	0	I (I)
LnRU	0.4	-0.65	-4.05	0	4.82	-0.77	32.35	0	I (I)
LnREC	-2.65	0	-5.17	0	27.01	0	46.71	0	I (0)
LnTI	-2.91	0	-9.62	0	26.86	0	83.13	0	I (0)
LnU	-4.76	0	-8.87	0	38.08	0	76.02	0	I (0)

1. Note: ***, **, *report the significance level at 1%, 5%, and 10%, relatively.

Table 5 Co-integration Analysis

Pedroni Co-integration				
Alternative hypothesis: common AR coefs. (within-dimension)				
			Weighted	
	Statistic	Prob.	Statistic	Prob.
Panel v-Statistic	-0.480074	0.00	0.316585	0.03
Panel rho-Statistic	1.008994	0.05	0.66081	0.07
Panel PP-Statistic	-0.433265	0.05	-0.965242	0.05
Panel ADF-Statistic	0.320377	0.03	-1.13798	0.03
	Statistic	Prob.		
Group rho-Statistic	1.428935	0.0235		
Group PP-Statistic	-0.779057	0.0718		
Group ADF-Statistic	-1.139289	0.0273		
Kao Residual Cointegration Test				
	t-Statistic	Prob.		
ADF	-2.350547	0.0094		
Residual variance	0.010257			
HAC variance	0.007226			

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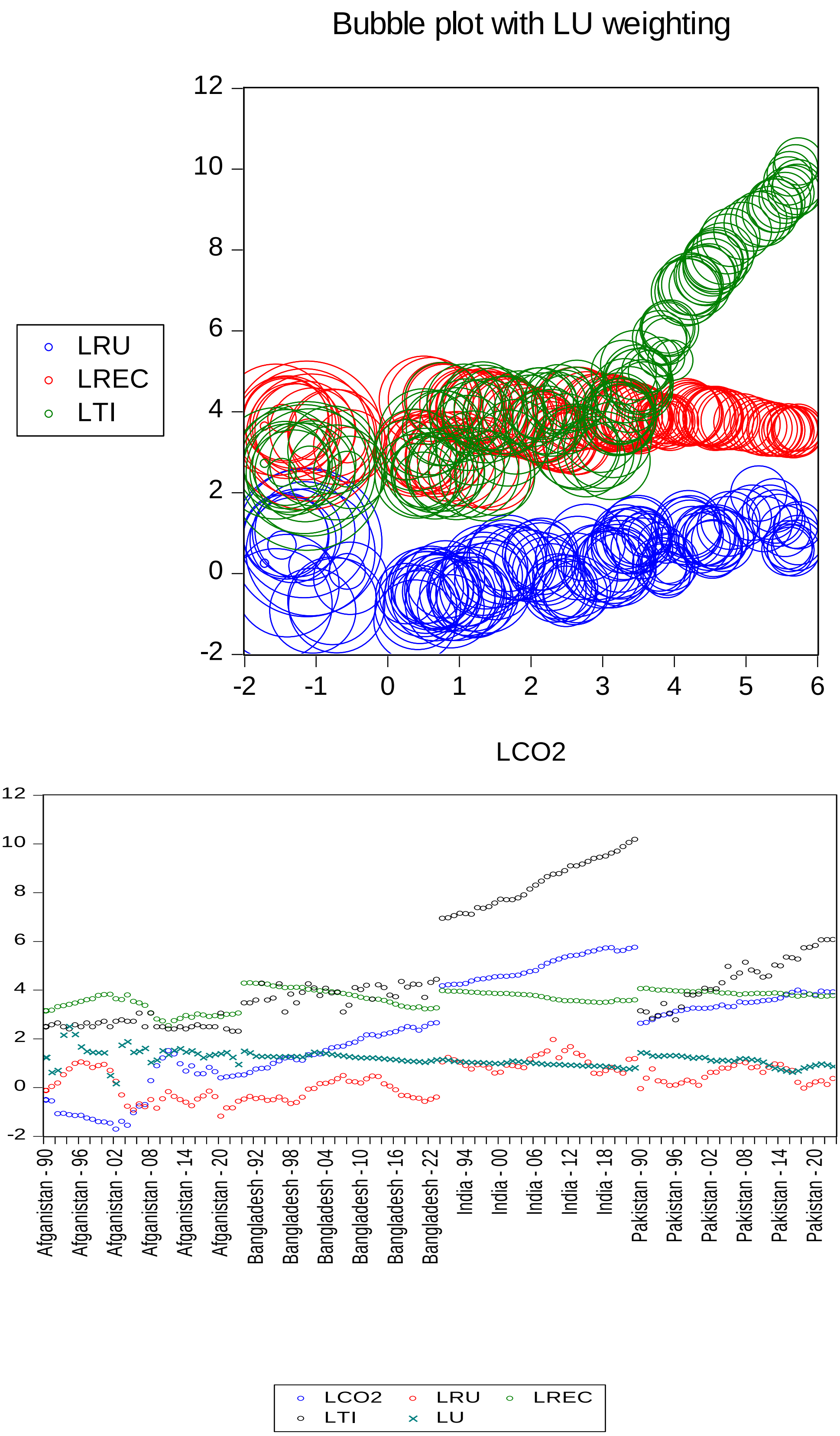

Figure 4, Single graph comparing first variable with all other variables.

Table 6, CS-ARDL Model

	Long Run Equation			
Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LRU	-0.542	0.579	-0.935	0.352
LREC	-1.478	0.718	-2.060	0.042
LTI	1.255	0.302	4.158	0.000
LU	2.088	1.627	1.283	0.202
	Short Run Equation			
COINTEQ01	-0.02	0.01	-1.26	0.21
D(LRU)	0.08	0.05	1.44	0.15
D(LREC)	-1.61	0.10	-16.24	0.00
D(LTI)	0.01	0.04	0.34	0.73
D(LU)	0.00	0.09	0.03	0.97

The table 1, suggest several important relationships between various factors and carbon dioxide (CO_2) emissions. First, the utilization of natural resources has a relatively beneficial impact on the environment, as a 1% increase in resource use leads to a 0.54% reduction in CO_2 emissions. This may indicate that more efficient or cleaner extraction methods could be employed, possibly supported by investment in cleaner technologies or resource management strategies. Second, renewable energy consumption demonstrates a significantly positive impact on reducing emissions. A 1% increase in renewable energy consumption results in a 1.47% reduction in CO_2 emissions. This highlights the importance of transitioning to renewable sources like wind, solar, and hydro, which have minimal direct emissions compared to fossil fuels. On the other hand, technological innovation appears to contribute to increased emissions, with a 1% rise in innovation leading to a 1.25% increase in CO_2 emissions. This could be due to innovations in industries that are energy-intensive or reliant on fossil fuels, indicating that technological progress might not always align with sustainability unless it specifically targets environmental improvements.

Lastly, urbanization plays a significant role in increasing CO_2 emissions. A 1% increase in urbanization leads to a 2.08% rise in emissions, suggesting that urban growth often results in higher energy demand, transportation emissions, and greater overall consumption of resources.

Short Run

a study by Arezki et al. (2014), it was discussed that countries rich in natural resources, particularly fossil fuels, tend to have higher carbon emissions due to the direct environmental impact of resource extraction. On the other hand, countries that have invested the proceeds from these rents into green technologies have been able to decouple carbon emissions from economic growth to some extent

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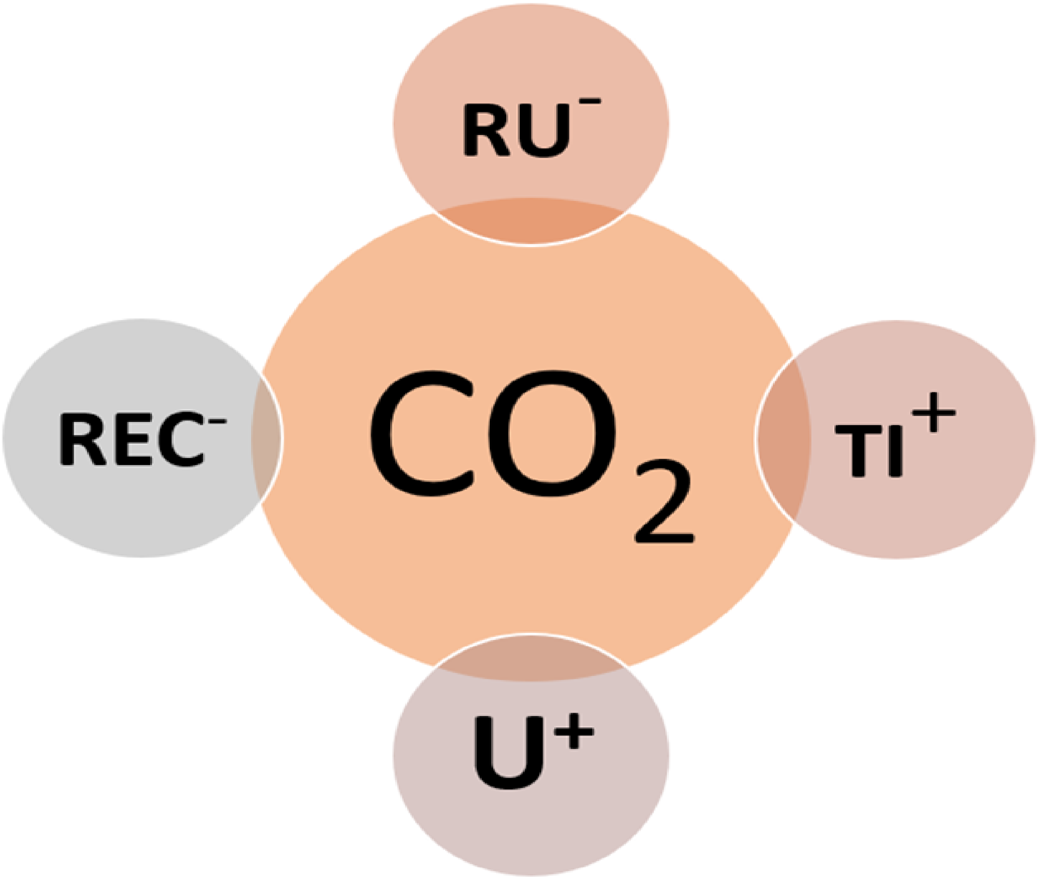

Figure 5, Summary of Model

Table 7, Dumitrescu Hurlin Panel Causality Tests

Pairwise Dumitrescu Hurlin Panel Causality Tests

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LREC does not homogeneously cause LCO2	3.19	0.88	0.38
LCO2 does not homogeneously cause LREC	3.36	1.03	0.30
LRU does not homogeneously cause LCO2	3.72	1.34	0.18
LCO2 does not homogeneously cause LRU	3.39	1.05	0.29
LTI does not homogeneously cause LCO2	5.37	2.74	0.01
LCO2 does not homogeneously cause LTI	7.00	4.14	0.00
LU does not homogeneously cause LCO2	2.89	0.63	0.53
LCO2 does not homogeneously cause LU	7.03	4.17	0.00

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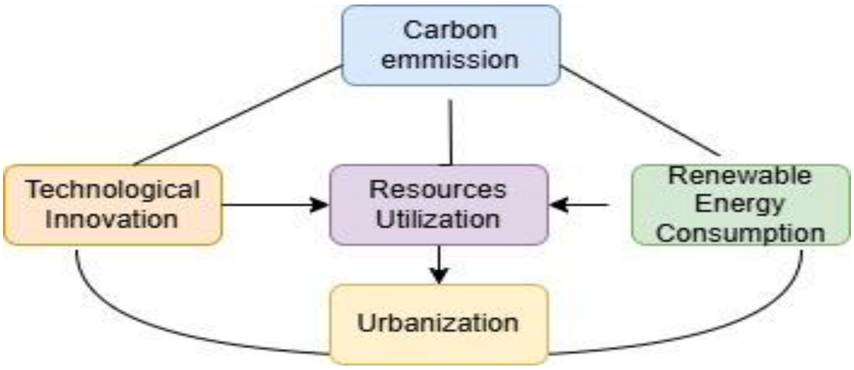

Figure 6, Dumitrescu Hurlin Panel Causality Tests

Table 7, The results of the Pairwise Dumitrescu-Hurlin Panel Causality Tests analyze the causal relationships between variables in a panel data framework, where the null hypothesis is that one variable does not homogeneously cause the other across the panel. Here's an interpretation of the results: LREC does not cause LCO2: The W-Stat (3.19), Zbar-Stat (0.88), and p-value (0.38) suggest no significant causality from renewable energy consumption to carbon emissions at conventional significance levels. Similar results (W-Stat: 3.36, Zbar-Stat: 1.03, p-value: 0.30) indicate no significant reverse causality. The W-Stat (3.72), Zbar-Stat (1.34), and p-value (0.18) show no significant causality from resource utilization to carbon emissions. Likewise, no significant reverse causality exists (W-Stat: 3.39, Zbar-Stat: 1.05, p-value: 0.29). The W-Stat (5.37), Zbar-Stat (2.74), and p-value (0.01) indicate significant causality from technological innovation to carbon emissions. This suggests that technological innovation has a notable impact on carbon emissions in the panel data. The reverse causality is also significant (W-Stat: 7.00, Zbar-Stat: 4.14, p-value: 0.00), showing that carbon emissions influence technological innovation. W-Stat (2.89), Zbar-Stat (0.63), and p-value (0.53) show no significant causality from utilization to carbon emissions. Significant reverse causality exists (W-Stat: 7.03, Zbar-Stat: 4.17, p-value: 0.00), indicating that carbon emissions affect utilization.

Table 8 FMOLS and DOLS robustness test results

FMOLS					**OLS**			
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LREC	-2.173	0.122	-17.755	0.000	-2.24	0.14	-16.45	0.00
LRU	-0.161	0.068	-2.353	0.020	-0.22	0.09	-2.57	0.01
LTI	0.173	0.046	3.785	0.000	0.14	0.06	2.15	0.03
LU	0.013	0.122	0.103	0.918	-0.20	0.25	-0.81	0.42

The FMOLS analysis indicates that renewable energy consumption and resource utilization both have a negative and statistically significant impact. In contrast, technological innovation (TI) exerts a significant positive effect on carbon emissions, with a 1% level of significance. These findings are supported by the DOLS results. Additionally, the FMOLS estimator highlights that Urbanization has a positive and statistically significant effect on CO2 emissions. Both FMOLS and DOLS results consistently underscore the positive and highly significant influence of technological innovation on CO2 emissions. Meanwhile, the PMG-ARDL analysis corroborates the FMOLS findings by showing a negative and significant relationship between renewable energy consumption and resource utilization at a 5% significance level.

Figure 7 presents a scatter plot matrix that visually depicts the relationships between multiple variables. The matrix consists of a grid of scatter plots, each illustrating the relationship between two variables. This visualization aids in identifying correlations, clusters, and outliers within the dataset, offering valuable insights into data distribution patterns.

Figure 8 showcases a combined cross-sectional pie distribution, illustrating how a variable is distributed across various categories or groups. This visual representation enables a quick comparison of proportions among categories, helping to identify disparities or patterns in the dataset.

Figure 9 displays a quantile–quantile stacked cross-section, providing a visual depiction of a variable's distribution across different quantiles. It compares the distribution of the variable within each quantile, highlighting any variations or trends. This representation enhances the understanding of the variable's distributional characteristics and provides a comprehensive view of its overall distribution.

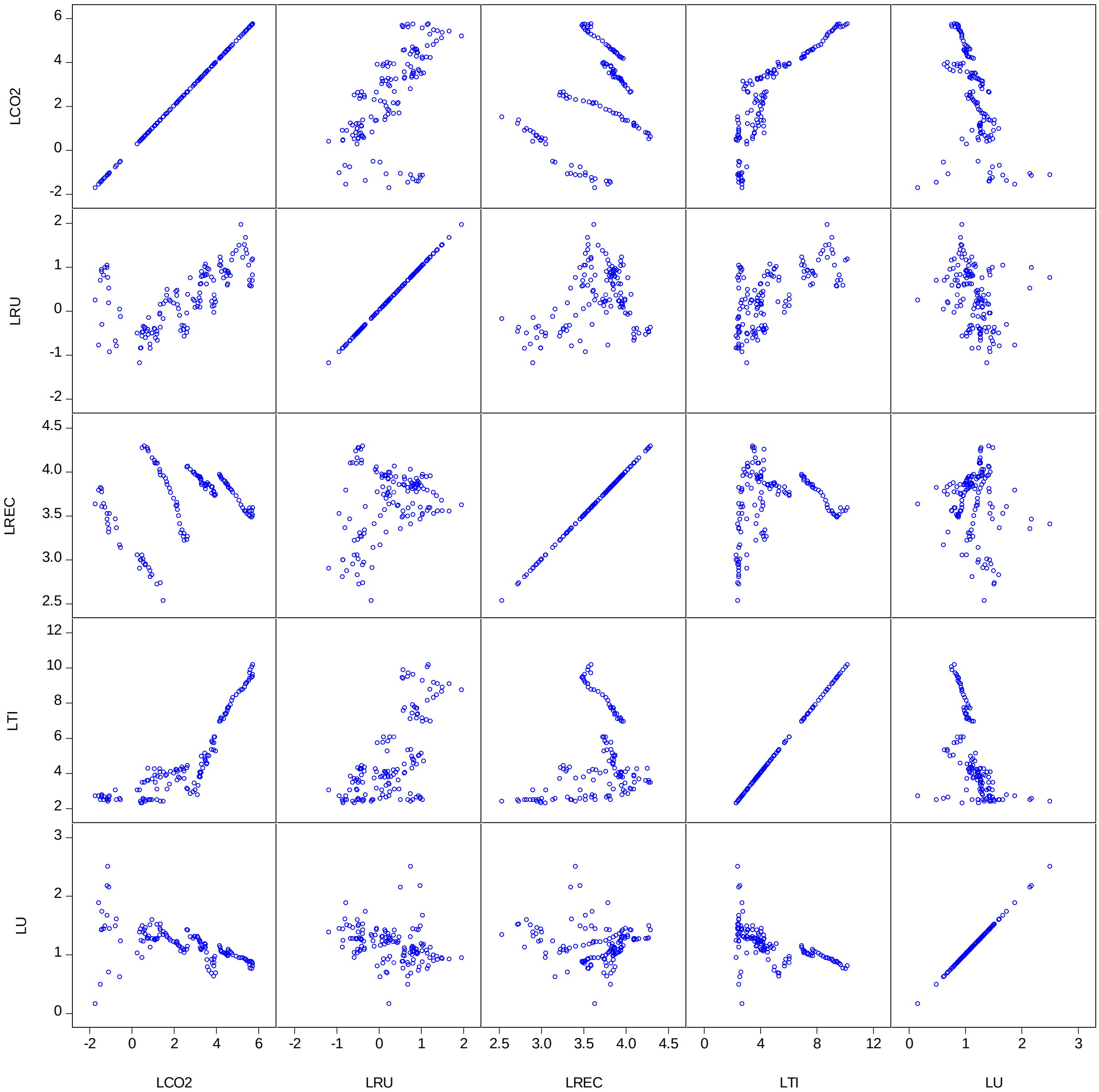

Fig. 7. Scatter plot matrix.

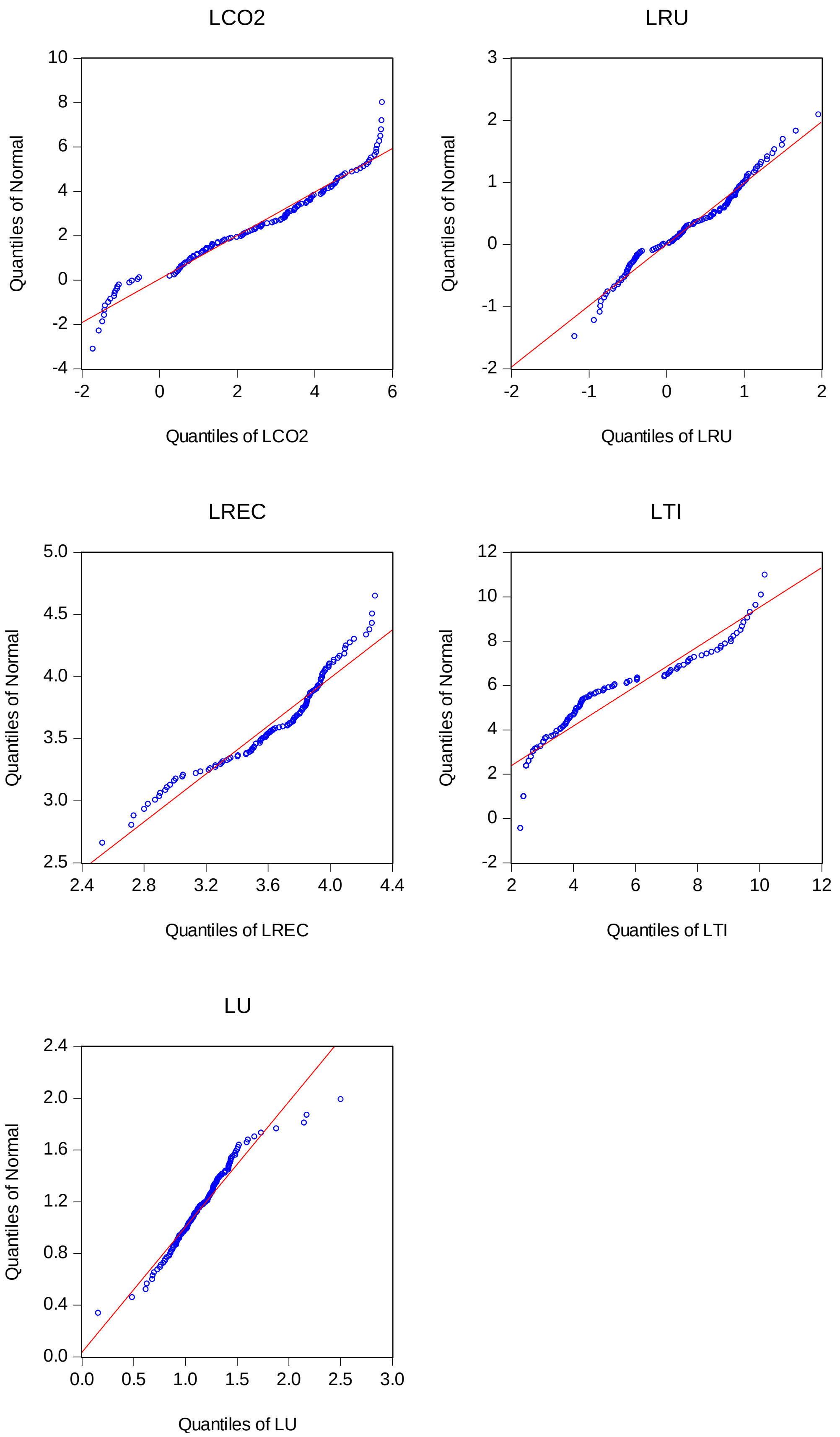

Figure 8 Quantile-quantile stack cross-section plots.

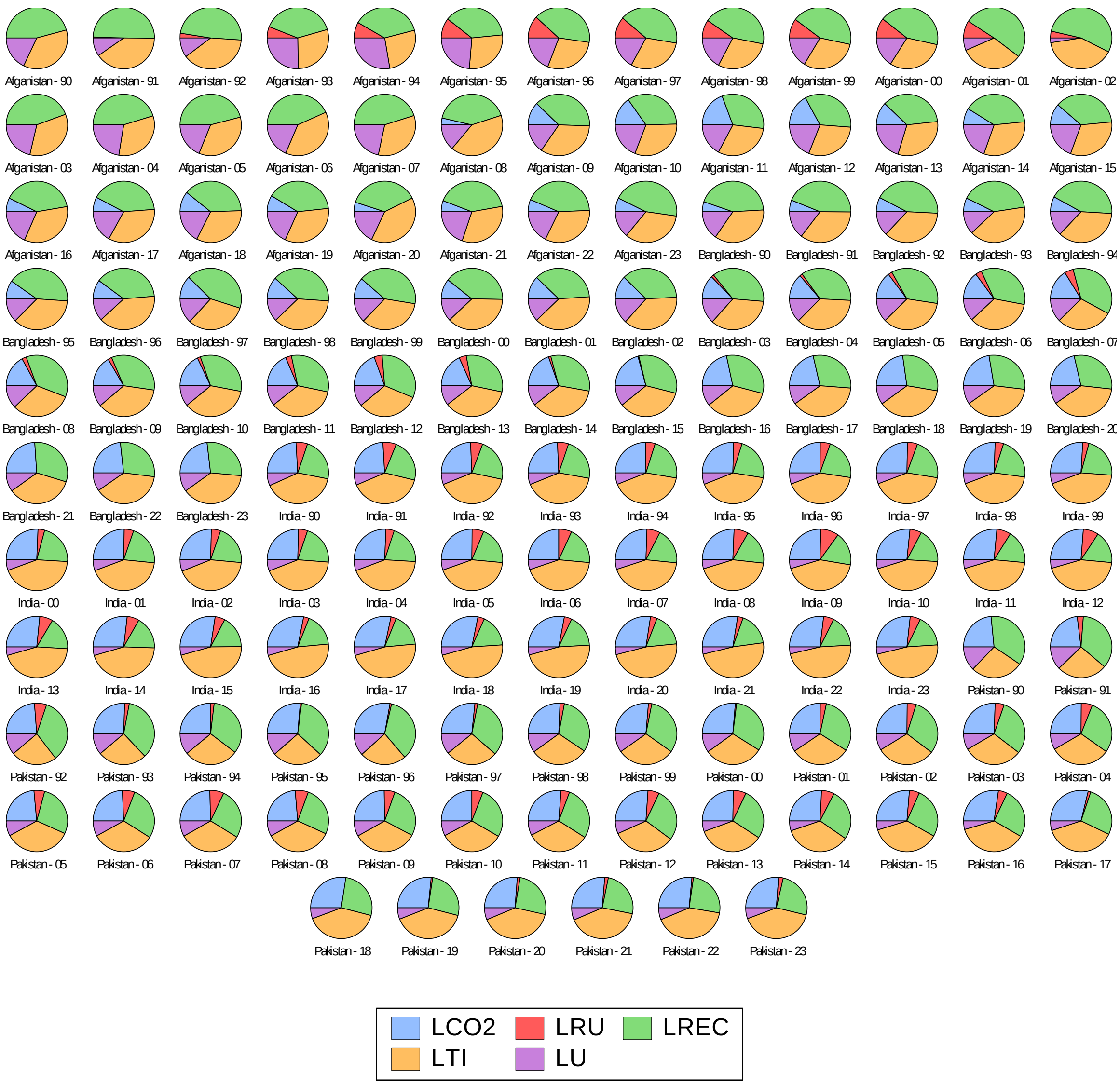

Fig. 9. Combined cross-section pie distribution diagrams.

5. Conclusion and Policy Implication

(a) Conclusion

Resources, Utilization, renewable energy consumption, technological innovation, Urbanization, and carbon emission are key to the Akhand Bharat. The sustainable development and prosperity of Akhand Bharat—a conceptual vision of an interconnected and united South Asia—rests on key pillars such as resource optimization, effective utilization, renewable energy consumption, technological innovation, Urbanization, and carbon emission reduction. These factors collectively shape the region's ability to balance economic growth with environmental sustainability. The judicious management of natural and human resources ensures equitable distribution, addressing disparities while unlocking the region's vast potential. Emphasizing renewable energy consumption will aid in meeting the growing energy demands of the population while mitigating the environmental impact of fossil fuels. Technological innovation serves as a catalyst for economic transformation, fostering industries that align with sustainable development goals. Furthermore, Urbanization opens pathways for trade, cultural exchange, and investment, providing a platform for Akhand Bharat to integrate into the global economy. Crucially, reducing carbon emissions is imperative to combat climate change, which disproportionately impacts this region due to its vulnerability to rising temperatures, erratic weather patterns, and sea-level rise. By leveraging these pillars strategically, Akhand Bharat can lay the groundwork for long-term sustainability, regional harmony, and global competitiveness.

(b) **Policy Implication**

Implement integrated resource management strategies to balance the demand and supply of essential resources like water, minerals, and land. Encourage circular economy practices to minimize waste and maximize the value extracted from resources. Foster regional collaborations for equitable sharing of transboundary resources, such as rivers and forests. Establish incentives for renewable energy projects, including subsidies for solar, wind, and hydropower installations. Enhance cross-border energy trade to optimize the region's diverse energy mix and improve energy security. Promote decentralized energy systems, enabling rural communities to access clean and affordable energy. Invest in research and development (R&D) to create locally relevant technologies, particularly in agriculture, manufacturing, and energy sectors. Support tech-driven startups and small businesses by providing funding, mentorship, and infrastructure. Establish innovation hubs across the region to promote knowledge sharing and collaboration. Strengthen trade agreements and regional economic cooperation to create a unified market. Develop infrastructure that facilitates seamless connectivity, including roads, railways, and digital networks. Promote cultural diplomacy and people-to-people exchanges to foster goodwill and mutual understanding. Commit to regional climate action plans aligned with global agreements like the Paris Accord. Transition to low-carbon industries through tax incentives and regulations. Enhance climate resilience by investing in sustainable urban planning, disaster management, and adaptive agriculture. Establish governance frameworks that prioritize sustainability and encourage joint action on common challenges. Create platforms for policy dialogue among nations in the region to address shared concerns, including environmental degradation and resource scarcity. Develop regional funds to support green initiatives and capacity building. This suggests that renewable energy consumption and resource utilization, as measured in the data, do not have a direct or homogeneous impact on carbon emissions in the panel. The bidirectional causality between technological innovation and carbon emissions implies a strong interconnection. Technological advancements may both influence emissions (e.g., through innovations in energy efficiency) and be driven by the pressures of carbon reduction goals. The significant reverse causality from carbon emissions to utilization indicates that higher emissions may prompt changes in how resources or energy are utilized, potentially in response to environmental policies or regulations. Policymakers should focus on fostering technological innovation as a means to address carbon emissions, given its significant causal relationship. While renewable energy and resource utilization may not show a direct causal impact in this analysis, they remain crucial components for broader sustainability strategies.

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