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Research Article

Impact of Urbanization and Usage of Green Energy Sources on Environmental Decline in Pakistan

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Abstract

This study aims to investigate the impact of urbanization, green energy and economic growth on environmental footprints using 24 years data from 2000 to 2024 and employing various econometric techniques such as ARDL approach and associated tests. Extensive research has been conducted globally on these relationships but there is still gap in understanding the nature of empirical links among these variables. This research addresses that gap by conducting a country-specific analysis using the Autoregressive Distributed Lag (ARDL) model, Correlation Matrix and associated diagnostic tests. The findings predict the negative impact of urbanization, green energy consumption and economic growth on CO2 release and positive impact on environmental quality, supporting the Environmental Kuznets Curve hypothesis. The analysis found a significant role in promoting the balanced environment of green energy consumption, urbanization and economic growth. The analysis suggests that policymakers should promote green energy usage by fiscal incentives and subsidies to reduce the reliance on traditional energy sources.

Keywords*:* Urbanization, Green energy sources, economic quality, environmental decline

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1. Introduction

1.1. Urbanization

Urbanization refers to the movement of people from rural areas to urban areas. According to oxford dictionary, the definition is urbanization is as "As more people start to live and work in core region, towns and cities get larger a process a known as Metropolitan expansion". Over fifty percent of the world's population at this time lives in metropolitan areas, a phenomenon known as urbanization. Metropolitan expansion is steadily rising in developing nations. Pakistan is undergoing a rapid urban transition, recording the fastest pace of urbanization in South Asia, with more than one-third of its population living in urban areas and projections indicating that urban population will constitute nearly half of the national population by the mid-2020s (UN DESA, 2022). International evidence shows that urbanization is closely associated with economic expansion, higher productivity, employment generation, and technological advancement, particularly where cities are supported by effective institutions and infrastructure, as urban centers account for over 80 percent of global economic output (World Bank, 2023; UN-Habitat, 2022).

In the context of the Pakistani economy, the urban centers can be considered the dominant force in the economy, contributing a combined 55 percent of the GDP and 95 percent of the federal taxes in a few large urban centers (World Bank, 2024). Karachi contributes significantly to national earnings as well as taxation, whereas the rest of the major cities show per head earnings exceeding the national average. In line with recent research findings, the poverty rate in cities in Pakistan has been found to remain lower compared to the rural areas, thereby identifying cities as hubs for earnings (UN-Habitat, 2023; Asian Development Bank, 2022). As per the Pakistan Bureau of Statistics 2023, Pakistan's Urban Population is 93.88 million people (38.88%), which comprises 48.75 million males (including transgender persons), whereas the females are 45.14 million. In

contrast, the Rural Population in the country is 147.61 million (61.12%), consisting of 147.61 million (61.12%), with 75.60 million males (including transgender individuals) and 72.02 million females. Pakistan's population based on gender distribution is displayed in Figure 1.

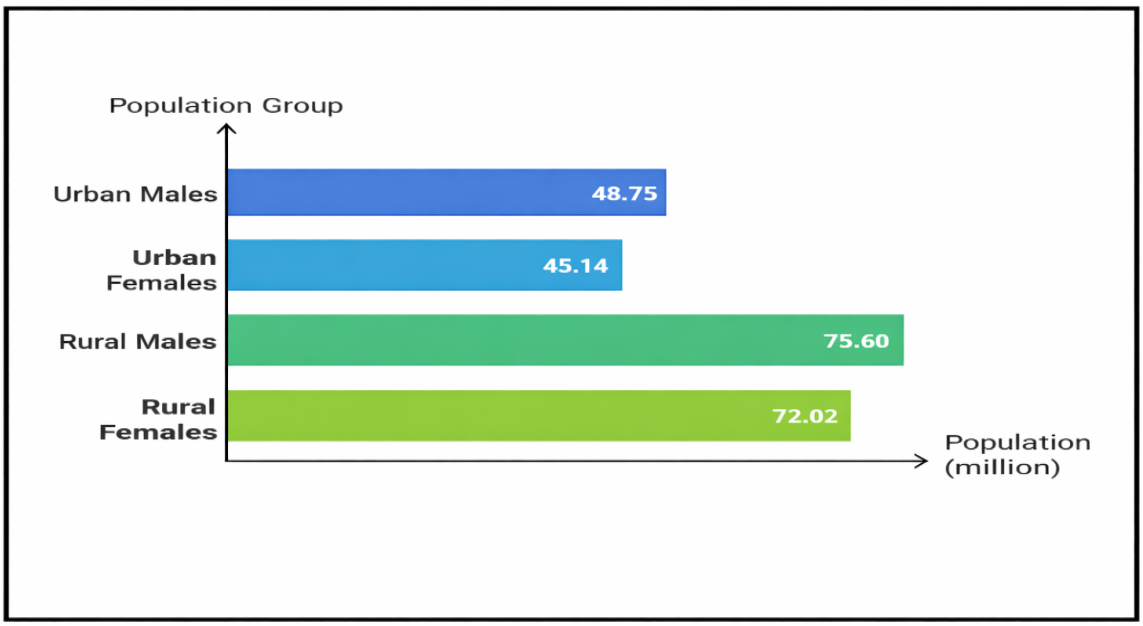


Figure 1: Gender-based categories of population

Source: Based on 7th Population and Housing Census, (2023).

Barriga Cabanillas et al., (2025), in his study challenged these official figures and claims that the real urban population of Pakistan is much larger than the official data suggest because it is based on administrative classification, which is based only major cities. If we examine urban population through the Degree of Urbanization (DOU) framework it disclosed that about 88 percent of Pakistan's population lives in those areas which possess urban features. Around 46 percent of the population live in high-density cities and about 42 percent in moderately dense urban centers. This large difference with official data considers only 39 percent of the population to be urban. This wide divergence between

politically defined limits and technically derived spatial classifications. A direct comparison between DOU categories and official data is not possible due to the absence of disaggregated census statistics, which validates the investigation carried out at tehsil level, confirming a significant overlapping between DOU-defined areas and both primary and secondary urban centers. The official statistics inflate the size of the rural population. The Housing and Population Census 2023 treat 61 percent of population as rural, whereas DOU-based estimate disclosed that scattered residential areas and villages collectively account for only 12 percent of population, with shares of 8 percent and 4 percent, respectively. The gap emerges between official data and DOU findings because official data include densely populated towns (11 percent), semi-dense towns (2 percent), and suburban or peri-urban zones (29 percent) into rural population, despite their high demographic density and integration into urban economic areas (Barriga Cabanillas et al., (2025). The difference between official estimates and degree of urbanization (DOU estimates are highlighted in Figure 2.

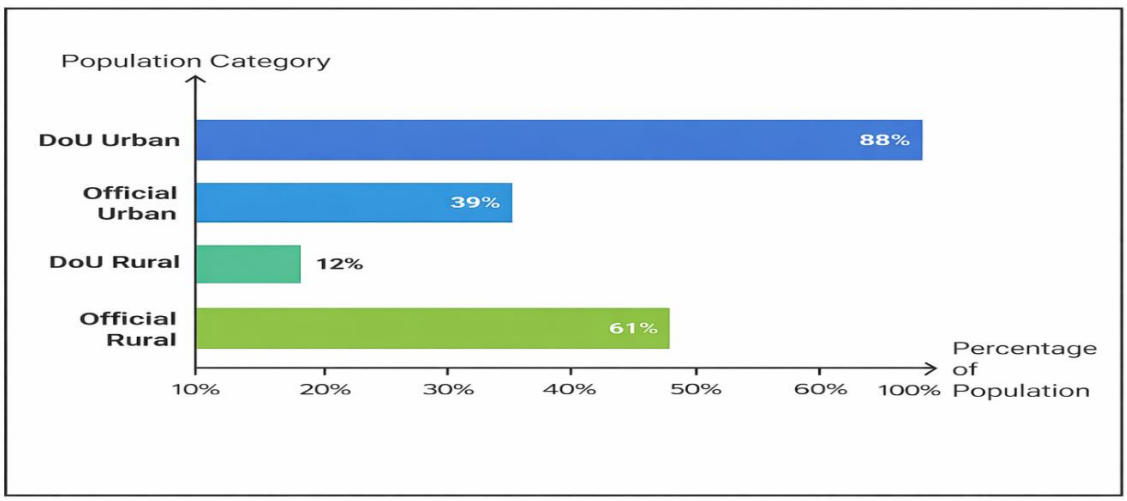


Fig 2: Comparison of Pakistan's population under official and DOI methods.

Source: Based on the study of Barriga Cabanillas, et al., (2025).

Three key factors are responsible for expansion of metropolitan population. The growth of non-rural families themselves is the first factor contributing to the genuine population expanding. The second is the expansion and growth of urban regions as rural areas are converted to urban areas; and third is a net movement from rural to urban areas, which raises the population of towns and cities. Over time, the spillover of urban activities turns rural areas close to urban centers. Natural population upswing and migrant settlement in these urban places are the main causes of all these rises in population density. People relocate to cities for a variety of reasons that include seeking higher wages, education for their children, better living standard and better communication system. The rate of urban population is increasing. Resources are scarce in relation to the population, and the increasing metropolitan population causes numerous issues. Most industries are located close to cities and use finite sources, which diversely influence the climate. An inadequate waste management system pollutes the environment. The sanitation and sewerage systems in emerging nations are unable to function adequately due to the fast increase in urban population. The availability of clean water is one of the main issues since all these issues have a large significance on the water quality. Due to the growing metropolitan population and the inability of the limited resources to fulfill demand, the cultivated area is declining. To meet growing demand, all out farming and the usage of mix breed kernel are being employed, which lowers soil fertility and accelerates soil contamination. Chocking, automotive, and commercial activities in populated areas also inflate environmental issues. It is also a fact that, now, urban areas are not ready to absorb more people migrating from rural areas.

1.2 CO_2 Emissions

Pakistan's carbon dioxide (CO_2) emissions have risen significantly over recent decades, reflecting. Increased energy consumption from fossil fuels and economic activities, with the latest data showing emissions near 201 million tons in 2023, a slight decline from 2022

but still well above historical levels and indicative of a long-term upward trend. The energy sector, comprising the burning of oil, gas, and coal for electricity generation and industrial use, is the key source of greenhouse gases, while agriculture and transport sectors also contribute significantly to CO_2 emissions, and non-renewable energy sources continues to produce higher emissions. Academic research confirms that excessive use of fossil fuel and rising power demand are the main contributors to rising CO_2 level. Technological innovations and renewable energy development can play a significant role in mitigating emissions if they are supported by targeted policy and investment. Currently, Though Pakistan's emissions level is moderate compared to global totals, yet it underscores the importance of transition toward green energy sources to meet climate goals and reduce environmental impacts associated with persistent high CO_2 release (Ali, Bakhsh, & Yasin, 2019; Kahia, Omri, & Jarraya, 2021; Iftikhar, Khan, & Żywiołek, 2024; Kusiyah, et al., 2024; Joyo, et al., (2025). The trends of CO_2 emissions are provided in Figure 3.

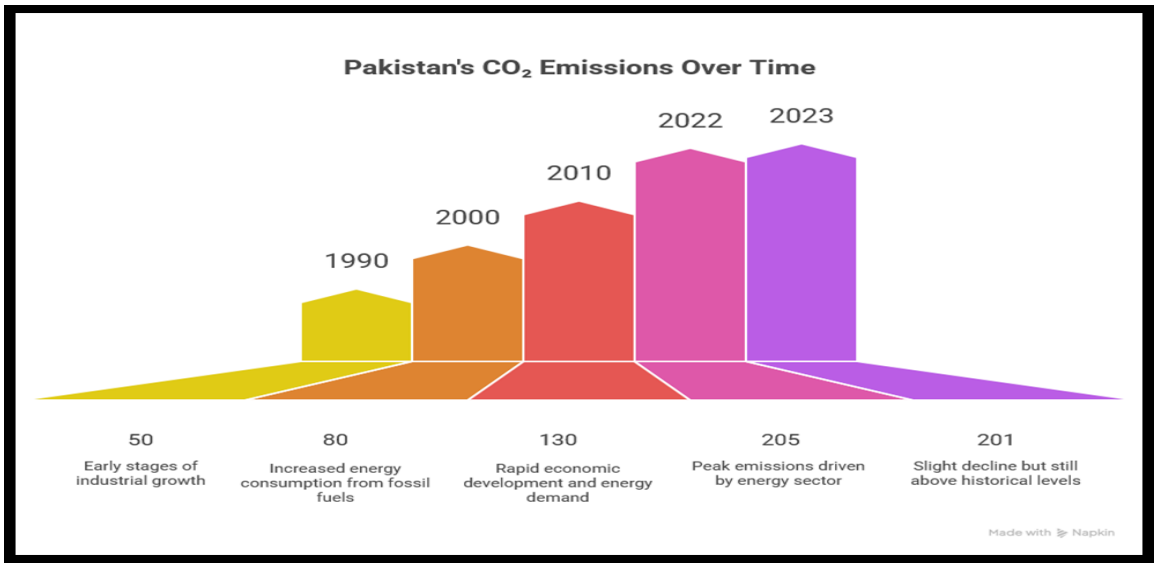


Fig 3: Carbon emission trends in Pakistan during 1990-2023

Source: World Bank, 2024.

However, Pakistan committed to cut 20 % emissions by 2030 and it is conditional to global financial assistance. This target is moderate as compared to 55% of the European Union and 52% of the United States and 30% of China's 30 %,

1.3 Green Energy

Green energy is the hottest topic for researchers. According to various scholars, green energy is defined as energy extracted from sources like sunlight, wind, water or terrestrial heat that produce little to no greenhouse gas emission. The Environmental Protection Agency (EPA) and other organizations recognize green energy as an essential component in minimizing greenhouse gas emission and mitigating climate change. Solar energy utilizes photovoltaic cells to capture sunlight and convert it to energy. Wind energy is produced with the help of wind turbines. Moving water such as rivers, ocean tides, and seas produces hydro energy. The earth's internal heat system contributes to the generation of geothermal energy. Energy obtained from organic materials such as wood and Agri-waste biogas is assumed as biomass energy (Friedlingstein, et al. (2025).

Pakistan's energy sector is passing through a transitional phase in which renewable sources and renewable energy is contributing to the national electricity mix as a strategy to cut reliance on traditional fuels. According to official energy data, renewables (including solar, wind, hydropower, nuclear and hydel) are producing over 50 % of total electricity generation in FY 2025. The share of thermal power has reduced to 40%. This highlights a dramatic shift from the traditional dominance of thermal energy (Achieving energy sustainability of Pakistan's power sector, 2025). Presently, Hydel and renewable energies have a major share in electricity generation due to capacity additions, especially in solar and wind, supported by fiscal incentives and net-metering policies, which encourage households and business firms to adopt green energy. Latest research disclosed that renewables are gaining momentum and are projected to rise more as the government has set a target of around 60 % share by 2030 (Energy Policy Evolution in Pakistan, 2025).

Academic research corroborates these trends, noting the expanding role of renewable technologies in Pakistan's power sector as policymakers prioritize sustainability goals and climate commitments. Government of Pakistan has repealed all power purchase agreements with independent power producers, closing door for production of energy by fossil fuels. The rising share of renewables in electricity generation can be seen in Figure 4.

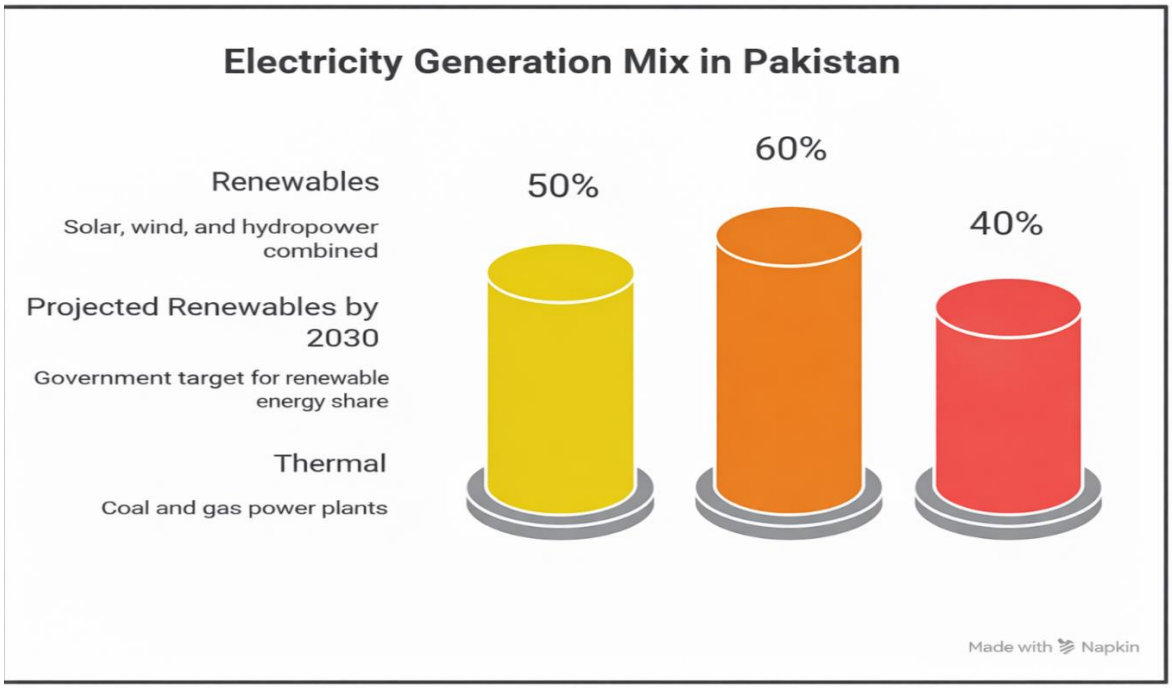


Fig 4: Share of various sources in electricity generation.

Source: Data extracted from the study of Joyo, et al (2025).

The review of existing literature reveal that existing research has investigated the link between urbanization and environmental decline or the role of green energy in environmental quality separately, without integrating these two aspects in the context of Pakistan. This gap leaves uncertainty about whether green energy usage can mitigate the

adverse environmental outcomes of urbanization, especially in the broader context of economic expansion. Hence, this analysis seeks to analyze the impact of urbanization, green energy usage and economic growth on environmental deterioration in Pakistan. The findings of current study will clarify whether green energy can balance the environmental costs of Metropolitan expansion in the pursuit of economic development. Hence, the objectives of the study are the following:

1. To analyze the Influences of urbanization on CO_2 release.
2. To analyze the impact of renewable energy consumption on CO_2 release.
3. To examine the impact of Economic growth on CO_2 release.
4. To identify relationships between urbanization, renewable energy consumption, economic growth and CO_2 release.

To explore these objectives, we suggested following research questions:

1. How does urbanization affect environmental influence on CO_2 release?
2. How does green energy impact CO_2 release?
3. How does economic growth influence CO_2 release?
4. What is the relationship between urbanization, green energy, economic growth, and CO_2 release?

2. Literature Review

Barriga Cabanillas et al., (2025) re-examined the issue of urbanization in Pakistan by employing satellite imagery alongside the Degree of Urbanization framework. His findings are quite different from official population census. The official records estimate that 39 percent of the people live in urban areas, the study claims that the actual share of population living in urban areas is near to 88 percent. This wide gap is created due to the use of administrative definitions that fail to capture real settlement patterns and population density. They argue that recent urban growth is being driven by secondary cities and peri-urban zones rather than major cities. The official census excluded them from formal urban

categories. Such inconsistencies between functional and administrative definitions carry serious implications for urban planning and fiscal capacity, as the residents of misclassified areas do not have to pay property tax. Liu and Bae (2018) studied the relationship between economic growth at the individual level and the degree of Metropolitan expansion and its outcomes on CO_2 releases per person, energy severity, industrialization and Metropolitan expansion in China from 1970 to 2015. By using vector auto regression methodology and the vector error correction model, they captured system integration, short- and long-term relationship. Long run results suggested that 1% positive change in CO_2 release is associated with an increase in real GDP, energy severity, industrialization, and Metropolitan expansion by 1.1%, 0.6%, 0.3% and 1.0%, respectively. There exists long-run response Granger causality in releases, real GDP and industrialization. Gasimli et al. (2019) studied how energy, trade, urban expansion, and the environment interact with each other in Sri Lanka. In this analysis, they used time series statistics to see if there were problems with unit roots and hidden structural breaks. About structural breaks, long run relationships were confirmed with bounds testing that included carbon releases, energy resource depletion, income level, trade liberalization, urbanization. Both the long and short run outcomes indicate that there is an increase in carbon release with energy depletion. Rahman & Alam (2021) discussed the connection of clean energy, population density, urbanization and their impacts on environmental pollution in Bangladesh using data from 1973 to 2014. These techniques revealed that while the use of clean energy improved environmental quality, other variables such as population density, Metropolitan expansion, and economic growth had a negative effect on the environment. A unidirectional relationship of CO_2 emissions was identified with clean energy, economic growth, and urbanization. Wang et al. (2021) examined the effect of urbanization on Cabon dioxide release in developing countries which is one of the most pressing issues. The concern is

even greater in Ghana because the Ghanaian government recently set goals for higher economic growth alongside lower carbon emission. Kwakwa, et al. (2023) also studied the carbon dioxide release in Ghana concerning the phenomena of urbanization, fertilizer application, foreign direct investment (FDI), and the evolution of information and communication technology (ICT). The analysis spanned from 1971 to 2018 and applied the autoregressive distributed lag regression technique on time series statistics to test the environmental Kuznets curve (EKC) research. The findings state that even though the EKC hypothesis is unsupported for total carbon releases, urbanization negatively impacts total carbon release and efficiently assists in decreasing development, while FDI and ICT infrastructure negatively affect it in the long and short run. Urbanization and fertilizer applications interact to assist in the reduction of carbon releases, both total and sectorial. Although ICT contributes to lowering release in certain sectors, it was insufficient to reduce overall emissions significantly. Ali et al. (2019) examined the impact of Metropolitan expansion on CO_2 release in Pakistan using time series data from 1972 to 2014. The outcomes showed that urbanization and carbon release were causally correlated. There was a one-way short-term causal link in 5 years between urbanization and CO2 emissions. Othman & Ali Bakht (2017) analyzed the relationship between CO2 release and economic growth, domestic investments, energy consumption, urban expansion and financial development. They used VECM Granger causality together with the F-bounds test. They confirmed the long, inverted U-shaped relationship between CO2 release and Metropolitan expansion. Azam and Khan (2016) also investigated the relationship of urbanization and environmental decline, measured by carbon dioxide releases, in four South Asian Association for Regional Cooperation (SAARC) countries—India, Bangladesh, Sri Lanka, and Pakistan utilizing annual time series data from 1982 to 2013 and employing Ordinary Least Square (OLS) method. Their finding reveals that Urbanization and the environment had a negative association in Bangladesh and India,

whereas during the analysis period, Sri Lanka and Pakistan experienced significant positive effects, respectively.

2.1 Nexus between Green Energy Resources and Environmental Quality

Baek (2016) investigated the impacts of nuclear and renewable energy consumption on CO_2 release, given certain levels of income and energy use in the United States. The ARDL model was used to analyze data from 1960 to 2010. Their findings indicated that the use of nuclear energy does indeed lead to a decrease in CO2 emissions both in the short term and the long term, whereas renewable energy only contributes to a reduction in the short term. Additionally, they observed that an increase in per capita income results in higher CO_2 release over the long term. These findings align with the Environmental Kuznets Curve (EKC) in the short term. Lastly, energy consumption was found to negatively influence the reduction of CO2 release in both short and long terms. Paramati et al. (2017) investigated the link between green energy, economic growth and CO2 release in G20 countries. The analysis of panel data showed that the use of green energy significantly lowers CO_2 release and accelerates economic growth. These findings provide policy implications to replace traditional energy sources (coal, gas and oil) with green energy sources in response to growing energy demands. It will lower CO_2 release and foster balanced economic growth in the G20 countries. Saidi and Omri (2020) analyzed how renewables affect carbon release and economic growth across 15 countries that consume a lot of green energy. They applied VECM and FMOLS methods. With FMOLS, they also highlight that there is an economic upswing during periods when carbon releases are declining. In addition, the authors demonstrated, by means of the VECM Granger causality test, that during both short and the long run, economic upswings were causally triggered by green energy; however, in the long run, the release of CO_2 was causally neutral, while in the short run, it was green energy that was causally effective. In addition, they also noted the existence of a bidirectional

causality relation between economic upswing and the release of CO_2 in the short and long run.

2.2. Nexus between Economic Growth and Environment

Apergis and Payne (2019) studied the link between economic growth and CO_2 release during the period spanning from 1995 to 2016 in OECD countries. They confirmed Environmental Kuznets Curve (EKC) hypothesis, which states that CO_2 increases in the early stages of economic upswing, but decreases when per capita income reached certain threshold. They detected bidirectional causality which indicates that economic upswing has an influence over releases, and the environment also demands change in economic activities. They argue that the diffusion and innovation of green technologies play a critical role in facilitating the EKC turning point. They proposed more proactive approaches, like decreases in the cost of carbon mechanisms supported by policies, carbon priced policies, investments in renewables resources, and robust energy efficiency improvements, as a way of more efficiently mitigating releases. Nasir and Rehman (2019) disclosed how economic progress affected CO_2 release across South Asian countries using time series data spanning from 1990 to 2015 and employing panel statistics model, they identified a nonlinear confirming the Environmental Kuznets Curve (EKC) hypothesis whereby CO_2 release grow with economic expansion but decline after a specific income threshold. They suggested that Policy framework should focus on the implementation of more stringent release limit policies, the evolution of energy efficiency, and the construction of green energy facilities. The authors highlighted the need for regional cooperation to exchange best evolution and balanced practice strategies.

In the light of reviewed literature, we framed the following null and alternate hypotheses for testing through time series data and statistical methods:

Ho: Urbanization negatively correlates with CO_2 release.

H_1: Urbanization positively correlates with CO_2 release.

Ho: Renewable Energy use negatively correlates with CO_2 release.

H_1: Renewable Energy use positively correlates with CO_2 release.

Ho: Economic growth positively correlates with CO_2 release.

H_1: Economic growth negatively correlates with CO_2 release.

All reviewed studies provide conflicting findings, providing no clear direction in how the issue of rising CO_2 release can be addressed. It implies that there are significant gaps in academic literature which demand further deeper investigation to identify the link between CO_2 release, environmental quality and economic growth, which is the focus of this study.

3. Data and Methodology

This analysis examines how urbanization and use of green energy impact environmental decline in Pakistan. For this analysis, we used 34 years data spanning from 1990 to 2024 and employed the ARDL approach, which is an effective technique in handling small statistics samples and full usage in identifying the cointegration relationship among variables which justified whether our analysis will be helpful for the future research or will be useful to manage current period energy and environmental issues. The variables, their definitions and sources are presented in Table 1.

Table 1:

List of Variables and their Description.

Variables	**Description**	**Sources**
CO2	Carbon dioxide emission (% change from 1990)	WDI (2025)
URB	Urban population growth (annual %)	WDI (2025)
REC	Renewable energy Consumption (% total energy usage)	WDI (2025)

GDP	Gross domestic product growth (annual %)	WDI (2025)

Source: The Author

We constructed an econometric model to estimate the cointegration between Urbanization, Renewable Energy use, GDP and CO2 release. Co2 release is dependent variable while all other variables are independent. The model is expressed in the following equation:

$$CO2 = \beta 0 + \beta_1 URB + \beta_2 REN + \beta_3 GDP + \epsilon$$

Where:

CO_2 = Carbon emission is dependent variable.

URB = Urbanization is independent variable.

REN = Renewable energy consumption is independent variable

GDP = Gross domestic product growth is controlled variable.

ϵ = Error term

The analysis used E-Views software to specify the econometric model. This model will explore the relationships between urbanization, green energy usage, Economic growth and CO2 emissions, which is proxied for environmental quality. We used different statistical tools for computing numerical results. These include:

- Descriptive statistics to summarize data.
- Unit root tests to check the stationarity of variables.
- ARDL Bound testing approach to examine trends over time.
- Diagnostic tests for heteroscedasticity and autocorrelation**.**
- Tests to diagnose the stability of models.

The conceptual model based on selected variables is shown in Figure 5.

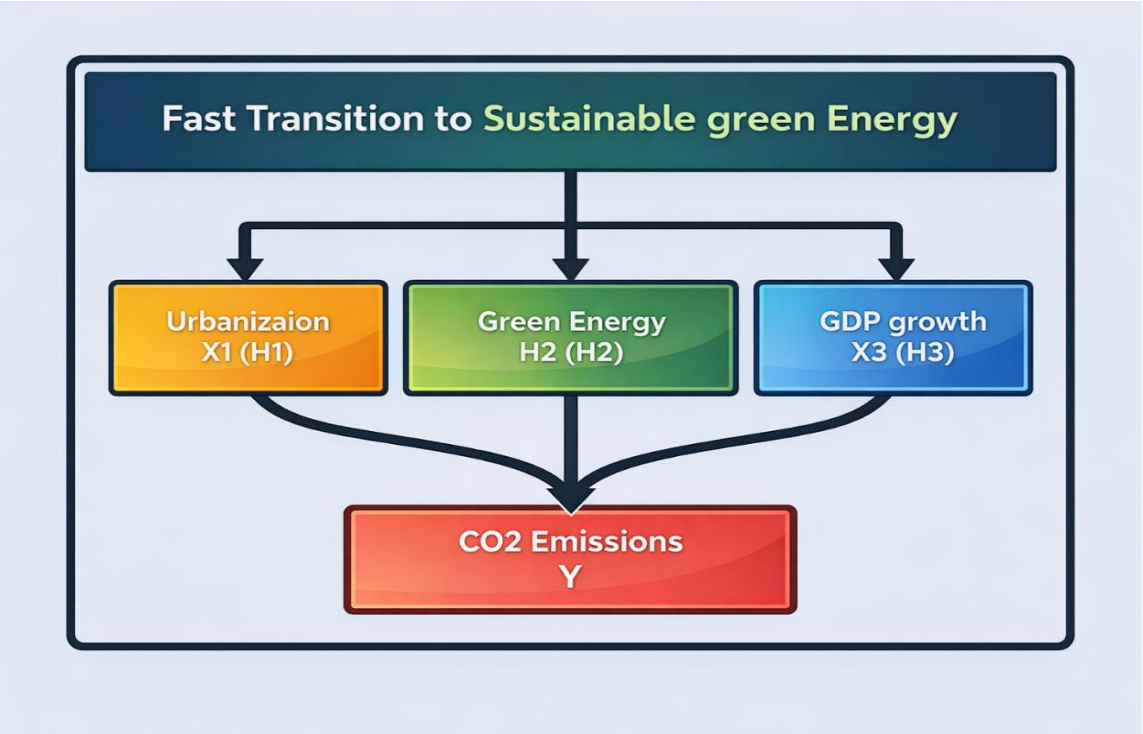


Fig 5: Hypothesized Model

4. Results

4.1 Descriptive Statistics

Table 2 provides descriptive statistics which show that all the variables are normally distributed. Descriptive statistics also confirm that the statistics are appropriate for time series analysis. The values for skewness, kurtosis, and the Jarque-Bera test show that the variables CO_2, URB, REC, and GDP follow a normal distribution, which supports the reliability of further econometric estimations. The mean and standard deviation values further indicated stable behavior of the variables over the observed period, without extreme outliers or abnormal volatility.

Table 2:

Descriptive statistics

	CO2	URB	REC	GDP
Mean	155.6281	2.677451	46.06786	3.995366
Median	144.9923	2.623998	46.60000	4.217942
Maximum	260.7671	3.429947	51.50000	7.831256
Minimum	70.46979	1.877864	41.23571	-1.274087
Std. Dev.	55.64543	0.476189	3.138562	2.162462
Skewness	0.113516	-0.077228	0.049670	-0.407543
Kurtosis	2.041850	1.735301	2.076568	3.098486
Jarque-Bera	1.009996	1.690958	0.898537	0.702150
Probability	0.603507	0.429352	0.638095	0.703931
Sum	3890.703	66.93628	1151.696	99.88415
Sum Sq. Dev.	74313.95	5.442154	236.4137	112.2298
Observations	25	25	25	25

Source: Author own calculations using E-view software**.**

4.2 Correlation Analysis

We used Correlation Matrix to determine the nature of association between pairs of variables. It implies that when a variable increases another variable also increases in the same direction or vice versa. The estimated results are shown in Table 3.

Table 3:

Correlation Matrix results

	CO2	**URB**	**REC**	**GDP**
CO2	1	-0.68394	-0.91928	-0.1600456

URB	-0.6839428	1	0.592321	-0.0048734
REC	-0.919284	0.59232	1	0.112133
GDP	-0.1600456	-0.0048718	0.112131	1

Source: Author own calculation using E-view software.

The correlation analysis indicated that there are important relationships between some variables. In particular, the strongest negative correlation was noted between CO_2 release and green energy consumed (REC) and metropolitan expansion. This means that when more green energy is utilized and urban expansion is increased, CO_2 release may be low. There is no evidence to establish cause and effects.

4.3 Unit Root Test

Two tests are generally used to identify stationarity among variables. These are ADF and PP tests, which we employ to check stationarity. Their findings are presented in Table 4.

Table 4:

Findings of ADF and PP Test

Variables	**ADF**		**PP**	
	Level	**1st Difference**	**Level**	**1st Difference**
CO2	0.7637	0.0001	0.7578	0.0002
URB	0.4983	0.0079	0.4716	0.0954
REC	0.5753	0.0015	0.6814	0.0000
GDP	0.0109	0.0001	0.0116	0.0000

Source: Author own calculations using E-view software.

Before using the ARDL model for identifying the long-term relationship between the variables, first, we check if the variables are stationary. Time series data sometimes suffers stationary issues and Unit Root tests are employed to detect it. The outcome of the ADF-

based unit root test shows some variables do display the unit root problem in the case of the level examination of variables. On the other hand, the first difference of analysis shows all variables are free from unit root problem. Among our variables, only GDP is stationary at levels, meaning all other variables are non-stationary, which means that at difference of the first all other variables are stationary. Hence, this allows us to use ARDL approach for further analysis.

4.4. Bound test

This test is used to check long-term cointegration among variables (Narayan, (2005). The findings of this test are shown in Table 5.

Table 5:

ARDL Bounds test.

F-Bounds Test	Null Hypothesis: No levels relationship			
Test Statistic	Value	Significance.	I (0)	I (1)
F-statistic	10.97765	10%	2.37	3.2
K		5%	2.79	3.67
		2.5%	3.15	4.08
		1%	3.65	4.66

Source: Author own calculation using E-view Software.

The results of Bounds test confirm the existence of a long run cointegration among the variables. Since computed F-statistic (10.98) exceeded all the upper bound critical values at the conventional significance levels, the null hypothesis, which states that there is no long-term association, is rejected.

4.5 ARDL Model for long-term relationships

The Autoregressive Distributed Lag (ARDL) model is widely employed in econometric analysis because it is the most suited for identifying long-run relationships among variables, particularly when they are integrated into different orders, i.e., I (0) and I (1). Contrary to traditional

cointegration methods, the ARDL approach does require that all variables must be integrated at the same level, making it particularly useful in applied research with limited time-series observations. These characteristics make the ARDL framework a robust and flexible tool for analyzing economic, financial, and environmental relationships, especially in developing-country like Pakistan where data constraints are common (Pesaran, Shin, & Smith, 2001; Narayan, 2005). Table 6 demonstrate long-term findings of ARDL model.

Table 6:

ARDL model estimated Outcomes.

Levels Equation				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
URB	-40.81376	7.594318	-5.374249	0.0001
REC	-12.53560	1.497585	-8.370547	0.0000
GDP	-9.179343	2.147330	-4.274771	0.0008
C	888.9623	53.84714	16.50900	0.0000

***Dependent variable is CO_2 emissions**

Source: Author own calculation using E-view Software.

In the ARDL long-run estimation, the outcomes show that all independent variables have statistically significant negative coefficients. Increases in urbanization, green energy consumption, and GDP are associated with decreases in CO_2 releases by 40.81%, 12.53%, and 9.17% respectively. It means that a one unit increase in urbanization leads to 40.81 decrease in environmental degradation. Similarly, a one unit increase in renewable (green) energy consumption is associated with a decrease in CO_2 emissions by 12.53% eventually. Further, a one unit increase in GDP growth is associated with a decrease in CO2 emissions by 9.17% in the long-term if all other factors remain constant. Hence, all three null

hypotheses are validated by empirical analysis. These findings underscore the potential of balanced urban development, clean energy transitions, and economic growth to mitigate environmental decline. These findings also support *Adaptive management theory developed by* Holling (1978) and further refined by Walters, 1986) which regards the importance of the continuing learning process, flexibility and adaptability in response to change and uncertainty, emphasizing that the policymakers and managers of the economy should design the policies and initiatives to manage and modify the human systems and ecosystems on a regular basis to manage their negative effects. ARDL long-term unique impact of urbanization, green energy consumption and GDP growth is highlighted in Figure 6.

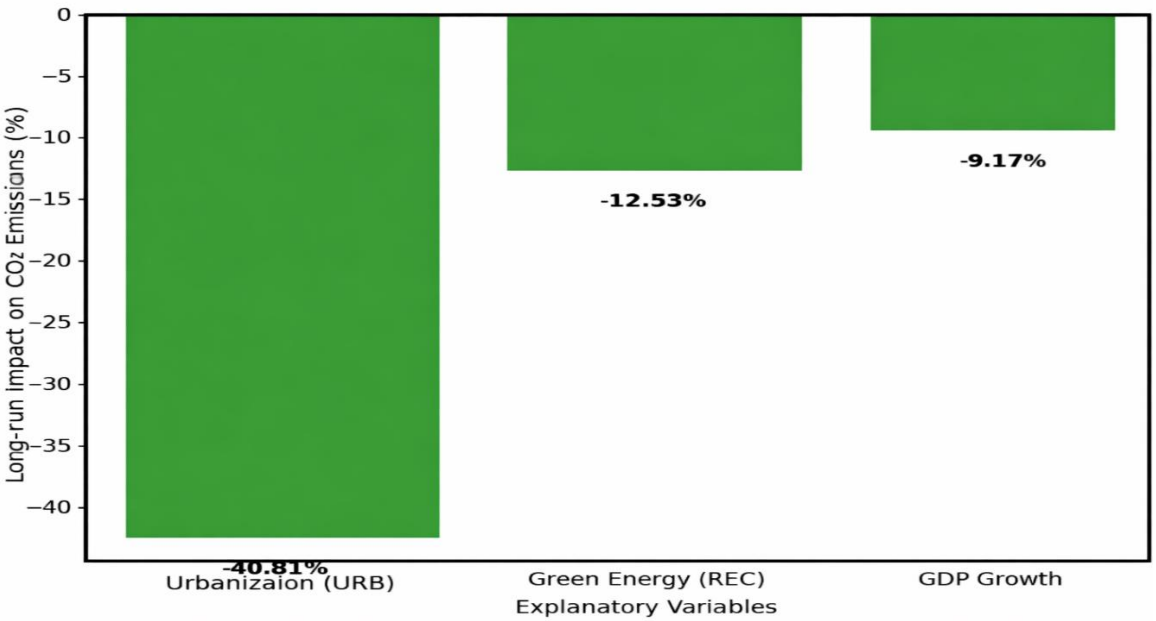


Fig. 6: Long-term Unique impact of explanatory variables on CO2 emissions**.**

The long-term green energy transition shown in the above figure highlight the fact that Pakistan is rapidly moving towards green energy sustainability**.**

4.6 Error correction Model

This Model (ECM) is widely employed in empirical analysis to identify the short-run dynamics of a system while ensuring consistency in its long-run equilibrium relationship. When variables are cointegrated, deviations from long-run equilibrium may occur place in the short run; this model includes an error-correction term which denotes the speed at which these deviations are corrected over time. This permits scholars to differentiate between short-term adjustments and long-term causal links among variables, reflecting a more realistic representation of economic behavior. In fact, the ECM is a valuable tool, which is commonly used in time-series analysis for understanding both equilibrium restoration and quick interactions among variables as suggested by Engle & Granger, (1987) and Banerjee et al., 1993). Table 7 shows the estimated results of ECM.

Table 7:

Error Correction Model Results

Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(URB)	7.412291	11.86367	0.624789	0.5422
D (URB (-1))	40.20946	15.42314	2.607085	0.0207
D(GDP)	-1.816104	0.705515	-2.574154	0.0221
D (GDP (-1))	2.478002	0.798159	3.104649	0.0078
CointEq (-1) *	-0.776129	0.092389	-8.400631	0.0000

Source: Author own calculation using E-view software.

Using ECM to examine the short-run dynamics reveals that the long-run findings are still valid. The existence of a long-run equilibrium is confirmed by negative error correction term (CointEq (-1)) value of -0.776. Such a coefficient value indicates that 77.60% of short-run disequilibrium is balanced, on average, within one period. In the short term, CO_2

release respond immediately to GDP and to lagged urbanization, both of which are statistically significant predictors in the model.

4.7. Diagnostic tests

4.7.1 Multicollinearity Test

Multicollinearity is the problem and if it exists in the model and regressors are correlated with each other, then the findings of regression analysis would be spurious. Variance Inflation Factor toll is used to detect this issue. The estimated results of VIF are provided in Table 8.

Table 8:

Variance inflation Factor

	Coefficient	Uncentred	Centered
Variable	Variance	VIF	VIF
CO2 (-1)	0.011912	56.91620	6.480160
URB	45.83180	58.41490	1.639407
REC	3.860317	1448.484	5.452555
GDP	1.426862	5.187243	1.179719
C	12026.35	2127.728	NA

Source: Author own calculation using E-View Software.

This test shows that there is no multicollinearity among the variables and further analysis can be conducted.

4.7.2 Diagnostic tests

We used different tests are used to check the issues of Heteroscedasticity and Serial correlation and correct model specification. The findings of these tests are given in Table 9.

Table 9:

Results of Diagnostic Tests

Names of tests	**Prob-Values**	**Findings**
Heteroscedasticity (Breusch-pagan-Godfrey)	0.7590	Data is free from problem of heteroscedasticity.
Serial Correlation (Breusch-Godfrey Serial Correlation LM test.	0.5246	Data is free from problem of serial correlation.
Ramsey Reset Test	0.3356	Model is correctly specified.

Source: Author own calculation using E-view Software.

The results indicate that there is no severe problem of heteroscedascity, Serial correlation and misspecification of model (Ramsey, (1969).

4.7.2 Normality test

This test used to check normal distribution of residuals. The estimated findings are plotted in Figure 7.

Fig 7: Normal distribution of residuals.

Fig. 6: The probability value of Jarque-Bera is insignificant, so it means model's residuals are normally distributed.

4.7.2 Stability tests

We used the CUSUM and CUSUM of squares tests to check stability of model and consistency in the data over the period of study. The outcomes of this model show that it is stable, which is indicated by the CUSUM and CUSUM of squares which show the blue line remains between two red lines. The stability of the statistics is illustrated in Figure 8 and 9.

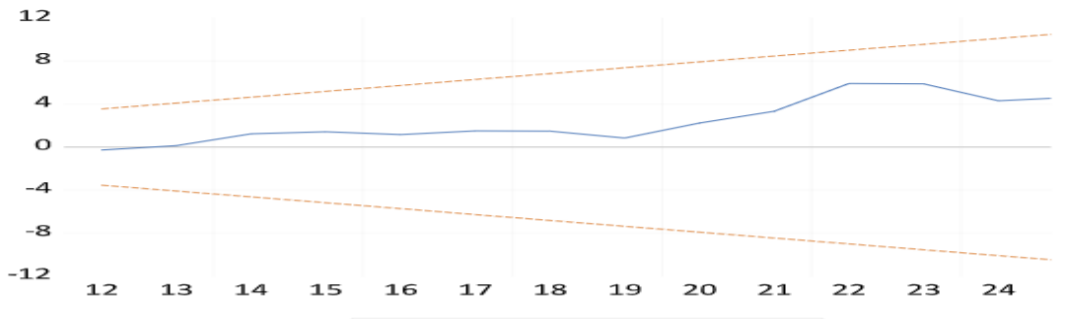
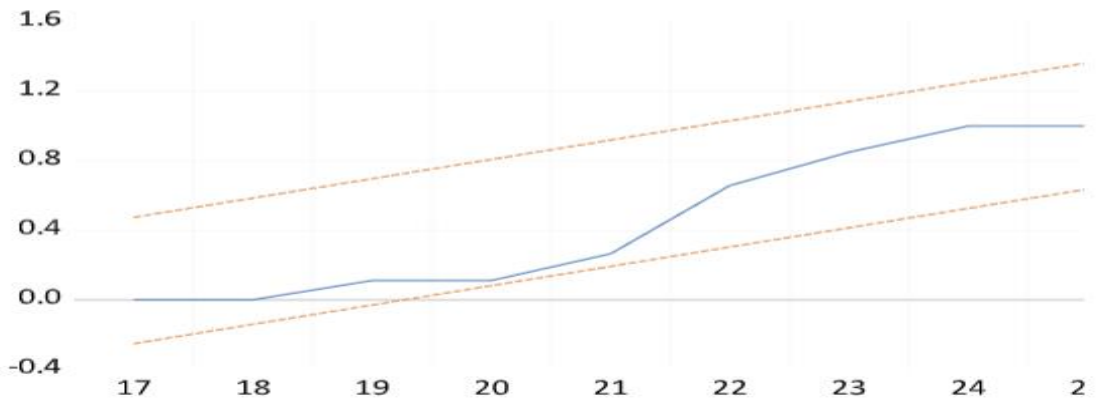


Fig 8: CUSUM test results



: **Fig 9:** CUSUM Square test results.

Source: Authors draw these two diagrams using E-view software.

5. Findings

The empirical analysis offers a rigorous examination of the dynamic relationship between environmental deterioration (measured by CO_2 emissions), urbanization (URB), renewable energy use (REC), and economic growth (GDP) using a robust econometric framework. The ARDL long-run findings reveal that explanatory variables, urbanization (URB), renewable energy consumption (REC), and gross domestic product (GDP) have a significant negative link with CO_2 emissions at the 1% significance level. The coefficient for urbanization (-40.81) shows that an increase in the urban population is associated with a substantial decrease in CO_2 emissions. This finding confirms the environmental benefits of urban agglomeration, such as increasing energy efficiency, appropriated infrastructure, and strong environmental regulations in urbanized regions. These findings are corroborated with Ma and Ogata (2024), Ragged (2018) Wang & liu et al. (2021) Pan &Ashraf et al. (2023) Ali. Rahim & Ribadu (2017). In the same way, renewable energy use shows a strong negative link with CO_2 release (coefficient = -12.53), suggesting the effectiveness of clean energy sources in reducing environmental footprints. These findings corroborated other studies such as Nathanial et al. (2020), Kahia et al (2021), Kusiyah et al (2023) Dong et al. (2019) Baek (2016). GDP also shows a negative and significant coefficient (-9.17), suggesting that economic growth, under certain conditions, contributes to environmental quality. The findings support the *Environmental Kuznets Curve* (EKC)-type relationship, wherein economic development promotes investment in green technologies, environmental regulations, and energy efficiency. Overall, the long-run results predict that urban planning, renewable energy adoption, and economic growth can play a key role in minimizing CO_2 emissions in the long-term.

5.1 Theoretical contributions

The results of this study are in line with the theoretical framework outlined in the *Environmental Kuznets Curve* (EKC), *Ecological Modernization Theory* (EMT) and *Adaptive management theory.* The negative significant coefficient of GDP in the analysis suggests that the country may have touched the EKC turning point, where further economic growth contributes to environmental improvement. Similarly, the negative link between urbanization and CO_2 release aligns with EMT's assumption that urban development, when accompanied by latest infrastructure and strong governance, can gear up environmental sustainability. Furthermore, the inverse link between renewable energy use and CO_2 emissions reinforces the theoretical approach that green energy adoption is central to decarbonization efforts. Similarly, *Adaptive management theory* postulates that changes can be managed to create balance between environment-growth nexus. In short, the findings validate these theories in the context of this study, proving that urbanization, clean energy transition, and economic development under proper institutional and policy frameworks can be compatible with environmental protection.

5.2 Policy implications

This study identifies numerous policy implications to guide strategies for balanced economic growth and environmental safety. Key recommendations include promoting balanced urbanization through compact city development, public transportation networks, and green infrastructure, supported by smart city initiatives and energy-efficient building codes. Accelerating green energy deployment via incentives for renewables, grid modernization, and rural electrification is essential, alongside fostering green economic growth through industrial policies that prioritize clean technologies and a shift to service-based sectors. Strengthening environmental regulation with emission standards, capacity building, and public awareness, as well as encouraging innovation in clean technology through R&D funding and public-private partnerships, are also emphasized. These policy

measures align with the study's empirical findings and support integrated UN's Sustainable Development Goals, particularly SDG 7 suggests *Affordable and Clean Energy*, SDG 11 suggests *Sustainable Cities and Communities,* and SDG 13 proposes *Climate Action*. By implementing urban planning initiatives, expanding green energy adoption, and pursuing balanced economic policies, the nation can advance toward a low-carbon economy while maintaining economic robustness.

5.3. Limitations and ideas for further research

Despite the valuable insights about urbanization, green energy use, economic growth and the decline of CO_2 release in Pakistan. This study has some limitations. The analysis examines CO_2 release in isolation as the only metric for assessing the decline of the environmental footprints. Other factors, such as the decline of the ambient air, pollution of the water bodies, or loss of the environmental quality due to deforestation, were excluded due to unavailability of latest data and time constraints. The urbanization dimension of the analysis is based only on the growth of the urban population, which does not capture the full complexity of the varied dimensions of urbanization. The analysis does not conduct a regional or international comparison, implies that the findings emanating from this research may not be generalized to other nations that may possess varying levels of development, socioeconomics, or energy usage. Additionally, the influence of urbanization, green energy usage, and the environment of issues such as industrialization, technological development, energy costs, and government policy were ignored to focus on selected issues.

Considering the findings and the limitations of this research, several avenues have been identified for future studies. For instance, an important way future research could broaden the scope to examine various dimensions of environmental decline, including measuring air quality, levels of water pollution, and deforestation, to advance the comprehensiveness of the analysis. Moreover, case studies of major urban centers in

Pakistan (e.g., Karachi, Lahore, Islamabad) could provide city-specific insights that national-level analysis may overlook. By pursuing these avenues, future studies can enrich the academic understanding of the nexus between urbanization, green energy consumption, economic growth and environmental sustainability, while also equipping policymakers with more nuanced strategies.

Data Availability statement:

The corresponding author will provide data, which is used in the findings of this study, on strong request.

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