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Research Article

A COMPARATIVE ANALYSIS OF RENEWABLE AND NON-RENEWABLE ENERGY RESOURCES IN PAKISTAN

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Abstract

The fossil fuels are being used excessively in Pakistan to meet growing energy demand without considering its negative effect on environment and the society. People cannot adopt renewable energy due to unaffordability and its high upfront cost. The primary objectives of this study is to compare renewable and non-renewable energy resources relationship with economic growth and to see how income inequality influences the adoption of renewable energy using a time series dataset spanning from 1986 to 2022 and employing dynamic ARDL-Error Correction modeling approach to determine short and long-term relationship between renewable, non-renewable energy resources, net per capita income and industrialization on economic growth. The study's findings reveal a negative link between non-renewable resources and economic growth both in short- and- long-term. However, a positive link was observed between renewable energy resources and economic growth, confirming Environmental Kuznets Curve hypothesis and providing valuable fresh insight for policymakers and stakeholders to focus on promotion of renewable energy resources to sustain economic growth.

Keywords: Renewable resources; nonrenewable resources; GDP growth; population growth. industrialization.

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1. Introduction

The global energy landscape is undergoing a significant shift from fossil fuel-based production and consumption to renewable energy sources, offering substantial benefits worldwide. Consumers, often burdened by high energy costs, are finding financial relief through the adoption of renewables. According to Juliana Marino (2024), switching to renewable energy sources like solar panels could save U.S. consumers up to $1,500 annually, while significantly cutting greenhouse gas emissions. A survey conducted by Lawrence Berkeley National Laboratory, which included 500,000 U.S. households, found that the median household saved $691 per year by using solar energy. Additionally, the Los Angeles Times reported a 2.4% reduction in California's emissions due to cleaner fuels and increased use of electric vehicles. However, Roth (2020) notes that clean energy initiatives disproportionately benefit wealthier households. Research from California indicates that affluent families, particularly white households, tend to consume more energy to meet their needs, while low-income families lack financial resources to purchase expensive clean energy systems. As a result, they end up paying a higher percentage of their income on electricity bills. This disparity is not confined to the U.S.; high costs and policies favoring the wealthy class also preventing from clean energy adoption by low-income populations in countries like Pakistan. Some scholars argue that renewable energy sources are inexhaustible, as their supply is not diminished through use. Wind continues to blow, the sun shines daily, and water remains in motion, providing a consistent and sustainable energy supply. In contrast, non-renewable resources are finite, having formed over hundreds of thousands of years under immense pressure from organic material. Extracting these resources is not only costly and time-intensive but also environmentally destructive (Asif, 2022).

The global shift toward renewable energy aligns with the UN's Sustainable Development goals. In 2020 alone, the world's renewable energy capacity grew by 45%, in China and the United States contributing over 92 and 19 gigawatts, respectively (International Energy Agency, 2022). During the same period, coal consumption fell by 4%. According to the U.S. National Renewable Energy Lab, the country's energy infrastructure could transition to 80% renewables by 2030, with the potential to reach 100% and achieve the UN's zero-emission target by 2050. Similarly, a study by Finland's LUT University, in collaboration with the Energy Watch Group, outlines a roadmap for the global transition to 100% renewable energy by 2050 (Anser et al., 2020).

A joint study by the International Energy Agency (IEA) and Imperial College London (2022) highlights the superior return on investment (ROI) for renewable energy compared to fossil fuels in the U.K., U.S., and the European Union over 5- to 10-year periods. In Germany and France, the average ROI for renewables was 20.7% and 178.2%, respectively (Baitanayeva et al., 2020). The U.K. and the U.S. recorded returns of 75.4% and around 200%, respectively, for renewables, compared to just 8.8% and 97.2% for fossil fuels during the same period (Burney, 2020). These figures demonstrate that renewable energy is not only cost-effective but also offers substantial financial returns, encouraging private energy firms in the U.S., EU, and China to increase their investments in green energy projects.

The cost of fossil fuels has risen sharply in recent years. In the first quarter of 2021, coal prices tripled, crude oil prices doubled, and natural gas prices increased sevenfold. The World Bank's energy price index rose by more than 76% between January 2020 and April 2022, marking the steepest increase since the 1970s (Pata, 2018a; Wei, Zhang, Wang, 2022). Energy prices are projected to remain high in the long term, disproportionately impacting poorer households globally. Some Western governments have implemented price caps, tax reductions, and rebates to

protect vulnerable consumers from soaring energy costs (Anser et al., 2020). In developing countries like Pakistan and India, however, energy prices have consistently exceeded average household incomes, making energy access a constant challenge (Hafeznia, 2017).

In Pakistan, the situation mirrors global trends, with increasing adoption of renewable energy due to soaring energy costs. Households that have switched to solar power have reduced their electricity bills by more than 80%. By August 2024, over 14% of households in Pakistan had adopted solar energy. As in developed countries, the primary beneficiaries of clean energy in Pakistan are also wealthy households capable of affording the upfront costs of solar panel installation, while much of the population continues to rely on expensive fossil fuels. Provincial governments are now offering subsidies and concessionary loans to encourage middle-income families to switch to solar energy (Ahmad & Wu, 2024). The industrial, agricultural, and services sectors in Pakistan are also moving toward solar and wind energy. The current research provides confusing and scattered findings. Hence, there is an urgent need to investigate the impact of renewables and non-renewable energy resources on economic growth in Pakistan. The primary objective of this study is to analyze the impact of renewable and nonrenewable energy resources on GDP growth. Other objective of the research is to assess the role of net per capita income in changing behavior of the people from non-renewable to renewable energy adoption and influence of industrialization on economic growth. To explore these objectives this study will address the following research questions:

RQ1: How do renewable and non-renewable energy resources influence economic growth?

RQ2: How does per capita income influence the behavior of people to adopt green technologies?

RQ3: How does industrialization and population growth influence economic growth?

The remainder of the paper is structured as follows: Section 2 reviews existing literature, identifies research gap, and highlights the novelty of the study. Section 3 delineates the data, empirical strategy, and econometric model employed to identify the relationship between renewable and non-renewable resources and other variables on economic growth. Section 4 presents the results and ensuing discussion, while Section 5 provides findings, theoretical contributions, limitations, and suggestions for future research.

2.Literature review and hypotheses development

2.1 Energy Resources and Economic Growth

Ahmad et al. (2022) underscores the pivotal role energy resources play in fostering economic growth and sustainability. The study pleads for a transition towards renewable energy sources, particularly in emerging nations like Pakistan, which faces severe energy crisis and high energy production and consumption costs. Abbasi et al. (2022) disclosed that Pakistan is bearing the cost of using fossil fuels just to accelerate economic growth, suggesting shifting this strategy. Erdogan and Okumus (2020) also concluded that high fossil fuels cost can be reduced by opting renewable energy sources and improving environmental quality. Tugcu et al. (2012) and Rahman et al. (2020) endorsed the findings of previous studies and concluded that renewable energy can play a crucial role in boosting financial development. Acaravci and Akalin (2017) further underscore the importance of increasing share of renewable energy in economic growth, while Gozgor et al. (2018) support this by highlighting the benefits of renewable energy to gain long-term sustainability.

2.2 Environmental impact of Energy Resources

Borzuei and Moosavian (2022) discuss the environmental benefits of green energy, arguing that it improves environmental quality by reducing greenhouse gas emissions. Wang Lei (2021) identified that the consumption of fossil fuels is detrimental to the environment, while renewable energy provides a cheaper and beneficial alternative for controlling CO_2 emissions. Chaudhary et al. (2021) analyzes the adverse impact of CO_2 emissions and nonrenewable resources on economic growth in Pakistan, aligning with these findings and emphasizing on the shifting of energy model as the world is moving towards green energy for sustainable growth.

2.3 Renewable vs. Nonrenewable Energy Sources

The discussion over the comparative impacts of renewable versus nonrenewable energy sources remains a hot topic among researchers. Rehman (2020), in his empirical analysis, used data from five Asian countries, found a positive association between economic growth and both energy types, though renewable energy emerges as the more beneficial and viable long-term option for sustainability. Expanding on this, Le and Chang (2020) used data from 102 countries and disclosed that renewable energy sources play a critical role in curbing emissions in developing countries compared to advanced nations. Sharif et al. (2019), in their study of 74 countries, further supports this idea by highlighting that renewable energy consumption helps significantly cut CO_2 emissions.

2.4 Energy Consumption and Economic growth

The link between energy consumption and economic growth has been extensively investigated by different scholars. Murad and Alam (2018), in their empirical study, examine the interplay between energy pricing, technological innovation, and economic growth, and conclude that long-term energy pricing and technological advancements negatively impact nonrenewable resources. The causal relationship

between FDI and energy is explored by Doytch & Narayan (2016), and they have identified that FDI accelerate economic growth, but it has no effect on the patterns of energy consumption. For example, Destek and Sinha (2020), in their cross-sectional analysis of selected 24 countries, found that trade openness as well as renewable energy have the potential to foster sustainable development.

2.5 Environmental Kuznets Curve and Energy Consumption

Some studies have employed the *Environmental Kuznets Curve (EKC) theory* to investigate relationship between energy consumption and environmental degradation The results from these studies are mixed. For instance, Dogan and Ozturk (2017) and Ulucak and Bilgili (2018) applied the EKC model to assess how GDP and energy consumption influence carbon emissions in the United States. They found that reliance on renewable energy helps cut emissions. In Pakistan, Danish et al. Based on Prado et al. (2017) acknowledged that CO2 originates from fossil fuels emphasizing upon the need of adopting green energy technologies to trim down environmental footprints. Awan & Yaseen, 2017; Haizam et al. (2018) also investigated the benefits of green energy technologies and identified that consumption of non-renewable sources is detrimental to environmental quality and human health and, therefore, they should be replaced with renewable energy sources.

2.6 Impact of Energy Resources on CO_2 Emissions

The close link between energy resources and CO_2 emissions has been established by empirical studies and it is still a dominant topic in current literature. Zaidi et al. (2018), in their empirical analysis, concluded that excessive use of fossil fuels is the main cause of CO_2 emissions in Pakistan, suggesting adopting non-fossil fuel strategy to resolve this issue. Jebli et al. (2016), in their study on OECD countries, found that fossil fuels consumption bolsters carbon emissions, while green energy and international trade to reduce it. Similarly, Dogan and Seker (2016) suggested

the adoption of cleaner energy to reduce environmental quality because they identified fossil fuel as a key driver of CO_2 emissions.

2.7 Impact of Population Growth on Environmental Quality

The scholar extensively explored the link between population growth and environment since Malthus (1798) warned of negative impact of population growth on per capita income and predicted diminishing return on agriculture production due to soil inelasticity. Solow (1956) supported this view, arguing that high population growth slows economic progress by necessitating higher investments to maintain output levels. Shi (2003) confirmed this theory by identifying a negative correlation between population growth, economic development, and environmental degradation. Ghanem (2018) also found that a 1% increase in population growth leads to a 2.4% rise in CO_2 emissions, which, in turn, increases the death rate. Wang (2021) conducted a cross-sectional study of 152 countries and concluded that CO_2 emissions are closely linked to aging, life expectancy, and population density, and that emissions adversely affect economic and environmental conditions.

2.8 Link between Net Per Capita Income and Environment

Carson et al. (1997) diagnose a link between income levels and environmental quality, suggesting that rising per capita income positively affects environmental conditions. Bah et al. (2020) explored this link in Sub-Saharan Africa, supporting the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental quality deteriorates during early stages of growth but improves once a certain income level is reached. Dogan and Inglesi-Lotz (2020) examined the relationship between GDP per capita and CO_2 emissions using data from 1993 to 2017. They found N-shaped relationship, where pollution initially increases but eventually decreases with rising income as is predicted by EKC. A concise overview of literature is summarized in Table 1.

Table 1

Summary of reviewed literature

Major topics	**Authors**	**Key Findings**
Energy Resources and Economic Growth	Ahmad et al. (2022), Abbasi et al. (2022), Erdogan & Okumus (2020), Tugcu et al. (2012), Rahman et al. (2020), Acaravci & Akalin (2017), Gozgor et al. (2018)	Renewable energy contributes to economic growth and sustainability, especially for developing countries. Shifting to renewable energy mitigates high energy costs and CO2 emissions.
Environmental Impact of Energy Resources	Borzuei & Moosavian (2022), Wang Lei (2021), Chaudhary et al. (2021)	Renewable energy improves environmental quality by reducing greenhouse gases. Nonrenewable energy resources negatively affect economic growth due to CO2 emissions.
Renewable vs. Nonrenewable Energy Sources	Rehman (2020), Le & Chang (2020), Sharif et al. (2019)	Renewable energy is better for long-term sustainability and mitigating emissions. Cross-sectional studies

Major topics	**Authors**	**Key Findings**
		show developing countries benefit more from renewable energy.
Energy Consumption and Economic Development	Murad & Alam (2018), Doytch & Narayan (2016), Destek & Sinha (2020)	Technological innovation reduces nonrenewable energy's role in economic growth. Trade openness combined with renewable energy drives sustainable development.
Environmental Kuznets Curve (EKC) and Energy Consumption	Dogan & Ozturk (2017), Ulucak & Bilgili (2018), Danish et al. (2017), Haizam et al. (2018)	EKC theory suggests economic growth initially increases emissions, but renewable energy reduces emissions in the long run, supporting environmental sustainability.
Impact of Energy Resources on CO2 Emissions	Zaidi et al. (2018), Jebli et al. (2016), Dogan & Seker (2016)	Nonrenewable energy increases CO2 emissions, while renewable energy helps mitigate them.

Major topics	Authors	Key Findings
Impact of Population Growth on Environmental Quality	Malthus (1798), Solow (1956), Shi (2003), Ghanem (2018), Wang (2021)	Population growth negatively impacts GDP and increases CO2 emissions. High population density and CO2 emissions are linked with lower life expectancy and aging issues.
Net Per Capita Income and Environmental Impact	Carson et al. (1997), Bah et al. (2020), Dogan & Inglesi-Lotz (2020)	Per capita income can positively impact environmental quality, with pollution decreasing as economies mature. EKC hypothesis is supported.
Research Gap and Novelty	Ahmad et al. (2022), Abbasi (2022), Li et al. (2022), Acar & Dincer (2014), Gokgoz (2018), Usman et al. (2011)	There is a need for long-term analysis of energy resources' impact on economic growth. Limited studies explore barriers to transitioning from nonrenewable to renewable energy.

Source: The Authors

2.9 Hypotheses development

In the light of objectives of study and reviewed literature the following hypotheses are proposed:

Ho: Renewable energy resources negatively correlate with GDP growth.

H_1: Renewable energy resources positively correlate with GDP growth.

Ho: Nonrenewable energy resources negatively associate with GDP growth.

H_1: Nonrenewable energy resources positively associate with GDP growth.

Ho: Net per capita income negatively correlates with GDP growth.

H_1: Net per capital income positively correlates with GDP growth.

Ho: Population growth negatively associates with GDP growth.

H_1: Population growth positively associates with GDP growth.

Ho: Industrialization negatively correlates with GDP growth.

H_1: Industrialization positively correlates with GDP growth.

2.10 Research gap

While considering the cited studies in the literature review, we find some specific research gaps within the limitations and findings of the research work of other scholars. Some scholars like Ahmad et al. (2022) and Chaudhary et al. (2021) focus on Pakistan's energy crisis. Similarly, the studies of Erdogan and Okumus (2020) emphasize on using renewables but do not address how small countries like Pakistan can eliminate fossil fuel subsidies without being given to low-income households. Most previous researchers (e.g., Tugcu et al., 2012; Rahman et al., 2020) advocated for renewable energy's microeconomic benefits but ignored distributional impacts, such as job losses in fossil fuel industry or energy poverty in rural areas during transition. For example, Sharif et al. (2019) highlight CO_2 reduction in 74 nations but ignores how renewable development might displace marginal communities or increase inequalities. Further, some scholars like Bah et al. (2020) and Dogan & Inglesi-Lotz (2020) analyzed EKC but found conflicting

results (inverted U-shaped vs N-shaped curves). Other scholars explored energy consumption, but they did not probe energy conservation awareness or cultural norms that influence emissions (Ghanem (2018) and Wang (2021); Solow (1956) and Shi (2003). There are some studies (Murad and Alam 2018; Awan, 2015; Doytch & Narayan (2016) on energy pricing and technology but lacks analysis on sector-specific decarbonization like agriculture vs. manufacturing or viability of green technologies (green hydrogen, carbon capture) in developing countries. Some studies (Abbasi et al., 2022) identified Pakistan's dependency on fossil fuel but failed to examine how political leadership will eliminate it in this existing of strong lobby in the country and abroad. Dogan and Ozturk (2017) and Haizam et al. (2018) assessed short-term renewable impacts. There are very few studies on long-term resilience systems (e.g., grid stability during climate shocks and maintenance cost of renewable infrastructure in the long run. None of the study examined grid maintenance cost. These gaps emphasize the need for nuanced, localized research than broad generalization specifically in the countries like Pakistan, which are more vulnerable to climate change. The specific study can provide fresh insights to policymakers and other stakeholders to frame evidence-based strategies to phase-out fossil fuel energy systems.

3. Data and Methodology

This study aims at comparing renewable and non-renewable energy resources along with other variables and their impact on economic growth in Pakistan, using time series data from 1986–2022 sourced from World Bank's World Development Indicators, Asian Development Bank, Pakistan Economic Survey and the State Bank of Pakistan. These sources are also popular and reputable in the study area as researchers use them extensively. GDP growth is the dependent variable and annual population growth, net per capita income, renewable and non-renewable energy

resources, industrialization are independent variables. These variables were adopted from various established studies. The variables, their definitions and sources are presented in Table 2.

Table 2

Selected variables, their definitions and sources

Variable	Definition	Source(s)
GDP growth	The annual percentage changes in a country's economic output.	Murad and Alam (2018); Tugcu et al. (2012); Rahman et al. (2020); Ahmad et al. (2022); Abbasi et al. (2022)
Renewable resources	Resources that can be naturally replenished on a human timescale, such as solar and wind energy.	Usman et al. (2011); Le and Chang (2020); Wang Lei (2021); Borzuei and Moosavian (2022)
Nonrenewable resources	Resources that are finite and cannot be replenished, such as fossil fuels and minerals.	Zaidi et al. (2018); Ulucak and Bilgili (2018); Dogan and Ozturk (2017); Dogan and Seker (2016)
Population growth	The increase in the number of individuals in a population over a specific period.	Malthas (1780); Solow (1956); Ghanem (2018); Wang (2021)
Net per capita income	The average income per person, adjusted to population size.	Wang (2020); Bah et al. (2020)
Industrialization	Manufacturing goods.	Ali, et al., (2020).

Source: The Author.

The study employed various statistical techniques, including descriptive statistics, correlation analysis, Augmented Dickey-Fuller (ADF) tests, Autoregressive Distributed Lag (ARDL) model, and Error Correction Model (ECM) to estimate both the short-and-long-term relationships between dependent and independent variables. These methods are widely recognized and frequently used in empirical research to investigate the interconnections between variables (Banerjee et al., 1993).

Descriptive statistics (mean, median, variance, standard deviation) were applied to describe the key features of the dataset. Going this way deals with reading data distribution, finding trends and detect potential outliers. Correlation analysis was used to determine the degree of relationships between variables represented as correlation coefficients. To assess the stationarity of time series data, and to detect the presence of unit roots, we conducted an Augmented Dicky-Filler test (ADF). This step is crucial since non-stationary data may provide spurious results. We used the Autoregressive Distributed Lag (ARDL) model to estimate the relationships between variables; this procedure is useful as it provides insight on short and long-run dynamics, in addition to considering the possible order of integration of each variable (such that they are I (0) or I (1)). This method is flexible in the sense that it can choose lags of variables interests. We also used Error Correction Models (ECM) to uncover short-term deviations from the long-run equilibrium, and to compute the speed of adjustment of variables towards their long-run equilibrium levels (Gujarati 2003).

3.1 Conceptual framework

The conceptual model built based on the objectives of study and reviewed literature showing hypothesized link between explanatory and explained variables is presented in Figure 1.

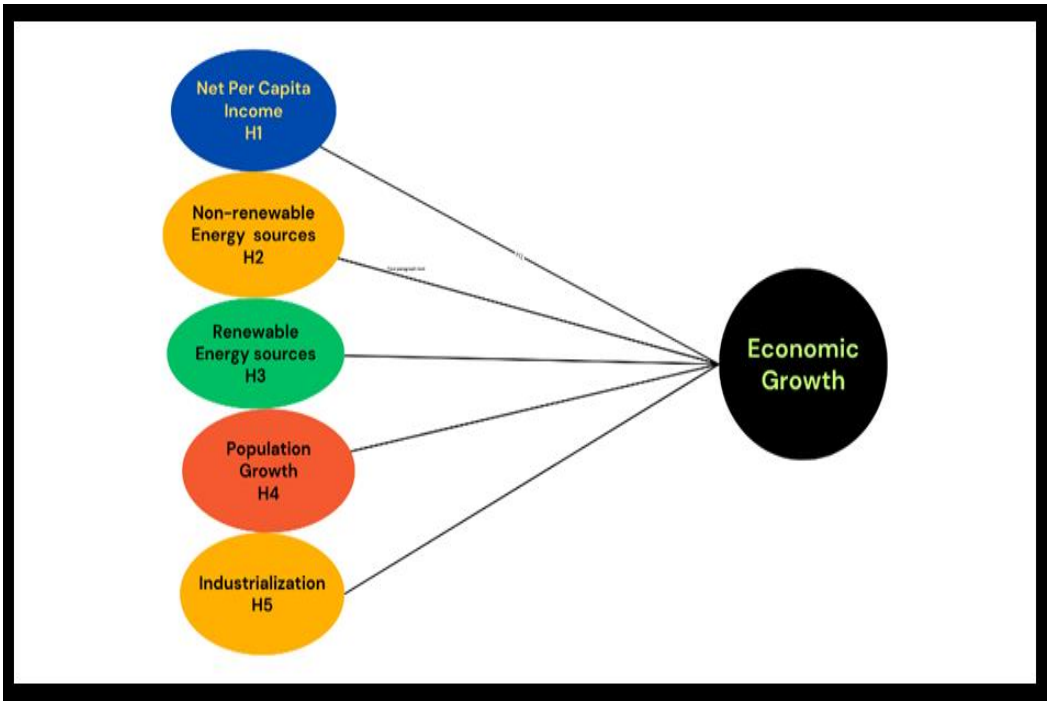

Fig. 1: Hypothesized model

3.2 Econometric model

The econometric model specified for this study is as follows: -

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + ut$$

Where:

Y = GDP growth.

b_0 = intercept.

X_1 = per capita income.

X_2 = nonrenewable energy resources.

X_3 = population growth.

X_4 = Industrialization growth.

X_5 = renewable energy resources.

Ut = Error term.

4. Results

4.1 Descriptive analysis

Descriptive technique is used to understand data, its patterns, trends and key characteristics of variables as suggested by Vetter, (2017). It explains big datasets and summarizes, such as average, measures of spread and distribution that enable us to explain the data easily. It also facilitates us to diagnose patterns, trends, and outliers in the dataset. It is often used as a first step in data analysis and provides a foundation for further analysis. We can make informed decisions based on the data if we understand its key characteristics. Table 3 shows the estimated results of descriptive statistics.

Table 3

Descriptive statistics results

	GDPG	NPCI	NRENG	RENG	POPG	INDG
Mean	4.9339	17.6647	30.3325	10934845.00	0.3024	42049.7000
Median	4.8465	17.9667	30.0800	2000000.00	0.3000	42325.5000
Maximum	10.2157	20.8183	32.9800	12100000.00	0.3700	77099.0000
Minimum	1.0144	14.1206	27.4600	0.0000	0.2500	6721.0000
Std. Dev.	2.0184	1.6504	1.8190	22389635.00	0.0292	24391.8500
Skewness	0.2250	-0.4086	0.2270	3.3371	0.2376	0.0132
Kurtosis	2.8269	2.1697	1.7331	1.1915	2.2880	1.5849

Source: Authors own calculation using E-views 9 software

The descriptive statistics highlight key insights into the behavior of various economic indicators. GDP growth (GDPG) exhibits a stable trend with minimal skewness and a platykurtic distribution, suggesting moderate fluctuations over time. Similarly, net per capita income (NPCI) reflects a consistent pattern, though its skewness indicates a slight concentration of higher values. Non-renewable

energy consumption (NRENG) shows low variation, with values clustering around the mean, while renewable energy consumption (RENG) demonstrates significant variability, as evidenced by a high standard deviation and strong positive skewness. This suggests that while renewable energy adoption is increasing, its distribution across different periods or regions remains uneven. Population growth (POPG) maintains a narrow range, indicative of steady demographic trends. Its low standard deviation and near-normal skewness point to consistent growth rates over time. Industrial growth (INDG), on the other hand, shows more variability, with a wide gap between its maximum and minimum values, reflecting differing levels of industrial activity. These findings suggest that while most economic and energy-related variables follow a stable pattern, significant variability exists in renewable energy consumption and industrial growth. Policymakers should focus on reducing volatility in these areas to ensure sustainable economic progress. Furthermore, efforts to balance energy consumption and improve per capita income could contribute to more stable and equitable economic development.

4.2 Correlation Matrix

Correlation matrix is employed to identify three types of relationship between two variables. These relationships may be positive, negative or zero. It lies between -1 (perfect negative correlation), +1 (perfect positive correlation) and 0 (no correlation). It provides invaluable visual representation of the relationships between multiple variables. It will also enable us to diagnose multicollinearity because high correlation between independent variables leads to unreliable regression models. Table 4 exhibits the estimated results of correlation matrix.

Table 4:

Correlation Matrix results

	GDPG	**GPCI**	**NRENG**	**RENG**	**POPG**	**INDG**
GDPG	1.0000					
GPCI	0.2292	1.0000				

NRENG	-0.0448	-0.6332	1.0000			
RENG	-0.0090	-0.5383	0.5589	1.0000		
POPG	0.1216	0.5788	-0.6933	-0.4048	1.0000	
IND	-0.4185	-0.6173	0.6092	0.5432	-0.4042	1.0000

Source: Authors own calculation using E-views 9 software.

Table 4 demonstrates that GDPG has negative correlation with NRENG and their correlation coefficient is -0.0448, GDPG has negative association with RENG, and their correlation coefficient is -0.0090, GDPG has positive correlation with POPG and their coefficient is 0.1216, GDPG has negative association with IND and their coefficient is -0.4185. GPCI has negative correlation with the NRENG that is -0.6332, GPCI has negative correlation with RENG that is -0.5383, GPCI has positive connection with POPG that is 0.5788 and it has negative correlation with INDG that is -0.6173. NRENG has positive correlation with RENG that is 0.5589, NRENG has negative correlation with POPG that is -0.6933 and NRENG has positive relationship with INDG that is 0.6092. RENG has negative association with POPG that is -0.4048 and it has positive correlation with IND that is 0.5432. POPG has negative relationship with IND that is -0.4042.

4.3 ADF Unit Root test

This test is used to check stationarity among variables to decide which econometric model should be used for data analysis. According to Dickey & Fuller, (1981), Ordinary Least Square (OLS) method is used if variables are stationary at level, if they are stationary at level and fist difference, then ARDL approach is used to analyze data. The results of ADF test are presented in Table 5.

Table 5

ADF Test results

Variables	Level (At Intercept)	Level (At Trend and Intercept)	1st Difference (At Intercept)	1st Difference (At Trend and Intercept)	Decision
GDPG	-4.903 (0.0036)	-5.118 (0.0062)	----------	--------	Stationary at level (Intercept)
NPCI	-1.777 (0.386)	-2.680 (0.249)	-7.145 (0.000)	-6.876 (0.000)	Stationary at 1st difference (Intercept)
NRENG	-5.816 (0.000)	-6.209 (0.000)	----------		Stationary at level (Intercept)
RENG	-4.741 (0.0004)	-3.988 (0.0035)	----------	----------	Stationary at level (Intercept)
POPG	-2.399 (0.9096)	0.158 (0.0998)	-5.927 (0.0043)	-4.639 (0.0037)	Stationary at 1st difference (Intercept)
IND	-2.420 (0.1425)	-0.239 (0.9899)	-2.182 (0.0215)	-0.431 (0.0029)	Stationary at 1st difference (Intercept)

Source: Authors own calculation using E-views 9 software.

The results show that the GDPG is stationary at level intercept. So, we do not accept our null hypothesis because no unit root problem exists. The variable net per capita income (NPCI) is stationary at 1st difference intercept with probability value 0.000. The variable Non-Renewable energy resources (NRENG) is stationary at level's intercept with probability value 0.0000. The next variable is Renewable energy resources (RENG), which is stationary at levels' intercept with probability value 0.0004. The Population growth rate (POPG) is found stationary at 1st difference intercept with probability value 0.0043, while Industrialization (IND) is found

stationary at 1st difference intercept with the probability value 0.0215, indicating no unit root problem exist, hence, we cannot accept null hypothesis. These results permit us to use ARDL model for further analysis.

4.4 ARDL Model

The Autoregressive Distributed Lag (ARDL) model is a common econometric method that allows us to analyze long-and short-run relationships among variables, in the case of those tool rooms involving non-stationary time series data as well (Pesaran & Shin, 1995). One of its primary features is the ability to bring variables of different orders of integration together unlike traditional tests such as Johansen test (Pesaran, Shin & Smith, 2001; (Johansen, 1995; Stock & Watson, 2015). The ARDL model is a popular tool used by researchers and analysts as it offers greater flexibility, ease of application and can much better accommodate diverse nature of data (Daniyal et al., 2023).The estimated results of the ARDL model are reported in Table 6.

Table 6

ARDL long-term estimates

Variables	Coefficient	Std. Error	t-Statistic	Prob. Value
NPCI	0.700009	0.000024	3.297668	0.0902
NRENG	-0.359300	0.162539	-2.211149	0.0364
RENG	1.108679	0.366610	3.024140	0.0059
POPG	0.070077	0.000023	3.340546	0.0207
IND	3.959728	28.424051	1.898383	0.0571
C	21.879041	16.091381	1.359675	0.1884

* Dependent Variable: Economic Growth (GDP growth)

Source: Authors own calculation using E-views 9 software.

The empirical results show that net per capital income is positively associated with GDP growth. It means a one unit increase in net per capita income is associated with an increase in GDP growth by 70% in the long term, if all other factors relation constant. These findings support (Hassan and S (2010) and Wahiba et al. (2014)]. However, nonrenewable resources have negative association with GDP growth, suggesting a one unit increase in nonrenewable energy is associated with a decrease in GDP growth by 35.93% in the long-term. These results are consistent both the findings of (Asiedu et al. (2021); Rahman et al. (2020). Renewable energy resources have positive association with GDP growth, indicating a one unit increase in renewable energy resources is associated with an increase of GDP growth by 11.08% in the long run. The findings of Rahman et al. (2020) and Asiedu et al. (2021) support these results. Population growth exhibits a positive association with GDP growth, suggesting that a one-unit increase in population growth rate is likely to lead to a 7% increase in GDP growth rate in the long run. These findings align with the results of Derek and Hodge (2009) and Dao and Quang (2019). Similarly, a positive relationship exists between industrialization and GDP growth. A one-unit increase in industrialization is likely to result in a 39.59% increase in GDP growth in the long run. These findings are also supported by the work of Jelilov et al. (2016) and Opoku et al. (2019).

Population growth exhibits a positive link with GDP growth, suggesting that a one-unit increase in population growth rate is likely to lead to a 7% increase in GDP growth rate in the long run. These findings align with the results of Derek and Hodge (2009) and Dao and Quang (2019). Similarly, a positive relationship exists between industrialization and GDP growth. A one-unit increase in industrialization is likely to result in a 39.59% increase in GDP growth in the long run. These findings are also supported by the work of Jelilov et al. (2016) and Opoku et al. (2019). Population growth is positively correlated with GDP growth. A one-unit

increase in the population growth rate is associated with a 7% increase in the long-term GDP growth rate. These findings are consistent with the results of Derek and Hodge (2009) and Dao and Quang (2019). Similarly, industrialization is positively correlated with GDP growth. A one-unit increase in industrialization is associated with a 39.59% increase in long-term GDP growth. These findings are also supported by the work of Jelilov et al. (2016) and Opoku et al. (2019).

4.4 Error Correction Model

The Error Correction Model (ECM) is an integral part of the ARDL approach, used to identify stationarity in time series data and to understand how short-term deviations of variables adjust back to their long-run equilibrium level after experiencing temporary shocks (Banerjee, 1998). It combines short-run adjustments with long-run equilibrium paths, revealing how variables respond to both short-term shocks and long-term trends (Stock and Watson, 2015). The ECM also helps us to gauge the speed at which variables return to their long-run equilibrium after a shock, which is crucial for understanding the stability and resilience of a system (Pu Chen, 2024). The ECM can be used to forecast future values of variables in short and long term.

The estimated outcomes of ECM are presented in Table 7.

Table 7:

ECM short run results

Variables	Coefficient	Std. Error	t-Statistic	Probability
D(NPCI)	0.749401	0.379341	1.975533	0.0615
D (NPCI (-1))	0.372235	0.321746	1.156923	0.2603
D(NRENG)	-0.491803	0.653769	-0.752257	0.4602
D (NRENG (-1))	1.038110	0.792332	1.310196	0.2043
D(RENG)	-0.000000	0.000000	-0.122635	0.9036
D(POPG)	-0.000043	0.000024	-1.806057	0.0853
D (POPG (-1))	-3.200020	18.026052	-0.177522	0.8608
D (IND (-1))	-9.228123	19.479221	-0.473742	0.6406
D (IND (-2))	11.447877	19.586714	0.584472	0.5651
D (IND (-3))	40.917976	19.130393	2.138899	0.0444
CointEq (-1)	-1.136762	0.193034	-5.888932	0.0490

*Dependent variable: Economic growth (GDP Growth.

Source: Authors own calculation using E-views 9 software.

The results in the above table show that NPCI is statistically significant and has a positive relationship with dependent variables. at lag 1. NRENG has negative and insignificant relationship with the GDPG. at lag 1. RENG has insignificant and negative relationship with GDPG. POPG has negative and significant link with GDP growth at lag 1. IND has negative and insignificant relation with GDP growth at lag 2 and at lag 3. INDG has positive and insignificant relationship with GDPG. The value of coefficient of coint-eq (-1) is -1.136762, suggesting that the variables take about six months to adjust from current to next period.

4.5 Comparison of ARDL and ECM Models

The comparative results of ARDL and ECM models are presented in Table 8.

Table 8

Comparison of short and long-term outcomes.

Short Run (ECM) findings	Long Run (ARDL) findings
Net per capita income (NPCI) is statistically significant and has positive relationship with GDP growth.	Net per capita income (NPCI) is significant at 10% level and at 5%, it has positive relationship with GDP growth.
Renewable energy (RENG) has negative and insignificant relationship with GDP growth.	Renewable energy (RENG) has positive and significant relationship with GDP growth at level 5%.
Nonrenewable (NRENG) has a negative and insignificant relationship with GDP growth.	Nonrenewable (NRENG) has a negative relationship with GDPG at 5 % significant level, the probability value of 0.0364.
Population growth (POPG) has negative and significant relationship with GDPG but at lag 1 POPG has negative and insignificant relationship with GDP growth.	Population growth (POPG) and GDP growth have positive and significant relationships, as the probability value is 0.0207. Both variables are significant at 5 percent level.
At lag 1 industrialization (IND) has negative and insignificant relationship with GDP growth.	Industrialization (INDG) and GDP growth have positive and significant relationship, as the probability value is 0.05. A one unit increase in INDG increases the GDP growth by 3.95

At lag 2 IND has positive and insignificant relationship with GDP growth. At lag 3 INDG has positive and significant relationship with dependent variable.	units. Industrialization plays key role in GDP growth in every country.

Source: The Author

4.5 Bound test

We used the bound test for calculation of long-term relationship between variables. This econometric tool provides valuable guidance to identify long-term association between variables (Pesaran, Smith, (1995) The results of ECM are presented in Table 9.

Table 9:

Bound test estimation

Model Summary: GDPG = *f* (NPCI, NRENG, RENG, POPG, INDG)		
F-Statistic value = 12.0322		
Level of significance	**Lower Bound**	**Upper Bound**
10%	2.46	3.37
5%	2.65	3.80
2.5%	2.94	4.18
1%	3.45	4.68

Source: Author's calculation using E-views 9 software.

The bound test's null hypothesis is that there is "no long-term association between variables." However, empirical results of Bound test indicate that the long-term association between variables exists as the calculated value of the F-statistics is bigger than the lower and upper limit values, and consequently we can reject null hypothesis. The calculated value of the F-statistics is 12.03, which is higher than lower bound and upper bond value. So, we can accept alternate hypothesis, which

states that there is a long-term association between GDP growth net per capita income, nonrenewable resources, renewable energy resources and industrialization.

4.6 Serial correlation and Heteroskedasticity checks

These issues in the model were checked through autocorrelation and Heteroskedasticity tests to detect whether the residuals (errors) of a regression model are correlated across observations. According to rule of thumb, residuals are uncorrelated. If it is present, it can lead to inefficient estimates, and standard errors may be incorrect, making hypothesis tests unreliable, and may lead to incorrect conclusions about relationships in the data (Stock, & Watson, (2015). Further, Heteroskedasticity occurs when the variance of the residuals is not constant, i.e., some residuals are more spread out than others. This is a common issue when dealing with cross-sectional data and resulting in biased standard errors. If it is occurred, the estimates of coefficients may be unbiased, but the standard errors will be wrong, leading to inaccurate confidence intervals and hypothesis testing (Gujarati,2003). The Breusch-Pagan test is commonly used to detect heteroskedasticity. Addressing these issues can lead to valid and reliable regression model outcomes. The estimated results of these tests are presented in Table 10

Table 10:

Autocorrelation and Heteroskedasticity tests

Name of the Test	**F-statistics value**	**Probability value**
Breush-Godfrey LM test for Serial Correlation	0.8014	0.6461
Heteroskedasticity test	0.4630	0.6351

Source: Authors own estimation using E-views 9 Software.

Table 10 elucidates as the p-value of 0.6461 is greater than the conventional significance level (usually 0.05 or 0.01), we cannot reject null hypothesis. This means that there is no significant autocorrelation detected in the model's residuals. As regards the outcomes of Heteroskedasticity test, the p-value of 0.6351 is also larger than the standard significance levels (0.05 or 0.01) and, as such, we cannot reject null hypothesis of homoskedasticity. This means that there is no heteroskedasticity in the residuals, suggesting that variance of the residuals is constant. Thus, the outcomes of both tests show that the model is free from autocorrelation and heteroscedasticity issues, and its results are valid and reliable.

3.6: Tests for stability of models

To check the reliability and the stability of the data we applied CUSUM test to confirm ADL model long run results in visual form. In this test we can see that the data is stable since cumulative sum of the square of recursive residues the CUSUM graph is located within the limits i.e. boundary lines at 5 percent significance level. The CUSUM test is applied to detect changes in the mean of a time series, and it accumulates the deviations from the mean over time, and if the cumulative sum exceeds a certain threshold, it reveals a change. This test is sensitive to small changes in the mean. The CUSUM Squared test is used to detect changes in the variance of a time series and monitor the squared deviations from the mean and it the cumulative sum exceeds a threshold; it leads to a change in variance. This test also helps us to identify outlier and extraordinary observations in a time series. These tests provide a compact assessment of stability process in the model. The estimated results of these two tests are exhibited in Figure 2 and Figure 3.

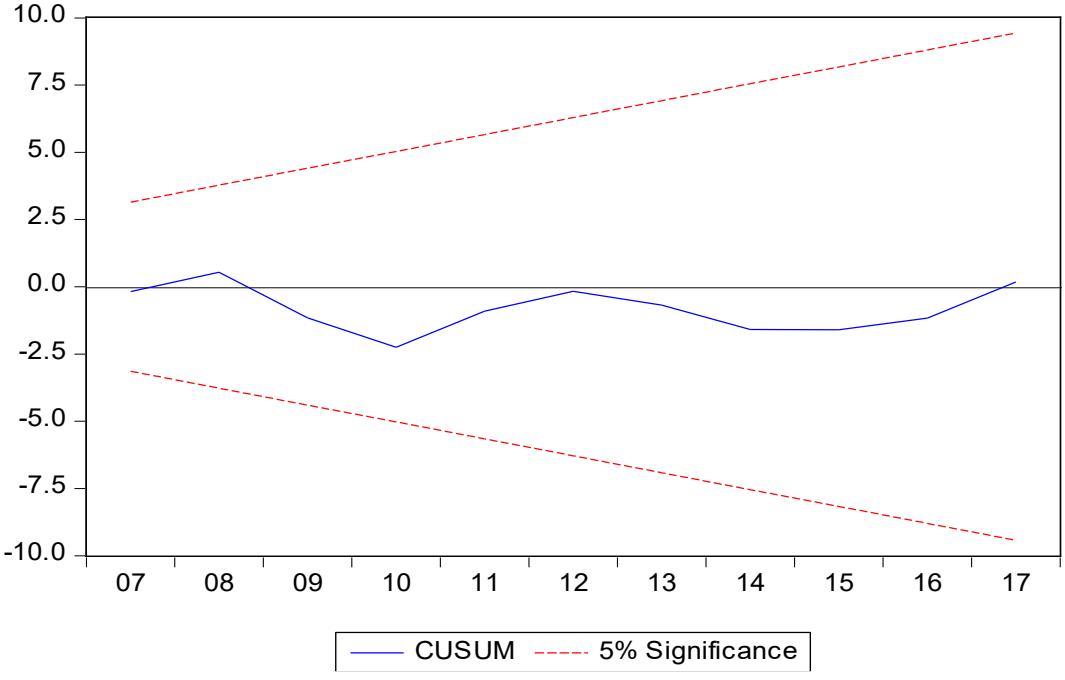

Fig 2: Recursive residuals' cumulative sum.

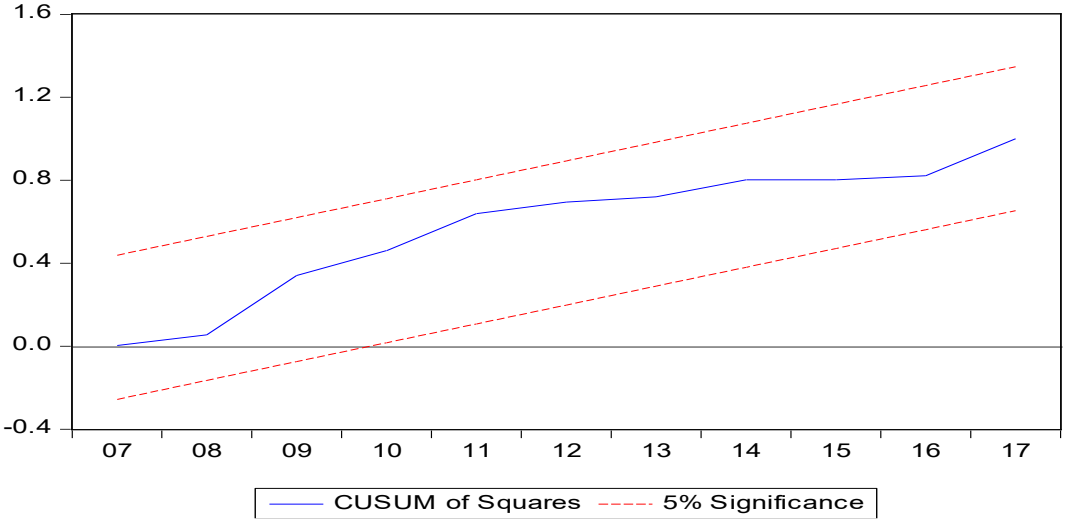

Fig 3: Cumulative sum of the square of the recursive residuals.

In these two Figures 2 and 3 we check the reliability and stability of the data. Now we use two tests, CUSUM at 5 % significance and CUSUM of square at 5%

significance. After using the CUSUM test, the data is stable and reliable. The cumulative sum of the square of recursive residues the CUSUM graph is located within the limits and significance at 5 % level. Moreover, the CUSUM sum of squares is also significant at 5 % level; it is inside boundary lines. The results show the stability of the model in the study period.

5. Discussion

5.1 Main findings

The empirical analysis underscores the urgent need to address Pakistan's energy challenges, particularly its heavy reliance on costly non-renewable energy sources like gas, oil, and other fossil fuels. This dependency, coupled with rising global oil prices, has contributed to an increase in external debt, which negatively affects GDP growth. While policymakers may see non-renewable energy as a short-term solution to meet growing demand, this approach is not sustainable in the long term.

The results from the ARDL and Error Correction Model reveal a negative short-term relationship between renewable energy and GDP growth, but a positive long-term relationship. These findings are in line with Kuznets' (1955) *Environmental Kuznets Curve (EKC) theory*, which suggests that environmental degradation initially worsens with economic growth but improves as the economy progresses. Similar conclusions are drawn by studies of Xue et al. (2021), Shah et al. (2022), Ahmad et al. (2024), and the Los Angeles Times (2024), which highlight the role of renewable energy in promoting economic growth and reducing CO_2 emissions. Thus, first null hypothesis (Ho) is accepted.

Additionally, the analysis indicates that non-renewable energy resources have a detrimental effect on GDP growth both in the short and long term. This highlights the importance for policymakers in Pakistan to reduce the country's reliance on non-renewable energy sources across various sectors. These findings align with the work of Awan, 2015; Wang et al. (2022), who examined the effects of renewable and non-renewable energy, and Yang et al. (2021), who analyzed the relationship

between energy consumption and economic growth in emerging SREB economies. Consequently, the second null hypothesis **(Ho),** which asserts a negative relationship between non-renewable energy and economic growth, is accepted, while the alternative hypothesis is rejected due to the persistent negative associations between these variables. The empirical results also reveal a positive relationship between net per capita income and GDP growth, suggesting that income-boosting strategies are critical for promoting the adoption of renewable energy technologies. This finding is consistent with Awan, 2013; Roth (2020), who emphasized the importance of high income in facilitating the adoption of renewable energy. Thus, the third null hypothesis **(Ho)** is rejected, as the data do not support it.

A more complex relationship between population growth and GDP growth is observed, with a negative correlation in the short term and a positive correlation in the long term. This points to the necessity of policies that manage population growth and encourage urban development. Moreover, enhancing the skill set of the population is crucial for transforming it into valuable human capital, as suggested by Awan, 2011, Liu et al. (2023), Hanif (2018), and Dong et al. (2018). Therefore, the fourth null hypothesis **(Ho),** which claims a negative link between population growth and GDP growth, is rejected, while the alternative hypothesis **(H1)** is supported by the empirical findings. Lastly, the fifth null hypothesis **(Ho)** is rejected, as the results indicate a positive relationship between industrialization and economic growth. The relationship between different independent variables with GDP growth during the period from 2000 to 2025, are displayed in Figure 4.

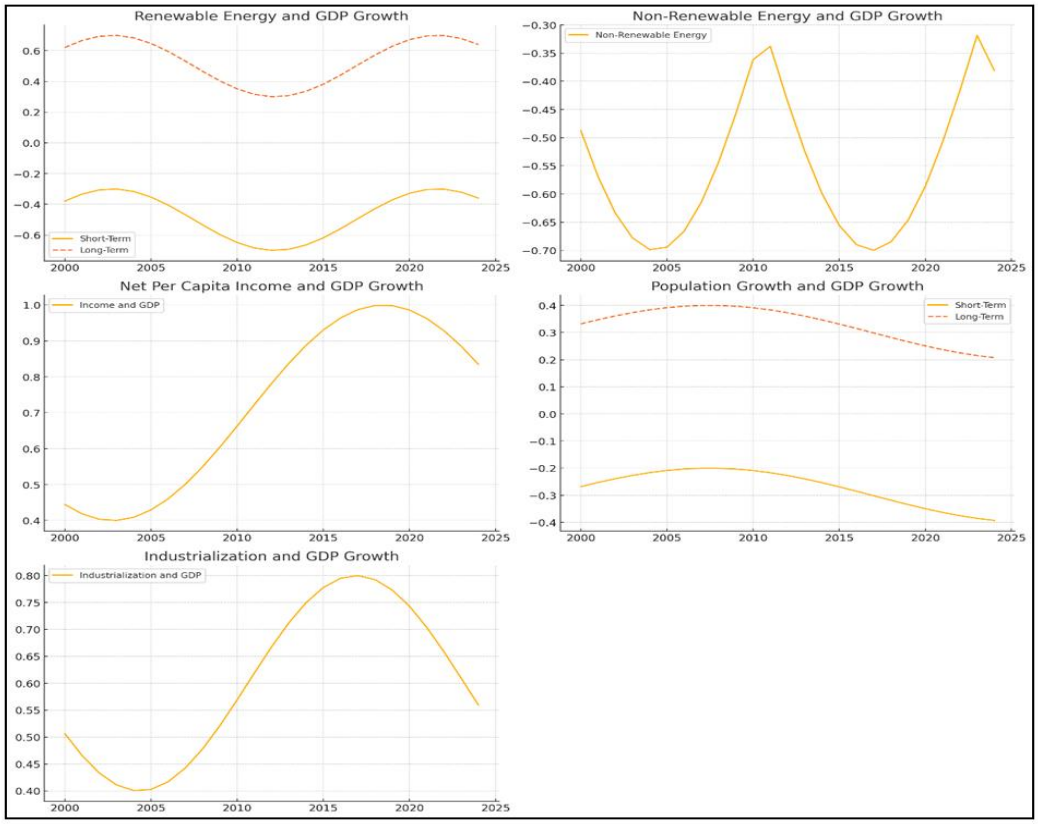

Fig 4 Relationships between explanaroty variables and GDP growth:

5.2 Explanatory Power and Predictive Relevance of the Model

The explanatory power of the model highlights how explanatory variables account for the variation in the dependent variable, GDP growth. In this study, key explanatory variables include net per capita income (NPCI), non-renewable energy (NRENG), renewable energy (RENG), population growth (POPG), and industrialization (IND). The coefficients and p-values suggest that these explanatory variables have statistically significant association with GDP growth. The constant term depicts the baseline level of GDP growth when all explanatory variables are absent. Overall, the model effectively illustrates the dynamics of GDP growth, showing strong explanatory power (Stock & Watson, 2015). Predictive

relevance is determined through the model's capacity to predict future values of GDP growth based on the explanatory variables. The Error Correction Model (ECM) findings show quick impacts of changes in the independent variables on GDP growth. While the variables, such as NPCI and IND, demonstrate short-term predictive power, other variables like NRENG and RENG, do not. The significant cointegration term indicates the model's strong predictive relevance over the long term, specifically in estimating how quickly the system returns to equilibrium level after a brief disturbance (Banerjee et al., 1998; Stock & Watson, 2015).

For theoretical contributions, the empirical results support the EKC hypothesis proposed by Kuznets (1955), which posits that economic growth initially stunts GDP growth, this effect is overtime when it becomes positive. These results are consistent with those of Awan, 2015; Acaroğlu and Darude (2023). Additionally, the study lends support to Ajzen (1980) and his *Theory of Planned Behavior* that highlights the role of attitudes, norms and perceived behavioral control in renewable energy adoption as documented in research by Curtis et al., Weiler & Ham (2010), Adjakloe et al. (2020).

Despite its valuable contributions, this research encounters some limitations. For example, this study focuses on Pakistan, reducing its scope at global level and limiting its generalizability to other countries. Further, this research used time series data from 1986 to 2022, and one can assume that it may not capture the effects of all external shocks and policy shifts during the study period. However, the results of this study. These data limitations could impact the robustness of the results particularly in developing countries. Additionally, this study considers only energy resources, ignoring other potential factors influencing the nexus between energy and economy and some of these factors include technological advancements. International trade, capital flow and diverging geography and environmental

conditions. These limitations provide research gaps, inviting the researchers to conduct further research on these issues and bridge the gaps mentioned.

5.5 Conclusions and Policy Implications

This research provides crucial insights for policymakers by underscoring the significance of transitioning to renewable energy. The empirical findings reveal that non-renewable energy has a detrimental effect on GDP growth in both the short and long term. This highlights the pressing need to reduce dependence on costly fossil fuel imports. Furthermore, the unchecked population growth in developing countries like Pakistan demands urgent attention. It is critical to implement effective population control measures and manage the existing population in a way that maximizes its contribution to economic development. Additionally, the current industrialization policy in Pakistan does not sufficiently regulate the adoption of clean technologies and energy-efficient practices. Therefore, it is essential to steer industrialization towards green technologies and energy-saving methods. This would help reduce the high costs associated with energy production and consumption, fostering economic prosperity while also addressing environmental concerns.

Data statement

The data that is used in this study will be made available by the corresponding authors on reasonable requests.

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