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ASYMMETRIC DYNAMICS OF RENEWABLE ENERGY CONSUMPTION AND ECONOMIC GROWTH FOR SUSTAINABLE DEVELOPMENT IN PAKISTAN

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ABSTRACT

Growing economic growth, rising in energy demand, urbanization, and environmental deterioration are all contributing factors that create pressure to achieve sustainable development. The sources of non-renewable energy usage contributed to increase carbon emission. The shifting to renewable energy consumption is becoming an important policy goal. Hence, this study main aim is to examine the Asymmetric effects of renewable energy consumption, energy intensity, and urbanization on sustainable development in the context of Pakistan. This study used the annual time-series data covering the time-period from 1990-2024. To capture the Asymmetric effects of the candidate variables, this study used the Non-Linear Autoregressive Distributed Lag Approach (NARDL). The study findings conjecture that a positive shocks in renewable energy consumption, economic growth, and energy intensity significantly contributes to increase sustainability. However, a negative shock in renewable energy consumption leads to decrease the sustainability level. Increased energy intensity generally has an adverse effect , but managed and planned urbanization promotes green growth. The study findings conjecture that Pakistan may increase the adoption of renewable energy by offering financial incentives, improving energy efficiency through technical developments, encouraging sustainable urbanization, and incorporating environmental concerns into economic growth strategies, with these focused efforts, Pakistan will be in a position to achieve low-carbon, sustainable economy.

Keywords: *Renewable energy consumption, Sustainable development, Economic growth, Asymmetric effects, Energy Intensity.*

1. INTRODUCTION

The transition to a green economy has become a global challenge as countries attempt to solve the intricate problems of social welfare, economic growth, and environmental degradation. The Brundtland Commission defines sustainable development as “the current generation responsibility is to fulfill their needs without compromising future generation ability to fulfill their own needs” (Burton, 1987). In this context, renewable energy consumption (REC), economic development

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(ED), and efficient resource utilization are fundamental components in establishing the sustainable future. In developing economies like Pakistan, integrating growth objective with environmental sustainability has become a crucial emphasis in policy discussions, particularly in the light of increasing energy demands, escalating carbon emissions, and urbanization (Khalid et al., 2022).
The REC is essential in ensuring a sustainable development, as it helps in decreasing dependence on fossil energy and greenhouse gas emission, and improves energy security (Fatima et al., 2025). Pakistan is already facing significant challenges in energy supply and solar energy, wind energy, hydropower and biomass have been identified as essential factors in diversifying its energy mix. The linkages among sustainability and REC have been extensively reviewed in the international literature, and empirical evidence shows that the increased REC significantly contributes to improved environmental quality and economic stability (Khalid et al., 2022). However, such associations are usually asymmetric, i.e., there are no significant probability that the positive and negative shocks of REC will have the same effect on sustainability. Understanding these asymmetries are critical for making effective policies in the emerging economies. Economic growth is an important measure of sustainable development, especially when measured by GDP per capita. New economic output is an opportunity to invest in clean technologies and modern infrastructure. The association between growth and the environment in developing countries usually involves trade-offs. Unless a sustainable approach is taken, rapid industrialization may create further environmental degradation (Gasimli et al., 2022). The green growth policies are necessary as the growth pattern experienced in Pakistan over the past decades has been defined by the higher environmental costs. Additionally, structural economic factors like industrial composition and efficiently allocation of resources directly influence on the sustainability path (Khalid et al., 2022).
The energy consumption usage divided by a unit of GDP is called energy intensity, or the efficiency with which an economy uses its energy resources. The intensity of high energy consumption is also a sign of ineffective production methods, use of old technology, and less adoption of energy-saving measures (Azra et al., 2023). Technological innovation, modernization of the industrial processes and changes in consumption patterns are the key ways to reduced energy intensity in Pakistan. These measures have the potential to significantly improve environmental and economic conditions in Pakistan. Additionally, the direct association among carbon emissions and energy intensity are an important parameter that must be considered in the determination of the association among energy consumption and sustainability. Urbanization is another concept of sustainable development, or more precisely, the population (%) living in urban centers. Although, urban centers tend to be the centers of innovation and economic progress which contribute significantly to living standards, they are also characterized by an intense struggle with environmental issues, such as increased energy use, increased waste output, and air pollution. The pace of urbanization and the means used to implement the process have become a major issue of concern in Pakistan. The adoption of REC sources and energy conservation programs in cities, as well as city planning, may play a critical role in establishing urbanization as a desirable component of sustainability programs.
Despite the increased literature on REC, economic growth and sustainable environmental, there are limited empirical studies using both asymmetry and frequency domain analysis to examine the dynamics in the Pakistani context. The majority of prior research have been based on linear models, which imply the equality of the relationships between variables and, thus, do not take into consideration the fact that the effect of positive and negative shocks may be different (Shin et al.,

2014). Moreover, the available literature on Pakistan is based on bivariate or triradiate systems that do not admit that sustainability is multidimensional and incorporates the utilization of REC, economic development, and environmental outcomes (Bilgili & Baglitas, 2022). Findings of cross-country studies often generalize conclusion that is not necessarily relevant to country-specific policies and institutions, as well as socioeconomic environments in which interventions are supposed to be applied (Apergis and Payne, 2010). To design more effective energy transition and sustainable development policies in Pakistan, a comprehensive framework that includes the dissection of asymmetry is crucial to derive stronger insights.

Section 2 of the current study briefly reviewed the literature review. Section 3 described the model, methodology, and data sources. Section four explained the results and discussions, while section five summarized the findings and suggested some policy implications.

2.Literature Review

As Pakistan economy continuous to grow, it is imperative to explore how sustainable growth can be foster through the effective utilization of REC sources. Numerous researches have proved that REC is a positive contributor to economic development as well as environmental sustainability. Banga et al. (2022) in their research on 174 countries showed that REC could contribute greatly to economic prosperity across developing and developed economies. Similarly, Abbasi et al. (2020) applied a nonlinear ARDL model in Pakistan and showed that REC and non-renewable energy (NRE) have asymmetric effects on economic growth. This result shows that more complex models are required to handle this complexity. The implementation of REC has been shown to enhance economic growth in other developing Asian economies and also helps to reduce greenhouse gas emissions (Wenlong et al., 2023). Other studies concerning the linkage between natural resources and renewable energy have reiterated that Pakistan possesses the potential to utilize solar, wind, and hydropower in a sustainable manner to develop its economy (Ilyas et al., 2024). Additionally, a study on power industry of Pakistan demonstrated that concentrating on REC sources helps the economy to reduce CO_2 emissions while also lowering electricity costs, suggesting the advantages of renewable energy sources for the economy and environment (Khan et al., 2024). The results show that a higher percentage of REC can be used to achieve better results of sustainable development. However, there is a gap in the body of literature where little research has been conducted on the asymmetric and frequency effects of the renewable energy, an area that the proposed study will cover.

The relationship between sustainable development and economic growth has numerous dimensions. An expanding economy can definitely afford to spend on clean infrastructure and improved social welfare. But when this type of growth is not controlled, especially in the developing world, there can be more challenges to the environment. An analysis of the emerging Asian economies, including that by Anwar et al. (2022), found that an increase in the per capita GDP is often linked to a rise in greenhouse gas emissions unless a country experiences a significant transition to cleaner energy as well. Abbasi et al. (2020) established that the association among energy use and economic growth is complex and does not follow a straightforward pattern in Pakistan. Such complexity highlights the importance of policy interventions that are considered necessary to lead the country to a more sustainable future. Banga et al. (2022) have determined that although REC may play a significant role in advancing the growth of a country, most developing countries still depend on NRE sources of energy to support their developmental requirements. This is usually very expensive to the environment. Abbasi et al (2022) focused on the power sector of Pakistan and shows that the development of the renewable energy sector can effectively reduce the cost of electricity and significantly reduce emissions, proving the viability of pursuing both economic growth and environmental goals simultaneously. Moreover, the recent study by Ilyas et al. (2024) has brought to light the idea that cleaner electricity-driven energy policies could effectively decouple economic growth and environmentally friendly environment, which can be a promising strategy in the future. All this research is pointing to one direction: A growing GDP per capita is the key to the development of a specific country, but it can be incompatible with the idea of sustainability and environmental protection without high adherence to clean energy policies.

The Energy Intensity (EI) is a major indicator of energy efficiency and a statistic for sustainability, representing the amount of energy spent per unit of economic output. One of the fundamental concepts of sustainability is resource decoupling where the economy of a country increases but at the same time its energy consumption and carbon emissions are reduced. Research on emerging economies has shown there is a lot of potential in this field and that there is a need to lower the energy intensity in order to enhance economic growth and environmental performance. Ziolo et al. (2020) conducted a study for nineteen European countries, 1995-2015, and found an inverse ass between EG and EI, that can be attributed to decreased in energy intensity due to energy-saving measures and transition to less energy-intensive activities. Azhgaliyeva et al. (2020) concluded that higher EG, higher energy prices, and efficient energy policies decreases the energy strength in the context of 44 Non-OECD and OECD economies.

Voumik et al. (2023) undertake research on new industrialized countries and explain the complex relationships between industrialization, trade openness, financial development, and energy intensity. In addition, Bai and Raza (2024) offer sector-specific data related to Pakistan covering the time period from 2000 - 2020 and are based on the LMDI decomposition, they indicate that EI is still a pronounced adverse economic factor, even though labor productivity has increased. Although, asymmetric or frequency-domain adjustments of energy intensity have not been exhaustively researched in Pakistan, there is ample evidence around the world, using structural decompositions and econometric panels, that sustainable development depends on the reduction of energy intensity by technological advancement, enhancing efficiency and the structural transformation of the economy.

Urbanization plays an important role in a country's sustainability process. Urban areas serve as hubs for innovation, fostering service-oriented economies and renewable infrastructure. However, they impose significant pressures on energy systems, resources, and the environment. According to Burger et al. (2019), there is an exponential rise in energy use per capita and CO_2 emissions as a country undergoes urbanization, leading to heightened environmental stress. Urbanization has been shown to increase energy intensity in a global survey encompassing seventy-two countries from 2000 to 2014. Empirical studies in OECD contexts, Poumanyvong and Kaneko (2010), indicate that in high-income countries, urbanization leads to a reduction in energy consumption because of expanding efficiency and economies of scale due to economies of scale and efficiency improvements. However, in middle-income or developing contexts, the effects of urbanization may be positive or neutral. In the context of Pakistan, Khan and Majeed, (2023) note that the rise in urbanization, especially in cities like Karachi and Lahore, has led to a surge in energy demand and environmental impact, while also creating opportunities for the coordination of renewable infrastructure planning. While limited studies address asymmetric or frequency-domain effects, the global academic community concurs that effective urban planning, alongside robust

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infrastructure and renewable energy systems, is essential for guiding urban development towards sustainability, taking into account both immediate and future implications.

2. Methodology

The current study examines the role of urbanization, EG, EI and REC on sustainable development in the context of Pakistan utilizing the annual time series observations covering the time span from 1990-2024. The variables descriptions are given in below table #1.

Table 1: Variables Descriptions

Variable Name	Symbol	Measurement/Unit	Source
Sustainable Development	SDI	Sustainable Development Index (Score)	(SDI, 2024)
Renewable Energy Consumption	REC	% of total final energy consumption	WDI
Economic Growth	GDP	Constant 2015 US$	WDI
Energy Intensity	EI	Energy use per GDP	WDI
Urbanization	URB	% of total population	WDI

The functional form of the equation is given below:

$SDI_t = f\ (REC_t, GDP_t, EI_t, URB_t)$ ……………………………………(1)

Where SDI shows sustainable Development, REC is the renewable energy consumption, GDP indicate GDP per capita, EI represents energy intensity, and UBR shows urbanization.

To capture the asymmetric effects of the candidate variables, this study employed the Non-Linear Autoregressive Distributed Lag Approach (NARDL) to capture the positive and negative shocks of the candidate variables.

The empirical equation for the NARDL model is as follows:

$SDI_t = \alpha_0 + \beta_1 REC^+{}_t + \beta_2 REC^-{}_t + \beta_3 GDP^+{}_t + \beta_4 GDP^-{}_t + \beta_5 EI_t + \beta_6 URB_t + \varepsilon_t$…………..(2)

α_0= intercept term, $REC^+{}_t$, $REC^-{}_t$ represents positive and negative shocks in the renewable energy consumptions. $GDP^+{}_t, GDP^+{}_t$ shows positive and negative shocks in the economic growth. ε_t = Error term, t shows the time period. Energy intensity, and urbanizations are taken as the control variables.

3. Results and Discussion

Table # 2. explains the descriptive stats of all variables that is used in this study. The variable SDI showed an average of 0.51, with scores ranging from 0.43 to 0.58. That suggests there has been some progress in sustainability, the changes have been moderate. We have found that REC made up a substantial proportion of the country's energy consumption, averaging 48.93% and fluctuating between 41.60% and 58.10%. Looking at economic growth, GDP per capita averaged $1,248.07, rising from a low of $950.88 to a high of $1,643.68, which points to a steady upward trend in the economy over the study period. We also observed a moderate variation in energy efficiency, with energy intensity averaging 4.43 and ranging from 3.83 to 5.08. Lastly, urbanization showed a

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consistent increase, with the population (%) living in urban areas increasing from 30.58% - 38.37%, on average 34.40% over the years.

Table 2: Descriptive Statistics

	SDI	REC	GDP	EI	UBR
Mean	0.51	48.93	1248.07	4.43	34.40
Median	0.52	47.95	1256.70	4.32	34.39
Maximum	0.58	58.10	1643.68	5.08	38.37
Minimum	0.43	41.60	950.88	3.83	30.58
Std. Dev.	0.05	4.36	223.95	0.36	2.22

Table # 3 shows the results of Unit root testing (ADF test) and indicate that at level all variables are non-stationary. However, at first difference all variables are stationary. *ln* shows the natural logarithmic of renewable energy consumption, GDP per capita, and energy intensity are significant at 1% level. However, the Sustainable Development Index and urbanization variables are stationarity at I(1) at 10% level. These results confirm that all variables are stationary at I(1), supporting the use of cointegration analysis.

Table 3: Stationarity Results

	ADF Test			
Variable	I(0)	Prob.	I(1)	Prob.
*ln*SDI	-1.01	0.74	-2.85	0.06***
*ln*REC	-1.20	0.66	-5.46	0.00*
*ln*GDP	0.64	0.99	-4.67	0.00*
*ln*EI	-2.13	0.23	-4.28	0.00*
*ln*UBR	1.45	0.30	-3.51	0.06***

*, and *** shows significant at 1 and 10% respectively

Table 4 shows the bound test results. The results indicate that F-Stat value is greater than the upper bound at each significance level. The short-term and long-term coefficients are evaluated after estimated the cointegration relationship among variables.

Table 4: ARDL Bound Co-integration

ARDL F-Bounds Test		Significance Level	I(0)	I(1)
F-Statistic	16.96*	10%	1.99	2.94
k	6	5%	2.27	3.28
		1%	2.88	3.99

Table 5 shows the long-term results. The coefficient of positive REC is significant at 10% level. The coefficient of positive REC shows that a 1% increase in REC leads to increase 0.98% sustainable development. However, a 1% decrease in REC reduces the sustainable development by 8.06%. These findings suggest an asymmetric relationship among REC and sustainable development. Such asymmetries are consistent with the literature highlighting that positive and negative changes in energy variables can have different long-term impacts due to structural and policy-related adjustments (Shin et al., 2014).

The coefficient of EI is significant at 5% level, indicating that a 1% rise in EI decreases the Sustainable development by 0.73% in the long run. The results conjecture that a higher EI , often reflecting inefficient energy use, can hinder sustainable economic outcomes. Similar negative long-run effects of energy intensity have been documented in studies examining energy efficiency and growth linkages (Galay, 2018).

Additionally, the variable positive GDP is significant at 5% level, indicating that a 1% positive shock in GDP increases the dependent variable by 1.03% in the long run. However, negative GDP coefficient is significant at 10% level, reveals that a 1% decrease in GDP lead to decrease sustainability development. These results imply that both expansions and contractions in GDP affect the Sustainable development, although the magnitude of positive shocks is larger. Such asymmetry is in line with the findings of NARDL-based macroeconomic studies that show differential impacts of positive and negative growth episodes (Shin et al., 2014).
The variable Urbanization coefficient is significant at 5% level, indicating that as urbanization increases by 1%, the sustainable development increases by 3.86%. This result reflects the substantial role of urban development in shaping long-term economic and environmental outcomes, consistent with evidence from urbanization-growth-environment studies (Liddle & Lung, 2010; Sadorsky, 2014).

Table 5: Long run Results of NARDL

Variable	Coefficient	Std. Error	t-Statistic	Prob.
*ln*REC_POS	0.98	1.96	0.50	0.06*
*ln*REC_NEG	8.06	8.27	0.97	0.03**
*ln*EI	-0.73	0.91	0.80	0.04**
*ln*GDP_POS	1.03	0.98	1.04	0.03**
*ln*GDP_NEG	0.33	1.18	0.28	0.08*
*ln*URB	3.86	3.41	1.13	0.03**

***, **, * shows significance at 1, 5 and 10% respectively

Table 6. report the dynamic results of NARDL model and explain significant asymmetric effects of REC, GDP, and urbanization on SDI. Positive shocks in RE increase SDI by 0.22% in the current period and 0.31% in the following period, while negative shocks in REC decreases SDI by 0.38% in both the current and lagged periods, indicating stronger impacts from reductions in renewable energy use. EI has no significant immediate effect at level. While, its lagged value indicates that a 1% increase in EI leads to decrease SDI by 6% level. The Positive GDP coefficient is significant at 5% level indicates that if GDP increases by 1% the SDI increases by 0.10%. However, the negative GDP coefficient indicate that a 1% decrease in negative GDP, the SDI increases by 0.33%.Additionally, a 1% increase in urbanization the SDI increases by 3.87%. These findings are consistent with the evidence from Asymmetric NARDL studies, which show that positive and negative changes in key economic and environmental variables can produce different short-run effects (Shin et al., 2014; Galay, 2018; Liddle & Lung, 2010).
A steady long-term equilibrium relationship between the variables is confirmed by the error correction term (ECT), which is -0.09% and statistically significant at the 1% level, confirming the existence of a stable long-run equilibrium relationship among the variables. This coefficient implies that around 9% of the short-run disequilibrium adjusts to the long-run equilibrium in each period, showing a relatively slow but consistent rate of adjustment (Pesaran et al., 2001).

Table 6: Dynamic Results of NARDL

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
SDI(-1)	0.91	0.10	9.08	0.00*
*ln*REC_POS	0.22	0.10	-2.13	0.04**

*ln*REC_POS(-1)	0.31	0.18	1.72	0.01**
*ln*REC_NEG	0.38	0.15	2.60	0.02**
*ln*REC_NEG(-1)	0.38	0.13	2.83	0.01**
*ln*EI	0.01	0.03	0.36	0.72
*ln*EI(-1)	-0.06	0.03	1.98	0.06***
*ln*GDP_POS	0.10	0.03	3.08	0.01**
*ln*GDP_NEG	0.03	0.10	0.31	0.08***
*ln*URB	0.37	0.09	4.30	0.00*
ECT	-0.09	0.01	-13.37	0.00*
C	-1.33	0.26	-5.10	0.00*

*, **, and *** shows significancy at 1, 5 and 10% respectively

Table 7 explain the results of Wald test. The results show the rejection of null hypothesis (No asymmetric relationship exist among variables) has been rejected for both ln REC and ln GDP. Therefore, the results confirm that the Asymmetric relationship exist among variables. The chi-square value of LM test is 0.27, shows no evidence of serial correlation, and the Heteroskedasticity test (0.76) indicates that the model is free from heteroskedasticity.

Table 7: Diagnostic tests

Test	Hypothesis	$\chi 2$ (P-Value)	Decision
Wald Test (*ln*REC)	H_0: No Asymmetric Relationship among LREC	0.01	Asymmetric Relationship among LREC
Wald Test (*ln*GDP)	H_0: No Asymmetric Relationship among LREC	0.00	Asymmetric Relationship among LREC
LM Test	H_0: No Serial Correlation	0.27	No serial correlation exists
Heteroskedasticity Test	H_0: Homoskedasticity	0.76	No heteroskedasticity exist

10. Conclusion and Recommendation

In this paper, the authors have analyzed the asymmetric nature of association among REC, EG, EI, urbanization, and sustainability in Pakistan through the NARDL framework where the Sustainable Development Index (SDI) was the dependent variable. All the variables were observed to be stationary at the integrated of order one I(1), ARDL bounds test affirmed the presence of long-term cointegrating relationship. The Wald test of both REC and GDP showed that positive and negative shocks have different effects on sustainability. The long-run estimates indicated that SDI is positively affected by renewable energy consumption, GDP and urbanization, and negatively affected by energy intensity. Short-run dynamics also demonstrated that negative renewable energy and GDP shocks can have different effects than positive shocks, and thus asymmetric modeling is critical. The absence of serial correlation and heteroskedasticity was proved with diagnostic tests, and this fact indicates the results credibility.

In general, the results indicate that the policy that considers the different effects of positive and negative changes in key economic and environmental indicators should serve as the trajectory for Pakistan's transition to a greener economy. The results indicate that policies must take into account the asymmetric role of REC, GDP, EI, and urbanization on sustainability in Pakistan. Favorable renewable energy surprises strengthen sustainability, which implies that it is necessary to increase the pace of investments in clean energy and develop solar and wind farms, as well as provide fiscal support. To minimize environmental deterioration, it is significant to decrease the EI by increasing efficiency, using advanced technologies, and through awareness campaigns. Green growth should be enhanced by encouraging sustainable transport, green spaces and energy efficient buildings. When negative shocks need to be compensated, stable and inclusive economic growth should be prioritized and policy monitoring, through asymmetric analysis, should be done continuously to bring Pakistan nearer to a more sustainable future.

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