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An Asymmetric Analysis of Renewable Energy in Mitigating Carbon Emissions in Pakistan

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ABSTRACT

To achieve sustainable growth, energy is incumbent because all modern production is based on it. Unfortunately, about 80% of the global population uses polluted energy, adversely damaging the environment. The present study asses the asymmetric role of renewable energy in the mitigation of CO2 emissions in Pakistan. The Non-linear ARDL econometric approach is used to estimate the empirical results of the time series data from 1980 to 2020. The study found that positive change in renewable energy adversely declines CO2 emissions while negative change increases CO2 emissions. Additionally, the HDI and trade openness lessens CO2 emissions, while urbanization increases CO2 emissions. The study recommends that Pakistan should promote eco-friendly consumption patterns. Pakistan should focus on promoting renewable energy resources, which will help combat the upsurge in industrial and housing carbon dioxide emissions.

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1. Introduction

Environmental damage, carbon dioxide, and global warming are the most pressing ecological issues in recent years (Amjad, 2023). Massive concentrations of carbon and other gases in the environment are regarded to be among the world's most serious environmental threats. As a result, policymakers are paying attention to mitigating the carbon elements (Edh Mirzaei, Hilletoft, & Pal, 2021). This study explores the role of renewable energy (RE) on CO_2 emissions in Pakistan.

Pakistan has been blessed with various RE sources, including nuclear, hydropower, bioenergy, biomass, solar, wind, geothermal, and sea waves (Wang, Asghar, Zaidi, & Wang, 2019). These clean energy resources reduce energy reliance on fossil and transition toward more eco-friendly energy. It does not address environmental concerns but offers many other social and economic benefits (Ullah, Pinglu, Ullah, & Hashmi, 2022). Clean energy utilization provides a solution to preserve natural resources by reducing water pollution, acid rain, biodiversity loss, and air pollution (Alam, Apergis, Paramati, & Fang, 2021; Yahya & Rafiq, 2020). In the literature, several studies pointed out that clean energy uplifts the environmental quality by mitigating the carbon elements (Khurshid et al., 2022; Sial, Arshed, Amjad, & Khan, 2022).

Despite the diverse range of cleaner energy resources, 82% of Pakistan still relies on polluted energy resources (WDI, 2022a). One primary reason for dependence on polluted energy is existing infrastructure. Over the last few decades, Pakistan has spent massive funds to establish oil, gas, and coal networks (Rafique & Rehman, 2017). These energy resources are cheaper and more easily accessible than clean energy resources.

In recent decades, Pakistan has undergone fast urbanization and persistent population expansion, contributing to a remarkable energy consumption spike. Urbanization has caused a substantial movement of people from rural regions to cities, resulting in increased urban infrastructure and energy demand (Almulhim & Cobbinah, 2023). Urbanization needs more energy for housing, transportation, industry, and services, magnifying the total energy consumption (Amjad, 2023). This urbanization trend has been strongly related to more outstanding living standards and increasing access to contemporary conveniences, which substantially depend on energy, adding to the growing EC levels (Asghar, Amjad, & Rehman, 2023).

The HDI is another determinant of the environment. UNDP (2023) generated this index using income, health, and education (Wang et al., 2022). Higher HDI scores decrease the carbon elements by improving standards, healthcare, and education (Banday & Kocoglu, 2023). As people meet the basic necessities of life, they become more aware of the environment and prefer to adopt sustainable behavior. Governments also prioritize environmental issues by implementing different strategies and policies to reduce the carbon elements in the atmosphere (Ukaogo, Ewuzie, & Onwuka, 2020; Wang, Shi, & Chen, 2023).

Additionally, Trade openness (TO) is another factor affecting carbon elements. It shows three types of environmental effects: the scale effect, the innovation effect, and the composition effect (Balsalobre-Lorente, Topaloglu, Nur, & Evcimen, 2023). The scale effect refers to an overall increase in the size of the economy due to trade openness. When a country opens its border for trade, it accesses the largest markets for trade its products. The scale effect also increases the economies of scale and the production unit's efficiency (Cheng et al., 2023). The innovation effect displays that trade increases innovation and technologies. The international industries motivate the domestic unit to adopt new technologies and best practices for production (Ovuakporie, Pillai, Wang, & Wei, 2021). The composite effect demonstrates a nation's trade composition change due to trade openness.

According to our best knowledge, a number of the past research in Pakistan in present literature discuss the nexus between energy consumption and CO_2, and adopted simple techniques such as cointegration regression, simple ARDL, and OLS. Besides, the current study inspects the non-linear of RE on CO_2 by employing NARDL to analyze the empirical analysis is limited.

2. Literature Review

The section examines the role of renewable energy (RE), HDI, trade openness (TO), and urbanization (UR) on CO2 emissions. There is limited literature that examines the asymmetric effect of RE on CO_2. Çıtak, Uslu, Batmaz, and Hoş (2020) explored the role of RE in eight US states from 1997 to 2017 in the USA. The results were estimated by using the NARDL approach. The study found that the asymmetric impact of RE has changed from state to state. Jiang et al. (2022) also estimated the asymmetric impact of RE China's environment using the NARDL approach. The study revealed that positive shocks of RE declined environmental pollution while negative shocks increased environmental degradation.

A multiple researcher has inquired the role of RE on CO_2. Sarkodie and Adams (2018) highlight the adverse effects of RE on CO_2 due to ineffectiveness in processes and worldwide constraints on the infrastructural projects that demanded nuclear waste management. Hassan, Baloch, and Tarar (2020) and Lau, Choong, Ng, Liew, and Ching (2019) found that RE reduce CO_2 in the BRICS countries. In the G-20 countries, Pao and Chen (2019) postulated that RE is the optimum choice and the most cost-effective way of reducing CO_2. In Latin America, Ozturk (2017), in Turkey Adebayo (2023), and Pakistan, Majeed, Ozturk, Samreen, and Luni (2022) explored that RE enhances the quality of air and is the ultimate solution for lowering CO_2. In Pakistan, Azam, Rafiq, Shafique, and Yuan (2021) and OECD countries, Usman and Hammar (2021) suggested that increasing RE benefits carbon reduction.

The HDI is a composite of various indicators, including average lifespan, schooling, and per capita income. Sinha and Sen (2016) inspect the links between HDI and environmental indicators in the BRICS economies from 1980 to 2013. They discovered that HDI declined CO_2. Pervaiz, Faisal, Rahman, Chander, and Ali (2021) inspect the link between HDI and CO_2 in selected countries from 2000Q1 to 2014Q4. The study found that HDI declined carbon emissions.

Urbanization (UR) is also considered a significant contributor to environmental pollution. Hossain (2012) inferred an insignificant relation between UR and CO_2 in Japan from 1975 to 2011. Shahbaz, Hye, Tiwari, and Leitão (2013) examine the association between UR and CO2 in the United Arab Emirates (UAE). This study's findings revealed that UR increased CO_2. Doğan, Chu, Ghosh, Truong, and Balsalobre-Lorente (2022) inspected the connection between UR and CO_2 in the US from 1960 to 2010. The findings of this study showed that UR enhanced CO_2 in the long run. Ali, Bakhsh, and Yasin (2019) highlighted the effect of UR on CO_2 in Pakistan. The findings discovered a substantial positive influence of UR on CO_2. In developing countries, Liang, Wang, and Li (2019) explored that the urbanization index increased environmental pollution.

Trade openness (TO) plays a significant role in the mitigating the CO_2. Shahbaz, Nasreen, Ahmed, and Hammoudeh (2017) examined the TO on CO_2 in 105 countries from 1980 to 2014 by applying FMOSL. The study found that TO declined CO_2 in all regions. Wang and Wang (2021) explored that TO declined carbon intensity in lower-income countries, while in higher income, this relationship become inverse. Bhatti and Fazal (2021) found a positive relationship between energy consumption and CO2 emissions.Ahakwa et al. (2023) examined the TO on environmental sustainability in BRI countries. The study explored that TO improved environmental sustainability.

After reviewing the literature, it is observed that there are limited studies of the asymmetric impact of RE on CO_2 (Çıtak et al., 2020; Jiang et al., 2022). In contrast, several studies examined this relationship by using the symmetric analysis (Adebayo, 2023; Hassan et al., 2020; Ozturk, 2017; Pao & Chen, 2019; Sarkodie & Adams, 2018). This study contributes to the literature in multiple ways: this is the first study that examined the asymmetric impact of renewable energy on CO_2 in Pakistan. This study uses the large time frame by using the NARDL approach. Hanif, Nawaz, Hussain, and Bhatti (2022) investigated the relationship under the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between environmental degradation and economic development.

Based on the above literature, the following hypothesis is constructed.
H_1: We assume the asymmetric impact of RE on carbon emissions
H_2: We hypothesize that HDI has a direct relationship with carbon emissions
H_3: We hypothesize that urbanization increases carbon emissions.
H_4: We hypothesize that trade openness impacts carbon emissions

3. Data and Methodology

The data of empirical model is collected from Pakistan from WDI (2022b) from 1980 to 2020. Carbon emission (CO_2) is used as the dependent variable which is measured in per matric tons. Thus, renewable energy has a main independent variable: Hydro energy production is used as a proxy of (RE), and other independent attributes such as HDI, trade (TO), and Urbanization (UR). To evaluate the connection among RE, HDI, TO, UR, and CO_2 the functional form is written as:

$$CO2 = f\ (REN, HDI, TO, UR) \quad (1)$$

The present investigation converts all variables to natural logarithm form to extract the long-run elasticities of coefficients and obtain consistent outcomes (Amjad, 2023; Amjad, ur Rehman, & Batool, 2022; Rani, Amjad, Asghar, & Rehman, 2022, 2023).

$$LNCO_{2t} = \beta_0 + \beta_1(LNRE_t) + \beta_2(LNHDI_t) + \beta_3(LNTO_t) + \beta_4(LNUR_t) + u_t \quad (2)$$

$LNCO_2$ = Natural logarithmic carbon dioxide emissions
LNRE= Natural logarithmic renewable energy
LNHDI= Natural logarithmic human development
LNTO= Natural logarithmic trade openness
LNUR= Natural logarithmic urbanization

It is hypothesized that the causal relationship of RE is non-linear and assumed to positive and negative series. This senero is discussed in NARDL model (Shin, Yu, & Greenwood-Nimmo, 2014). Basically, NARDL is the modification of ARLD suggested by Pesaran and Smith (1995). The prequisits of NARDL is the same as ARDL method. It is applied in the case of mixed integration order and is suitable for a small sample size (Asghar et al., 2023). As a result, to meet our research objectives, we chose this model over the previous models.

$$LNCO_{2t} = \beta_0 + \beta_1(LNRE_t^+) + \beta_2(LNRE_t^-) + \beta_3(LNHDI_t) + \beta_4(LNTO_t) + \beta_5(LNUR_t) + u_t \quad (3)$$

In equation (2), $LNRE_t^+$ and $LNRE_t^-$ denotes the positive and negative series of RE. We used NARDL to estimate the coefficients and its partial sum process, the positive and negative components is summarized as follows:

$$LNRE_t^+ = \sum_{i=1}^{t} \Delta LNRE^+{}_i = \sum_i^t max(\Delta LNRE_i, 0) \quad (4)$$
$$LNRE_t^- = \sum_{i=1}^{t} \Delta LNRE^-{}_i = \sum_i^t min\ (\Delta LNRE_i\ , 0) \quad (5)$$

The long run dynamic of NARDL can be integrated into the following equation as:

$$LNCO_{2t} = \beta_0 + + \phi LNCO_{2t-1} + \beta_1(LNRE_t^+) + \beta_2(LNRE_t^-) + \beta_3(LNHDI_t) + \beta_4(LNTO_t) + \beta_5(LNUR_t) + \sum_{i=1}^{p-1} f LNCO_{2t-i} + \sum_{i=0}^{q-1}(r_1^+ LNRE_t^+ + r_2^- LNRE_t^-) + \sum_{i=0}^{n} r_3 \Delta LNHDI_{t-k} + \sum_{i=0}^{n} r_4 \Delta LNTO_{t-k} \sum_{i=0}^{n} r_5 \Delta LNUR_{t-k} + u_t \quad (6)$$

The error correction term (ECT) are included in equation (6), and its new equation can be written as:

$$LNCO_{2t} = \beta_0 + + \phi LNCO_{2t-1} + \beta_1(LNRE_t^+) + \beta_2(LNRE_t^-) + \beta_3(LNHDI_t) + \beta_4(LNTO_t) + \beta_5(LNUR_t) + \sum_{i=1}^{p-1} \mathit{f} LNCO_{2t-i} + \sum_{i=0}^{q-1}(r_1^+ LNRE_t^+ + r_2^- LNRE_t^-) + \sum_{i=0}^{n} r_3 \Delta LNHDI_{t-k} + \sum_{i=0}^{n} r_4 \Delta LNTO_{t-k} \sum_{i=0}^{n} r_5 \Delta LNUR_{t-k} + \alpha ECT_{t-1} + u_t \quad (7)$$

In equations (6 and 7), Δ presents the difference operators.

4. Results and Discussions

Table 1 elaborates on the results of the descriptive analysis of concerning variables. The mean values of LNRE, LNUR, and LNTO are less than their standard deviation, showing a lower level of dispersions in the series, while mean values of LNCO2 and LNHDI are less than their standard deviation present higher dispersions (Amjad, 2023; Amjad, Asghar, & Rehman, 2021). Furthermore, all skewness values are non-zero present the asymmetric distribution. Kurtosis values are less than three presenting the mesokurtic distribution. The insignificant probability value of Jarque-Bera shows the lack of autocorrelation in the series (Abbas et al., 2024; Aslam, Zhang, Amjad, Guo, & Ji, 2023).

Table 1
Descriptive Statistics

	LNCO2	**LNRE**	**LNUR**	**LNTO**	**LNHDI**
Mean	-0.2886	3.8946	3.5232	3.4553	-0.7364
Median	-0.2762	3.8704	3.5258	3.4906	-0.7215
Maximum	0.0427	4.0620	3.6154	3.6506	-0.5763
Minimum	-0.6080	3.7400	3.4202	3.2069	-0.9113
Std. Dev.	0.1630	0.0818	0.0572	0.1309	0.1050
Skewness	0.1734	0.2700	-0.1441	-0.3367	-0.0958
Kurtosis	2.5784	2.3862	1.9089	1.9332	1.6757
Jarque-Bera	0.3849	0.8632	1.6450	2.0558	2.3126
Probability	0.8249	0.6495	0.4393	0.3578	0.3146
Sum	-8.9459	120.7313	109.2197	107.1142	-22.8284
Sum Sq. Dev.	0.7975	0.2009	0.0982	0.5143	0.3310

Table 2 explored the correlation matrix outcomes. The correlation between HDI, RE, and UR is 0.78, less than 0.80, showing the absence of multicollinearity between the variables. Furthermore, the correlation matrix also shows that CO2 positively correlates with TO and UR, a reverse relationship with RE and HDI (Abid, Ghafoor, Javed, & Amjad, 2022).

Table 2
Correlation Matrix

	LNCO2	LNRE	LNUR	LNTO	LNHDI
LNCO2	1				
LNRE	-0.5601	1			
LNUR	0.3339	-0.4278	1		
LNTO	0.5700	-0.5759	0.6271	1	
LNHDI	-0.5300	0.5309	-0.5959	-0.5939	1

Table 3
Unit Root Tests

	PP test statistics			**ADF test statistics**		
Variables	**Level**	**1st diff.**	**Decision**	**Level**	**1st diff.**	**Decision**
$LNCO_2$	-0.124	-0.564***	I(1)	-0.071	-0.564***	I(1)
LNRE	-0.234*		I(0)	-0.801***		I(0)
LNHDI	-0.345**		I(0)	-0.453***		I(0)
LNTO	-0.507***		I(0)	-0.507***		I(1)
LNUR	-0.234	-0.543***	I(1)	-0.655***	-0.556***	I(1)

Note: ***, **,* shows level of significance at 1%, 5%, 10% respectively

Table 3 shows PP unit root and ADF unit root tests (Hlouskova & Wagner, 2006). The ADF and PP tests provided more favorable results in the data's presence of constants and trends. Both of these unit roots explored that REN, HDI, and TO become stationary at level, while CO_2 and UR become stationary at 1st differences.

Table 4 demonstrates the bound test cointegration outcomes for ARDL and NARDL. We compare the F-statistics value with the critical value for the bound test cointegration. The f-statistics value (2.3595) of the ARDL test is less than the critical values, showing the absence of cointegration. Similarly, the F statistics value of the NARDL is greater than the upper bound value and outcomes show the occurrence of cointegration among the variables (Amjad et al., 2021; Khan, Khan, & Zafar, 2023).

Table 4
Results of Bound Test

ARDL			NARDL	
F-Statistics		2.3595	F-Stat.	5.5632
signific.	Lower-Bound	Upper-Bound	Lower-Bound	Upper-Bound
1%	3.41	4.68	3.15	4.43
2.5%	2.96	4.18	2.75	3.99
5%	2.63	3.79	2.45	3.61
10%	2.26	3.35	2.12	3.23

The output of NARDL is highlighted in Table 5. The value of ECM is -0.61, showing convergence toward the equilibrium in the long run (Asghar et al., 2023). The outcome of the positive part of RE infers that it mitigates CO_2 in Pakistan. On the other hand, the negative shocks in RE are also negatively linked to CO_2 (Çıtak et al., 2020; Jiang et al., 2022). For simplicity, the positive shocks of RE decline CO_2 while its adverse shocks increase CO_2.

Table 5
NARDL Outcomes

Selected Model: ARDL(2, 2, 1, 0, 0, 2)				
		Long Run Coefficients		
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNRE_POS	-0.9930	0.4745	-2.0930	0.0538
LNRE_NEG	-2.9456	0.5146	-5.7242	0.0000
LNTO	0.1548	0.0802	1.9304	0.0727
LNUR	3.5496	1.3727	2.5858	0.0207
LNHDI	-3.6245	1.3357	-2.7135	0.0160
		Short run		
D(LNCO2(-1))	0.5259	0.2713	1.9385	0.0716
D(LNRE_POS)	-0.1569	0.4724	-0.3321	0.7444
D(LNRE_POS(-1))	1.4950	0.6570	2.2754	0.0380
D(LNRE_NEG)	-2.2916	0.3455	-6.6319	0.0000
D(LNTR)	0.0946	0.0443	2.1381	0.0494
D(LNUR)	2.1700	0.6681	3.2481	0.0054
D(LNHDI)	-0.6027	0.9398	-0.6412	0.5311
D(LNHDI(-1))	2.8917	1.0155	2.8475	0.0122
CointEq(-1)	-0.6113	0.2123	-2.8802	0.0114
		Wald Test		
LNRE	F-statistics (Prob.) =24.45(0.000)		Existed asymmetric relationship	

Further, the results from NARDL suggest that HDI significantly reduces CO_2. Trade openness (LNTO) is positively associated with carbon emissions: a 1% increase in the level of TO increases carbon emissions to about 0.15% in Pakistan in the long run. Similar findings were by Shahbaz et al. (2017) in 105 countries, Wang and Wang (2021) in lower-income, and Ahakwa et al. (2023) in BRI countries. Urbanization (LNUR) significantly increases CO_2. It shows a 1%

increase in the LNUR, which increases CO_2 by an average of 3.55%. Similar results were explored by Hossain (2012) in Japan, Shahbaz et al. (2013) UAE, and Doğan et al. (2022) in the United States.

The lower part of Table 6 shows the Wald test. The results of the current studies confirmed the presence of asymmetries for RE. The findings confirm that the NARDL estimation technique is better for discussing dynamic interactions among predictor variables and independent variables for asymmetries. This finding indicates that changes in the study's explanatory factors, whether positive or negative, have a significant impact. Hence, neglecting asymmetries may result in model misspecification and doubtful results.

The model passed all the diagnostic tests, which verified that it is free from all statistical issues. Further, statistical CUSUM and CUSUMSQ tests are employed to verify the stability of long-run attributes. Figure 1 demonstrate the CUSUM and CUSUMSQ, which confirms the stability of the model (Rafique, Hussain, Naushahi, Shah, & Amjad, 2023).

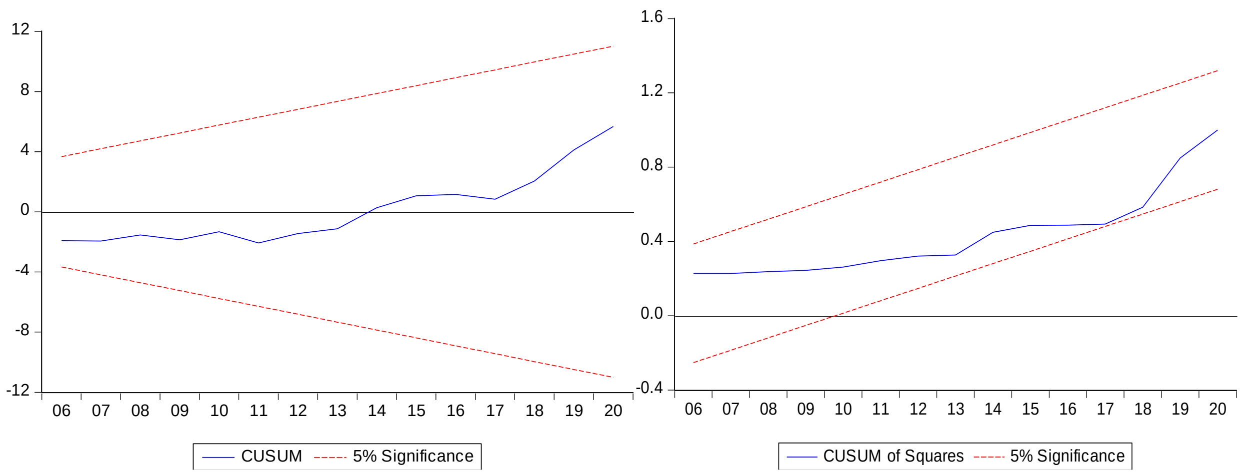

Figure 1: NARDL (CUSUM and CUSUMSQ)

Further, the dynamic multiplier adjustment analysis is highlighted in Fig. 2, indicating that positive and negative shocks in RE adjust toward a new equilibrium path. So, it verifies the asymmetric long-run association between RE and CO_2 emissions.

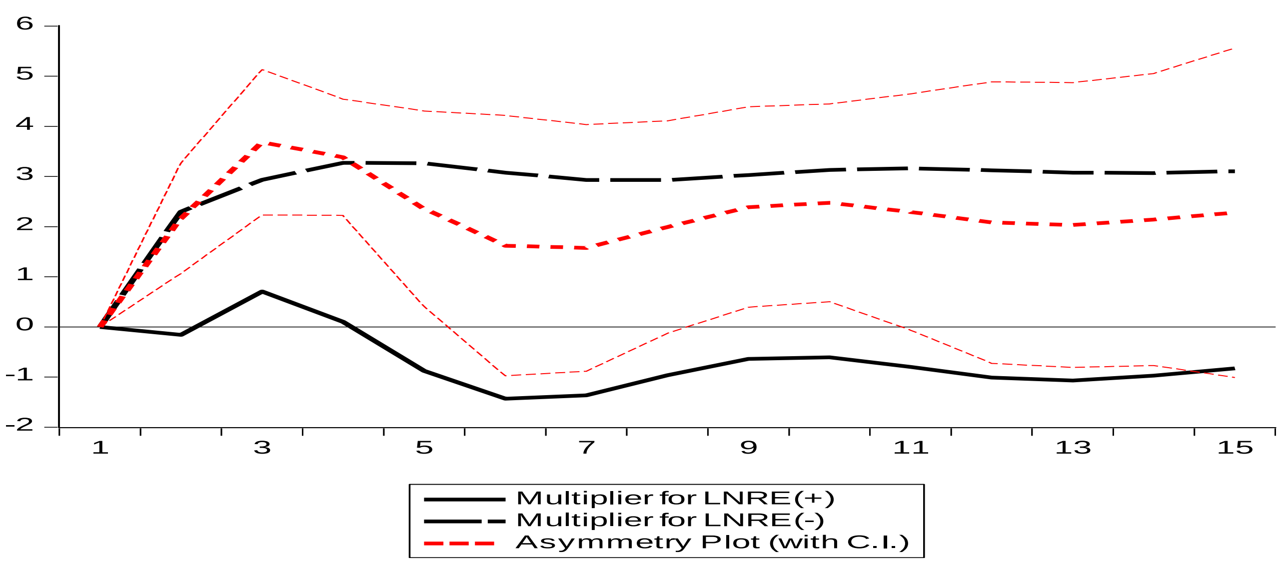

Figure 2: Non-linear Dynamic Multiplier Influence of RE

5. Conclusion and Policy Recommendations

The rising concern about environmental degradation has attracted much attention from researchers and policymakers worldwide. Extensive research work has been conducted on different determinants responsible for ecological damage. Few studies have looked at the asymmetric influence of renewable energy (RE) on CO_2 emissions, notably in Pakistan. This study examines the asymmetric role of RE on CO2 in Pakistan by controlling urbanization, trade, and HDI from 1990 to 2020. NARDL is a suitable approach for asymmetric analysis of the time series data. The correlation matrix and basic diagnostic test explore the authenticity of the present empirical model. The bond test gives evidence of long-run co-integration of the asymmetric renewable energy with CO2. The NARDL output shows that the positive value of renewable declines CO_2 while its negative value increases CO_2. These results show the promotion of renewable resources significantly reduces CO_2 in Pakistan. So, this study fulfills the first hypothesis about the validity of the asymmetric behavior renewable. Furthermore, the ECM value is negative, and less than one gives evidence of the convergence toward equilibrium. The Wald test proves the asymmetric behavior of renewable energy in the model. Additionally, the study found the HDI and Trade openness decline in CO_2. Urbanization escalates the CO_2.

This recommends that Pakistan promote renewable technologies to control and prevent global warming, which declines CO2. It helps mitigate the growing energy crisis and eliminate fossil energy dependency. By promoting wind and solar energy resources, Pakistan also gets rid of the oil shocks, which adversely affect every sector of the economy. This study extends the asymmetric analysis to different countries and may extend future research by using its application in other regions or countries.

Authors' Contribution

Amna Shafqat: introduction section and writing original draft and supervision
Sadia Idrees: interpretation of findings and writing original draft and supervision
Sarfraz Zaman: analysis and explanation results, proofreading, and supervision

Conflict of Interests/Disclosures

The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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