



Asymmetric Impact of Energy Consumption on CO₂ Emissions: A Case Study for Pakistan

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ABSTRACT

Efficient use of energy resources is one of the best solutions for protecting the world's ecosystem and achieving sustainability of economic growth. The present study has investigated the estimated symmetric and asymmetric relationship between energy consumption (EC) and CO₂ emission in Pakistan. For empirical testing, ARDL and NARDL approaches are employed from 1976 to 2019. The outcomes of NARDL found that positive and negative shocks in EC substantially increased CO₂ emission in the short run. However, in the long run, negative shock significantly decreases CO₂ emission, and positive shock insignificantly increases CO₂ emission in Pakistan. It is suggested that government should concentrate on clean energy production initiatives to promote the use of renewable energy. Similarly, it is anticipated that environmentally-conscious planning throughout the capital spending stage of manufacturing activities and the proper application of environmental levies will be beneficial in lowering carbon footprints associated with all sectors of the economy.

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1. Introduction

The sustainable and inclusive output growth is one of the most important indications of an economy's development and ability to address its shortcomings. Economic development is primarily concerned with improving the standard of living for its citizens while also providing a more sustainable environmental resource for future generations. Almost all economic activities directly or indirectly related to EC infer a considerable impact on the ecological system of the surrounding region. In addition, evidence indicates that urbanization, trade openness, financial progress, and output growth all impact environmental quality and sustainability.

According to the Center for Climate and Energy Solutions, electricity and heat emit 31 per cent of total greenhouse gas emissions. The share of transportation, manufacturing, agriculture, and forestry is 15 per cent, 12 per cent, 11 per cent, and 6 per cent, respectively, whereas 72 per cent of all emission comes from energy production. Pakistan's fossil CO₂ emissions reached 178 million tons in 2016, with CO₂ emissions per capita surpassing 0.87 tons in the same year. Pakistan has steadily transitioned from an agriculture-driven to an industry-led growth economy over the last several decades. Thus, an increase in energy demand resulting from this industry-driven boom. Likewise, carbon dioxide emissions are growing, and the nation is suffering from the consequences of climate change (Jianjun et al.,

2021; Shahzad, Kumar, Zakaria, & Hurr, 2017). Furthermore, the Global Climate Risk Index (GCRI) 2020 reported that Pakistan is the fifth most vulnerable country to global warming.

A number past studies are investigated the association between CO₂ emissions and various related variables. For example, Javid and Sharif (2016) examined the impact of financial development (FD), national output, energy utilization, and globalization index on CO₂ discharges in Pakistan. They confirmed the incidence of an environmental Kuznets curve (EKC). Similarly, Shahbaz, Shahzad, Ahmad, and Alam (2016) identified economic growth (EG), FD, and EU as determinants of environment quality (EQ). Additionally, Shahzad et al. (2017) explored the long-term connection between Pakistan's EQ, TRO, FD, and carbon dioxide emanations. The core objectives of current research are to empirically determine the optimal level of EU concerning CO₂ emanations in Pakistan. Additionally, the study assesses the linear and nonlinear relationship between EQ and carbon dioxide discharges and the role of FD, TRO, national income, and urbanization as determinants of ecological quality.

Globalization is well-known for assisting individuals, economies, and businesses in expanding their outsourcing business, exchanging commodities and service expertise, and minimizing migration on a global scale (Jahanger, 2022). As a universal phenomenon, globalization has impacted every individual in every part of world region regarding cultural, political, and socio-economic features. It benefits all countries by accelerating the growth and development process, which is required to address rising unemployment, poverty, and inequality. Globalization has been determined to have harmonies and environmental costs severely. For example, when the demand grows, a country's economic growth will outpace its energy consumption. CO₂ emissions originate from obtaining growth in national output through industrial development, urban growth, and energy usage, which deteriorates EQ. Global warming (GW), ecological disasters, and climate change contribute to the degradation of environmental quality. GW and temperature change when considered combined, have an impact on the socio-economic lives of people around the world (Agboola, Bekun, & Balsalobre-Lorente, 2021; Balsalobre-Lorente, Driha, & Sinha, 2020; Nawaz, Ahmadk, Hussain, & Bhatti, 2020). Globalization has been assessed as an essential concern to researchers of applied energy for several decades, and solid empirical regularity has been observed among unique pooled and time-series data structures (Jahanger, 2022).

Financial development affects national income as well as environmental quality. Literature supports both the direct and indirect impact of FD on an economy's ecological quality. Several scholars have documented that FD improves environmental quality through increased FD, R&D (Tamazian, Chousa, & Vadlamannati, 2009), easier access to finance environment friendly schemes, a boost in technological innovation (Yuxiang & Chen, 2011) relatively better governance. Rather than having a positive impact, various researchers noted that financial development polluted the ecological system because creditors purchased automobiles, houses, cars, refrigerators, and other items and installed more units of production that consume a large amount of energy, thereby increasing CO₂ emissions (Liu, Lan, Chien, Sadiq, & Nawaz, 2022; Shahzad et al., 2017; Xing, Jiang, & Ma, 2017).

Hence, climate concerns are becoming a significant concern for the government in Pakistan, as in all other developing countries. According to the government of Pakistan (GoP, 2020), Pakistan is among the leading countries that have grown global warming sensitivity in the previous 20 years. According to Eckstein, Künzel, Schäfer, and Winges (2019), the cost of environmental damage in Pakistan is high, with the nation losing 0.53 percent of its GDP and incurring economic damages of roughly 3792.53 million US dollars due to 152 extreme weather events between 1999 and 2018. Meanwhile, throughout the previous several decades, the country has experienced a growth in energy consumption, which is enormously beneficial to the level of various economic sectors.

World Data Atlas (WDA, 2020) states, that Pakistan's primary EC amplified at a 3.63 per cent annual rate from 1.74 quadrillions BTU in 1998 to 3.37 quadrillion BTU in 2017. In 2014, EC in terms of oil equivalent was 460.23 million tons, up from 446.01 million tons in 2001. In addition, the country has been hit by an acute energy disaster that has raised its dependency on imported oil. As a result, the country's economic electricity generation sector increased, resulting in a severe dearth of electricity and gas.

EC and EQ are linked in the current literature (Chen, Saleem, & Bari, 2019; Ozcan, Tzeremes, & Tzeremes, 2020). The studies of Hassan, Baloch, Mahmood, and Zhang (2019) and Baloch and Suad (2018) indicate that Pakistan may still be developing, with growing manufacturing activities infuriating the country's present energy demand. Renewable and nonrenewable energy sources are used to meet this demand. Most energy is derived from traditional conventional fossil fuels, gas, and oil, resulting in high emissions (Chien, Hsu, Zhang, Vu, & Nawaz, 2022). The growing number of vehicles and modes of transportation, combined with a lack of high-level fuel worsens the EQ (Baloch, Khan, Ulucak, & Ahmad, 2020). Although, as asserted by (Zhang, Wang, & Wang, 2017) in their previous studies for Pakistan, renewable energy helped to control carbon emissions to some extent.

These studies employed symmetric econometric methodologies and relied on a single estimate of CO₂ emissions in the environment. Furthermore, just a few studies in the literature apply a nonlinear econometric technique to investigate the link between energy and carbon emissions (Baz et al., 2020; Munir & Riaz, 2020). As a result, our study adds to the current literature in the following ways. We use the symmetric ARDL technique to inspect the symmetric impact of energy use on carbon emissions. Additionally, the asymmetric ARDL method considers the nonlinear effects of energy use on carbon emissions.

The rest of the paper is organized as follows: Section 2 addresses the literature review, Section 3 details the data collection, Section 4 examines the model and methods, Section 5 gives the empirical evidence, and Section 6 concludes the study.

2. Literature Review

Economic growth is a structural transition that raises production activities and, as a result, the consumption of energy in the economy. As a result, growth is inextricably associated with energy consumption and inextricably related to emissions levels. Numerous research on this issue has produced inconsistent results due to differences in econometric methodology, sample size, and indicators used to quantify environmental quality. Javid and Sharif (2016) look at the effects of FD, EU, GDP, and TRO on per capita CO₂ emissions in Pakistan from 1972 to 2013 and found that the EKC phenomenon was present in the country's data. Following the ARDL technique, long and short-run outcomes revealed that the most significant contributors to carbon emissions were increases in FD, national income, and increased EU. The results of the ARDL model revealed that financial expansion and energy use was detrimental to environmental quality, and they recommended that environmentally friendly firms be supported to counteract CO₂ emissions. Moreover, the association of CO₂ discharges, TRO, EU, and FD in Pakistan using data from 1971 to 2011 was investigated by Shahzad et al. (2017). Their study revealed that CO₂ had an inverted U-shaped relationship with EU in the short run. There is also a meaningful link among these variables in the long run. It was found that there was unidirectional causality between EU, FD, and TRO and greenhouse gas emissions and bidirectional causality between FD and EU.

Bashir, Thamrin, Farhan, Mukhlis, and Atiyatna (2019) investigated the connection among Indonesia's EU, human capital, CO₂ emissions and EG from 2000 to 2015. The study employed the VECM, and the results revealed that causation occurs solely in CO₂ discharges and human capital. With the increases in energy consumption rises, economic growth increases and as a result so do carbon dioxide emissions also stimulates.

Ardakani and Seyedaliakbar (2019) explored the connection between EG, EU, and carbon dioxide discharge. A total of seven oil-rich states in North Africa and the Middle East were intended in research. Concerning EU and EG, it is expected that a quadratic polynomial technique for CO₂ emanation would be used. Furthermore, Muhammad and Khan (2019) inspected the impact of bilateral FD, EU, discharge of CO₂, and the role of capital stock on the EG of Asia-Pacific countries. Adebayo and Acheampong (2022) demonstrate the influence of globalization on carbon emissions in Australia over the time from 1970 to 2018. The study applied the Quantile-on-Quantile method to find the empirical analysis, revealing a positive association between EG and carbon emanations. While economic expansion has induced higher levels of carbon emissions, reducing CO₂ emissions can cause economic growth to stagnate or decline in some countries.

Furthermore, Abid, Mehmood, Tariq, and Haq (2022) probed the empirical affiliation among technical innovation, FD, and carbon emanations in developed nations using data from 1990 to 2019. The study showed, cross-sectional reliance was significant in panel countries. It has been discovered that FD, and technical innovation in the territories all have a statistically significant long-run and negative correlation with CO₂, according to the FMLOS estimator's findings. In a study conducted between 1980 and 2018, Abbasi, Adedoyin, Abbas, and Hussain (2021) investigated the impacts of energy diminution and the use of renewable energy (RE) on carbon emanations in Thailand. The study employed the Dynamic ARDL modeling framework. The findings proved that the rate of lessening had a considerable negative effect on carbon discharges in both the short and long run. In the short term, the studies discovered that RE had a substantial adverse impact on CO₂ emissions, which means an up surge in RE caused to reduce emissions. Baloch et al. (2020) investigated empirical affiliation of poverty, income disparity, and CO₂ discharges in Sub-Saharan African nations between 2010 and 2016. According to the data, poverty boosts CO₂ emissions in countries in Sub-Saharan Africa as a result of population growth.

Sharmin (2021) determined the association between the use of RE and non-renewable EU and CO₂ emissions. The researcher predicted a statistically significant positive link between non-renewable energy and GDP using the ARDL model. Still, a statistically significant negative correlation was expected between RE and emissions.

Moreover, Salari, Javid, and Noghanibehambari (2021) investigated the impact of energy usage by various sources like industrial consumption, non-renewable, renewable, and EC on CO₂ emissions with the help of static and dynamic econometrics models for the USA data. They identified a direct link between CO₂ emissions with all types of energy consumption except renewable energy, which demonstrated inverse relations.

3. Data

The present study uses energy usage, GDP per person, FD, TRO, and URB as determinants of carbon dioxide discharges in Pakistan. Table 1 depicts variables, their measurement units, and sources. CO₂ emission is a proxy for EQ with the metric tons per capita unit. Similarly, a series of domestic credit to the private sector is taken as a proxy of FD calculated in percent of GDP. Moreover, GDP per person and TRO are measured in US dollars. The urban population is given in million numbers, and the measurement unit of EU is KG of oil equivalent per capita.

Table 2 shows the association among the variables. CO₂ emission and financial development negatively correlate between them with a magnitude of -0.163. GDP per capita and CO₂ emission have a positive correlation with a volume of 0.862 and a negative correlation with financial development with a magnitude of -0.426. Urban Population shares a positive correlation with CO₂ emission and GDP per capita by 0.95 magnitudes and a negative correlation by -0.379. Trade openness positively correlates with CO₂ emission with a magnitude of 0.830, and trade openness negatively correlates with financial development with a magnitude of -0.432. GDP per capita and trade openness positively correlate with a magnitude of 0.992.

Table 1: Description and Source of the Variables

Code	Variable Name	Unit of Measurement	Source
CO ₂	CO ₂ emissions	metric tons per capita	WDI
FD	Domestic credit to the private sector	Per cent of GDP	WDI
GDP	GDP per capita	US Dollar	WDI
URB	Urban population	Population in Million	WDI
EU	Energy use	KG of oil equivalent per capita	WDI
TRO	Imports plus Exports	US Dollar	WDI

Table 2 also represents descriptive statistics of the variables like mean, standard deviation, kurtosis, skewness, range and the total number of observations. The arithmetic mean of CO₂ emission was 0.589 metric tons per capita, with the lowest standard deviation value among the given variables. Moreover, the kurtosis value was non-positive, revealing that the distribution of CO₂ emission had lighter tails than the normal distribution. The negative value of skewness indicates that the CO₂ series is skewed left during the study period.

Similarly, the average value of domestic credit to the private sector was 23.694 per cent of GDP, with a 3.356 magnitude of standard deviation. FD has relatively more tails than normally distributed data as kurtosis was positive, whereas it was also negatively skewed. From 1976 to 2019, Pakistan's average GDP per capita was 517.91 US dollars, with a relatively high variation as depicted by standard deviation and maximum and minimum values. GDP had more tail than normally distributed data and skewed to the right. Moreover, the average energy consumption value was 397.19 KG of oil equivalent per capita, TRO was 24186.45 US dollars, and the urban population was 38.302 million during the study period in Pakistan. Furthermore, the standard deviation of EU, TRO, and URB was 68.58, 22078.89, and 16.73, respectively. EU and URB had fewer tails, and TRO had more tails than normally. Moreover, the EU series was negatively skewed, whereas TRO and URB were negatively skewed.

Table 2: Correlation Matrix and Descriptive Analysis of the Variables

Variables	CO2	FD	GDP	URB	EU	TRO
CO2	1.000					
FD	-0.163	1.000				
GDP	0.862	-0.426	1.000			
URB	0.952	-0.379	0.954	1.000		
EU	0.989	-0.185	0.825	0.941	1.000	
TRO	0.830	-0.432	0.992	0.934	0.793	1.000

Descriptive Analysis						
	CO	FD	GDP	EU	TRO	URB
Mean	0.589	23.694	517.912	397.193	24186.45	38.302
Standard Deviation	0.169	3.356	315.127	68.577	22078.89	16.732
Kurtosis	-1.225	0.090	0.079	-1.412	0.393	-1.144
Skewness	-0.211	-0.609	1.010	-0.305	1.229	0.316
Minimum	0.308	15.589	101.165	284.975	1489.582	14.984
Maximum	0.872	29.786	1251.176	500.432	77073.469	69.956
Count	44	44	44	44	44	44

Figure 1: Graphical Representation of the Series

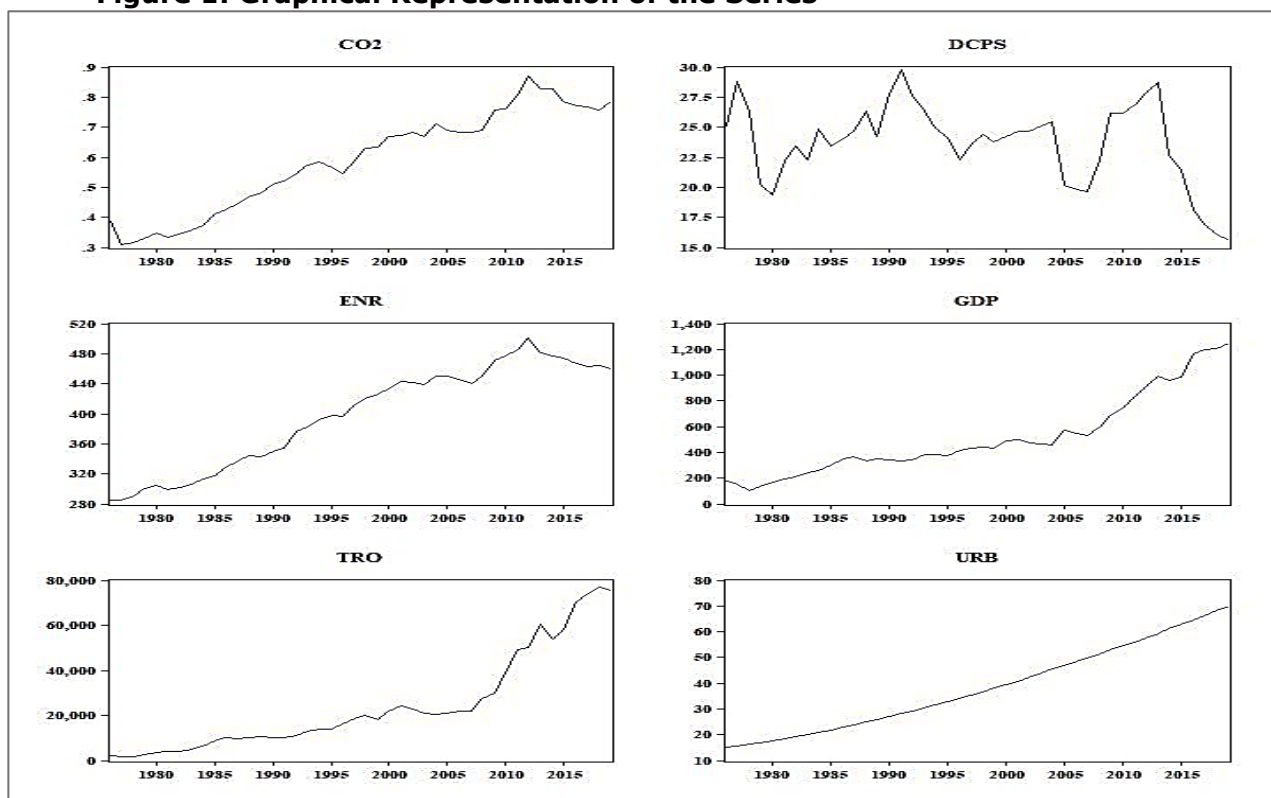


Figure 1, it is shown that CO₂ emission is on an increasing trend over the time from 1980-to 2010 and showing a decreasing trend in the last five years from 2015- to 2019. In the

second graph, DCPS is an indicator of the Financial Development Sector, and the graph shows fluctuations over time; in 1990, it shows the peak level and then a sudden decrease after 2010. In the third graph, Energy Consumption shows an increasing trend in the whole period until 2010, then a slight decline after 2010, which reduces CO₂ emission as energy consumption decrease. In the Fourth graph, GDP per capita shows an increasing trend. In the fifth graph, Trade Openness also indicates a growing trend, and then there is a steep increase in the TRO trend from 2009 and afterwards. In the sixth graph, URB (urbanization) also shows a continuously increasing trend from 1980-to 2010.

4. Empirical Methodology

As mentioned above, the core intent of the current study is to examine the symmetrical and asymmetrical effect of energy consumption on CO₂ emanation and some critical determinants of environment quality per person, URB, and TRO as control variables in the case in of Pakistan. Therefore, the following function is used for the empirical analysis;

$$CO_2 = f(EU, GDP, FD, TRO, URB) \dots\dots\dots (1)$$

Where, equation (1) represents that carbon dioxide is a function of utilization of energy (EU), per head gross domestic product (GDP), financial growth (FD), globalization/trade openness (TRO), and urbanization (URB). Several studies (Abid et al., 2022; Adebayo & Acheampong, 2022; Bashir et al., 2019; Chontanawat, 2020; Javid & Sharif, 2016; Odugbesan & Rjoub, 2020; Shahbaz et al., 2016; Shahzad et al., 2017; Szymczyk, Şahin, Bağcı, & Kaygin, 2021) analyze the relationship of urbanization, GDP per capita, energy usage, TRO, FD, human capital with EQ employing various econometric techniques for different regions. For estimation purpose the study uses ARDL and NARDL models to inspect the short run and long run coefficients.

To empirically examine the phenomenon of EKC, ARDL model and NARDL models will be used. The preceding step of the ARDL model is to investigate the stationarity of the variables and confirms the order of integration of these variables because we cannot use ARDL if any variable in the model is stationary at I (2).

$$\Delta CO_{2t} = \delta_0 + \sum_{n=1}^p \delta_1 \Delta CO_{2t-k} + \sum_{n=1}^p \delta_2 \Delta EU_{t-k} + \sum_{n=1}^p \delta_3 \Delta GDP_{t-k} + \sum_{n=1}^p \delta_4 \Delta FD_{t-k} + \sum_{n=1}^p \delta_5 \Delta TRO_{t-k} + \sum_{n=1}^p \delta_6 \Delta URB_{t-k} + \gamma_1 \Delta CO_{2t-1} + \gamma_2 \Delta EU_{t-1} + \gamma_3 \Delta GDP_{t-1} + \gamma_4 \Delta FD_{t-1} + \gamma_5 \Delta TRO_{t-1} + \gamma_6 \Delta URB_{t-1} + ECM_{t-1} + \varepsilon_t \dots\dots\dots (2)$$

Equation (2) has the advantage of finding both short-term and long-term assessments in a single equation. The coefficients along with the symbol of delta reflect the short run estimations in equation (2) whereas $\gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5,$ and γ_6 denote for the long run estimated coefficients and ε_t is the error term. To make long-term predictions, the first step is to determine how the variables involved are cointegrated with one another. The bound test is used to determine whether or not there are cointegration relationships among the variables exist. The error correction model (ECM) is estimated to ensure that the model is converging.

Particularly noteworthy aspects are the impacts of EU on carbon dioxide emanations, both symmetrical and asymmetrical. Shin, Yu, and Greenwood-Nimmo (2014) suggested a nonlinear ARDL empirical technique used in this study as a basis for the results. This method investigates the asymmetrical influence of a sequence of shocks by separating the series into positive and negative shocks. The present study to examine the asymmetrical link between EU and CO₂ emissions in Pakistan, in this study, the major purpose is to establish whether CO₂ emission has an asymmetrical or symmetrical impact on Pakistan. NARDL decomposes the energy into two parts, one reporting the energy usage with positive shock and the other with negative shock. The functional form is given as follows:

$$EU_t^+ = \sum_{j=1}^t \Delta EU_t^+ = \sum_{j=1}^t Max(EU_t^+ 0) \dots\dots\dots (3)$$

$$EU_t^- = \sum_{j=1}^t \Delta EU_t^- = \sum_{j=1}^t Max(EU_t^- 0) \dots\dots\dots (4)$$

Here, the partial sum of energy consumption is represented by two variables in the equations (3) and equations (4). In contrast, the NARDL or asymmetric error correction model is represented by another variable in the equation (5). To denote the NARDL equation, two partial variables sum, EU_t^+ and EU_t^- , must be substituted in the equation (3).

$$\Delta CO_{2t} = \delta_0 + \sum_{n=1}^p \delta_1 \Delta CO_{2t-k} + \sum_{n=1}^p \delta_2 \Delta EU_{t-k}^+ + \sum_{n=1}^p \delta_3 \Delta EU_{t-k}^- + \sum_{n=1}^p \delta_4 \Delta GDP_{t-k} + \sum_{n=1}^p \delta_5 \Delta FD_{t-k} + \sum_{n=1}^p \delta_7 \Delta TRO_{t-k} + \sum_{n=1}^p \delta_8 \Delta URB_{t-k} + \gamma_1 \Delta CO_{2t-1} + \gamma_2 \Delta EU_{t-1} + \gamma_3 \Delta GDP_{t-1} + \gamma_4 \Delta FD_{t-1} + \gamma_5 \Delta TRO_{t-1} + \gamma_6 \Delta URB_{t-1} + ECM_{t-1} + \varepsilon_t \dots\dots\dots (5)$$

Following equation (5) calculation, the present study used the Wald test to assess asymmetries in both the short and long runs. The Wald test determines whether joint short-run asymmetry should be accepted or rejected. Aside from accepting the alternative hypothesis, the study found that, in the short term, energy consumption and carbon emissions have an asymmetrical relationship with one another. Additionally, if the null hypothesis is rejected over time, the Wald test is used to demonstrate the asymmetric nature of the effect.

5. Results

This segment is discussing the outcomes of the empirical econometric evaluation. Before empirical econometric analysis, the stationarity of the series was examined to select an appropriate econometric approach. Therefore, the study has employed two tests for the unit root analysis, Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). Table 3 shows the outcomes of these two tests, where all variables have unit root at level, except urbanization, and they convert to stationary series after taking the first difference. This indicate that both tests reach the same conclusion that the selected variables have a mixed order of integration with I(0) and I(1). Therefore, we may apply the ARDL technique.

Table 3: Outcomes of the Unit Root Analysis

Variables	ADF test statistic			PP test statistic		
	Level	ΔX_i	Decision	Level	ΔX_i	Decision
CO2	-0.69 0	-8.538***	I (1)	-0.695	-8.302***	I (1)
FD	-1.288	-5.889***	I (1)	-1.585	-5.688***	I (1)
EU	-2.111	-5.085***	I (1)	-1.968	-5.110***	I (1)
GDP	-0.224	-6.110***	I (1)	-0.119	-6.251**	I (1)
TRO	-0.480	-5.583***	I (1)	-1.475	-5.615***	I (1)
URBP	-3.066**		I (0)	-8.594***		I (0)

The symmetric and asymmetric ARDL approach results are presented in Table 4, containing the short run and long run results and some diagnostic statistics. Indicators of FD, EU and URB have a positive association with CO₂ emanation in SR and LR, as depicted in the results of the linear ARDL model. The results are matched with Chontanawat (2020), who examined the causality and cointegration of EU and CO₂ discharges in Asian countries. Similarly, Szymczyk et al. (2021) found positive relationships between energy utilization, metropolitan population, and CO₂ emissions in OECD. Javid and Sharif (2016) identified the same results for FD and EU in Pakistan. Moreover, Anwar, Younis, and Ullah (2020); Bashir et al. (2019); Odugbesan and Rjoub (2020) employed various econometric techniques and reported similar outcomes for different world regions. The estimated value of the bound test is highly significant and substantially greater than the critical value advocating the presence of cointegration in the model. Likewise, the estimated coefficient of ECM is significant and negative, confirming the model's convergence with the magnitude of -0.629 regarding long run stability in response to any shock in the model. Similarly, the RESET test is considerably significant, depicting stability in the model. The LM test shows that no problem of autocorrelation prevails in the model.

The finding of the nonlinear ARDL model is also presented in Table 4. Estimated coefficients of positive parts of energy usage, negative parts of energy usage, and urbanization are significant with positive signs in the short run. This specifies that nonlinear connection between EU and CO₂ emanation exists in magnitude but not in the direction in the short run in Pakistan. Moreover, in the long run, estimates FD, negative part of EU, TO, and urbanization are directly related to CO₂ Emissions. A 1% decrease in EU causes a rise in carbon dioxide emission by 1.54%, with a statistically significant value. Further, 1% raise in EU causes a reduction in CO₂ discharge by 0.219% but with an insignificant value. This also deduces a non-linear relationship between EU and CO₂ emanation in magnitude but in the opposite direction. This reveals that energy consumption is not efficiently used, and eco-friendly energy consumption technology has not been introduced in Pakistan. Moreover, there is a need to

invest in renewable energy to contain environmental pollution, as suggested by Salari et al. (2021), encouraging subsidizing renewable energy sources for efficient energy utilization.

Trade openness and urbanization have a significant long-run relationship with CO₂ emission, depicting a positive association. Being a developing country with the non-existence of strict rules for the environment related to international trade, Pakistan is facing degradation of the environment with the increase in trade liberalization. This fact proves the natural hypothesis, as highlighted by Mutascu (2018) in France, that during low to medium frequency of trade openness, CO₂ emissions increased. In contrast, the relationship reversed when the frequency of trade openness was high. Co-movement of CO₂ emissions with urbanization may be due to unplanned and inefficient urban development, causes not only misuse of resources but also an acute threat to ecological health (Anwar et al., 2020; Hao, Shah, Nawazb, Barkat, & Souhail, 2020). This could be improved by promoting green and sustainable urbanization with strict regulation and usage of renewable energy in metropolitan areas. This was also identified by Abid et al. (2022) in Pakistan and provided policy implications to improve environmental quality. Similar to the symmetric ARDL model, the Bound test confirms cointegration among the variables. Furthermore, ECM is negative and significant, with a 0.843 speed of adjustment. The calculated value of the LM test does not reject the null hypothesis.

Table 4: Results of ARDL NARDL Model

Variables	Coefficient	T-stats	Coefficient	T-stats
Short Run Coefficients				
$\Delta DCPS_t$	0.091**	2.32	0.054	1.085
$\Delta DCPS_{t-1}$			-0.091	-1.679
ΔEU_t	1.288***	5.13		
ΔEU_t^+			0.830**	2.357
ΔEU_{t-1}^+			0.743**	2.141
ΔEU_t^-			1.299***	3.932
ΔGDP_t	-0.063	-1.12	-0.087	-1.206
ΔTRO_t	0.074	1.78	0.007	0.133
ΔURB_t	6.437**	2.57	0.589***	3.506
Long Run Results				
$DCPS_t$	0.145**	2.58	0.223***	4.106
EU_t	0.838***	3.04		
EU_t^+			-0.219	-0.604
EU_t^-			1.541***	4.092
GDP_t	-0.101	-1.03	-0.103	-1.232
TRO_t	0.119	1.56	0.152**	2.744
URB_t	0.377**	2.19	0.699***	4.071
Constant	-5.852***	-7.26	-6.144***	-4.929
Diagnostics				
F-Test/ ARDL Bounds Test	16.523 [1%]		4.098 [2.5%]	
ECM	-0.629***	-6.182	-0.843	-5.624
Breusch-Godfrey Serial Correlation LM Test	0.179		0.891	
RESET	2.457*		0.011	

6. Conclusion

Efficient use of energy resources is one of the best solutions for protecting the world’s ecosystem and achieving sustainability of economic growth. However, excessive use of energy leads to a severe threat to the environment quality of the globe. The present study has investigated the symmetric and asymmetric relationship of EU and CO₂ emanation in Pakistan. For empirical analysis, ARDL and NARDL approaches are employed for 1976 to 2019.

Linear ARDL identified a positive association of FD, EU and URB with CO₂ emanation in SR and LR. Furthermore, non-linear ARDL estimated statistically significant coefficients for positive parts of EU, negative parts of EU, and URB with positive signs in the short run, indicating asymmetry between EU and environment quality in magnitude but not in the direction in the short run Pakistan. Moreover, in the long run, estimates demonstrate that FD,

negative part of EU, TO, and URB are directly related to CO₂ emission, which again confirms asymmetry.

Adopting clean production technology is critical for preventing environmental damage. As a result, moving to clean and the RE is predicted to help countries construct energy development policies, reduce their fossil fuel footprint, and enhance EQ. Furthermore, it is suggested that government should concentrate on clean energy production initiatives to promote RE. Moreover, strict rules and regulations for protecting the ecological system with promoting green and sustainable urbanization would be encouraged to contain environmental degradation. The present study can be extended to divide the EU into renewable energy, non-renewable energy, industrial energy, residential energy etc., to identify the relative importance of the usage of various energies to overcome the problem of environmental degradation. It can also be extended by constructing an environment performance index for Pakistan as Szymczyk et al. (2021) used for OECD countries.

Reference

- Abbasi, K. R., Adedoyin, F. F., Abbas, J., & Hussain, K. (2021). The impact of energy depletion and renewable energy on CO₂ emissions in Thailand: fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy*, 180, 1439-1450. doi:<https://doi.org/10.1016/j.renene.2021.08.078>
- Abid, A., Mehmood, U., Tariq, S., & Haq, Z. U. (2022). The effect of technological innovation, FDI, and financial development on CO₂ emission: evidence from the G8 countries. *Environmental Science and Pollution Research*, 29(8), 11654-11662. doi:<https://doi.org/10.1007/s11356-021-15993-x>
- Adebayo, T. S., & Acheampong, A. O. (2022). Modelling the globalization-CO₂ emission nexus in Australia: evidence from quantile-on-quantile approach. *Environmental Science and Pollution Research*, 29(7), 9867-9882. doi:<https://doi.org/10.1007/s11356-021-16368-y>
- Agboola, M. O., Bekun, F. V., & Balsalobre-Lorente, D. (2021). Implications of social isolation in combating COVID-19 outbreak in Kingdom of Saudi Arabia: its consequences on the carbon emissions reduction. *Sustainability*, 13(16), 9476. doi:<https://doi.org/10.3390/su13169476>
- Anwar, A., Younis, M., & Ullah, I. (2020). Impact of urbanization and economic growth on CO₂ emission: a case of far east Asian countries. *International Journal of Environmental Research and Public Health*, 17(7), 2531. doi:<https://doi.org/10.3390/ijerph17072531>
- Ardakani, M. K., & Seyedaliakbar, S. M. (2019). Impact of energy consumption and economic growth on CO₂ emission using multivariate regression. *Energy Strategy Reviews*, 26, 100428. doi:<https://doi.org/10.1016/j.esr.2019.100428>
- Baloch, M. A., Khan, S. U.-D., Ulucak, Z. Ş., & Ahmad, A. (2020). Analyzing the relationship between poverty, income inequality, and CO₂ emission in Sub-Saharan African countries. *Science of the Total Environment*, 740, 139867. doi:<https://doi.org/10.1016/j.scitotenv.2020.139867>
- Baloch, M. A., & Suad, S. (2018). Modeling the impact of transport energy consumption on CO₂ emission in Pakistan: evidence from ARDL approach. *Environmental Science and Pollution Research*, 25(10), 9461-9473. doi:<https://doi.org/10.1007/s11356-018-1230-0>
- Balsalobre-Lorente, D., Driha, O. M., & Sinha, A. (2020). The dynamic effects of globalization process in analysing N-shaped tourism led growth hypothesis. *Journal of Hospitality and Tourism Management*, 43, 42-52. doi:<https://doi.org/10.1016/j.jhtm.2020.02.005>
- Bashir, A., Thamrin, K. M. H., Farhan, M., Mukhlis, M., & Atiyatna, D. D. P. (2019). The causality between human capital, energy consumption, CO₂ emissions, and economic growth: Empirical evidence from Indonesia. *International Journal of Energy Economics and Policy*, 9(2), 98-104.
- Baz, K., Xu, D., Ali, H., Ali, I., Khan, I., Khan, M. M., & Cheng, J. (2020). Asymmetric impact of energy consumption and economic growth on ecological footprint: using asymmetric and nonlinear approach. *Science of the Total Environment*, 718, 137364. doi:<https://doi.org/10.1016/j.scitotenv.2020.137364>
- Chen, S., Saleem, N., & Bari, M. W. (2019). Financial development and its moderating role in environmental Kuznets curve: evidence from Pakistan. *Environmental Science and*

- Pollution Research*, 26(19), 19305-19319. doi:<https://doi.org/10.1007/s11356-019-05290-z>
- Chien, F., Hsu, C.-C., Zhang, Y., Vu, H. M., & Nawaz, M. A. (2022). Unlocking the role of energy poverty and its impacts on financial growth of household: is there any economic concern. *Environmental Science and Pollution Research*, 29(9), 13431-13444. doi:<https://doi.org/10.1007/s11356-021-16649-6>
- Chontanawat, J. (2020). Relationship between energy consumption, CO2 emission and economic growth in ASEAN: Cointegration and causality model. *Energy Reports*, 6, 660-665. doi:<https://doi.org/10.1016/j.egy.2019.09.046>
- Eckstein, D., Künzel, V., Schäfer, L., & Wings, M. (2019). *Global climate risk index 2020*. Bonn: Germanwatch.
- GoP. (2020). Economic survey of Pakistan. Retrieved from http://www.finance.gov.pk/survey_1920.html
- Hao, W., Shah, S. M. A., Nawaz, A., Barkat, M. Q., & Souhail, A. (2020). COVID-19 epidemic spread and the impact on public health & safety policy: an analysis of the adoption of preventive measures and effective management: evidence from Pakistan. *Revista Argentina de Clínica Psicológica*, 29(4), 722-736.
- Hassan, S. T., Baloch, M. A., Mahmood, N., & Zhang, J. (2019). Linking economic growth and ecological footprint through human capital and biocapacity. *Sustainable Cities and Society*, 47, 101516. doi:<https://doi.org/10.1016/j.scs.2019.101516>
- Jahanger, A. (2022). Impact of globalization on CO2 emissions based on EKC hypothesis in developing world: the moderating role of human capital. *Environmental Science and Pollution Research*, 29(14), 20731-20751. doi:<https://doi.org/10.1007/s11356-021-17062-9>
- Javid, M., & Sharif, F. (2016). Environmental Kuznets curve and financial development in Pakistan. *Renewable and Sustainable Energy Reviews*, 54, 406-414. doi:<https://doi.org/10.1016/j.rser.2015.10.019>
- Jianjun, H., Yao, Y., Hameed, J., Kamran, H. W., Nawaz, M. A., Aqdas, R., & Patwary, A. K. (2021). The role of artificial and nonartificial intelligence in the new product success with moderating role of new product innovation: a case of manufacturing companies in China. *Complexity*, 2021. doi:<https://doi.org/10.1155/2021/8891298>
- Liu, Z., Lan, J., Chien, F., Sadiq, M., & Nawaz, M. A. (2022). Role of tourism development in environmental degradation: A step towards emission reduction. *Journal of environmental management*, 303, 114078. doi:<https://doi.org/10.1016/j.jenvman.2021.114078>
- Muhammad, B., & Khan, S. (2019). Effect of bilateral FDI, energy consumption, CO2 emission and capital on economic growth of Asia countries. *Energy Reports*, 5, 1305-1315. doi:<https://doi.org/10.1016/j.egy.2019.09.004>
- Munir, K., & Riaz, N. (2020). Asymmetric impact of energy consumption on environmental degradation: evidence from Australia, China, and USA. *Environmental Science and Pollution Research*, 27(11), 11749-11759. doi:<https://doi.org/10.1007/s11356-020-07777-6>
- Mutascu, M. (2018). A time-frequency analysis of trade openness and CO2 emissions in France. *Energy policy*, 115, 443-455. doi:<https://doi.org/10.1016/j.enpol.2018.01.034>
- Nawaz, M. A., Ahmad, T. I., Hussain, M. S., & Bhatti, M. A. (2020). How energy use, financial development and economic growth affect carbon dioxide emissions in selected association of south east asian nations. *Paradigms. SI (1)*, 159-165.
- Odugbesan, J. A., & Rjoub, H. (2020). Relationship among economic growth, energy consumption, CO2 emission, and urbanization: evidence from MINT countries. *Sage Open*, 10(2), 2158244020914648. doi:<https://doi.org/10.1177/2158244020914648>
- Ozcan, B., Tzeremes, P. G., & Tzeremes, N. G. (2020). Energy consumption, economic growth and environmental degradation in OECD countries. *Economic Modelling*, 84, 203-213. doi:<https://doi.org/10.1016/j.econmod.2019.04.010>
- Salari, M., Javid, R. J., & Noghanibehambari, H. (2021). The nexus between CO2 emissions, energy consumption, and economic growth in the US. *Economic Analysis and Policy*, 69, 182-194. doi:<https://doi.org/10.1016/j.eap.2020.12.007>
- Shahbaz, M., Shahzad, S. J. H., Ahmad, N., & Alam, S. (2016). Financial development and environmental quality: the way forward. *Energy policy*, 98, 353-364. doi:<https://doi.org/10.1016/j.enpol.2016.09.002>
- Shahzad, S. J. H., Kumar, R. R., Zakaria, M., & Hurr, M. (2017). Carbon emission, energy consumption, trade openness and financial development in Pakistan: a revisit.

- Renewable and Sustainable Energy Reviews*, 70, 185-192.
doi:<https://doi.org/10.1016/j.rser.2016.11.042>
- Sharmin, M. (2021). Relationship of renewable and non-renewable energy utilization with CO2 emission of Bangladesh. *Energy Economics Letters*, 8(1), 49-59.
doi:<https://doi.org/10.18488/journal.82.2021.81.49.59>
- Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281-314): Springer.
- Szymczyk, K., Şahin, D., Bağcı, H., & Kaygın, C. Y. (2021). The effect of energy usage, economic growth, and financial development on CO2 emission management: an analysis of OECD countries with a High environmental performance index. *Energies*, 14(15), 4671. doi:<https://doi.org/10.3390/en14154671>
- Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. *Energy policy*, 37(1), 246-253. doi:<https://doi.org/10.1016/j.enpol.2008.08.025>
- WDA. (2020). World Data Atlas. Retrieved from <https://knoema.com/atlas/Pakistan/Primary-energy-consumption>
- Xing, T., Jiang, Q., & Ma, X. (2017). To facilitate or curb? The role of financial development in China's carbon emissions reduction process: a novel approach. *International Journal of Environmental Research and Public Health*, 14(10), 1222.
doi:<https://doi.org/10.3390/ijerph14101222>
- Yuxiang, K., & Chen, Z. (2011). Financial development and environmental performance: evidence from China. *Environment and Development Economics*, 16(1), 93-111.
doi:<https://doi.org/10.1017/S1355770X10000422>
- Zhang, B., Wang, B., & Wang, Z. (2017). Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. *Journal of cleaner production*, 156, 855-864. doi:<https://doi.org/10.1016/j.jclepro.2017.03.203>