https://doi.org/10.52131/jee.2023.0401.0031

*i*RASD Journal of Energy & Environment

Volume 4, Number 1, 2023, Pages 01 - 15

Journal Homepage:
https://journals.internationalrasd.org/index.php/jee

How Do Nuclear and Renewable Energy Effects the Environment? A Case Study of Pakistan

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ARTICLE INFO

Article History:
Received: February 13, 2023
Revised: April 18, 2023
Accepted: April 21, 2023
Available Online: June 30, 2023

Keywords:
Nuclear Energy Consumption
Renewable Energy Consumption
Carbon Emission
EKC hypothesis
Pakistan

JEL Classification Codes:
Q41, Q42, Q51, R11

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

Based on the Environmental Kuznets Curve (EKC) theory, this research seeks to probe the impact of nuclear and renewable energy on carbon emissions in Pakistan. In order to analyze Pakistan's cointegration from 1990 to 2022, this study uses the ARDL technique. The findings provided empirical support for the Environmental Kuznets Curve (EKC) theory and demonstrated that the use of nuclear and renewable energy resources is linked to lower carbon dioxide (CO2) over the long term. Carbon dioxide emissions from burning fossil fuels, which are used for most of the world's energy needs, have been steadily rising in recent years. Policymakers recognize this and are working to reduce reliance on nonrenewable energy sources while increasing nuclear and renewable energy use.

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Citation: Ali, S. W., & Khalid, S. (2023). How Do Nuclear and Renewable Energy Effects the Environment? A Case Study of Pakistan. *IRASD Journal of Energy & Environment*, *4*(1), 01–15. https://doi.org/10.52131/jee.2023.0401.0031

1. Introduction

Nuclear energy, obtained by nuclear reactions, has arisen as a highly contested and contentious topic due to its environmental impact. Nuclear power is a promising alternative to fossil fuels because it can provide large amounts of electricity while emitting minimal greenhouse gas emissions. Nuclear energy offers both advantages and disadvantages in terms of environmental effects. Low greenhouse gas emissions, high energy density, and continuous power output are all benefits of nuclear energy. Furthermore, it produces radioactive waste, Uranium mining, and environmental disruption, all of which harm the environment. Renewable energy, often known as clean energy, has shown to be an essential instrument in minimizing environmental deterioration and solving climate change challenges. Renewable energy sources contribute to environmental improvement, including reduced greenhouse gas emissions, improved air quality, water conservation, biodiversity preservation, and sustainable economic development.

Numerous academic studies have pointed to carbon dioxide (CO2) and other greenhouse gas (GHG) emissions as the principal causes of global warming. When fossil fuels are burned, they release carbon dioxide (CO2). Therefore, many studies have been

done to identify the causes of CO2 emissions and their potential mitigation. Studies from the past are typically divided into one of three categories based on the variables they used. The first grouping, the income-energy-CO2 nexus, consists mainly of the previously mentioned factors. The research Pao and Tsai (2010) indicates a positive and statistically significant correlation between energy use and pollution. As predicted by the Environmental Kuznets Curve (EKC) hypothesis, the results show that a panel of BRIC countries exhibits the inverted U-shaped pattern. Studies by Bhatti, ur Raheem, and Zafar (2020); Hanif, Nawaz, Hussain, and Bhatti (2022); Lean and Smyth (2010) corroborate this claim as well, with results that are consistent with the ASEAN average. Two recent empirical studies one by Pao, Yu, and Yang (2011) and another by S. S. Wang, Zhou, Zhou, and Wang (2011) support the idea of the Environmental Kuznets Curve (EKC) for a panel that includes the BRIC nations and China. The study's findings corroborated previous findings that CO2 emissions are elastic concerning energy consumption, but FDI is inelastic. Baek and Kim (2011) observed that higher energy usage degrades environmental quality in developed and developing countries. The research above from Pakistan provides additional evidence for the same conclusion Shahbaz, Lean, and Shabbir (2012) and Yavuz (2014) for Turkey.

The second research group investigated the viability of nuclear power as a potential substitute for traditional fossil fuels, aiming to mitigate carbon emissions at reduced levels. The empirical model, referred to as the nexus of income, energy consumption, nuclear power generation, and CO2 emissions, demonstrates a correlation between CO2 emissions and various factors, including nuclear power generation (consumption) and income and energy consumption. Furthermore, the studies above presented additional empirical support for asserting that nuclear power negatively influences environmental conditions. Menyah and Wolde-Rufael (2010) they conducted their investigation across 19 nations encompassing both industrialized and developing economies, while Iwata, Okada, and Samreth (2010) specifically examined the case of France. Furthermore, Baek and Kim (2013) carried out a study that showed the negative effects of nuclear energy use on the deterioration of the environment in Korea. This was true even though nuclear energy is frequently seen as a more environmentally friendly and sustainable energy option than fossil fuels. This, however, was the situation that developed. According to the study above, nuclear energy has an ongoing negative influence on the environment Baek and Pride (2014) in 12 different nations, including the United States of America, France, Japan, Canada, Spain, and Korea (Baek, 2015).

Iwata, Okada, and Samreth (2012) used a panel data methodology to examine how France's heavy reliance on nuclear power has affected the country's natural resources. Among the many variables that have contributed to the loss of the ecosystem, the researchers have concluded that the use of nuclear energy is significant. However, research by Baek and Pride (2014) suggests that nuclear power can significantly reduce CO2 emissions in countries where it is used extensively to generate electricity. Multiple studies have demonstrated that nuclear power and other renewable energy sources can drastically cut carbon dioxide emissions. Due to its acknowledged significance in assessing carbon dioxide emissions, nuclear energy, and societal and economic well-being, using renewable energy sources has been a prominent focus of the research mentioned above and, in a study, covering 19 countries, Apergis, Payne, Menyah, and Wolde-Rufael (2010) concluded that the usage of nuclear energy was significantly more effective than the installation of renewable energy sources in reducing carbon dioxide (CO2) emissions.

Additionally, the third group has focused mostly on empirically investigating the potential effect renewable energy sources may have on carbon dioxide (CO2) emissions within a limited time frame. It is also worth noting that few studies have considered energy usage as a potential factor. While it might seem that increasing energy use would also increase CO2 emissions, this is not the case (Baek, 2015). Previous studies have largely ignored the issue of energy consumption. The primary goal of this research is to contribute to the existing body of work on cointegration by thoroughly investigating the long- and short-term factors that influence CO2 emissions. This research aims to assess the impact of the EKC hypothesis on the short- and long-term implications of Pakistan's income, energy

consumption, nuclear power, and use of renewable energy on the country's carbon dioxide emissions. The Auto Regressive Distributed Lag (ARDL) model, widely used in econometrics, has been implemented. When looking at the effects of explanatory factors on a target variable across time, the Autoregressive Distributed Lag (ARDL) model is a popular econometric paradigm.

2. Literature Review

In recent years, a substantial amount of scholarly research has been undertaken to examine the relationship between economic development and the deterioration of the natural environment. Grossman and Krueger (1991) conducted a significant study examining the association between income and environmental degradation. Their findings revealed a distinctive inverted U-shaped pattern in this relationship. This observation implies the presence of an initially positive association between financial affluence and the deterioration of the environment. Nevertheless, this association reaches a state of equilibrium once a specific income level is achieved. According to the hypothesis of the Environmental Kuznets Curve (EKC), it is suggested that in the early phases of economic development, there is a positive association between per capita income and environmental degradation.

Nevertheless, during a pivotal moment, a notable shift transpires, resulting in a reduction in levels of pollution. This phenomenon continues until it reaches a particular threshold, at which juncture it undergoes a subsequent decline. This statement remains valid until a critical turning point, at which pollution triggers a decline. Scholars have recently employed the Environmental Kuznets Curve (EKC) theory to examine diverse energy systems, aiming to enhance their comprehension. Numerous studies have been undertaken to ascertain the efficacy of nuclear energy and alternative renewable energy sources in mitigating the release of pollutants (Shafiq, ur Raheem, & Ahmed, 2020). Numerous empirical investigations have demonstrated that using energy sources with reduced ecological impact can effectively mitigate the pace of environmental degradation (Farooq, Gillani, Subhani, & Shafiq, 2023). The study conducted by Apergis and Payne (2012) examined the correlation between the utilization of renewable energy (REC) and the levels of carbon dioxide (CO2) emissions in the United States (USA). The investigation findings indicate that the implementation of REC notably influences mitigating CO2 emissions.

Subsequent studies have provided evidence supporting the notion that renewable energy certificates (RECs) yield favorable environmental outcomes. Subsequent studies have provided further evidence indicating that the Renewable Energy Certificate (REC) program significantly influences the extent to which carbon dioxide emissions are mitigated. Several distinct lines of investigation have individually arrived at a consistent finding, indicating that adopting Renewable Energy Credits (REC) has had a notable effect in mitigating carbon dioxide emissions.

In their study, Shafiei and Salim (2014) investigated the various factors that impact carbon emissions in countries belonging to the Organization for Economic Cooperation and Development (OECD) from 1980 to 2011. They used the Stochastic regression and Technology (STIRPAT) model. The study's findings suggest that renewable energy sources are correlated with reduced energy consumption, whereas non-renewable energy sources are correlated with elevated levels of carbon emissions. The theory known as the Environmental Kuznets Curve (EKC) has been developed through extensive research and serves as a framework for understanding the relationship between urbanization and environmental degradation. According to this perspective, the principal objective of the policy is to mitigate climate change by promoting urbanization and adopting renewable energy sources.

Polzin, Migendt, Täube, and von Flotow (2015) researched to assess the impact of government policy on the adoption of and investment in renewable energy. The study's

results highlight the need for the incorporation of tech-driven regulations. The policy mandate also emphasizes the importance of long-term institutional investment in green energy sectors. As a result, it has been proposed that OECD nations provide tax incentives to these financiers. However, these policy shifts' impact on the economy and the environment must be carefully considered. Based on our data, this section evaluates studies investigating the connections between environmental quality, economic growth, energy consumption, FDI, natural resources, and renewable energy sources.

The correlation between national income and environmental quality was studied by Al-Mulali (2014) across 129 nations. The researchers reviewed data from 1980 to 2012 and found that higher real incomes have a negative impact on ecosystem health. This research also confirms that using renewable energy sources positively correlates with improving environmental quality. In addition, Jebli, Youssef, and Ozturk (2016) investigated the ties between carbon dioxide emissions, foreign trade, GDP growth, and energy use. The findings of this study support the Environmental Kuznets Curve (EKC) hypothesis and underline the significance of transitioning to renewable energy sources and promoting international trade as essential means of mitigating climate change. This line of thinking makes sense since it presumes that industrialized countries will take part in transmitting ecologically sustainable technology, leading to a long-term reduction in carbon emissions. The elements were discovered to have a mutual, additive effect on one another.

Hassan, Wang, Khan, and Zhu (2023) examined how foreign direct investment (FDI), energy consumption, and economic growth influenced carbon emissions in the ASEAN-5 region. This study employed a panel quantile regression strategy to assess whether or not FDI could reduce carbon emissions and by how much. Even more so, scientific research shows that economic development has harmed ecological- and human health in countries with high pollution levels (Wang, Gillani, Nazir, & Razzaq, 2023). At various quantiles, researchers discovered that various factors had varying effects on emissions (Fazal, Gillani, Amjad, & Haider, 2020; Nazir, Gillani, & Shafiq, 2023). Al-Mulali, Ozturk, and Solarin (2016) analyzed the environmental impacts of REC use in 58 countries. The research shows that using REC can help reduce one's environmental impact. Another study, Farooq, Subhani, Shafiq, and Gillani (2023) shows that environmental tax rate also have a negative impact on environmental pollution. Twelve countries discovered that using RECs (renewable electricity certificates) decreased CO2 emissions Baek (2015). The research also indicated that using renewable energy sources reduces carbon dioxide emissions and slows global warming.

According to research by Destek, Ulucak, and Dogan (2018), using renewable energy reduced carbon dioxide emissions in 27 European countries. They reasoned that using renewable energy would reduce greenhouse gas emissions and decrease global warming. A global analysis was conducted on the relationship between renewable energy certificates (RECs) and carbon dioxide (CO2) emissions (Hu, Xie, Fang, & Zhang, 2018). According to the survey results, utilizing REC reduces CO2 emissions by the opposite amount. For every percentage point that renewable energy is used, carbon dioxide (CO2) emissions are reduced by the same amount.

According to studies by S. P. Nathaniel and Iheonu (2019), using renewable energy sources decreases carbon dioxide emissions in 54 African countries. According to the findings, for every 1% increase in REC, CO2 emissions dropped by 0.05%. According to Acheampong, Adams, and Boateng (2019), this is true for 46 African countries. According to the literature, nuclear energy's potential positive benefits on South Africa's environmental sustainability have been studied extensively (Sarkodie & Adams, 2018). The research shows that nuclear power might make South Africa's energy system more sustainable and reduce the rate of environmental degradation there. The outcomes of this study revealed that REC caused a significant cut in CO2 emissions in the nations studied.

In addition, as revealed by Dogru et al. (2020), decreasing CO2 emissions in OECD member nations with REC alone is doable. Switching to renewable energy, however, was

found to cut CO2 emissions worldwide dramatically and in OECD nations (Dogru et al., 2020). This study's findings demonstrate that REC effectively reduced national carbon dioxide emissions. According to Destek and Sinha (2020), increasing REC led to a decreased ecological footprint in several OECD countries. We picked these states at random. This was a huge step forward in their study. Destek and Sinha (2020) researched to verify the validity of the Environmental Kuznets Curve in terms of carbon footprint. Twenty-four OECD nations were studied to see how they fared after switching to alternative and conventional energy sources and lowering trade barriers. In order to evaluate data from 1980 to 2014 and account for the interconnection of countries, the study employed complex methodologies. This means that the concept of an inverted U-shaped Environmental Kuznets Curve does not hold water in OECD nations, as our study demonstrates. The U-shaped relationship between economic expansion and environmental damage underpins this finding.

Nathaniel and Khan (2020) conducted studies in multiple nations for their study. This study aimed to examine the environmental effects of using renewable energy sources in these countries. The study results showed that when renewable energy sources were used, the environmental conditions in each country were noticeably better. Incorporating renewable energy technology and advocating for its use may help alleviate environmental problems and propel sustainable development in several places, as seen by these findings. Recent research Sharma, Sinha, and Kautish (2021) confirmed that switching to renewable energy sources effectively lowers carbon dioxide emissions.

Cui, Weng, Nadeem, Rafique, and Shahzad (2022) conducted research in 20 nations and provided data to back the contention that switching to renewable energy sources reduces environmental impact. Using renewable energy sources has been shown to reduce environmental impact. Carbon dioxide (CO2) emissions are decreased in 22 top remittance-receiving nations using renewable energy sources (Zafar, Saleem, Destek, & Caglar, 2022). The United States of America, China, India, Mexico, and the Philippines fall into this category. Ali, Yaseen, Anwar, Makhdum, and Khan (2021) study supports the premise that using renewable energy sources can assist in reducing emissions. The data demonstrate a positive correlation between real GDP growth and emission increases across 128 nations from 1995 to 2019. The results also provide credence to the Environmental Kuznets Curve (EKC) theory, at least for these countries.

Du, Jiang, Adebayo, Awosusi, and Razzaq (2022) found evidence supporting the Environmental Kuznets Curve (EKC) theory in the MINT nations. Moment quantile regression is used to analyze the correlation between pollution and economic development in these nations. In addition, the results corroborate a steady association between CCO2 emissions and exogenous factors (Gillani & Sultana, 2020). Research using MMQR (Multivariate Quantile Regression) shows a positive correlation between GDP growth, the high-tech industry, foreign direct investment, and carbon dioxide emissions over quantiles ranging from 0.1 to 0.90. However, between the 10th and 90th quantiles, there is a negative correlation between CO2 emissions and the share of renewable energy used.

Khan, Tan, Hassan, and Bilal (2022) tested the Environmental Kuznets Curve (EKC) hypothesis in the context of the Group of Seven (G-7) economies. The study participants investigate the factors contributing to environmental degradation and how they relate to using renewable energy sources. Using FMOLS and DOLS, which are "fully modified ordinary least squares" and "dynamic ordinary least squares," respectively, the authors evaluate data from 1996 to 2019. Researchers have linked the use of renewable energy to a worsening of environmental circumstances. The findings of this research lend further credence to the EKC theory. On the other hand, Saidi and Mbarek (2016) looked into how NEC affected CO2 emissions in nine industrialized nations. The findings showed that NEC did not significantly affect CO2 emissions. Carbon dioxide emissions, renewable energy, and nuclear power were all studied by (Menyah & Wolde-Rufael, 2010). The study found that carbon dioxide emissions were only little affected by REC use.

According to research Menyah and Wolde-Rufael (2010), solar energy has a negligible effect on the total carbon dioxide emitted by the G-7 countries. Khoshnevis Yazdi and Shakouri (2018) found no evidence of a correlation between renewable energy certificates (REC) and carbon dioxide emissions in Germany. Recent studies have shown that the impact of REC on carbon dioxide emissions in MENA countries is negligible (S. P. Nathaniel, Alam, Murshed, Mahmood, & Ahmad, 2021). According to the findings of Pata (2018, 2021), hydropower and other forms of renewable energy have a negligible effect on Japan's CO2 emissions. However, these energy sources' efficiency appears inadequate in Turkey. Nuclear power as an energy source, rather than alternatives based on fossil fuels, is also rising. Nuclear power plants convert the thermal energy created by nuclear reactions, particularly fission, into usable electrical power. Nuclear power facilities generate electricity without emitting greenhouse gases like carbon dioxide (CO2) or methane (CH4). As a result, reducing carbon dioxide emissions and mitigating the consequences of climate change can be aided by increasing the proportion of nuclear energy in the overall mix of energy sources. Climate change is also harmful for the agricultural production (Shafiq, Gillani, & Shafiq, 2021).

Sovacool (2008) investigated the correlation between nuclear power and CO2 emissions in 25 countries over a 40-year year. The negative correlation between nuclear energy use and carbon dioxide emissions was shown to be statistically significant. The study's authors also discovered a correlation between a more significant contribution from nuclear power to the overall energy balance and lower carbon dioxide emissions. Iwata et al. (2010) investigated how nuclear power and environmental issues are connected. The study's findings suggest that France's nuclear power program contributes to the country's overall carbon dioxide emissions. Greenhouse gas emission from various energy sources was examined by Wiedenhofer, Lenzen, and Steinberger (2013). The findings demonstrated that nuclear power generated less pollution per kilowatt-hour than any other source. The measured quantity was significantly lower when compared to sources that rely on fossil fuels.

Nathaniel et al. (2021) investigated the negative impacts of nuclear power on environmental quality in the G7 countries. The study's findings link nuclear energy use among the G7 countries to reduced environmental pollution. Using FMOLS and VECM statistical methods, Saidi and Omri (2020) investigated the nuclear energy hypothesis across eleven OECD nations. Six of the OECD's fifteen member countries have significantly decreased CO2 emissions due to NEC's efforts. According to a recent study, NEC also has a major impact on India's air quality (Bandyopadhyay & Rej, 2021). A negative connection between NEC and pollution levels was demonstrated using multivariate panel data analysis in some nations, including China, Canada, the United States of America, Germany, India, Russia, Korea, Iran, and Great Britain.

Al-Mulali (2014) aimed to investigate whether or not CO2 emissions vary between countries based on their utilization of nuclear power. Panel fully modified ordinary least squares (FMOLS) and the Pedroni cointegration test were used to analyze the data. The research examined the 30 countries that use the most nuclear power globally. The authors of this study determined that nuclear power negatively influenced carbon dioxide emissions after considering a wide range of factors. The data was analyzed using a panel data technique. According to Ozcan and Ulucak (2021), India's carbon dioxide emissions are inversely proportional to the country's use of nuclear energy (NEC). Using a panel data approach, the study investigated the matter. According to the results, the percentage of CO2 emissions decreased for every percentage point rise in NEC. Ozcan and Ulucak (2021) discovered that CO2 emissions are inversely related to India's NEC. NEC consumption emerges as a crucial component in assessing the potential of nuclear energy and renewable electricity to improve environmental conditions in 123 countries (Khan et al., 2022). In addition, studies by Hassan et al. (2023) showed that China can gain from switching to nuclear power by reducing its environmental impact on the world.

A review of the most recent academic literature reveals a dearth of investigation into how nuclear and renewable energy use in Pakistan affects carbon emissions. This study aims to shed light on the impact that nuclear and renewable energy transitions have had on carbon dioxide emissions in Pakistan.

3. Data and Methodology

Developing an acceptable methodology and proper procedures is necessary for a research study to succeed. Consequently, the next part will discuss the procedures and methods applied in the present investigation. To explore the short-term and long-term effects of nuclear, renewable, and nonrenewable energy on environmental deterioration in Pakistan from 1990 to 2022, the data used in this investigation comes from World Development Indicators (WDI, 2023). The functional form for the current analysis is as follows:

$$CO_2 = f(GDP, GDP^2, NEU, REU, NREU) \quad (1)$$

According to Equation 1, carbon emission (CO_2) is the dependent variable, economic growth (GDP), nuclear energy consumption (NEU), renewable energy consumption (REU) and nonrenewable energy consumption (NREU) are independent variables. Equation 1 can be written in a time-series form as:

$$CO_{2_t} = \alpha_o + \alpha_1 GDP_t + \alpha_2 GDP^2{}_t + \alpha_3 NEU_t + \alpha_4 REU_t + \alpha_5 NREU_t + \epsilon_t \quad (2)$$

According to equation 2, $\alpha_o$is intercept, α_1 to α_5 represents the effects of economic growth, nuclear energy, and renewable and nonrenewable energy on carbon emission, t represents the time period from 1990 to 2022 and ϵ_t represents the error term. Variables description and unit are represented in Table 1.

Table 1
Variable Description and Measurement

Variables	Description of variable	Source
Carbon emission (CO2)	"CO2 emissions (metric tons per capita)"	WDI (2023)
Economic growth (GDP)	"GDP growth (annual %)"	WDI (2023)
Nuclear Energy Consumption (NEU)	"Alternative and nuclear energy (% of total energy use)"	WDI (2023)
Renewable Energy Consumption (REU)	"Renewable energy consumption (% of total final energy consumption)"	WDI (2023)
Nonrenewable Energy Consumption (NREU)	"Fossil fuel energy consumption (% of total)"	WDI (2023)

Numerous methodologies have been put forth in academic literature to ascertain the inherent characteristics of the integration relationship between variables. Two commonly used methods for estimating cointegration in econometric analysis are the Residual-based technique and the Maximum Likelihood approach, which were introduced by Johansen and Juselius (1990). Engle and Granger (1987) were the original proponents of the Residual-based approach. For either method to be deemed applicable, all variables under consideration must possess an equivalent order of integration.

However, there is a complexity that emerges when there is a mixing of integration orders, such as in the analysis that is being presented here. In order to overcome this issue, the analysis uses a technique known as Autoregressive Distributed Lag or ARDL for short. This technique was created by (Pesaran, Shin, & Smith, 1996, 2001). The application of the Autoregressive Distributed Lag (ARDL) model is not restricted to a particular order of integration, as it can be utilized successfully for time series data with integrated of order zero (I(0)), integrated of order one (I(1)), as well as mixed order integration. This is because the ARDL model can effectively model time series data with integrated of order zero (I(0)), integrated of order one (I(1)), and mixed order integration.

The initial step in time series analysis entails assessing the stationarity of the data to minimize the risk of spurious regression. The Augmented Dickey-Fuller test is employed to ascertain the stationarity of the data. Cointegration is a statistical technique used to identify and analyze enduring relationships between variables over an extended period of time. The Autoregressive Distributed Lag (ARDL) model is commonly employed to capture the persistent associations observed in data. Conversely, the Error Correction Model (ECM) is employed to analyze and comprehend the short-term interactions among the variables. The bound test allows for multiple lags for each variable in the model. Equation 3 presents the functional representation of the Autoregressive Distributed Lag (ARDL) model.

$$CO_{2_t} = \alpha_o + \sum_{i=1}^{p} \beta_1 \Delta CO_{2_{t-1}} + \sum_{i=0}^{p} \beta_2 \Delta GDP_{t-1} + \sum_{i=0}^{p} \beta_3 \Delta GDP^2{}_{t-1} + \sum_{i=0}^{p} \beta_4 \Delta NEU_{t-1} + \sum_{i=0}^{p} \beta_5 \Delta REU_{t-1} + \sum_{i=0}^{p} \beta_6 \Delta NREU_{t-1} + \beta_7 CO_{2_{t-1}} + \beta_8 GDP_{t-1} + \beta_9 GDP^2{}_{t-1} + \beta_9 NEU_{t-1} + \beta_{10} REU_{t-1} + \beta_{11} NREU_{t-1} + \varepsilon_t \quad (3)$$

The Bound test examines the existence of the long run relationship among the variables. According to the null hypothesis, there does no exit the long run relationship between the variables used in the study, which is:

$$H_o = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = 0$$

While the alternative hypothesis is that there exists a long run relationship between the variables

$$H_o \neq \beta_7 \neq \beta_8 \neq \beta_9 \neq \beta_{10} \neq \beta_{11} \neq 0$$

Pesaran et al. (59) found that the null hypothesis is rejected if the calculated F-statistics value exceeds the upper bound critical values. On the other hand, the null hypothesis is found to be acceptable if the F-stat value is found to be smaller than the upper bound critical values.

4. Results and Discussion

In this section, we discussed the descriptive statistics and empirical results to examine the effect of nuclear, renewable and nonrenewable energy in the presence of the EKC hypothesis on Carbon emission.

Descriptive statistics are paramount in data analysis, as they enhance data comprehension by offering concise summary measures. The absence of descriptive statistics poses difficulty in identifying the inherent patterns or trends within unprocessed data. The presentation of the descriptive statistics summary is designed to optimize its usefulness and promote understanding. Furthermore, the descriptive statistics table provides essential summary measures, such as the total number of observations, the mean value, the standard deviation, and the minimum and maximum values of the dataset. This aids in the facilitation of another estimation. Table 2 shows a summary of the statistics for all of the chosen variables that were used in the study.

Table 2
Summary Statistics

Variables	Mean	Std. Dev.	Max	Min
CO2	0.706405	0.109287	0.918888	0.505906
GDP	4.391514	2.625139	14.24826	-1.274087
NEU	3.322957	0.674867	4.284932	2.008989
REU	48.76864	4.360953	58.09129	42.09
NREU	61.46676	7.018293	80.02711	52.30527

Table 3 shows the results of the Augmented Dickey-Fuller unit root test, which confirmed that the mixed order of integration exists. Hence Auto Regressive Distributive Lag Model (ARDL) is appropriate in this case. Furthermore, the ARDL bound test confirms the model's long run relationship, as explained in Table 4.

Table 3
Unit Root Test

Variable	t-stat	Prob.	Decision
CO2	-4.71334	0.004***	I(0)
GDP	-3.851242	0.0269**	I(0)
NEU	-5.61473	0.000***	I(1)
REU	-5.40132	0.000***	I(1)
NREU	-1.73816	0.077*	I(1)

Note: *, **, *** shows 10%, 5% and 1%. significance level.

Table 4
ARDL Bound Test

Test Statistic	Value	k
F-stat	9.703794	5
Critical Value		
Level of Significance	**I_0 Bound**	**I_1 Bound**
10%	2.26	3.35
5%	2.62	3.79
1%	3.41	4.68

According to Table 4, the calculated value of the bound test is more significant than all the significance levels, confirming a long run relationship in the model. ARDL short run results are given in Table 5.

Table 5
ARDL Short Run Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2MT(-1))	1.475***	0.259	5.687	0.002
D(CO2MT(-2))	1.591**	0.410	3.878	0.012
D(CO2MT(-3))	0.538**	0.164	3.286	0.022
D(GDP)	-0.009	0.005	-1.906	0.115
D(GDP(-1))	0.014**	0.005	3.163	0.025
D(GDP(-2))	0.015*	0.008	2.002	0.102
D(GDPSQ)	0.000	0.000	-0.505	0.635
D(GDPSQ(-1))	-0.001	0.001	-1.644	0.161
D(GDPSQ(-2))	-0.001	0.001	-1.406	0.219
D(NEU)	0.019*	0.009	2.174	0.082
D(NEU(-1))	-0.017*	0.007	-2.234	0.076
D(NEU(-2))	-0.019*	0.008	-2.226	0.077
D(REU)	-0.032***	0.002	-13.294	0.000
D(REU(-1))	-0.010	0.009	-1.123	0.312
D(REU(-2))	0.018**	0.006	2.871	0.035
D(NREU)	-0.003	0.004	-0.868	0.425
D(NREU(-1))	-0.015**	0.006	-2.676	0.044
ECM(-1)	-0.642**	0.210	-3.051	0.038

According to the data in Table 5, increasing GDP has positive and negative effects on the average amount of carbon emissions in the short run. Further, although not statistically significant, including the square root of GDP's lag negatively impacts carbon emission levels. Similarly, nuclear or renewable energy significantly and negatively affects global warming. In the short run, there is little evidence of an effect on carbon emissions from using nonrenewable energy sources. A statistically significant negative coefficient in the error correction term suggests a long-term link in the model. The outcomes of the bound test also lend weight to this observation. The convergence of the model to its equilibrium is confirmed at a yearly rate of 64% by the error correction term.

Table 6 shows GDP squared, NEU, and REU significantly and negatively affect carbon emissions. Carbon emissions positively relate to GDP and nonrenewable energy, proving that the EKC hypothesis holds for Pakistan. The findings are consistent with the underlying theory; details are provided below.

Table 6
ARDL Long Run Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.150***	0.091	12.581	0.000
GDP	0.018***	0.004	4.647	0.006
GDPSQ	-0.001*	0.000	-2.054	0.095
NEU	-0.019***	0.002	-8.980	0.000
REU	-0.016***	0.001	-21.687	0.000
NREU	0.006***	0.001	7.020	0.001

There is a positive and direct relationship between GDP and carbon emissions, suggesting that rising GDP releases more carbon into the atmosphere. However, a negative link is seen when GDP is squared, indicating that rising GDP is associated with declining carbon emissions. This research lends credibility to the non-linear link between GDP and carbon emissions postulated by the Environmental Kuznets Curve (EKC) theory. Emissions rise at the start of this connection and then gradually fall off. An inverted U-shaped pattern is predicted to exist between economic development and environmental degradation under the Environmental Kuznets Curve (EKC) theory.

According to the hypothesis, environmental deterioration increases during times of economic growth before leveling off once a certain level of economic development has been reached. In Pakistan, there is a correlation between GDP and carbon emissions because economic growth stimulates manufacturing and increases energy consumption. As Pakistan's economy has developed in recent decades, so has its reliance on fossil fuels, resulting in a sharp increase in carbon emissions. However, according to the Environmental Kuznets Curve (EKC) concept, the positive association between GDP and carbon emissions recorded at the outset will eventually reverse. This trend can be explained by the propensity of wealthy countries to invest more in programs that protect the environment and foster the creation of sustainable technology (Apergis & Payne, 2012; Dogan & Inglesi-Lotz, 2020; Katircioglu, 2014).

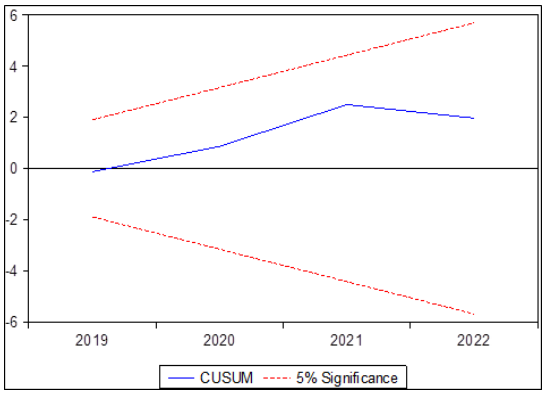
It is evident from Table 6 that nuclear power has a negative effect on emissions of carbon dioxide. Nuclear power plants emit much less carbon and produce less carbon dioxide than their coal-fired counterparts. Pakistan might reduce its impact on global warming and its reliance on fossil fuels by increasing its use of nuclear power. The negative effects of nuclear energy on greenhouse gas emissions have also been confirmed by these research (Baek & Kim, 2013; Baek & Pride, 2014; Cui et al., 2022; Iwata et al., 2010; Saidi & Omri, 2020). However, there is a trade-off in the form of higher carbon emissions when switching to renewable energy. Greenhouse gases are not produced while converting renewable energy sources like the sun and the wind into electricity. This suggests they may help reduce pollution by lowering carbon dioxide emissions and other pollutants (Hu et al., 2018; S. Nathaniel & Khan, 2020; Saidi & Omri, 2020).

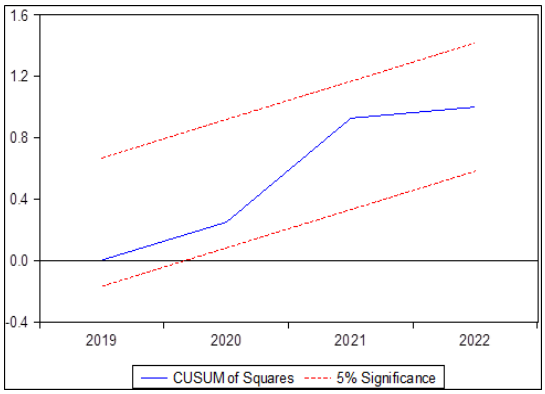
The data in Table 6 show that using nonrenewable energy sources is linked to more carbon dioxide being released into the atmosphere. Burning fossil fuels like coal, oil, and natural gas is the primary source of carbon emissions because they are the most widely used nonrenewable energy sources. Carbon dioxide (CO2) and other greenhouse gases are released into the atmosphere when fossil fuels are used to produce electricity, propel vehicles, operate industrial facilities, or warm homes. Carbon emissions have been shown to rise in tandem with nonrenewable energy sources Chen, Wang, and Zhong (2019); Shafiei and Salim (2014), which this research has confirmed.

Further, the model diagnostics are given in Table 7, and model dialogistic tests include autocorrelation, Heteroscedasticity, R- square, adjusted R- square and normality test. Moreover, all these tests confirm that the results are unbiased and efficient. In addition, CUSUM and CUSUM sq graphs test for the validation of the long run relationship in the model, and both the graphs confirm that the long run relationship exists in the model.

Table 7
Model Diagnostics

Test	Prob.
R-squared	0.999
Adjusted R-squared	0.996
Autocorrelation	0.193
Heteroscedasticity test	0.354
Durbin-Watson stat	3.266
Normality test	0.721





5. Conclusion

Considering the Environmental Kuznets Curve (EKC) concept, this study looks into how nuclear and renewable energy sources affect carbon emissions in Pakistan. This article's research uses WDI numbers from 1990 through 2022. This investigation examines the long-term and short-term connection between nuclear and renewable energy sources and carbon emissions using the popular Autoregressive Distributive Lag (ARDL) method. Controlled factors, including GDP, GDP squared, and nonrenewable energy consumption, are incorporated into the study. The ECM suggests a long-term link between the variables, and the findings of the ARDL Bound test confirm this. In addition, there appears to be a long-term connection between the variables, with the data showing an annual pace of adjustment of 64%. At the same time, utilizing GDP and GDP2 helps prove the existence of the EKC hypothesis in Pakistan.

Furthermore, nuclear and nonrenewable energy has shown a negative effect on the carbon emission level, which means that nuclear and nonrenewable energy are environment friendly while nonrenewable energy distracts the environment. According to the study, the country's policymakers should switch quickly to a low-carbon, sustainable energy system to stop climate change, cut carbon pollution, and ensure we have enough energy. The goal of this strategy is to encourage more use of nuclear and renewable energy sources while discouraging the use of nonrenewable energy.

Authors Contribution
Syed Wajahat Ali: data collection, data analysis, data interpretation, write-up
Salman Khalid: study design, critical revision, incorporation of intellectual content, drafting

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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