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Assessing the Influence of Renewable Energy Sources on CO2 Emissions: New Insights from Pakistan

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ABSTRACT

In today's global landscape, it is crucial to have a comprehensive understanding of carbon dioxide (CO2) emissions in developing nations such as Pakistan. This knowledge is vital in informing effective policymaking and promoting sustainable development. This study investigates the impact of renewable energy (RE) on environmental degradation in Pakistan from 1990 to 2021. This study utilized the renowned ARDL econometrics to analyze the impact of renewable energy consumption (REC), economic growth (EG), trade (TR), financial development (FD), energy consumption (EC) and FDI on carbon emission. The study's findings confirm the presence of a hypothesis in the case of Pakistan. Additionally, the results indicate that certain factors have a negative impact on carbon emissions while others have a positive impact. The study's findings indicate that embracing renewable energy sources, enhancing energy efficiency, and enacting legislative measures to decrease CO2 emissions are the most effective strategies for tackling climate change. Additionally, the study proposed that policymakers should prioritize encouraging and supporting using renewable energy sources in Pakistan. This involves establishing a conducive environment for investment in renewable energy projects, providing financial support, and promoting research and development in the renewable energy sector.

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1. Introduction

Current research disproves the claim that environmental degradation only affects wealthy nations. Environmental degradation appears to be an issue only in industrialized nations. Global greenhouse gas (GHG) emissions are high regardless of industrialization.

Repairing disaster-damaged infrastructure, natural resources, and agricultural land costs lives. These occurrences concern economics and environmental experts the most. Global environmental concern affects everyone. GHG-emitting states prioritize this. CO_2 is the leading greenhouse gas emitter, per the (World Bank, 2017). China emits 21.6% of global CO_2. Pakistan emits 0.9% of global, and the energy sector emits 65%. Countries with the most significant greenhouse gas emissions must cut CO_2 emissions. Countries that emit many greenhouse gases from electricity have problems. The use of energy sources is pragmatic and promotes economic progress. Reducing CO_2 emissions may slow EG, so countries are worried. Business-wide globalization has altered global social, economic, and political situations.

The escalating worldwide energy demand has resulted in increased carbon emissions due to the traditional dependence on fossil fuels, further exacerbating concerns regarding climate change (Beck & Mahony, 2018). As a result, there has been significant momentum in the imperative to shift towards renewable energy sources, distinguished by their minimal ecological footprint and capacity for enduring sustainability (Lucon et al., 2014).

Sharma (2011) stated that economic and industrial growth damage the environment. According to Lau, Choong, and Eng (2014), ASEAN members seek maximal EG—environmental degradation results from ASEAN economies' exploitation of natural resources. Acquaye et al. (2017) state that emerging economies are worried about environmental degradation. This applies to ASEAN economies especially. This is caused by pollutant-generating companies moving from developed to underdeveloped nations. He, Lu, Mol, and Beckers (2012) stated that industrial waste pollution in rivers worries Asian economies. Asians become sick from contaminated water. Bajpai (2018) reports that various Asian economies, including ones with the oldest established economic systems, have grown the most recently. China is the world's second-largest economy, followed by Singapore at the thirteenth and India at the sixth. Saboori and Sulaiman (2013) linked economic progress to environmental deterioration, deforestation, and population health. The economy grows yet affects the environment. Energy usage and environmental degradation have been extensively studied by researchers from various countries, including (Aydin & Esen, 2018; Huang, Hwang, & Yang, 2008; Presno, Landajo, & González, 2018). The use of traditional sources places limitations on both the amount of energy that is available and the influence that it has on the environment.

Conventional fossil fuels like coal and oil provide most of the world's energy. Energy (2019) reported that EC-related CO_2 is at an all-time high. Roy and Schaffartzik (2021) say the world's excessive EC, filled mainly by fossil fuels, causes significant CO_2 and other environmental difficulties. Thus, reducing CO_2 and transforming energy systems are top priorities for all nations. China surpassed the US as the largest carbon emitter in 2019, accounting for 27.2% of world emissions.1 Over the past 30 years, the region's rapid EG has been connected to annual increases in environmental pollution indices, notably carbon emission intensity. China faces tremendous internal and international pressure to reduce emissions (Zhao, Shang, & Song, 2020).

China is cutting carbon intensity and emissions (Li, Wang, Yang, Wang, & Wu, 2018). In June 2015, the corporation pledged to cut CO_2 by 60–65% from 2005 by 2030. China proposed to the UN General Assembly in September 2020 to become "carbon neutral" by 2060. Zero net CO_2 through offsetting, reduction, and storage is carbon neutrality (Mallapaty, 2020). CO_2 must be measured for China's 2030 carbon neutrality objective. China promotes RE as a fossil fuel alternative to reduce CO_2. A huge step toward "carbon neutrality." China's significant CO_2 from old energy technologies makes energy transformation increasingly important (Ren, Wang, Wang, & Liu, 2015; Zhao, Shang, & Song, 2019). The energy revolution is about renewables. High pollution and CO_2 make the current energy infrastructure unsuitable for growth (Gosens, Kåberger, & Wang, 2017). Studying CO_2 and RE is important because renewable energy replaces fossil fuels (Rahman & Velayutham, 2020).

Renewable energy adoption is unequal. Switching to renewable energy makes it hard to link heat and electricity generation (Nastasi & Basso, 2016). National renewable energy adoption depends on environmental infrastructure, financial resources, scientific concerns, legal and regulatory frameworks, and capabilities. Direct CO_2 emissions vary per country. Recent studies reveal that rising nations adopt more. Institutions may affect renewable technology and CO_2 reduction in countries. These studies explored numerous aspects affecting the adoption of renewable energy. Policy choices were rigorously analyzed (Jacobsson & Lauber, 2006; Johnstone, Haščič, & Popp, 2010). Adoption costs and willingness to pay were studied. Academic research has ignored how regional institutional differences affect CO_2 emissions and renewable energy use. Policy strongly impacts renewable energy deployment. According to (REN21, 2017) and (Adib et al., 2015) in the Renewables Global Status Report, government policies drive most RE progress. One hundred sixty-four nations set renewable energy goals in 2015, and 145 launched assistance programs.

The potential implementation of renewable energy sources may encounter obstacles related to institutional and administrative procedures and infrastructure considerations. These issues can impede implementation entirely or result in expenses surpassing early projections. Therefore, it is imperative to effectively address these limitations in order to ensure the successful integration of renewable energy sources. The predominant focus of the current discourse has revolved around the role that policy should assume in addressing these fundamental issues. Through disseminating our research outcomes, we intend to contribute to the continuing discourse surrounding the significance of institutions.

Pakistan is facing the significant consequences of climate change and is taking proactive steps to reduce its CO_2. Renewable energy sources have emerged as promising alternatives in pursuing an environmentally conscious and sustainable future. The influence of renewable energy sources on CO_2 emissions in Pakistan is complex and significant. Unlike fossil fuels, renewable energy sources such as solar, wind, and hydroelectric power produce electricity without harmful emissions being released into the Earth's atmosphere. Through the replacement of electricity generation from fossil fuels, this environmentally friendly energy source effectively decreases the release of CO_2 emissions. In addition, a strong renewable energy industry promotes awareness of energy conservation and efficiency. There is a growing demand to investigate other possibilities, such as intelligent power grids and energy-saving technology, as the use of fossil fuels decreases. This domino effect contributes further to the decrease in carbon emissions. In 2019, 26% of Pakistan's electricity generation came from hydropower, avoiding millions of metric tons of CO_2 emissions[1](Carbon Brief). If the government successfully achieves its ambitious goal of incorporating 60% renewable energy sources into the energy mix by 2030, the resulting decrease in emissions would be even more substantial.

In this study, we investigate the influence of renewable energy sources on the amount of carbon dioxide emitted in Pakistan. This study has significant policy and practical ramifications for Pakistan's sustainable development and climate change mitigation initiatives. Planning and expansion of sustainable energy can be enhanced with quantitative data on the correlation between national CO_2 emissions and the penetration of renewable energy. To phase out carbon-intensive fossil fuels, the empirical findings can inform investments and policy decisions regarding expanding solar, wind, and hydropower capacity. This study will provide insight into Pakistan's electricity generation, transportation, industrial, agricultural, and infrastructure sectors as it strives to transition to a low-emissions economy and meet the increasing energy requirements of the country. Legislation, infrastructure, and incentive programs can be significantly reduced to expedite renewable energy adoption and incorporate the gleaned insights. In order to achieve economic growth while preserving ecological sustainability, the analytic approaches might also inspire other developing nations to conduct

[1] https://interactive.carbonbrief.org/the-carbon-brief-profile-pakistan/

comparable empirical investigations into the advantages of renewable energy. Data-driven initiatives aimed at promoting clean and sustainable development within Pakistan's energy and economic framework could potentially be informed by this pertinent study.

2. Literature Review

It has become an essential topic of research to investigate the confluence between the adoption of renewable energy sources and the degradation of the environment. This is because countries are working hard to balance their energy needs and the ecological sustainability of their systems. This literature review presents a detailed overview of recent research, which provides insights into the complex link between renewable energy sources and their ecological effects. The review also provides information about potential solutions to this relationship.

Feridun, Ayadi, and Balouga (2006) and Wijen and van Tulder (2011) argued that globalization plays a role in accelerating environmental degradation in developing nations. This is even though globalization has the potential to negatively affect the environment due to the depletion of natural resources necessary for industrial development. Doytch and Uctum (2016) conducted a study to analyze how globalization has contributed to the degradation of the natural environment between 1984 and 2011. The analysis results indicate that as FD becomes more globalized, the inflow of investments that degrade the environment and have a negative impact on it increases. According to Dreher (2006), globalization has encouraged developed economies to invest globally in green technologies, and that this is a result of the connection that it has facilitated between developing and developed economies. In addition, Dreher (2006) argued that globalization has altered the dynamic between emerging and industrialized economies.. Li, Xu, and Yuan (2015) investigated the relationship between globalization and CO_2 emissions. The degree of globalization can be assessed through the metric of trade openness. The findings of the conducted research indicate that globalization negatively impacts CO_2 emissions. Shahbaz, Mahalik, Shahzad, and Hammoudeh (2019) examined the correlation between CO2 emissions and globalization in eighty-seven distinct economies in their study. The research shows that high- and middle-income economies will reduce their carbon output as a result of globalization in the future years. Globalization, on the other hand, has been demonstrated to have a beneficial impact on the reduction of environmental harm in nations with low per capita GDP.

Jaunky (2011) examined the influence of monetary factors on environmental degradation in thirty-six prosperous economies between 1980 and 2005, employing the Generalized Method of Moments (GMM). The data demonstrates a clear correlation between income and CO2 emissions. Saboori and Sulaiman (2013) investigated the correlation between two variables and revealed a strong relationship among variables. The economic expansion and the rise in economic activities in Malaysia have both had detrimental effects on the environment. Nguyen (2018), Al Mamun, Sohag, Mia, Uddin, and Ozturk (2014), Asif, Sharma, and Adow (2015) and Dar and Asif (2017) studies that have carried out to investigate the connection between two factors and the impact that they have on the local environment. They noted that economic expansion and environmental degradation are both factors that contribute to environmental degradation. Researchers such as Cole and Neumayer (2004), Parikh and Shukla (1995) and Ma and Du (2012) have concluded that there is a connection between the use of energy, the rise of industrialization, the expansion of metropolitan areas, and the deterioration of the environment. On the other hand, excessive energy consumption can adversely affect the surrounding ecosystem. Zhang and Cheng (2009) investigated whether or not there is a connection between China's environmental degradation and the country's rising energy consumption, expanding urban population, and rapid economic expansion. According to the paper's findings, the deterioration of the environment and the growth of the economy contribute to the acceleration of the process of environmental degradation.

Heath and Mann (2012) provided a comprehensive analysis of environmental effects. By taking a holistic view of renewable technology life cycles, this method uncovers indirect emissions from manufacture and disposal and direct emissions. If lawmakers want to make intelligent choices regarding renewable energy's impact on the environment, they need these kinds of thorough evaluations. According to Lund, Lindgren, Mikkola, and Salpakari (2015), renewable energy sources like solar, wind, hydro, and geothermal power are essential in reducing environmental damage caused by traditional energy production methods.

Shahbaz, Mallick, Mahalik, and Sadorsky (2016) analyzed the effects of various factors on EC over four decades. They utilized the ARDL econometrics model to inspect the influence of urbanization, FD, globalization, and economic expansion between 1971 and 2012. The purpose of their investigation was to determine if globalization had an impact on EC during that specific period. According to the findings of the data analysis, it would appear that globalization has a detrimental effect on the amount of energy that is required in India. On the other hand, EC is negatively impacted by economic development, but urbanization and economic growth have good economic consequences. According to Managi and Kumar (2009), there is a correlation between the amount of CO_2 emissions and the degree of commercial openness, and this correlation is generally favorable. As a result of the findings of the investigation, it was discovered that trade has a role in lowering production costs. This is why businesses may engage in extended manufacturing without being held accountable for their environmental impact, which is detrimental to Mother Earth in the long run. Multiple researchers have found that the amount of transparency in business transactions significantly affects the overall amount of carbon dioxide emissions, and this influence is negative.

The study by Le, Chang, and Park (2016) compared nations with varying income levels to see whether there are any differences in the correlation between "trade openness and carbon dioxide emissions. The research findings suggest that countries with higher incomes are significantly less impacted by trade openness on the environment than economies with lower or moderate incomes. Sadorsky (2011) investigated the correlation between the expansion of the financial sector and the deterioration of the environment. Integrating energy into economic development processes facilitates the advancement of FD. Overconsumption of energy results in a rise in CO_2 emissions and harms the nearby ecology. A study by Shahbaz, Hye, Tiwari, and Leitão (2013) examined the link between CO2 emissions and economic growth. They argued that a rising economy would help bring CO2 emissions down. Their point was that economies that are doing well are more likely to have adopted energy-efficient technology, which means that CO_2 emissions are going down and energy consumption is going up. Katircioğlu and Taşpinar (2017) investigated the correlation between economic growth and several elements contributing to environmental degradation in Turkey. An increase in monetary resources is a key factor in economic growth, which is responsible for an increase in EC and, by extension, CO_2 levels. The research by Nasreen, Anwar, and Ozturk (2017) investigated the influence of different variables on environmental quality, including GDP, population growth, energy consumption, and money circulation. Although their effects differ, environmental deterioration is influenced by population density", EC (ecological carrying capacity), and economic development. Nevertheless, it is important to acknowledge that economic progress does yield a beneficial impact.

Creutzig et al. (2017) conducted a comparative analysis of renewable energy adoption and carbon mitigation across several locations to gain a worldwide perspective. This study emphasizes the importance of tailoring renewable energy techniques to unique contexts, as it reveals regional disparities in their performance. An analysis of the global perspective facilitates the identification of effective models and enhances comprehension of the obstacles encountered by various economies. You and Lv (2018) examined globalization's effect on carbon dioxide emissions in eighty-five nations between 1985 and 2013. The results confirmed that globalization negatively influences carbon dioxide emissions through an indirect contribution. After performing direct research into the influence, the findings suggested that economic globalization directly favorably contributes to environmental degradation. This was the conclusion reached by the investigation. Akadiri, Lasisi, Uzuner, and Akadiri (2019) investigated globalization's impact on Kuznet's environmental factors. The study found that carbon dioxide emissions negatively affected tourism and real income, but globalization and EC were positively affected. The objective of the research conducted by Haseeb, Xia, Danish, Baloch, and Abbas (2018) was to pinpoint the causes of environmental decline in the BRICS countries. These factors included urbanization, EC, financial advancement, globalization, and EG. The effects of globalization and urbanization on the deterioration of the environment are, at best, mixed. This is despite the fact that increasing energy consumption and material economic gain are primarily favorable. Throughout their research, Pao and Tsai (2010) investigated the connection that exists between increasing energy use, growing economies, and the deterioration of ecosystems. According to the research, EG and EC are both responsible for the degradation of the environment in the economies that comprise the BRICS group.

In their study, Zhang, Mu, Chan, and Zhou (2018) conducted an econometric analysis and found a negative link between the utilization of renewable energy and carbon emissions in four oil-producing African countries. The quantitative perspective provides a rigorous statistical methodology, enabling researchers to demonstrate causal linkages and quantify the extent of emissions reduction. Wang et al. (2019) explain the importance of decentralized renewable energy systems, emphasizing their ability to reduce carbon emissions by providing localized and sustainable energy solutions. The scalability and diversity of these systems offer a promising option for mitigating emissions. Using renewable energy sources reduces air pollutants, contributing to environmental improvement. The study by Zhang, Yang, Su, Nie, and Duan (2023) shows that integrating renewable sources into energy systems results in decreased air pollution levels, improved air quality, and better overall health for the general population. The importance of this correlation is particularly evident in metropolitan environments, where traditional energy sources often contribute to the emergence of pollution and respiratory issues.

Saidi and Omri (2020) investigated the influence of significant renewable energy consumption (REC) in 15 nations on carbon dioxide emissions and economic growth. The nations included in this category include the United States, Denmark, Germany, Iceland, Norway, and Sweden. This study examines statistical data from 15 countries demonstrating significant amounts of renewable energy consumption (REC) from 1990 to 2014. This study employs the fully modified ordinary least squares (FMOLS) and vector error correction model (VECM) methodologies to compute values. This study utilizes the FMOLS and VECM estimating methods to analyze the effects of shifting to renewable energy sources on emissions and GDP growth. The FMOLS methodology offers evidence supporting the favorable correlation between the exploitation of renewable energy sources and economic growth while also leading to a simultaneous decrease in CO_2 emissions. The benefits of switching to renewable energy sources support the veracity of this assertion. The immediate and long-lasting results of the VECM Granger causality test demonstrate a positive and statistically significant correlation between economic growth and the proliferation of renewable energy sources. This association exhibits reciprocal causation. The two variables appear to have a causal relationship based on the little short-term data available. However, the current long-term studies do not provide evidence of a causal relationship between RE and CO_2 emissions. Increased CO_2 emissions and higher levels of economic production may appear to be favorably connected in both the short and long term.

The paper suggests that countries with a high level of renewable energy adoption can achieve economic advantages by further expanding their utilization of renewable energy sources while reducing carbon emissions. The article's referenced sources do not disclose the origin of the data utilized by the researchers. This study uses two ways of looking at the data: the stochastic influences by regression on population, wealth, and technology (STIRPAT) method and the moments-quantile regression (MM-QR) method with fixed variables. We use fixed-effect ordinary least squares (OLS) models to deal with cross-sectional dependency and random-effect generalized least squares (GLS) models to deal with serial correlation. To accomplish this, we employ Driscoll-Kraay standard errors. Empirical research demonstrates that using renewable energy sources and allocating resources towards green technologies have varying impacts on CO_2 emissions.

Moreover, it is seen that these components combine in a manner that has a more significant adverse effect on different levels of CO_2 emissions. This statement is valid irrespective of the quantile employed for assessing emissions. The ability of renewable energy to decrease greenhouse gas emissions is directly related to the willingness of governments to invest in research, development, and implementation of green energy. The interaction term significantly impacts countries with relatively low CO_2 emissions. Based on the findings, allocating resources toward renewable energy technologies such as catalytic converters present a highly effective approach to reducing carbon dioxide emissions. This idea was one of many that were examined throughout the research. The paper examines theoretical and practical consequences while offering recommendations for future research endeavors(Baloch et al., 2021).

Saqib et al. (2022) investigated the interaction effect between green energy technology expenditure and RE in the context of CO_2 emission reduction in G7 nations. The present analysis utilizes statistical data about the G7 nations from 1990 to 2017. The sources listed in the report do not provide any information identifying the specific source of the data that the researchers used. Two ways are used in this study to look at the data: STIRPAT (which stands for Stochastic Impacts by Regression on Population, Wealth, and Technology) and MM-QR (which stands for Moments-Quantile Regression with Fixed Effects). Different models are used to look at cross-sectional dependence and serial correlation. These models use fixed-effect ordinary least squares (OLS) and random-effect generalized least squares (GLS). Standard errors derived from the Driscoll-Kraay method are applied for this purpose. Utilization of renewable energy sources and investment in green energy technology have been shown to have various adverse effects on carbon dioxide emissions, according to the conclusions collected from empirical research.

Furthermore, it has been observed that the interaction between these elements has a more significant negative impact across a range of CO_2 emission levels. This assertion is correct regardless of the quantile that is used for the evaluation of emissions. Research has shown that governments commit fewer resources to developing and implementing environmentally friendly power sources when the effectiveness of renewable energy to reduce greenhouse gas emissions decreases. The interaction term demonstrates a disproportionately significant effect in countries with smaller carbon dioxide emissions. The study suggests that allocating resources toward renewable energy technology, such as catalytic converters, is a highly efficient approach to mitigating carbon dioxide emissions.

Khan, Oubaih, and Elgourrami (2022) researched to investigate the relationships between governmental policies, CO2 emissions, renewable energy sources, and information and communication technology. This study utilizes two sources of time series data: the WDI and the WGI. As far as the investigation is concerned, the years 1985 through 2020 are included. Throughout this investigation, various econometric models and analyses were employed. Tests such as unit root tests, Zaviot-Andrew structural break tests, ARDL limits tests, causality tests, and a dynamic ARDL simulations model are examples of tests in this category. This work utilized a dynamic autoregressive distributed lag (ARDL) simulation model and conducted tests for limit conditions, unit roots, structural breaks, causality, and other relevant studies. The findings demonstrate a strong correlation between GDP, long-term carbon dioxide levels, renewable energy, information and communication technology, and government transparency and accountability. The remark above accurately represents the consensus derived from scholarly research. Several elements have been recognized as significant catalysts for the lowering of CO_2. These aspects encompass effective administration, the use of advanced technologies, and the utilization of sustainable energy sources. The data suggests that Morocco's reduction of CO_2 emissions can be linked to several reasons, such as the practical usage of information and communication technology (ICT), the adoption of renewable energy sources, and competent leadership. The research offers several recommendations for actions Morocco should implement to address climate change and mitigate carbon dioxide emissions.

Fang (2023) examined the impact of investments in RE, advancements in environmentally favorable technologies, and increased industry on China's sustainable development progress—information collected annually from 32 provinces in China between 2005 and 2019. The study uses various econometric methods, such as instrumental variable estimation, cross-sectional dependency analysis, unit root testing, and one-step and two-step generalized method of moments (GMM) procedures. The driving reason underlying the increased trajectory of China's CO_2 emissions has been identified as the economic complexity index. Reinvestment in renewable energy sources, advocacy for environmentally friendly technology advances, and a more sustainable industrial framework are all potential avenues toward reducing CO_2 emissions. The progress of eco-friendly technologies and industrial infrastructures is impeded by the limited influence of renewable energy experts on these aspects, significantly affecting CO_2. Even though the sources provided do not provide adequate depth, the study's findings are utilized to provide recommendations for creating policy.

Mamkhezri and Khezri (2023) researched to assess the influence of RE on worldwide CO_2 emissions. This study gathered data from a diverse group of 54 nations from 2003 to 2017. They used the panel unit-root test and the Kao panel cointegration test to check for data stability and long-term correlations. Furthermore, the models consider a diverse range of control factors in addition to the usual variables like GDP per capita and RE generation. The results confirmed a reduction in the rate of rise of CO2 emissions during times of economic prosperity, which supports the EKC hypothesis. There is a widespread consensus that urbanization and international trade have a negative impact on ecosystems. This is something that has been well accepted. Because of the existence of a "spillover effect," it has been proved that investing in research and development positively impacts the environment. This is because of the "spillover effect."

Consequently, it contributes to the economy's overall expansion and encourages the utilization of renewable and sustainable energy sources. As well as providing an overview of the current level of research and development efforts concerning lowering CO_2 emissions, this study emphasizes the significance of the mix of renewable energy sources. The conclusions of this study are of significant significance for adopting development methods that are favorable to the environment. Considering the significant impact of R&D and the adoption of RE in reducing CO_2 emissions, this study strongly supports the policy suggestion of shifting towards more advanced and environmentally friendly energy sources.

Usman (2023) investigated the interplay between green energy technology expenditure and RE impact regarding the reduction of CO_2 emissions in G7 nations. The primary emphasis of his attention was the correlation between the two. The present study is based on data obtained from the G7 countries, covering the period from 1990 to 2017. This study utilized two distinct regression models: the STIRPAT model, which incorporates random effects on population, wealth, and technology, and the MM-QR model, which considers fixed parameters. This study employs the Driscoll-Kraay method to calculate standard errors, utilizing fixed-effect ordinary least squares (OLS) and random-effect generalized linear models. These models are employed to tackle cross-sectional dependence and serial correlation challenges. Empirical data analysis demonstrates that investing in green energy technologies and utilizing renewable energy sources have various adverse impacts on CO_2 emissions.

Furthermore, it is seen that the interaction between these two elements has a more significant detrimental effect on CO_2 emissions throughout various distribution levels. In contrast to conventional energy sources, investments in green energy technology exhibit a comparatively reduced adverse environmental footprint. Regardless of the quantile used for evaluating emissions, this statement holds. There is an inverse proportionality between the amount of money governments invest in green energy technology and the amount of CO_2 emissions reduced by using RE. In addition, countries with lower CO_2 emissions per capita have a more pronounced interaction term. According to the study's findings, there is a pressing necessity to enhance investment in environmentally beneficial energy technologies, such as catalytic converters, to mitigate CO_2 emissions. The imperative additionally substantiates the inclusion of this rule to mitigate the release of greenhouse gases.

Despite studies examining the relationship between renewable energy and pollution in Pakistan, much remains unknown. Using an integrated modeling and policy analysis strategy can provide more comprehensive insights compared to the singular application of quantitative or qualitative methods. The breakdown of emissions reductions and contributions from solar, wind, and hydroelectric sources is not provided. Using scenario modeling in energy planning is imperative due to the reliance on historical data in most research projects. Further investigation is required to design the most effective rules and incentives for using renewable energy to mitigate emissions. The understanding of the interplay between the expansion of renewable energy, energy availability, energy security, and emissions is currently lacking. Examining Pakistan's transition to renewable energy and emissions concerning its regional counterparts can provide valuable insights for other nations. This study employs an interdisciplinary approach and utilizes mixed methodologies to analyze the intricate dynamics of Pakistan's renewable energy, energy security, and emissions. It further incorporates various renewable energy sources into policy scenarios to demonstrate their potential contributions. Addressing these knowledge gaps will enhance the effectiveness of policymaking and planning in renewable energy.

3. Data and Model

This study explores the intricate connection between RE and CO_2 emissions in Pakistan. It analyzes time series data from 1990 to 2021, sourced from the WDI. After verifying the variables' stationarity, we used the ARDL to look at the unbiased impact of REC on CO_2 emissions in Pakistan. An in-depth understanding of the temporal dynamics among variables is achieved with the help of ARDL. Moreover, it captures both short- and long-run linkages, which creates it for understanding complex relationships. This part clearly explains how the data was collected, identifies the specific variables being studied, and describes how the ARDL model was used. These steps are essential to investigate the research topics being addressed thoroughly. The dependent variable in this study was CO_2, and the independent variables were REC, energy use, trade, economic growth, FDI and financial development. Detailed below is the model's specification:

$$CO2 = f(REC, EU, TRADE, GDPPC, FDI, DCPS) \quad (1)$$

Table 1
Description of the Variables

Variable	Description	Measurement
CO_2	CO_2 Emission	Kilo Ton
REC	Renewable Energy Consumption (REC)	% of total final EC
EU	Energy Use (EU)	
TRADE	TR % of GDP (TR)	% of GDP
GDPPC	GDP Per Capita (GDPPC)	Annual %
FDI	Foreign Direct Investment (FDI)	% of GDP
FD	Domestic credit to the private sector (FD)	% of GDP

The econometric methodology is given as follows.

$$CO2_t = \beta_0 + \beta_1 REC_t + \beta_2 EU_t + \beta_3 TRADE_t + \beta_4 GPDPC_t + \beta_5 FDI_t + \beta_6 DCPS_t + \varepsilon_t \quad (2)$$

Equation 2 states that β_o represents the intercept, while β_1 to β_6 coefficients reflect variations in REC, energy use, trade, economic growth, FDI, and financial development. The time period from 1990 to 2021 is denoted by subscript t, while the error term is represented by ε.

In order to find the integration relationship between variables, various well-known methods have been suggested in the literature. One famous approach is the work of Johansen and Juselius (1990), while another is the work of (Engle & Granger, 1987). Both methods can be used only if all variables have the same order of integration. However, as observed in the current investigation, a new issue arises with an alternative integration sequence. Pesaran and Shin (1995) introduced an ARDL method to address this issue.

Ensuring that the data is stationary is crucial in the initial stage of time series analysis to avoid biased regression. In order to ensure that data is stationary, the Augmented Dicky Fuller test is used. The Error Correction Model (ECM) is used to capture short-term dynamics in co-integration, while ARDL is used to capture long-term interactions between variables. By utilizing the bound test, it is possible to include different lags for each variable in the model. The functional form of ARDL is represented by Equation 3:

$$CO_{2_t} = \gamma_o + \sum_{i=1}^{p} \gamma_1 \Delta CO_{2_{t-1}} + \sum_{i=0}^{p} \gamma_2 \Delta REC_{t-1} + \sum_{i=0}^{p} \gamma_3 \Delta EU_{t-1} + \sum_{i=0}^{p} \gamma_4 \Delta TRADE_{t-1} + \sum_{i=0}^{p} \gamma_5 \Delta GDPPC_{t-1} + \sum_{i=0}^{p} \gamma_6 \Delta FDI_{t-1} + \sum_{i=0}^{p} \gamma_7 \Delta DCPS_{t-1} + \gamma_8 CO_{2_{t-1}} + \gamma_9 REC_{t-1} + \gamma_{10} EU_{t-1} + \gamma_{11} TRADE_{t-1} + \gamma_{12} \Delta GDPPC_{t-1} + \gamma_{13} FDI_{t-1} + \gamma_{14} DCPS_{t-1} + \varepsilon_t \quad (3)$$

Here, γ1 to γ7 represent the short-term dynamics, while γ8 to γ14 demonstrate the long-term relationship. In order to get a complete picture, you have to look at current and future patterns. We will employ an F-test to determine the presence of a statistically significant and enduring association between the variables. Variables are deemed co-integrated when the F-statistic value exceeds the critical value of the upper bound. If the critical value of a lower limit is more significant than the F-statistic, it indicates no co-integration among the model variables. Furthermore, a definitive outcome is absent because the F-statistic value falls within the range defined by the two limits.

4. Results and Discussion

4.1. Unit Root Test

In time series analysis, the unit root test is an analytical procedure to ascertain whether the examined data contains a unit root. If the underlying mechanism that produces the data has an exact root of the characteristic equation, or 1, then the time series has a unit root. These findings suggest that the time series lacks a stable mean over time, as evidenced by the stochastic trend and random walk behavior. In other words, it implies that the activity is uncomplicated. The unit root test is crucial as it helps determine whether a time series is non-stationary by detecting the presence of a unit root.

Consequently, conventional statistical methodologies, which rely on the assumption of series stationarity, might prove unsuitable in this context. In the context of time series studies, including regression, non-stationary time series may yield misleading results. The ADF test determines whether a time series possesses a unit root as its underlying structure. On the other hand, the alternative hypothesis asserts that the time series is stationary and does not contain a unit root. This is in contrast to the null hypothesis, which asserts that the time series is non-stationary and does contain a unit root. In order to conclude that the time series is stationary, it is necessary first to reject the null hypothesis and then draw the conclusion that the time series does not contain a unit root. In addition, the p-value that was generated by the ADF test was discovered to be lower than the specified significance level, which is usually established at 0.05.

Table 2
Unit Root Test

Variable	Level	1st Difference	Order of Integration
CO2 Emission (CO_2)	0.0053		I(0)
REC (REC)	0.350	0.001	I(1)
Energy Use (EU)	0.761	0.004	I(1)
TR % of GDP (TR)	0.392	0.000	I(1)
GDP Per Capita (GDPPC)	0.014		I(0)
Foreign Direct Investment (FDI)	0.054		I(0)
Domestic Credit to the private sector (FD)	0.699	0.007	I(1)

The results of ADF shown in Table 2 confirm that their mixed order of integration, like FDI, CO_2 Emissions, and GDP, have an I (0) order of integration, while REC, Energy Use, TR, and Domestic Credit to the Private Sector are stationary at I (1). The estimation of a model containing a mix order integration, so the Auto Regressive Distributive Lag Model (ARDL) econometric model is applied to examine the lengthy as well shot run estimates.

4.2. ARDL Bound Test

In econometrics, the bound test is a statistical method utilized to determine whether or not a long-term connection exists between two or more variables contained inside a time series dataset. It is frequently used in cointegration analysis, focusing on non-stationary time series that may exhibit a stable long-term connection. However, it signifies a consistent, enduring connection between various factors, even though they may display erratic fluctuations in the short-term, resembling random movements. The bound test is a specialized method employed to assess the presence of cointegration within a set of variables. The objective of the upper bound I_1 and lower bound I_0 is to align the bound values with the F statistics. Cointegration is detected in the provided data when the F-statistics value surpasses the predetermined threshold. Conversely, cointegration is not present if the F-statistics value falls below the set threshold.

Table 3
ARDL Bond Test

Test Statistic	Value	K
F-statistic	3.295	7
Significance level	I_0	I_1
10%	2.03	3.13
5%	2.32	3.50
2.50%	2.60	3.84
1%	2.96	4.26

According to the data presented in Table 3, the F-statistic value of 3.295 is higher than the 10% significant threshold value. The findings of this study provide evidence that there is a long-term association between CO_2 emissions and the independent variables utilized in this investigation. The findings of this research are comparable to those of other studies carried out in the past for the same purpose (Khan et al., 2022).

4.3. Long Run and Short Run Estimates

Table 4 shows that the most critical factors influencing Pakistan's CO_2 emissions are energy consumption, TR, GDP per capita, and domestic credit to the private sector. CO_2

emissions are positively impacted by energy consumption, TR, and GDP and negatively impacted by REC, GDP per capita square, and domestic lending to the private sector.

Table 4
Short and Lond Run Estimates

Short Run Estimate				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(CO2KT(-1))	-0.118	0.136	-0.869	0.407
D(CO2KT(-2))	0.144	0.137	1.054	0.320
D(REC)	-0.037***	0.007	-5.177	0.001
D(EU)	0.001*	0.001	1.926	0.086
D(TR)	-0.114*	0.059	-1.949	0.083
D(TR(-1))	-0.058	0.041	-1.416	0.190
D(GDPPC)	0.000	0.000	0.537	0.604
D(GDPPC(-1))	-0.001**	0.000	-3.208	0.011
D(GDPPCSQ)	0.000	0.000	-1.019	0.335
D(GDPPCSQ(-1))	0.000**	0.000	3.086	0.013
D(FDI)	0.011	0.008	1.326	0.217
D(DCPS)	-0.003	0.003	-1.122	0.291
D(DCPS(-1))	0.003	0.002	1.604	0.143
CointEq(-1)	-0.986***	0.175	-5.644	0.000
Long Run				
REC	-0.047***	0.009	-5.407	0.000
EU	0.001*	0.001	1.927	0.086
TRADE	0.167**	0.073	2.282	0.048
GDPPC	0.001***	0.000	6.995	0.000
GDPPCSQ	-0.000***	0.000	-4.687	0.001
FDI	0.011	0.009	1.279	0.233
DCPS	-0.009*	0.004	-2.168	0.058
C	13.728***	0.555	24.741	0.000
Model Diagnostics				
Auto-correlation Test				0.190
Heteroscedasticity Test				0.981
Ramsey Reset Test				0.672

The significant correlation between the utilization of renewable energy and the decrease in CO_2 emissions in Pakistan highlights the crucial significance of harnessing RE sources to alleviate environmental damage. The empirical data demonstrates a robust inverse relationship, suggesting that a 1% rise in RE use leads to a 0.047% decline in CO_2 emissions. The theoretical underpinnings of this phenomenon correspond to the intrinsic characteristics of renewable energy sources. Renewable energy sources such as solar, wind, hydro, and geothermal power are not reliant on combustion processes like coal and oil. Combustion operations substantially impact the emission of CO_2 into the environment. Incorporating alternative energy sources is vital in reducing the overall environmental impact of energy production. In addition, RE technologies tend to produce fewer greenhouse gas emissions during power production than traditional methods. The environmentally beneficial aspects of increased use of RE are further enhanced by the carbon-neutral or even carbon-negative qualities of specific sources, like biomass (Haq, Nawaz, Akram, & Natarajan, 2020). In addition, the decreased reliance on fossil fuels and the natural energy efficiency of renewable technology contribute to a more environmentally friendly energy landscape. The ongoing advancements in technology within the industry continuously enhance the efficiency and viability of renewable energy solutions, bolstering their contribution to reducing CO_2 emissions and fostering an eco-friendlier energy model.

The study's findings indicate a robust association between the utilization of RE and the escalation of CO_2 emissions. CO_2 emissions from power plants are reduced significantly when RE sources like solar, wind, and hydropower are extensively used. When used to generate electricity instead of coal, oil, or natural gas, renewable energy significantly reduces CO_2

emissions. Reduced emissions of greenhouse gases have been observed in nations where the use of renewable energy sources has increased rapidly. Adopting renewable energy sources is widely accepted as a viable technique for reducing climate change by decreasing greenhouse gas emissions (Baloch et al., 2021; Hanif, Nawaz, Hussain, & Bhatti, 2022). It has been shown that RE sources have few lifetime emissions, making this approach particularly relevant in shifting away from carbon-intensive fossil fuels (Xiang et al., 2021). The findings were also confirmed by the study of Xu, Sheraz, Hassan, Sinha, and Ullah (2022), revealing RE's contribution to decreasing 2.5% of total CO_2 emissions. Raza, Shah, Sharif, and Shahbaz (2022) discovered that there is an average 0.29% reduction in CO2 emissions for every 1% increase in the utilization of renewable energy. Paramati, Mo, and Gupta (2017) conducted a study with the help of 28 developing and developed countries, in which findings revealed that the use of RE significantly reduces CO_2 emissions. Chien, Hsu, Ozturk, Sharif, and Sadiq (2022) suggested in their study that by using 100% RE, Pakistan will reduce 71% of CO_2 emissions by 2050.

Energy use is closely linked to the release of CO_2 into the atmosphere. The connection between EC and CO_2 emissions is evident, especially given the growing global need for energy, primarily met through the combustion of fossil fuels such as coal, oil, and natural gas. The steady increase in CO_2 emissions over the past few years is at least partially attributable to our continued use of fossil fuels. Since fossil fuels are primarily used in commercial and industrial settings, the increasing demand for energy from these sectors exacerbates emissions. A critical challenge in addressing climate change is the urgent requirement to decrease CO_2 emissions, which result directly from the combustion of fossil fuels. It is essential to prioritize energy efficiency measures and the use of renewable power sources in order to solve this issue effectively. If we are serious about reducing the harmful effects of climate change and CO_2, we must act now to implement these policies. The findings have been confirmed by the study of (Lin & Raza, 2019; Rehman, Rauf, Ahmad, Chandio, & Deyuan, 2019; Sharif, Raza, Ozturk, & Afshan, 2019).

Trade openness has a significant and positive impact on the CO_2 emission. The positive correlation between a nation's CO_2 emissions and trade openness, as measured by its trade-to-GDP ratio, is well-established. Elevated emission levels frequently characterize countries with greater trade-to-GDP ratios. This correlation can be attributed to trade and several factors, including transportation, increased output, foreign investment, and an increased demand for energy derived from fossil fuels (Ahmad et al., 2023). The beneficial effects of this phenomenon are observed to be more pronounced in more developed economies, as supported by empirical data and modeling analyses. The expansion of global TR interconnection has resulted in an increase in TR volumes and the development of complex supply chains, which have contributed to a significant increase in CO_2 emissions. This phenomenon is especially prevalent in wealthy nations. Thus, the impact of TR openness on national emission levels is considered significant. Feriansyah, Nugroho, Septiavin, and Nisa (2022) conducted a study using the panel data of ASEAN countries, and the results revealed that TR significantly increases CO_2 emissions. Raihan, Muhtasim, Pavel, Faruk, and Rahman (2022)"s study revealed that 0.51% emission of CO_2 increases by 1% increase in TR (% of GDP). Apergis and Payne (2009) conducted research in America that revealed a significant impact of TR percentage of GDP on CO_2 emission in the long and short run.

The findings validate a hypothesis regarding Pakistan, in which specific factors initially contribute to elevated CO_2 emissions but subsequently exhibit a declining trend beyond a certain threshold. Initial results indicate that EG significantly impacts CO_2 emissions, with a distinct inverse relationship between 1% increases and CO_2 emission levels. When the GDP is higher, there is a connection between increased levels of industry, more significant usage of transportation, higher demand for electricity, increased consumption patterns, increased production of waste, and other factors that contribute to emissions. The available data suggests a connection between the rise in a nation's GDP per capita and the subsequent rise in its CO_2 emissions. This correlation may have several possible explanations, one of which is that the economy of the entire world continues to be supported by the combustion of fossil fuels. The possibility of a disconnection between GDP and emissions is raised by some research when income levels rise. Most of this research has concentrated on efficiency benefits, which is probably the main reason. The findings of a recent study conducted by Feriansyah et al. (2022) that analyzed panel data from ASEAN countries revealed an important finding: there is a positive correlation between the GDP per capita and the amount of carbon dioxide emissions. It was discovered by Raihan et al. (2022) that there is a substantial correlation between the GDP per capita and CO_2 emissions in Pakistan over the long run and the short term. A recent study by Xu et al. (2022) discovered that in the top five nations for carbon emissions, there is a correlation between rising GDP per capita and CO_2 emissions. The study found that CO_2 emissions increased by 0.50–1.21 percent for every one percent increase in GDP per capita. Consistent with previous studies, this one found that GDP per capita substantially impacted CO_2 emissions in OECD nations (Shahbaz, Hye, Tiwari, & Leitão, 2013). Gosens et al. (2017) provided additional evidence that GDP per capita significantly impacts CO_2 emissions.

The influence of domestic lending to the private sector on CO_2 emissions is ultimately substantial and negative. The rapid growth in domestic credit provided to the private sector substantially affected the rise in CO_2 emissions generated by both industrialized and developing nations. Multiple economic activities—construction, resource exploitation, industrial investment, output, and consumption—benefit from an increase in the quantity of private credit that is accessible, according to research. However, it is essential to consider that these activities frequently necessitate the combustion of fossil fuels, resulting in increased CO_2 emissions. According to the extant empirical evidence, expanding domestic credit is pivotal in stimulating economic expansion.

Nevertheless, it is crucial to observe that this expansion is also associated with increased domestic emissions. Urbanization, industrial formation, and commercial energy consumption are profoundly influenced by an economy's exponential expansion of private credit. These modifications are conceivable due to using fossil fuels, including coal, oil, and gas, as energy sources. According to Xu et al. (2022), there was a positive link between the amount of domestic credit granted to the private sector and the amount of CO_2 emissions. According to the statement, a correlation was found between increased levels of domestic credit granted to the private sector and increased carbon dioxide emissions detected. Shahbaz, Tiwari, and Nasir (2013) conducted a study in Cambodia using the ARDL method to identify a correlation between CO_2 emissions and domestic credit. Jalil and Feridun (2011) conducted a study in China to evaluate the association between domestic credits and CO_2 emissions using the VECM. The study showed that there was a significant relationship between the two. The findings of their investigation revealed a significant and long-lasting association between the variables that were indicated earlier. A recent investigation by Raihan et al. (2022) revealed a positive correlation between CO_2 emissions and domestic credit extended to the private sector. Song, Zhao, and Shang (2020) discovered a correlation between domestic credit and CO_2 emissions in a recent study. Specifically, they observed that a 0.10% increase followed a 1% rise in domestic credit in CO2 emissions.

According to the results of Table 4, the model diagnostics section also confirms that the results are unbiased and efficient. Further, for the model’s stability, the study used the CUSUM and CUSUM square tests, and the results of the CUSUM and CUSUM square tests are given below.

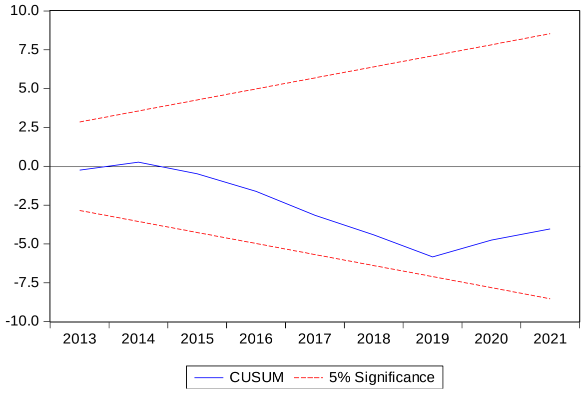

Figure 1: CUSUM Test

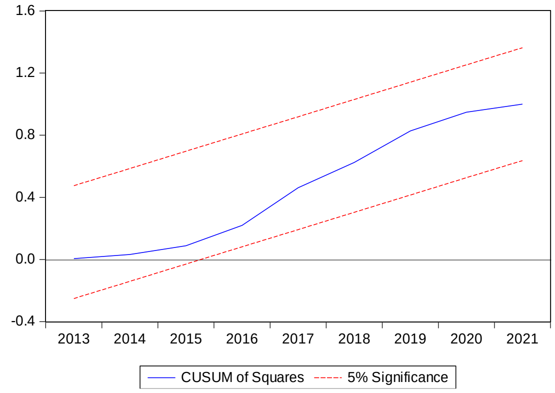

Figure 2: CUSUMSQ Test

The model's stability and efficiency are supported by the findings depicted in Figure 1 and Figure 2. These statistics confirm the strength and reliability of the model and establish the impartiality of the long-term outcomes. The visual representations provide evidence that enhances the general credibility of the analytical framework, hence bolstering the trustworthiness of the research conclusions.

5. Conclusion

This study found that renewable energy and FD reduce Pakistan's CO_2 emissions, further energy use, and trade openness increase the carbon emission level in Pakistan. Moreover, the results also confirmed that the EKC hypothesis exists in Pakistan's case. These findings highlight the need to isolate fossil fuel usage from global TR and growth. The research recommends increasing RE infrastructure spending, energy efficiency rules, sustainable production system incentives, and TR and credit laws to deter carbon-intensive businesses. Green economics could cut Pakistan's GHG emissions. Thus, the nation should exploit its rising middle class, RE, and natural resources. With government regulations and financial incentives, RE, climate-smart agriculture, sustainable manufacturing and construction, and environmental commodities trade can cut CO2.

5.1. Policy Recommendations

The findings revealed that RE, financial and income development may reduce emissions, while private finance promoted emissions. Several essential policy responses followed. First, incentive programs, grid infrastructure, and finance mechanisms should be prioritized above RE production to speed the transition to sustainable electricity. To maximize carbon reduction, the policy must support environmentally friendly commodities trade, climate-smart industry and construction norms, and sustainable agriculture practices. Additionally, concerted energy-saving efforts targeting domestic appliances, commercial organizations, and industrial sectors may reduce the constant demand for electricity. Monetary policy and financial regulation should consider climate change risks to prevent emissions from unconstrained credit expansion. 5. EG policies should prioritize low-carbon sectors, human capital, and technology above fossil fuels. Finally, government, industry, and civil society efforts must be coordinated to accomplish this complete plan. Pakistan may achieve sustainable, low-carbon development with the right policies. Green financing, innovation, and resource use are some of these methods.

Authors' Contribution:
Muhammad Ali Zafar: introduction, literature search, data collection.
Muhammad Azhar Bhatti: study design and concept, writing-original draft.
Muhammad Atif Nawaz: help in data analysis, data interpretation.
Tusawar Iftikhar Ahmad: proofreading, critical revision.

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