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Evaluating the Impact of Renewable and Non-Renewable Resources on CO_2 Emissions and Sustainability

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Abstract

This study analyzes Pakistan's energy system, distinguishing between renewable and non-renewable energy sources. We examine energy production decisions as Pakistan's energy sector faces significant challenges, including environmental concerns related to carbon emissions from nonrenewable energy generation methods, using historical data and analytical tools. In essence, we evaluate the relationship between renewable and nonrenewable supplies in conjunction with GDP, trade, and population, which quantify changes in land use and track related carbon emissions. This analysis will provide valuable insights into the environmental consequences of different energy production methods in Pakistan. Regression analysis will be employed in the study to demonstrate how the aforementioned variables influence CO2 emissions, utilizing data from 1990 to 2020. Additionally, the ARDL test is used to obtain accurate results, accounting for unit roots and lag variables. According to previous research, non-renewable energy sources directly correlate with CO_2 emissions, but renewable energy sources have an adverse effect on CO_2 emissions. While we cannot be certain of the details until we have crunched the figures, we want to contribute to Pakistan's adoption of wiser energy policies. Consider ways to increase the use of renewable energy, better plan the use of land for sustainable energy projects, and reduce carbon emissions in keeping with regional and global environmental objectives. Finding the right course of action for a cleaner, greener energy future is what we are all about in the end. Essentially, climate change, being a global threat, is becoming a serious concern; therefore, a sustainable approach needs to be studied and applied accordingly.

Keywords: Renewable energy, non-renewables, land use, ARDL, sustainability
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1. INTRODUCTION

Energy is a fundamental requirement for human development, but sadly, the world's energy reserves vary greatly from nation to nation. The global energy crisis has the greatest impact on Pakistan's social, economic, and environmental well-being of any given problem. This study aims to explore the relationship between various energy sources in terms of cost, yield, and other factors. Moreover, examining the impact of energy sources on Pakistan's climate. Pakistan is diverse in that its social, environmental, and climatic traits vary from one area to another. Pakistan is severely affected, even though it contributes very little to CO_2 emissions. Pakistan's climate change vulnerability is attributed to several factors, including its generally warm climate, location in an area where temperature increases are predicted to be higher than the global average, and the country's mostly arid and semi-arid land area (with 60% receiving less than 250 mm of annual precipitation and 24% receiving between 250 and 500 mm).

Additionally, Pakistan's rivers are primarily fed by the Hindu Kush-Karakoram Himalayan glaciers, which are predicted to recede rapidly due to global warming. Furthermore, Pakistan's predominantly agrarian economy makes it particularly vulnerable to the impacts of climate change. A necessary commodity for modern economies is energy. Consequently, the technologies used in its manufacturing and consumption are becoming increasingly significant. Energy security and sustainable development are closely related to the availability of a clean, reasonably priced, and consistent supply of energy in a variety of forms. One of Pakistan's biggest concerns is climate change. Pakistan is highly reactive to changes in the climate. Pakistan's climate has undergone significant changes over the past few decades, with a major impact on both the environment and its people, similar to the rest of South Asia. The Himalayan glaciers are melting due to heat, drought, and other harsh weather, which is raising the water level in the Pakistani river. Pakistan ranked fifth among nations affected by climate change-related extreme weather events between 1999 and 2018.

Numerous natural calamities, such as cyclones, floods, droughts, heavy rains, and earthquakes, can occur in Pakistan. Scientific studies indicate that climate change was a major factor in the catastrophic floods of 2022, which directly affected over 30 million people in Pakistan and caused property destruction, fatalities, and home displacement. Climate change is a serious threat to Pakistan's security and economy. With 2 tons of emissions annually per person, Pakistan emits fewer greenhouse gases (GHGs) per person than the global average. Pakistan's GHG emissions account for less than 1% of worldwide emissions. In Pakistan, energy-related activities such as burning fuel for heat, powering transportation, and producing electricity accounted for 43% of the country's 408 million tons of CO_2 equivalent in GHG emissions in 2015.

Pakistan's energy sector is currently in a transition period, trying to resolve the dual task of supplying growing energy needs and addressing climate change. Given the increasing understanding of the negative environmental impact of energy production, it is increasingly important to determine whether different energy sources affect the amount of CO_2 emissions. The present research examines the intricate relationship between various elements of Pakistan’s power sector, with a particular emphasis on renewable versus non-renewable resources and their impact on carbon emissions. Previous research has made it clear that transitioning to renewable energy sources is one way to help mitigate the effects of climate change. On the other hand, new forms of green energy, such as solar, wind, and hydropower, appear to be promising alternatives that can be used to mitigate carbon emissions while promoting environmental sustainability.

In this study, to define the relationship between renewable and non-renewable energy and the emissions of carbon, we run the Augmented Dickey-Fuller (ADF) test to assess whether variables are stationary or non-stationary. P-values below 5% or 10% indicate stationarity. Variables like CO_2, FFCp, RECp, and GDP are stationary. To address autocorrelation, we used the Autocorrelation Function (ACF)and Partial Autocorrelation Function (PACF). A Correlogram is used to visualize autocorrelation portions. The Autoregressive Distributed Lag (ARDL) model is used to analyze relations in time series data. It accommodates non-stationary variables without requiring differencing, aiding in policy exploration and forecasting.

Overall, the findings of this study are expected to help policymakers, experts, and stakeholders who play a key role in shaping Pakistan's energy policy. Specifically, by researching the environmental consequences of various energy production methods, this study aims to inform the development of policies that promote the expansion of renewables, the efficient use of land for sustainable energy projects, and reductions in carbon dioxide emissions in line with regional and global environmental goals. In conclusion, given the growing threat of climate change, there has never been a greater need to prioritize a sustainable approach to energy production. While we may face several challenges in Pakistan’s energy space, there are indeed greener and cleaner ways forward. This study aims to provide evidence and recommendations that facilitate informed decision-making and contribute to the development of a more sustainable and reliable energy sector in Pakistan.

2. LITERATURE REVIEW

The world's energy landscape is undergoing a fundamental shift as countries seek ecologically friendly and sustainable solutions to meet their energy needs. Modern countries rely on energy to sustain economic growth, raise living standards, and improve people's quality of life. The regular dependence on non-renewable energy sources, such as coal, natural gas, and fossil fuels, has raised concerns about their limited availability and negative environmental impacts, particularly the atmospheric release of greenhouse gases like carbon dioxide (CO_2). Researchers have repeatedly found that the use of non-renewable energy sources, such as fossil fuels (coal, oil, and natural gas), has a negative impact on the climate.

There is a persistent increase in CO_2 emissions due to population growth, GDP growth, and industrialization, posing an alarming situation for the country. The repercussions of these increasingly unpleasant activities have triggered a surge in greenhouse gas emissions, which ultimately lead to drastic climate change. Such worrying situations prevailed worldwide (Cassarino et al., 2018). Since energy demand is rapidly growing, and these energies are extracted from conventional energy sources such as fossil fuels, carbon-generated energies, and crude petroleum, there is a gradual decline in the adoption of conventional methods (Nayyar et al., 2014).

On a worldwide basis, it is extremely important to figure out a balance between the need to reduce CO_2 emissions and the rising demand for power. The focus of the study, which is on CO_2 emissions from Pakistan's energy resources, is thus one of the principal focal points of this study (Raza & Lin, 2019). Global warming, environmental pollution, and energy scarcity are becoming problems for everyone on earth. The increase in global industry and excessive energy use is the main contributor to CO_2 emissions. The use of fossil energy has caused climate change by emitting GHGs, including CO_2 (Callan et al., 2009; Wu & Chen, 2017).

The methodology is described as using the Logarithmic Mean Division Index (LMDI) approach. This method can give important insights into the underlying elements and is frequently used to analyze variations in CO_2 emissions (Raza & Lin, 2019). The benefit of the LMDI method is that it may be used to break down variations in CO_2 emissions. The forecasting of emissions associated with fossil fuels follows the use of analytical components (Lin & Ahmad, 2017).

By analyzing the trade-offs between energy supply and priority ecosystem services, Martnez-Martinez's study reveals regions in South-Central Chile that are appropriate for developing renewable energy sources. Limited capacity for biomass, solar, and wind energy, as well as medium-to-low capacity for cultural services, was found after expert discussions. He concluded that more than half of potential hydropower plants can be positioned in areas with high capacity for regulation and maintenance, as well as medium capacity for service supply. Planning for land-based renewable energy is aided by this information, which also lessens social and environmental tensions (Martínez et al., 2022). In his research, Abraham Deka examined the role that renewable energy, energy efficiency, and forest resources play in halting environmental degradation. He utilizes data from 1990 to 2020 from European Union nations.

According to the findings, a 1% increase in GDP is associated with a short-term rise in carbon emissions of 5.62% and a long-term increase of 2.93%. Emissions decreased by 0.03 units and 0.098 units, respectively, due to energy efficiency and renewable energy. However, the carbon emissions of European countries are not significantly impacted by forest resources (Deka et al., 2023).

The study by Wang Long looks at the relationship between the use of renewable and non-renewable energy sources, climate change, and economic growth in five developing Asian nations between 1975 and 2020. According to the findings, using renewable energy slows global warming while using non-renewable energy accelerates it. In these nations, urbanization, investment in transportation infrastructure, and GDP growth all contribute to climate change. The study supports the inverted U-shaped EKC hypothesis for developing Asian economies and contends that switching from non-renewable to renewable energy sources is the most effective strategy for mitigating climate change (Wang et al., 2023). In his paper, Muhammad Asif examines the relationship between various energy sources, putting a particular emphasis on the cost, yield, and other factors. It concludes that nuclear energy and renewable energy derived from agricultural waste are the most popular sources due to their accessibility and long-term viability. A viable alternative for domestic and industrial energy production and consumption, bioenergy produced from agricultural waste is environmentally friendly and emits less pollution than nuclear energy (Asif et al., 2022). Mudassar Hussain, in his study, compared the costs and environmental effects of different energy sources, including diesel generators, non-renewable sources, and hybrid solar systems (WAPDA). According to the study, installing hybrid solar systems can reduce carbon dioxide emissions by up to 8,446.6 kg of CO2 and 6,131.725 kg over the next twenty-five years. With its low cost per electric unit, renewable energy can pay for its entire installation in just 8 years, saving $4,936.4375. Pakistan's unique geographic characteristics and year-round access to sunlight make it a prime candidate for the effective use of solar energy to cut CO_2 emissions and costs (Hussain et al., 2022). Ullah et al. (2020) emphasize that Pakistan's industrialization and energy crisis have highlighted the importance of alternative energy sources, CO2 emissions, and health-related issues. The use of renewable energy sources can satisfy energy needs while promoting environmental health. This study, which utilized data from 1998 to 2017, found that increased trade volume is associated with higher CO2 emissions and healthcare costs. However, renewable energy has a negative correlation with CO_2 emissions and health spending, underscoring its importance in enhancing environmental quality and reducing health expenditures. The results suggest that Pakistan's government needs to establish clear policy guidelines for the adoption of renewable energy in the industrial sector (Ullah et al., 2020).

This analysis revealed that a different scenario could help Pakistan meet its emissions reduction goal and offer customers a 23% annual savings. The electric power industry in Pakistan is confronted with issues such as demand-supply imbalances, frequent power outages, and growing fuel import costs. Pakistan has implemented incentives to promote the production of renewable energy. However, now, the sector accounts for almost 63% of the electrical supply. The interconnections between generation technologies, fuel resources, demand, capital investments, CO_2 emissions, production costs, and electricity pricing were examined using a dynamic model (Qudrat-Ullah, 2022).

The driving variables for CO_2 emissions from power generation in Pakistan from 1990 to 2019 are examined in this study. For measuring CO_2 emissions and their correlation with economic development, it utilizes the logarithmic mean Divisia index and Tapio's decoupling indicator. The findings indicate that activity and population are the main causes of increased CO_2 emissions, with only a slight buffering in the immediate future. The paper recommends encouraging energy-saving technologies and restructuring the industrial sector to reduce CO_2 emissions (Lin, 2022).

The primary objective of this research endeavor is to identify sustainable energy sources that can support Pakistan's economy, secure its energy supply, and create employment opportunities. The report recommends renewable energy technology with low operating and external costs as a viable solution. The Pakistani government should encourage technological advancement and the development of renewable energy sources. Pakistan aims to produce green hydrogen using its abundant renewable energy sources as a sustainable and secure energy source for the future. While geothermal energy has not yet fulfilled its potential for producing hydrogen, wind and biomass are effective renewable sources (Umar et al., 2022).

The study assesses Pakistan's conventional and renewable energy scenarios and finds that renewable energy accounts for only a small portion of the country's overall energy supply. Data on renewable energy installations, activities, projects, planning, and accomplishments of public sector organizations are highlighted. It offers recommendations for efficient resource management and technological application, which is helpful for Pakistan and developing nations (Sheikh, 2010).

For the study of Pakistan, the Low-Emission Analysis Platform (LEAP) software is being used to create scenarios for green energy policies (GEPs). To achieve 100% renewable energy supply by 2050 would be a challenging endeavor or an impossible one, but it is viable with the GEP model scenario (Raza et al., 2022). Meanwhile, the dependence of global energy systems (GESs) on fossil fuels is relatively high. Due to the significant economic expansion of the energy system (ES) over the last century, the world's need for clean energy has increased, driven by the depletion of fossil fuels, environmental degradation, and geographical imbalance (Afsharzade et al., 2016). Essentially, the Environmental Kuznets Curve (EKC) model holds for Pakistan in terms of the importance of using renewable and non-renewable energy sources. Between 1970 and 2012, a variety of econometric methods were employed. The findings provide strong evidence to support the existence of the EKC in Pakistan's context. The findings indicate that non-renewable energy use is primarily responsible for increasing carbon dioxide emissions, whereas renewable energy plays a significant role in reducing carbon dioxide emissions (Danish et al., 2017).

This study investigates the impact of carbon dioxide emissions on Pakistan's forestry, agriculture, livestock, energy consumption, population growth, rainfall, and temperature. According to the findings, agricultural production, livestock, energy consumption, and population expansion have a negative impact on carbon dioxide emissions, whereas forestry output, rainfall, and temperature have a favorable impact. Emissions are negatively impacted by the use of energy. According to the report, Pakistan's government should implement new regulations to increase agricultural output and combat climate change by focusing on industries such as forestry, livestock, agriculture, and energy. Pakistan must play a significant role in combating climate change due to its lower greenhouse gas emissions (Abdul et al., 2021).

Due to a shortage of fossil fuel resources and a struggling economy, Pakistan is experiencing an energy crisis. The nation needs to enhance its domestic energy resources, including hydropower, solar power, and wind power, to meet this goal. The nation's high solar insulation can be utilized to produce power, as well as other products such as solar water heaters and cookers. The paper examines the current state and prospects of solar energy consumption in Pakistan, highlighting the contributions of R&D organizations to the advancement of solar technology (Mirza, 2003). The author uses spatial-temporal decomposition data from 2006 to 2016 to examine Pakistan's performance in energy saving and CO_2 emissions reduction. The findings indicate that, while the GDP gap impact remains below average, the industry sector's economic efficiency and energy consumption efficiency are both above average. While the service sector exhibits a range of results, the agriculture sector performs on average in terms of structure and intensity impacts (Azam et al., 2021).

3. DATA AND VARIABLES

This study utilizes data from various credible sources, including the World Bank, the Pakistan Bureau of Statistics, and surveys such as the Household Income and Consumption Survey. Energy-related data is gathered from a variety of sources, including the Ministry of Energy's yearly reports and the Pakistan Energy Information Portal (PEIP), an online resource created by the Pakistani government. PEIP provides detailed information about energy reserves, production, consumption, and renewable energy sources. Additional data from prestigious international organizations, such as the International Energy Agency (IEA) and the United Nations Environment Programme (UNEP), enhances the analysis, providing a more comprehensive view of global energy trends. Additionally, insights from academic research papers and industry publications are utilized to provide a more in-depth understanding of various aspects of Pakistan's energy sector. This comprehensive approach ensures a thorough assessment of Pakistan's energy dynamics, facilitating a deeper understanding of the country's energy challenges and opportunities. Our study is based on time series data from 1980 to 2020. Table 1 presents key parameters, including the mean, median, and standard deviation, for the variables under consideration.

Table 1 : Descriptive Statistics

Variables	Description	Mean	Median	Standard Deviation
CO_2	Level of Carbon-Dioxide (Total CO_2 Emissions) in Pakistan	5.02	4.80	4.96
FFCP	Fossil fuel Consumption (Growth rate)	1.05	0.65	2.05
Forest	Forestation (Growth rate of plantation)	5.87	5.85	0.64
GDP	GDP Growth rate	4.73	4.46	2.26
Pollution	Growth rate of pollution in Pakistan	2.63	2.63	0.83
RECP	Renewable energy consumption (Growth Rate)	0.19	-0.40	3.82
Trade	Trade as a percent of GDP	31.49	32.41	4.45

4. MODEL SPECIFICATION AND METHODOLOGY

This paper employs various techniques to achieve its final outcomes. Initially, we use the Augmented Dickey–Fuller test (ADF) to distinguish between stationary and non-stationary variables. We will also use the Autocorrelation Function (ACF) and the Partial Autocorrelation Function

(PACF). In time series analysis, the ACF and PACF are critical for understanding the temporal connections within a dataset. The ACF calculates the correlation between a time series and its lagged variants, demonstrating the level of self-similarity at various time lags. It helps in the identification of autocorrelation patterns, revealing how previous values influence current ones (Ahmad et al., 2022). In contrast, the PACF quantifies the direct link between observations at various lags, removing the effects of intervening variables. This makes it valuable for determining the direct influence of previous data on current data, which helps identify the right lag structure for time series models, such as the Autoregressive Distributed Lag (ARDL) model in econometrics. Analysts can detect the presence of autocorrelation and partial autocorrelation by examining ACF and PACF plots, which aid in model selection and diagnostic procedures to ensure robust analysis of time series data (Ahmad et al., 2022).

As discussed earlier, we have mixed variables in our model; therefore, we will use the Autoregressive Distributed Lag (ARDL) model to carry out our analysis. The Autoregressive Distributed Lag (ARDL) model is a strong econometric method widely used for analyzing the interactions between variables in time series data. It combines autoregressive (AR) and distributed lag (DL) models to investigate both short- and long-term dynamics among variables. This model may accommodate a wide range of data kinds and relationships, including non-stationary variables and mixed frequencies, without the need for differencing. It captures dynamic interactions by integrating lagged variable values, making it appropriate for analyzing economic time series with non-stationary behavior. Furthermore, the ARDL model facilitates causal analysis, enabling the exploration of directional relationships and their magnitudes through model coefficients. The ARDL model is widely used in policy research and forecasting to examine the impact of policy changes or external shocks on economic variables. Overall, the ARDL model emerges as a versatile and necessary econometric tool, recognized for its capacity to reveal complex linkages and dynamics within time series data, particularly in economic and financial research.

In ARDL modelling, researchers frequently use varied lag durations for dependent and independent variables. They may also use distinct sets of independent variables in the model. AIC aids in the selection of the ideal ARDL model specification by providing a measure of each specification's relative goodness of fit while also taking into account the model's parameter count. Lower AIC values suggest a better balance of model fit and complexity. As a result, in ARDL modelling, researchers often choose the specification with the lowest AIC as their preferred model. This helps to avoid overfitting while also ensuring that the model accurately represents the underlying relationships in the data.

4.1. Empirical Model

After doing ADF testing, we are going to estimate the linear regression equation, which is as under:

$$CO_2 = f(GDP, Trade, Pollution, Foreset, RECP, FFCP)$$

We can represent the ARDL model equation as:

$$\begin{aligned} CO_{2t} = \beta_0 &+ \beta_1 CO_{t-1} + \beta_2 CO_{t-2} + \beta_3 CO_{t-3} + \beta_4 CO_{t-4} + \beta_5 FFCP_{t-1} \\ &+ \beta_6 FFCP_{t-2} + \beta_7 FFCP_{t-3} + \beta_8 FFCP_{t-4} + \beta_9 Forest_{t-1} \\ &+ \beta_{10} Forest_{t-2} + \beta_{11} Forest_{t-3} + \beta_{12} Forest_{t-4} \\ &+ \beta_{13} GDP_{t-1} + \beta_{14} GDP_{t-2} + \beta_{15} GDP_{t-3} + \beta_{15} GDP_{t-4} \\ &+ \beta_{16} Pollution_{t-1} + \beta_{17} Pollution_{t-2} + \beta_{18} Pollution_{t-3} \\ &+ \beta_{19} Pollution_{t-4} + \beta_{20} RECP_{t-1} + \beta_{21} RECP_{t-2} \\ &+ \beta_{21} RECP_{t-3} + \beta_{22} RECP_{t-4} + \beta_{23} Trade_{t-1} \\ &+ \beta_{24} Trade_{t-2} + \beta_{25} Trade_{t-3} + \beta_{24} Trade_{t-4} + \epsilon_t \end{aligned}$$

Where:

- CO_{2t} is the level of CO_2 emissions at time *t* (dependent variable).
- *FFCp*, $Forest_t$, GDP_t, $Pollution_t$, $RECP_t$, and $Trade_t$ are the independent variables at time t.
- $\beta_0, \beta_1, \beta_2 ..., \beta_{18}$ are the coefficients to be estimated.
- ϵ_t represents the error term

4.2. Augmented Dickey-Fuller test

In the ADF test we set our null hypotheses that variables have unit root test and hence the are non-stationary. While our alternate hypotheses say that our variables are stationary. We accept or reject our null hypothesis based on the P-values of ADF test. If these are less than the threshold of 5% (0.05) or 10% (0.10) then we reject the null hypothesis and our variables are stationary else, we fail to reject the null hypothesis. Based on the results, we infer from the table that Forest, Trade, and Pollution are non-stationary variables.

From Table 2 we can infer that we have mixed variables. Some are stationary and some depicts non-stationary pattern. Stationary data is a time series dataset in which statistical features such as mean, variance, and covariance are consistent over time. In other words, the data's behavior shows no major trend or seasonality, and its statistical properties are stable over time periods. Stationary data is essential for many statistical analysis and forecasting models because it allows for accurate forecasts based on past trends. Non-stationary data, on the other hand, shows changes in statistical features over time, which are frequently characterized by trends, seasonality, and irregular fluctuations. Non-stationary data presents issues for analysis and forecasting since the underlying patterns might shift unexpectedly, making it impossible to draw meaningful conclusions or make accurate forecasts.

Table 2: Augmented Dickey-Fuller Test for Unit Root

Variables	T-stats	P-value	Results
CO2	-5.237	0.001	Stationary
FFCp	-6.274	0.000	Stationary
Forest	0.042	0.956	Non-Stationary
Trade	-1.899	0.329	Non-Stationary
RECp	-6.938	0.000	Stationary
GDP	-3.413	0.016	Stationary
Pollution	-2.426	0.141	Non-Stationary

4.3. Regression Analysis

Table 3 represents the linear regression model of our variables. We can infer from the table that *RECp, FFCp* and Trade variable are insignificant. R-squared of this model is also very low, equal to 0.447, which means only 44.7 percent of the variation in the dependent variable is explained by the given independent variables.

4.4. Autocorrelation

A correlogram, known as an autocorrelation plot or autocorrelation function plot, depicts the autocorrelation function (ACF) of a time series that displays the correlation coefficients between the observations of a time series and their lagged values at various time intervals. By evaluating the patterns and magnitudes of these coefficients, analysts can detect the presence of autocorrelation in the data, which helps in identifying underlying temporal structures, such as seasonality or trends.

4.5. ARDL Model

We used Akaike Information Criteria (AIC) to identify the best ARDL model. The AIC is a statistical measure used to pick a model from a set of candidates. It balances the model's goodness of fit against its complexity, penalizing too complicated models. In the context of the Autoregressive Distributed Lag (ARDL) model, AIC can be used to compare different model specifications, such as lag lengths or variable inclusion.

Table 3: Regression Model Estimation Results

Variables	CO_2 (Dependent variable)
GDP	0.706*
	(0.358)
Trade	-0.244
	(0.183)
Pollution	-4.092*
	(2.217)
Forest	7.427**
	(3.298)
RECP	-0.183
	(0.170)
FFCP	0.446
	(0.355)
Constant	-23.93
	(12.02)
Observations	41
R-squared	0.448

*** p<0.01, ** p<0.05, * p<0.1

Table 4 displays the results of the ARDL model. The interpretation is as follows. The R-squared value in this model is 0.97, indicating that the independent variable accounts for 97 percent of the variation in the dependent variable. The consumption of renewable and nonrenewable energy sources has a significant impact on Pakistan's CO_2 levels. Aside from this, other variables have a substantial impact on the CO_2 level in Pakistan.

The variable of Fossil fuel consumption (*FFCP*) has a p-value equal to 0.06, which is less than 0.1. This implies that *FFCP* is significant at the 10 percent level, and it indicates that if the growth rate of consumption of fossil fuels, such as Coal, oil, and natural gas, increases, then the carbon dioxide growth rate increases by 0.69 units. Whereas if the rate of plantation (variable Forest) has a p-value equal to 0.04, which is also lower than 0.10, which means at the significant level of 10 percent, if Forest increases, then it would result in a decrease of 64.49 units in the carbon dioxide growth rate. GDP also affects the carbon dioxide growth rate. Our analysis shows that if GDP increases, then carbon dioxide growth rate also increases by 0.06 units at the significant level of 5 percent. Pollution and trade have a positive effect on carbon dioxide growth rate at the significant level of 10 percent and 5 percent, respectively. When Pollution and trade increase, then the carbon dioxide growth rate also increases by 14.37 and 1.03 units, respectively. Lastly, if the rate of consumption of renewable energy sources (RECP) increases, then the carbon dioxide growth rate decreases by 0.68 units at the significant level of 5 percent because the p-value of RECP is 0.01, which is less than the threshold of 0.05.

The ARDL model helps us understand how various factors influence the amount of CO_2 in Pakistan's atmosphere. Consider CO_2 to be the undesirable byproduct of burning coal, oil, and gas. When we burn these things for energy, we emit CO_2 into the atmosphere, which is bad for the environment. The model indicates that 97 percent of the time, the amount of CO2 in the air is explained by factors such as the amount of energy we consume and other variables. One major factor influencing CO_2 levels is the fuels we use for energy, such as coal, oil, and gas. When we utilize more of these, CO_2 levels rise. However, planting additional trees (known as forestation) can reduce CO_2 levels. Trees are nature's cleansers, taking up CO_2 and purifying the air for us. So, planting more trees helps to reduce CO_2 levels in the air.

Another factor influencing CO_2 levels is a country's gross domestic product (GDP). When a country's GDP rises, it usually signifies that people are purchasing and utilizing more goods, which often takes energy and might result in greater CO_2 emissions. So, as GDP rises, so may CO_2 levels. Then there is pollution and trade. Pollution occurs when dangerous substances enter the air, such as smoke from factories or exhaust from cars. When there is more pollution, CO_2 levels rise. Trade occurs when countries buy and sell goods with one another. When trade increases, more commodities are produced and shipped, which can result in increased CO2 emissions into the atmosphere. But there's some good news: adopting more renewable energy sources, such as wind or solar power, can help cut CO_2 emissions. When we use more renewable energy, we are generating cleaner power that emits less CO_2 into the atmosphere. According to the model, using more renewable energy can help reduce CO_2 levels. Understanding how these factors affect CO2 levels is crucial for informed decisions about energy use and environmental protection. By planting more trees, using cleaner energy sources, and being careful of our pollution and trade, we can contribute to a healthy planet with cleaner air for everyone to breathe.

Table 4: ARDL Model Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
FFCP	0.69	0.34	2.01	0.06
FOREST	-64.96	12.97	-5.01	0.04
GDP	0.06	0.02	0.23	0.41
POLLUTION	14.37	8.46	1.70	0.08
RECP	-0.68	0.07	-9.81	0.01
TRADE	1.03	0.15	6.83	0.02
Constant	-118.81	14.92	-7.96	0.02
LAGS				
CO2(-1)	-0.49	0.07	-6.64	0.02
CO2(-2)	-0.17	0.05	-3.46	0.07
CO2(-3)	0.08	0.12	0.67	0.57
CO2(-4)	-0.56	0.13	-4.46	0.05
FFCP(-1)	0.18	0.24	0.77	0.52
FFCP(-2)	1.86	0.22	8.33	0.01
FFCP(-3)	1.81	0.22	8.08	0.02
FOREST(-1)	-16.50	14.61	-1.13	0.38
FOREST(-2)	112.26	13.94	8.05	0.02
FOREST(-3)	-60.81	7.63	-7.97	0.02
GDP(-1)	0.01	0.22	0.05	0.96
GDP(-2)	0.46	0.23	2.05	0.18
GDP(-3)	-1.83	0.27	-6.84	0.02
POLLUTION(-1)	-3.86	2.13	-1.81	0.21
POLLUTION(-2)	-9.10	2.19	-4.16	0.05
POLLUTION(-3)	7.19	2.03	3.55	0.07
RECP(-1)	-0.13	0.05	-2.42	0.14
RECP(-2)	-0.07	0.06	-1.12	0.38
RECP(-3)	0.13	0.07	1.79	0.21
RECP(-4)	0.29	0.06	4.88	0.04
TRADE(-1)	0.25	0.11	2.26	0.15
TRADE(-2)	-0.03	0.12	-0.23	0.84
TRADE(-3)	0.05	0.13	0.39	0.73
R-squared	0.97			
F-stats	83.94			

5. CONCLUSION

In conclusion, the R-squared value in the model stands at 0.97, indicating a strong correlation, where 97% of the variance in Pakistan's CO_2 levels can be explained by various factors, primarily energy consumption. Fossil fuel consumption, with a p-value of 0.06, shows significance at the 10 percent level, meaning an increase in fossil fuel usage leads to a corresponding rise in CO_2 emissions. Conversely, variables like plantation (p-value of 0.04) and consumption of renewable energy sources (p-value of 0.01) exhibit significance at varying levels, demonstrating their potential to reduce CO_2 levels. The ARDL model helps elucidate the complex relationship between energy consumption, economic variables such as GDP, and environmental factors like pollution and trade, highlighting potential avenues for mitigating CO_2 emissions. Through measures such as increasing forestation and transitioning to renewable energy sources, Pakistan can work towards curbing CO_2 levels, thus contributing to environmental sustainability. to adequately respond to the challenges of climate change and make a transition to a more sustainable energy sector, Pakistan should implement the following set of policy measures:

Firstly, the country should develop a strategy that prioritizes targeted support for investments in renewable forms of energy. In particular, the country should stimulate investments in solar, wind, or new hydropower plants through a combination of tax breaks, subsidies, and improved regulatory circumstances. Meanwhile, the country should gradually remove subsidies from energy sources such as coal and oil to make them more expensive and ease the market's transition towards cheaper forms of energy.

Equally important, Pakistan must establish comprehensive renewable energy policies with ambitious goals for the production and utilization of renewable energy. These policies must be robust enough to explain how they will increase the amount of power generated from this source in the overall national energy mix and facilitate its integration into the national grid. Additionally, Pakistan should focus on investments in research and development (R&D) programs aimed at improving the efficiency, cost-effectiveness, and quality of renewable energy technologies. Such support includes development of innovative solutions for storing electrical energies, technologies for connecting grids with these sources as well as specific types of renewable systems that match geographical attributes and weather patterns unique to Pakistan.

Pakistan has good solar insulation and abundant solar resources, making it ideal for both PV and thermal power uses. Solar radiation is most concentrated in the South, Quetta Valley, and Central Punjab. The Annual Direct Normal Solar Radiation for CSP in Balochistan ranges from 7 to 7.5 kWh/m2/day in some areas and 6.5 to 7 kWh/m2/day in others.

Pakistan is developing solar power projects in Azad Kashmir, Punjab, Sindh, and Balochistan. The program is being developed by the International Renewable Energy Agency, China, and Pakistan's private sector. Pakistan aims to increase its renewable energy usage by 5% (approximately 10,000 MW) by 2030. Additionally, 10% of diesel fuel will be replaced with biodiesel by 2025(see Appendix Figure 1). A GIS wind speed map of 100 meters, including wind measurement stations. The data clearly shows that Sindh and Baluchistan have more wind potential than other provinces. According to Harijan (2008), Pakistan has around 346 GW of gross wind energy resources available. According to an assessment conducted by the Pakistan Meteorological Department (PMD), the Sindh-Gharo Wind Corridor has a vast wind power potential of approximately 44 GW, of which 11 GW is exploitable and may be connected to the grid.

Additionally, Pakistan's installed capacity was approximately 19,845 MW in 2016, with hydroelectric power accounting for roughly 20%. Much of the remainder is thermal, powered primarily by petrol and oil. According to a 2006 US Department of Energy analysis, the country's per capita energy consumption is predicted to be 14 million Btu, which is almost the same as India's but a fraction of other industrializing economies in the region, such as Thailand and Malaysia. Furthermore, the Pakistani government should also establish capacity-building and workforce development programs for the locals, where people from these areas can be trained in the skills needed for participating in solar energy development. For instance, training technicians, engineers, and policy makers in the planning, installation, and maintenance of solar energy systems throughout Pakistan would be a good choice.

To sum up, by following this policy recommendation, Pakistan can certainly decrease its carbon emissions and dependence on fossil fuels, which are the major causes of the current energy insecurity. This will also lead to a sustainable energy future to maintain environmental security and improved energy security for the coming generations.

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