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Assessing the Tri-Dimensional Nexus of Energy, Environment, and Economic Growth in Pakistan: An Empirical Study

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ABSTRACT

The energy sector plays a crucial role in boosting economic growth and improving the standard of living in Pakistan. However, the extensive use of energy from different sources, such as hydel, nuclear, and thermal energy, has resulted in significant impacts on environmental degradation and negative health impacts for local communities. The study examined the tri-dimensional nexus between different types of energy use, economic growth, and environmental degradation in Pakistan using the ARDL regression model with data spanning from 1972 to 2021. The empirical findings show that overall energy consumption, including hydro, nuclear, and thermal energy, has a positive and significant impact on economic growth in both the short and long term. This suggests that energy consumption is the main driver of economic growth, emphasizing the need for a sufficient supply of energy to meet the economy's needs. On the environmental front, the study lends support to the existence of the EKC hypothesis in the context of Pakistan. However, in the long run, biocapacity in terms of forest products has a positive effect, whereas hydro, nuclear, and thermal energy have a negative effect on environmental quality. But in the short run, nuclear and hydroelectric energy have a positive but insignificant effect on ecological footprints. These findings suggest the need for Pakistan to focus on reducing the use non-renewable energy and promoting the use of cleaner energy sources to mitigate environmental impacts. This study also highlights the importance of policymakers considering the environmental consequences of energy and growth when making decisions in Pakistan.

Keywords: Energy, Economic Growth, Environmental degradation, ARDL
JEL Classifications: O4, Q4, Q5

1. INTRODUCTION

In recent decades, there has been a substantial growth in socio-economic development and human welfare, which has resulted in a heightened demand for fossil fuels energy. Despite the efforts made by various nations to encourage the use of renewable energy, energy efficiency and conservation, fossil fuels remain the primary sources of energy production, accounting for 80% of energy production across different income levels (Al-Mulali et al., 2016).

In Pakistan, the energy sector plays a crucial role in supporting economic growth and improving the standard of living in Pakistan. However, the extensive use of traditional energy sources such as natural gas, oil, and coal, has resulted in significant environmental degradation and negative health impacts for local communities (Siddiqui and Qamar, 2019). Pakistan is heavily dependent on thermal energy, particularly coal and natural gas, to meet its energy demands. According to data from the Pakistan Ministry of Energy (MoE, 2021), approximately 60% of Pakistan's electricity is generated from thermal sources, with coal accounting for the largest share of thermal generation. The country also relies on natural gas for a significant portion of its energy needs, including electricity generation, transportation, and industrial processes. The reliance on thermal energy has several implications for Pakistan. First, thermal power plants emit large amounts of greenhouse gases, contributing to climate change and other environmental impacts (IPCC, 2014). Second, thermal energy is often associated with high production costs and low energy efficiencies, which can negatively impact energy security and affordability (IEA, 2020). Finally, Pakistan's dependence on imported fossil fuels increases its vulnerability to energy price volatility and supply disruptions (EIA, 2020). As a result, there is growing interest in developing alternative energy sources in Pakistan to reduce the country's dependence on thermal energy and improve energy security and sustainability (Shahbaz et al., 2019).

On the other hand, the country has a significant potential for hydropower generation, with an estimated 40,000 MW of potential capacity (Ministry of Energy Pakistan, 2022). Historically, hydropower energy has been the dominant source of renewable energy in Pakistan and has significant contribution to the electricity generation in country. However, in recent decade, Pakistan has started to focus on other clean energy, such as solar and wind energy, as well as exploring other new technologies such as tidal and geothermal energy. The shift towards other renewable energy sources was driven by several factors, including the need to diversify the energy mix, increasing concerns over the environmental impacts of hydropower, and the declining cost of alternative renewable energy technologies. As a result, the country has set ambitious targets for the development of renewable energy, with a goal of generating 20% of the country's electricity from renewable sources by 2025 (MoE, 2021).

Moreover, the transition to clean energy sources, such as solar and wind energy, can mitigate these negative impacts and contribute to sustainable development (Shahbaz et al., 2019). It is because these types of energies can reduce the aggregate volume of CO_2 emissions in the global environment. Furthermore, few studies argued that clean energy sources such as solar and wind are often touted as a solution to mitigate the negative impacts of traditional energy sources on the environment, however they can also have negative impacts on the ecology if not properly managed (Kontoleon, 2017; and Smallwood, 2013). Some of the ways renewable energy sources can harm the environment include:

1.1. Land Use

The installation of large-scale renewable energy facilities such as wind farms and solar panels often requires a large amount of land, which can result in habitat loss for wildlife and the displacement of local communities (Kontoleon, 2017).

1.2. Biodiversity

Renewable energy infrastructure, such as wind turbines, can pose a threat to bird and bat populations, as they can collide with the blades (Smallwood, 2013).

1.3. Water Use

Some renewable energy sources, such as bioenergy and hydropower, require significant amounts of water, which can lead to competition with other water uses such as agriculture, and impact water quality and availability (Mekonnen and Hoekstra, 2016).

Additionally, the environment is essential for economic growth, as natural resources provide the basis for many industries, such as agriculture, tourism, and forestry (World Bank, 2018). However, the degradation of the environment can negatively impact economic growth by reducing the availability of natural resources, increasing the cost of production, and affecting the health of local communities (Khan and Alam, 2016).

Considering these interrelationships, this study aims to assess the Tri-Dimensional Nexus of Energy, Environment, and Economic Growth in Pakistan, through an empirical analysis of data from various sources. The findings of this study will provide valuable insights for policy makers and stakeholders in the energy and environmental sectors, to inform the development of sustainable energy policies that support economic growth while mitigating environmental degradation.

1.4. Research Problems

The energy sector in Pakistan has significant implications for both the environment and the economy, and ongoing research is examining the specific impacts type of energy sources. The current state of development in the energy sector and barriers to growth must be considered in the transition to a more sustainable energy sector. Environmental degradation also affects economic growth, particularly for natural resource-based industries. Therefore, further research is needed to understand the interrelationships between energy, environment, and economic growth in Pakistan to inform policymaking. It is also important for investigating the potential of alternative energy sources, to improve energy security and sustainability.

1.5. Significance of Study

The current study holds both theoretical and empirical significance in the research. The theoretical significance of this study is highlighted by its contribution to the existing literature on the relationships between energy, environment, and economic growth in Pakistan. By examining the impacts of different types of energy sources on the environment and economy, the study provides a deeper understanding of the interconnections between these important areas. It also contributes to the theoretical framework on the transition to renewable energy sources and the role of alternative energy sources in improving energy security and sustainability. The research provides insights into the barriers to renewable energy development in Pakistan and the implications of economic growth and environmental degradation.

On the other hand, the empirical significance of the study lies in its provision of data and insights that are relevant to the policy-making process in Pakistan. By providing a comprehensive analysis of the current state of renewable energy development and the barriers to growth, the study informs policy decisions aimed at promoting sustainable energy practices. Additionally, the study also contributes to the empirical evidence base on the interrelationships between energy, environment, and economic growth in Pakistan, which inform the development of effective policies for mitigating the negative impacts of energy production and consumption. Moreover, the study provides valuable insights into the potential for the transition to renewable energy sources to contribute to sustainable development and improve energy security and affordability.

1.6. Organization of Study

The study is organized as follows; section 1 provides a brief introduction explaining recent developments and existing research problems. Section 2 provides the existing literature review of the study related to the understudy variables and their relationships. This section also explains the existing gap in area of environment-growth nexus. Section 3 explains theoretical and conceptual farmwork discussing various economic theories of environment-growth and energy. Section 4 explains the data collection, methodology and technique used for data analysis. Section 5 discusses the findings empirical, and section 6 explains the conclusion and policy suggestion.

2. LITERATURE REVIEW

In this section the literature of the past and recent studies being conducted. These papers are included based on availability, relevancy, and being informative and helpful for the methodology of this proposal.

The association between environment and economic growth is not as straight-forward as it was understood before 1957, when Kuznets (1957) proposed the EKC hypothesis, which says that initially income growth increases environmental quality but after reaching a certain limit the economy is able to replace traditional technology with new environment-friendly technology and thus it reduces the emissions. This indicates that there is a nonlinear association between environmental quality and economic growth. This hypothesis was validated by Khan and Alam (2016) and argued that income growth reallocates the environmental pressure in Pakistan.

Dai et al. (2022) conducted research on the correlation between energy and growth in OECD nations and explored the outlook for sustainable development in China. The study employed the energy Kuznets curve for these Nations. According to the findings, China exhibited a higher energy-economic rate at the turning point of energy compared to the Germany and United States. Moreover, China had made substantial strides in terms of urbanization rates, but its tertiary industry lagged that of the Germany and United States.

In term of ecological footprint, Yousaf et al., (2021) examined the per capita ecological footprint in South Asian countries, including Bangladesh, Maldives, Sri Lanka, India, Pakistan, and Nepal. By analyzing the bio-capacity and ecological footprint of material resources, the study found that these countries have an increasing ecological deficit, with the demand for resources exceeding their supply. The main contributors to the growing ecological footprint were cropland, carbon, and forest products. The results indicated a need for balancing the demand and supply of material resources in South Asia, and one potential solution could be the establishment of a carbon trading market, as carbon footprint is a major contributor to the ecological footprint in these countries.

Destek and Sarkodie (2019) conducted a study that explored the association between the per capita ecological footprint and non-renewable and renewable energy consumption, as well as trade openness, in 24 OECD countries between 1980 and 2014. The study utilized panel-based methodologies and discovered a U-shaped association between real income per capita and per capita ecological footprint, which supported the ECK hypothesis in OECD countries. Furthermore, the study revealed that an upsurge in the consumption of renewable energy and trade openness leads to a decline in the ecological footprint in these countries.

Baloch et al. (2020) explored the effect of per capita income growth, technological progress and natural resources on the per capita ecological footprint using a sample of 22 emerging nations between 1984 and 2016. The study aimed to address the challenges that arise from rapid industrialization and population growth, which have caused an increase in the consumption of natural resources and a rise in the per capita ecological footprint. Panel co-integration under CS-ARDL was applied to investigate the relationships between the variables. Their findings support the EKC hypothesis, showing an inverted U-shape association between ecological footprints and income growth. The study also revealed that the use of natural resources contributes to an increase in ecological footprint, while income growth has a negative effect on the quality of environment. However, the results indicate that technological innovations have a positive effect on the quality of environment.

Nathaniel (2021) conducted a study on the relationship between increasing urbanization and industrialization and the demand for biological capacity in the ASEAN region. The study investigated the impact of economic growth, trade activities, urban expansion, and primary and clean energy consumption on the per capita ecological footprint. The study used a panel data set between 1990 and 2016. To analyze the data, the study employed first and second generations unit root test statistics, cross-sectional dependence, and cointegration methods. The results indicated that income growth, trade, and primary energy have a significant effect on environmental degradation, while clean energy has a minimal impact on environmental quality. Their findings suggest that the region's growth is leading to environmental degradation, primarily due to emissions-intensive trade. Additionally, the study found a one-way causal relationship from urbanization to use of primary energy.

Khalid et al. (2021) conducted a study to examine the connection between growth, trade, financial development, and energy consumption (both renewable and primary) on the ecological footprint in the SAARC nations between 1990 and 2017. A variety of techniques, including longitudinal data analysis, panel co-integration test, second-generation panel stationarity, short-run long-run elasticity estimates, and D-H non-causality approaches, were employed in the study. Their findings reveal that primary energy consumption had a negative and significant effect on the environmental quality, while financial development had an insignificant but positive effect. Furthermore, trade openness in the full panel of SAARC countries was shown to have a negative impact on the ecological footprint.

Du et al. (2018) explores the association between real income growth and the environment in three East Asian countries, namely China, Japan, and Korea during the period from 1990 to 2013. The aim of the study was to examine how these countries strike a balance between sustainable growth, export demand, and environmental considerations. The study used two measures of trade development, namely export product diversification and market product diversification, to test the validity of the EKC hypothesis. The findings indicated that Japan and Korea displayed a U-shaped pattern, while China exhibited an opposite trend. Additionally, the results revealed that trade diversification had a significant positive impact on the ecological footprint in East Asian countries.

Sabir and Goru (2019) examined the impact of per capita real income, economic globalization, and technological innovation on the ecological footprint in five South Asian countries, namely Sri Lanka, Bangladesh, Pakistan, Nepal, and India, from 1975 to 2017. Patent applications were used as a measure of technological innovation. By using panel-ARDL co-integration approach, the authors found that there is a long-term correlation between innovation, globalization, per capita income, and ecological footprint per capita. The EKC hypothesis was supported in Nepal, Sri Lanka, Bangladesh, and Pakistan, but not in India. Furthermore, the study indicated that an increase in globalization had positive and significant effect on the environmental quality in all South Asian countries, while technological innovation was negatively but insignificantly associated with the ecological footprints in these nations.

Rehman et al. (2021) investigated the effect of income growth, globalization, fuel importation, trade, and energy consumption on the per capita ecological footprint of Pakistan from 1974 to 2017. Using the ARDL approach, other estimation techniques, the study revealed that in the long run, income growth, trade, globalization, and energy consumption had a negative impact on the per capita ecological footprint, while fuel importation had a positive impact. In the short run, all variables, except fuel importation, showed a positive relationship with the ecological footprint. Maximum likelihood approach results demonstrated that trade, energy consumption, globalization, and fuel importation had a positive relationship with the ecological footprint, while economic growth had a negative relationship. On the other hand, the Gaussian Model results showed that energy use and globalization had a positive relationship, while GDP growth, trade, and fuel importation had a negative relationship with the ecological footprint in Pakistan.

A study by Majeed et al. (2019) examined the relationship between the energy and water environment, economic growth, and renewable energy in 166 nations from 1990 to 2017. The empirical results using "Pooled OLS," "Random effect", and "Fixed effect regression models" support the N-shaped environmental Kuznets curve. The study shows that renewable energies, such as hydropower, solar power, and wind power can be used for sustainable development and environmental improvement.

Idrees and Majeed (2022) explore the effect of financial development and income inequality on environmental degradation in Pakistan from 1972 to 2018. Using the NARDL technique, the results indicate that income inequality causes rise in environmental degradation and carbon emissions. The nonlinear analysis confirms the disproportionate effect of inequality on environmental influences. However, the extended EKC approach did not exist in Pakistan.

Majeed et al. (2021) explored the association between use of energy, growth, and quality of environmental in Pakistan. He applied a nonlinear estimation technique to examine the asymmetric effects of both aggregate and heterogeneous forms of energy on quality of environmental. Research has found that adverse shocks have a significant impact on environmental impacts and that different sources of energy consumption have disproportionate effects on the environment, with oil consumption having a negative effect and gas consumption having a positive effect.

Rehman et al. (2021) conducted a study to evaluate Pakistan's ecological footprint by exploring the effects of energy consumption, globalization, trade, income growth, and imports of fuel products. The study employed a linear ARDL method and other econometric techniques. The study's findings revealed that energy consumption, globalization, trade, and income growth had a consistently positive impact on the per capita ecological footprint, whereas fuel imports had an adverse effect in the long run. However, in the short-run, energy consumption, globalization, trade, and GDP growth all had positive associations with the environment, whereas fuel imports had a negative impact on environmental sustainability.

Abbas et al. (2021) conducted a study that explored the effect traditional energy, clean energy, urbanization, transportation, and ecological footprint on CO_2 emissions in Pakistan. The researchers utilized ARDL and other models to ensure robust empirical findings. The empirical findings indicate that traditional energy had a substantial positive effect on the ecological footprint, while clean energy had a negative impact on CO_2 emissions. Urbanization and transportation were observed to have a significant influence on CO_2 emissions in both the long run as well as in the short run. The study found that traditional energy, renewable energy, and ecological footprints had a minimal impact on CO_2 emissions in the short term.

Destek and Aslan (2017) found that non-renewable biomass energy consumption positively impacts financial development in some countries, but at a significant environmental cost. This suggests that the current growth level may have negative consequences on resources for future generations.

Moreover, Fan and Lei (2017) investigated the relationship between economic development and quality of environmental in transportation in case of China. The study used time series data from 1995 to 2014 and employed different econometric techniques. Their findings indicated that CO_2 emissions and transport services had a positive impact on national income growth, highlighting the need to consider emissions associated with specific sectors and activities to mitigate environmental pollution.

Işik et al. (2017) used the ARDL model to investigate the relationship between economic growth, financial system growth, international trade, and tourism expenditures in case of Greece. The results of the analysis showed that CO_2 emissions were positively affected by economic growth, financial growth, trade openness, and expenditures on tourism. According to the authors, the tourism sector, which is a leading industry in the Greek economy, has significant long-term negative environmental consequences. As a result, they recommended that Greece should proactively address the threat posed by the tourism sector, given its dominance in the Greek economy.

Saleem et al.(2017), Investigated the role of GDP growth, sources of energy consumption, and other plausible hypothetical factors in CO2 emissions using evidence from selected Asian countries over the period of 1980–2015. The study used panel Fully Modified OLS (FMOLS) test, the panel Granger causality test namely the Dumitrescu-Hurlin test (2012) and the Innovative Accounting Approach. The results of FMOLS for the full panel set indicated the presence of an EKC hypothesis, where the impact of GDP growth and the square of GDP growth on CO2 emissions are positive and negative, respectively, in the context of 10 Asian economies. The findings of FMOLS for lower income economies did not support the EKC hypothesis; however, the results exhibit that high and upper middle income economies maintain the EKC hypothesis.

Destek (2017), Investigated the economic efficiency of biomass energy consumption for the period from 1980 to 2013 in top 10 biomass energy consumer countries. Findings indicated that economic growth is positively affected by biomass energy use in Brazil, China, Finland, Germany, Italy and Sweden. In addition, empirical findings from panel bootstrap causality test show that the growth hypothesis is valid for Brazil, Germany, India and Italy; the conservation hypothesis is supported in Sweden, the feedback hypothesis is confirmed in China and the US; the neutrality hypothesis is valid in Finland, Japan and the UK.

Arrow et al (1995) established that economic growth is not a panacea for environmental quality; indeed, it is not even the main issue. What matters is the content of growth--the composition of inputs (including environmental resources) and outputs (including waste products). This content is determined by, among other things, the economic institutions within which human activities are conducted. These institutions need to be designed so that they provide the right incentives for protecting the resilience of ecological systems. Such measures will not only promote greater efficiency in the allocation of environmental resources at all income levels, but they will also ensure a sustainable scale of economic activity within the ecological life-support system. Protecting the capacity of ecological systems to sustain welfare is of as much importance to poor countries as it is to those that are rich

Işik et al. (2019) conducted a study to analyze the influence of real income growth, population size, cleaner energy consumption, and fossil fuel energy on CO_2 emissions in case of United States from 1980 to 2015. Their findings suggested that the Environmental Kuznets Curve hypothesis is applicable for five states, including Ohio, Illinois, Florida, New York, and Michigan. Moreover, the study revealed that fossil fuel energy had a positive effect on CO_2 emissions in Texas, whereas energy consumption had a positive impact on CO_2 emissions in Florida, although the magnitude of this effect was lower than in other US states.

Using panel FMOLS technique, Azam et al. (2021) investigated the relationships between CO_2 emissions, overall energy, trade, human capital, and economic growth. Their findings revealed that real growth was significantly and positively influenced by human capital and trade volume, while being significantly and negatively influenced by CO_2 emissions and energy consumption.

Saboori et al. (2017) analyzed the relationship between use of oil, real economic growth, and quality of environmental in three Asian countries between 1980 and 2013. They used the Johansen co-integration test to check the connection among the proposed study variables. Their findings reveal that there is a unidirectional causality. For instance, use of oil causes real economic growth in China and Japan, while use of oil causes CO_2 emissions in South Korea.

Bhat (2018) investigated the effect of energy use and real economic growth on CO_2 emissions between 1992 and 2016. They used a Panel data set and employed Panel ARDL techniques to examine the relationship between the proposed variables. The empirical findings demonstrate that physical capital stock, labor force, population size, and real income per capita, and primary energy use have a positive impact on CO_2 emissions. This suggests that rise in investment level, supply of labor and use of primary energy leads to raise the level of CO_2 emission across the countries.

Sulaiman and Rahim (2017) explored the relationship between carbon dioxide emissions (CO_2), use of energy, and level of economic growth in Malaysia between the period of 1975 and 2015. They used the ARDL regression model to investigate the association among the study variables. The results showed that real economic growth is not affected by use of energy and CO_2 emissions, while use of energy and level of economic growth have a positive influence on CO_2 emissions. This study demonstrates a reverse causality from proposed variables.

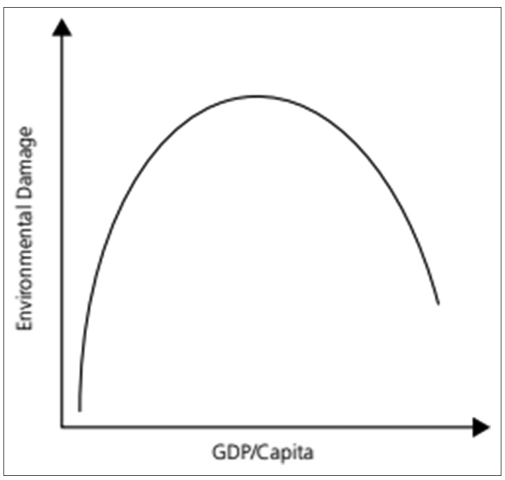
2.1. Summary of Literature Review

The growing trend of accepting the ideas of substituting energy from non-renewable to renewable energy is a fundamental driver of human well-being in achieving sustainable environmental quality without restricting economic growth. Yet some critics want to deny innovation's vast benefits and continue to bestow on mankind. This study summarized the existing literature regarding the Tri-Dimensional Nexus of Energy, Environment, and Economic Growth. However, the documented literature's findings are opposed to each other because of the use of different econometric approaches or functional forms of equations. For instance, many studies tested the EKC hypothesis using other determinants of environmental degradation, but few used a linear relationship between ecological footprint and economic growth. It can be the reason for proposed samples or selected countries that vary due to their natural resources or existing technology used for achieving sustainable growth and different preferences for environmental protection policies. Based on existing findings, it is generally believed that overall energy mix favors economic growth and but has serious challenges to human well-being by reducing the quality of eco-system. More specifically, the existing literature in this area of research is ambiguous and limited in the context of Pakistan regarding how ongoing energy security and environmental hazards affects their way of life; however, the short-term disruptive aspects of different form of energy utilization are real and deserve attention.

2.2. Research Gap

There is a lack of empirical research on the specific impacts of different types of energy sources on the environment and economy in Pakistan. Meanwhile, previous research primarily focused on the environmental impacts of renewable energy and limited research on specific types of energy. There is a need for a comprehensive empirical study to assess the Tri-Dimensional Nexus of Energy, Environment, and Economic Growth in Pakistan, considering each energy sources, and their specific types, to inform the development of sustainable energy policies.

Figure 1: Environmental Kuznets Curve Framework



Source: Kuznets, 1955

3. THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1. Theoretical Framework

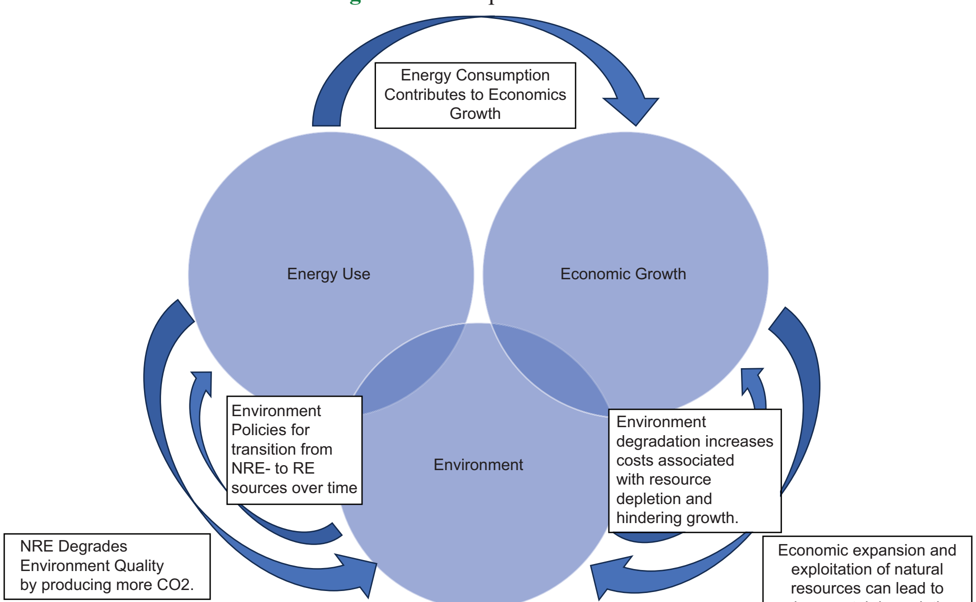
The following section outlines the theoretical framework that elucidates the association between the use of energy, and economic development, and their effect on the environment quality. The "Environmental Kuznets Curve" (EKC) Hypothesis was first introduced by Simon Kuznets in 1955, which suggests an association between quality of environmental and economic expansion. Kuznets provided empirical evidence to support the notion that there is an "inverted U-shaped" association between level of output per capita and indicators of quality of environmental, as depicted in Figure 1.

According to the EKC framework, in the initial stage as a nation's GDP per capita rises, quality of environment degrades in term of rise in CO_2 level. However, a certain point, further rise in real income per capita (GDP per capita) leads to a reduction in environmental damage. This is because people with low incomes prioritize meeting their basic needs and have limited resources to pollute. Once a specific level of income is reached, individuals or nations begin to weigh the trade-off between quality of environment and their consumption level. Hence the environmental damage rises at a slower rate. Eventually, individuals prioritize environmental quality over further consumption, and spending on emission reduction becomes dominant, stimulating economic growth.

3.2. Drivers of the Economy-Environment Relationship

In literature investigating the association between real growth and the quality of environment, the EKC framework is often employed (Grossman and Krueger, 1995; 1991). However, this relationship is complex and multi-dimensional, as demonstrated by various theoretical perspectives. Thes theories can be grouped into three categories. First: it is the scale effect, which demonstrates that real growth has a negative impact on the quality of environment.

Figure 2: Conceptual framework



As production and consumption increase, more raw materials are required, leading to more waste and pollution. This harms the environment and contributes to environmental degradation. The second category is the composition effect. This effect shows how the composition of production changes over time due to structural shifts along the growth path. Initially, economic expansion leads to industrialization, resulting in increased environmental harm as the balance shifts from agricultural to manufacturing goods. However, as the balance shifts from manufacturing industrial products to service operations, material consumption is reduced, and the negative environmental impacts of rapid economic expansion are minimized. The third category is the technical effect, which illustrates the influence of technological progress on the environmental implications of production. Technological advancements can result in increased production and the development of environmentally friendly technologies that benefit the environment, such as increased energy efficiency. However, they can also result in technological advancements that cause environmental damage, such as increased energy use.

Furthermore, it is important to consider that the association between real economic expansion and the quality of environment is not straightforward. While some studies have found evidence of an EKC relationship, others have found no such evidence (Stern, 2004). Additionally, other factors such as energy consumption can also have significant impacts on the environment and should be considered in any analysis of the relationship between the economy and the environment. The degree of these factors plays a role in determining the cause-and-effect association between economic expansion and environmental quality.

3.3. Conceptual Framework

The association between use of energy, economic expansion, and the ecological footprint can be explained by three theoretical perspectives as shown in Figure 2: The ecological modernization hypothesis, introduced by Huber (2000), is based on the idea that industrialized civilizations can address environmental challenges. The finite number of non-renewable resources on the planet is being rapidly depleted due to increasing production and expansion, leading to environmental degradation and unsustainability in ecology (Bekun et al., 2019). The "treadmill of production theory" asserts that environmental quality degrades as it is a direct outcome of economic expansion and exploitation of natural resources (Schnaiberg, 1980; Schnaiberg and Gould, 2000). Both "Ecological modernization theory" and "Endogenous growth theory" propose that technological advancements can aid in achieving sustainable economic growth while preserving environmental quality. Environmental transition theory also highlights that as societies' transition from traditional to industrial, energy consumption and urban infrastructure growth put the environment at risk, but as societies become wealthier, they adopt clean technology, implement stronger environmental regulations, and make structural changes to enhance their relationship with the environment.

3.4. Energy, Growth, and Environment Degradation

Considering environmental concerns, the transfer and development of technology in the energy sector varies based on the stage of innovation and period. During the industrialization era in the 1960s, the primary focus of energy consumption was on non-renewable sources, such as coal and oil-fired power plants. Kemp (1994) suggested that to address the current environmental issues, there is a need for more environmentally friendly technologies, such as transitioning away from hydrocarbon-based energy sources. The implementation of such radical technologies often requires extended development periods, specialized infrastructure, and significant institutional changes. The relationship between technological advancement and environmental policy has garnered increasing attention from policymakers, as seen in the work of Jaffe et al. (2002). By the late 1990s, rapid technological innovation had become prevalent, leading to a shift towards renewable energy sources in industrialized countries, while emerging nations continued to rely heavily on non-renewable energy. With the environmental challenges posed by non-renewable energy, policymakers are focusing more on transitioning to renewable energy sources. The literature on technological innovation and renewable energy highlights various processes through which innovation and renewable energy can help to improve environmental quality.

The benefits of renewable energy consumption and production have been documented in several studies (Majeed et al., 2019). One of the main advantages is that it does not emit pollutants, thus preserving the environment's quality. Additionally, the replacement of fossil fuels with renewable energy sources reduces future emissions and environmental damage (Bilgili et al., 2016). Unlike non-renewable sources, renewable energy does not deplete and is not burdened by resource extraction and mining operations (Akella et al., 2009; Tsoutsos et al., 2005). The use of renewable energy can also result in dynamic effects through economies of scale and spillover effects, thus improving environmental quality.

According to the theory of technological transfer, the international transfer of renewable energy technologies can drive innovation and spread to developing economies. Adopting renewable energy sources can also prevent thermal pollution caused by conventional energy sources (Akella et al., 2009).

Table 1: Data description and sources

Variables	Complete description	Data sources
ECO	Ecological footprint is measured as global hectares	Global Footprint Network
FP	Biocapacity measured as availability of Forest product in Country	
GDP	Gross Domestic Product measured as 2015 Constant USD (In million)	World Bank Indicator
GDPPC	Gross Domestic Product Per Capita measured as 2015 Constant USD	
TOP	Trade openness index measured as Import plus export % GDP	
GFCF	Gross fixed capital formation measured as 2015 Constant USD (In Million)	
LFPR	Labour force Participation Rate	
EC	Energy use/consumption (kg of oil equivalent)	Ministry of Energy, Pakistan
TE	Oil/Petroleum (tons)	
NE	Nuclear (GHW)	
HE	Hydel (GHW)	

However, some researchers argue that renewable energy sources may also harm the environment. Waste and combustible renewables are not considered clean energy and their heavy reliance may lead to increased emissions (Jebli and Youssef, 2017). Renewable sources such as "biofuels", "solar", "wind", and "geothermal" require a significant amount of land and water, thus increasing the ecological footprints and degrading the overall ecosystem (Al-Mulali et al., 2016). The intermittent of cleaner energy and the lack of appropriate storage technologies pose a challenge in ensuring consistent energy supply, often requiring support from fossil fuels (Heal, 2009; Forsberg, 2009). Moreover, the mitigating effect of renewable energy is limited and may not be seen until a certain point.

4. DATA AND METHODOLOGY

4.1. Data Sources

To meet the study's objective, we used the time series data covering the period from 1970 to 2021. The data of all variables (dependent and independent) is collected from domestics as well international source such as Handbook statistics of Pakistan, Pakistan Ministry of Energy, World Bank Indicator and Global Footprint Network. The variable's description is given in Table 1.

4.2. Model Specifications

Based on above literature, the exiting gap is filled using the general functions for the "Tri-Dimensional Nexus of Energy, Environment, and Economic Growth in Pakistan." The basic growth model could be specified as follows:

$$GDP = f(E, K, L, T) \tag{1}$$

The basic growth model 1 is specified the association between economic growth (GDP), energy consumption (E), while controlling for other factors such as level of investment (K), labor force (L), and trade (T). It is observed that the increase in labor force, physical capital, and trade are positively associated with economic growth. Additionally, the use of energy consumption positively associated with economic growth in Pakistan (Idrees and Majeed, 2022; Khan and Alam, 2016; and Siddiqui and Qamar, 2019). Therefore, we also examine the impact of nuclear, thermal, and hydel energy on real growth. The equation also represents the idea that the level of economic growth is a function of the use of energy and other controlled variables that jointly determine the level of growth in a country.

Furthermore, the extended model for environmental sustainability 2 captures the interrelationships between overall Environmental quality (Ecological footprint), overall energy consumption in general and the various energy sources such as nuclear, thermal, and hydel energy consumption (E), GDP per capita and GDP per capita squared (Representing EKC) as follows:

$$ECOPC = f(GDPPC, GDPPC^2\ E, FP) \tag{2}$$

This equation represents the idea that overall Environmental sustainability caused by human activities also followed by other literature such as (Idrees and Majeed, 2022; Majeed et al., 2019; Majeed et al., 2021; Rehman et al., 2021; Shahbaz et al., 2019) in context of Pakistan. To meet research objectives, this function used ecological footprint dependent variable and other independent variables such as the energy consumption (Nuclear, Thermal and energy generated from Hydel sources), biocapacity measured as forest product, per capita income and squared per capital income growth.

4.3. Empirical Procedure and Econometric Analysis

4.3.1. Unit root test (ADF)

The systematic procedure in the time series analysis is to check the existence of a long-term association which begins with confirming the order of integration of dependent and independent variables in an equation. Because time series variables are not always stationary and vary over time. Therefore, applying the OLS regression method is unreliable because it violates the important assumption of variables stationarity. The theoretical formulation of several economic models and their derived coefficients may mislead if this important assumption is ignored. As a result, a linear combination of dependent and independent variables having I(d) characteristics might provide insight into why certain linear combinations of I(1) series could be I(0). Therefore, the testing unit root of individual series is done through Augmented Dickey-Fuller (ADF), which is represented as model 3:

$$\Delta Y_t = \alpha_0 + \alpha_1 Y_{t-i} + \sum_{k=i}^{n.} d_k \Delta Y_{tk} + u_t \tag{3}$$

The y_t Equation 3 is a time series variable, and Δ is used as the first difference operator and u_t donates a white noise error term. The ADF unit root test has an advantage in containing individual intercept, intercept, and linear time trends.

4.3.2. Co-integration analysis

The economic theory of environmental degradation and economic growth may fluctuate and converge around a long-term equilibrium limiting Ceteris paribus conditions. However, in real life, it is not only economic growth that influences environmental conditions rather than other macroeconomic and policy factors. Owing to the difficulties of "spurious regression," it is possible that one will not have a long-term relationship with whether such movement is natural or may be due to other factors. In econometrics analysis, the co-integration approach is superficial to avoid such long-term associations and prevent problems like "spurious regression."

Several literature documented that there is possibility of having both the level I (0) and first differenced I(1) properties of dependent and independent variable. Therefore, ARDL (Autoregressive distributed lags) bound test approach of co-integration is more suitable to testing long association among the variables which was introduced by Pesaran et al. (1997). This approach of co-integration is superficial for having both the I(0) and I(1) properties of dependent and independent series. This method has other statistical benefits of generating asymptotically normal estimates of the long-run coefficients regardless of whether the underpinning regressors are purely I (1) or I (0) or mixture of both. According to this method, the short-run estimated coefficients are consistent, whereas long-run coefficients are super-consistent based on ARDL estimators. But before the ARDL regression estimations, the existence of co-integration between dependent and independent variables was a primarily step. Thus, the long-run and short-run impact of independent variables on both models (economic growth and environmental sustainability) is examined as follows.

$$\Delta y_t = \propto + \sum_{i=1}^{n} \beta_{1i} \Delta y_{t-i} + \sum_{i=0}^{n} \beta_{2i} \Delta X_{1t-i} + \sum_{i=0}^{n} \beta_{3i} \Delta X_{2t-i} + \sum_{i=0}^{n} \beta_{4i} \Delta X_{3t-i} + \ldots + \sum_{i=0}^{n} \beta_{ni} \Delta X_{nt-i} + \delta_1 y_{t-n} + \delta_2 x_{1t-n} + \delta_3 x_{2t-n} + \delta_4 x_{3t-n} + \delta_5 x_{4t-n} + \ldots\ldots + \delta_n x_{nt-1} + \varepsilon_t \quad (4)$$

y_t is a dependent variable and x_{1t}, x_{2t}… x_{nt} are independent variables. It is also assumed that yt~I(1) and independent variables are either I(1) or I(0). The ARDL co-integration method is not applicable in the presence of I (2) variable. Additionally, the existence of long-run co-integration is examined by the bound testing approach with the following hypothesis:

The null hypothesis for bound testing is;
H_0: δ1= δ2= δ3= δ4= δ5=.=Sn=0 ("No long-run relationship exists")

And the alternative hypothesis is;
H_0: δ1≠ δ2≠ δ3≠ δ4≠ δ5≠⋯≠ δn≠0 ("Long-run relationship exists")

F-statistic is used to identify the existence of a long-run association among the variables. The computed F-statistic value is compared with the critical values provided by (Pesran et al., 2001).

During the model selection procedure, different tests are used to ensure that the residuals do not have the problem of heteroscedasticity, non-normality, and autocorrelation problem. For identifying such kinds of problems, we use the White heteroscedasticity (ARCH) LM test (F-stat.), Jarque and Berra (1980) test (χ^2) of normality and Breusch-Godfrey Serial Correlation LM test (1978). Moreover, we detect the stability of the parameters of the estimated dynamic error correction model (ECM) with the help of cumulative sum (CUSUM) and cumulative sum of square (CUSUMSQ), both of which were proposed by Brown, Durbin, and Evans in 1975.

5. RESULTS AND DISCUSSION

To investigate the association between energy and growth, as well as quality of environment, this study examines the effect of both overall energy consumption and its types/sources on both outcome two variables (Real Growth and Environment). A comprehensive analysis of the effects of energy use on economic growth and environmental degradation can provide valuable insights into the potential trade-offs and synergies between economic development and environmental sustainability. The study employs rigorous econometric techniques to estimate the causal relationship between energy consumption and these two outcomes, while controlling for other important factors that may confound this relationship.

5.1. Correlation Analysis

Table 2 shows the pairwise correlations between eight variables related to economic and environmental factors. The variables include Gross investment (GFCF), labor force participation rate (LFPR), trade openness index (TOP), forest product representing biocapacity (FP), overall energy consumption (EC), hydel energy consumption (HE), thermal energy consumption (TE), and nuclear energy consumption (NE).

The results show that GFCF is strongly positively correlated with forest product FP, moderately positively correlated with LFPR, and weakly positively correlated with TE. However, LFPR is moderately positively correlated with HE and weakly positively correlated with TE. Moreover, the TOP is weakly positively correlated with LFPR and weakly negatively correlated with NE. whereas FP is positively correlated with GFCF and positively correlated with TE. EC is moderately positively correlated with LFPR and has weaker positive correlations with FP and TOP. HE is positively correlated with EC and moderately correlated with TE. However, TE is strongly positively correlated with EC and moderately positively correlated with FP. Lastly the correlation of NE is weakly negatively correlated with TOP and moderately positively correlated with FP. It is important to note that these correlations do not imply causations, to establish any causal relationships among these variables. Nonetheless, the results show statistical evidence of no multicollinearity among the regressors of economic and environmental factors.

5.2. Unit Root Test Statistics

The ADF test has an advantage in containing individual intercept, intercept (C), and linear time trends (C & T). Allowing C, and C & T, the results reported in Table 3. The estimated t-statistics indicate that there is mixed integrated series. Because GDP. EC, HE, NE, and LFPR were found to be statistically significant at a 5 and 10% level of significant. However, other variables such as ECOPC, TE TOP, FP and GFCF were found to be the first difference stationary allowing intercept and linear time trend. Thus, using the ordinary

Table 2: Correlation matrix

Variables	GFCF	LFPR	TOP	FP	EC	HE	TE	NE
GFCF	1.000	-	-	-	-	-	-	-
LFPR	0.579	1.000	-	-	-	-	-	-
TOP	0.072	0.298	1.000	-	-	-	-	-
FP	0.839	0.462	0.069	1.000	-	-	-	-
EC	0.453	0.564	0.070	0.882	1.000	-	-	-
HE	0.690	0.615	0.199	0.825	0.973	1.000	-	-
TE	0.619	0.527	0.040	0.904	0.996	0.953	1.000	-
NE	0.634	0.398	-0.225	0.649	0.734	0.637	0.739	1.000

Author estimate

Table 3: ADF test statistics

Variables	Level		First Difference	
	C	C&T	C	C&T
	T-stats	T-stats	T-stats	T-stats
GDP	−3.017**	−1.066	−5.158***	−5.670***
ECOPC	−1.54	−0.873	−7.916***	−8.304***
EC	−3.562**	0.946	−0.659	−3.405*
HE	−2.738*	−1.876	−7.804***	−8.500***
TE	−2.399	1.016	−1.332	−6.303***
NR	−2.745*	−3.04	−7.374***	−7.265***
TOP	−2.125	−2.572	−8.193***	−8.242***
FP	−1.321	−1.592	−6.944***	−6.913***
GFCF	−1.695	−2.489	−4.319	−4.532***
LFPR	−4.846***	−5.021***	−6.219***	−6.350***

Author estimate: ***, ** and * shows 1, 5 and 10% levels of significance. (C and C&T shows intercept and intercept and linear time trend)

Table 4: ARDL bound test (growth and energy)

Significance	Model 1A		Model 1B		Model AC		Model AD	
Level	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
10%	2.45	3.52	2.55	3.66	2.695	3.872	3.185	4.576
5%	2.86	4.01	2.97	4.17	3.146	4.411	3.718	5.213
3%	3.25	4.49	3.38	4.67	3.575	4.939	4.225	5.837
1%	3.74	5.06	3.89	5.26	4.114	5.566	4.862	6.578
F-statistics	7.63***		8.39***		9.228***		10.905***	

The author's estimate: ***, ** and * shows 1, 5 and 10% levels of significance

Table 5: ARDL bound test (Environment and energy)

Significance	Model 2A		Model 2B		Model 2C		Model 2D	
Level	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
10%	3.17	4.14	3.17	4.14	3.17	4.14	3.17	4.14
5%	3.79	4.85	3.79	4.85	3.79	4.85	3.79	4.85
3%	4.41	5.52	4.41	5.52	4.41	5.52	4.41	5.52
1%	5.15	6.36	5.15	6.36	5.15	6.36	5.15	6.36
F-statistics	8.205***		7.325***		6.413***		6.131***	

The author estimate: ***, ** and * shows 1, 5 and 10% level of significance

Table 6: ARDL regression model (Growth and Energy)

Long run coefficients of growth models				
Variables	Model 1A	Model 1B	Model 1C	Model 1D
GFCF$_t$	0.413***	0.434***	0.463***	0.442***
LFPR$_t$	0.899***	0.944***	1.007***	0.962***
TOP$_t$	−0.531***	−0.557***	−0.594***	−0.568***
EC$_t$	1.537***	-	-	-
HE$_t$	-	0.231***	-	-
TE$_t$	-	-	0.227***	-
NE$_t$	-	-	-	0.077**
C	−3.887***	−6.100***	3.023	−2.646***
Short Run				
ΔGDP$_t$	0.476***	0.500***	0.534***	0.510***
ΔGFCF$_t$	0.185***	0.194***	0.207***	0.198***
ΔLFPR$_t$	0.223***	0.234***	0.250***	0.239***
ΔTOP$_t$	0.401	0.421	0.449	0.429
ΔEC$_t$	0.084***	-	-	-
ΔHE$_t$	-	0.005	-	-
ΔTE$_t$	-	-	0.008	-
ΔNE$_t$	-	-	-	−0.002
ECM$_{t-1}$	−0.678***	−0.712***	−0.759***	−0.725***

Author estimate: ***, ** and * shows 1, 5 and 10% levels of significance

least square regression approach to investigate long run association between environment-energy and growth-energy is considered as "spurious regression." To deal with a mixture of integrated series I (0) and I(1) but not I(2), the ARDL bound test suggested by Pesaran et al. (2001) is an appropriate technique. Therefore, in next step ARDL regression approach is employed in this study.

5.3. ARDL Bound Test

Based on ADF statistics, it is confirmed that the ARDL regression model is most suitable to investigate the association between energy use and economic expansion as well as quality of environment. In this regard, we employed ARDL bound test to estimate long run association between growth and energy use (including other sources of energy) models as 1A, 1B, 1C, and 1D. Additionally, for environmental sustainability, the ARDL bound test approach is also used to estimate models as 2A, 2B, 2C, and 2D. For each model, the "null hypothesis" is stated that there is no long-term association, as opposed to the alternative hypothesis that there is a long-term association between dependent and independent variables. The results reported in Tables 4 and 5 show that the estimated F-statistics for economic growth models as 1A, 1B, 1C, and 1D found to be greater than the lower bounds I (0) and the upper bounds at the 1% level of significance. Therefore, the study rejects the null hypothesis for each estimated model. Additionally, the estimated F-statistics for environmental sustainability models reported as 2A, 2B, 2C, and 2D were found to be greater than the lower bound I (0) and the upper critical bounds at the 1% level of significance. Therefore, the study rejects the "null hypothesis" for each estimated model. It can be concluded that there is a long run association between overall energy (including other sources of energy) and environmental sustainability, while controlling other important factors in equations.

5.4. ARDL Long-Run Estimates of Economic Growth

Table 6 shows a long run as well as short run impact of overall energy use and its different types on real economic growth. The long run slope coefficient of GFCF suggests that a 1% increase in gross investment tends to increase economic growth by 0.413% in the long run. This result is consistent with the theoretical expectation that investment in capital goods leads to an increase in production capacity and productivity, resulting in economic growth (Solow, 1956). Earlier studies, such as Al-Mulali et al. (2013) and Tiwari et al. (2021), have also demonstrated a positive association between gross investment and economic growth in their analyses. Moreover, the long run slope coefficient of LFPR suggests that a 1% increase in the labor force participation rate leads to a 0.899% increase in economic growth in the long run. This suggests that a rise in the labor force participation rate leads to a higher supply of labor, which in turn tends to increase in production and economic growth (Becker, 1962). Earlier studies, such as Wang et al. (2022) and Ahmed and Azam (2016), have also found a positive and significant association between labor force participation rate and real level of output growth in their analyses. Meanwhile, the long run slope coefficient of TOP suggests that a 1% increase in overall trade leads to a decrease in economic growth by 0.531% in the long run. This result is unexpected and contradicts the conventional wisdom that trade openness is generally associated with higher economic growth. However, it is possible that trade openness may also lead to increased competition and a loss of domestic market share, which could reduce economic growth (Rodriguez and Rodrik, 1999). Earlier studies, such as Arain et al. (2021) and Khobai and Roux (2018), have also found mixed results on the association between trade volume and real output growth in the case of developing countries.

Furthermore, the long-term slope coefficient of overall energy consumption (EC) implies that an increase of 1% in energy consumption leads to an increase in real economic growth by 1.537%, holding all other factors constant. This indicates that energy consumption plays a crucial and positive role in the economic growth of Pakistan. As the elasticity of economic growth with respective to energy use is more than unitary elastic. Moreover, the positive role of energy use in relation to economic growth can be attributed to the fact that energy is a fundamental input in the production process of goods and services. Thus, energy consumption is a prerequisite for economic growth because it enables businesses to increase their production commodities, leading to higher real output level. This outcome is consistent with earlier studies that found a positive association between energy use and real economic growth. For example, the study by Apergis and Payne (2010) found that use of energy had a positive impact on real economic growth in the long run. This analysis was done using a sample of 12 OECD member countries. Similarly, Omri (2013) also revealed a positive association between use of energy and real economic growth in case of African countries.

Moreover, the coefficients of hydel energy use (HE), nuclear energy use (NE), and thermal energy consumption (TE) indicate that these energy sources also have significant and positive impact on real economic growth. For instance, in the long run a 1% increase in hydel energy use results in a 0.231% increase in real economic growth, all else being equal. Therefore, increasing the use of hydel energy can positively contribute to economic growth. Similarly, a 1% increase in nuclear energy use leads to a 0.227% rise in real output growth, while a 1% increase in thermal energy use results in a 0.077% increase in real output growth. These findings align with previous research reported a positive correlation between energy use from different sources and real output growth. For example, Khobai and Roux (2020) found that renewable energy consumption, including hydel energy, had a positive impact on real economic growth in Middle Eastern and North African countries. Additionally, Wang et al. (2022) reported that environmental regulation and financial support for green innovation in China resulted in an increase in nuclear energy usage, which positively contributed to economic growth. In conclusion, the significant and positive coefficients of HE, NE, and TE indicate that increasing the use of these energy sources can positively contribute to real output growth in the long run.

5.4.1. ARDL short-run estimates of economic growth

Meanwhile, in the short run, the overall energy use (EC) has a significant and positive impact on growth while the other sources of energy such as HE and NE have a positive but statistically insignificant impact on real economic growth. It suggests that the main cause of economic growth is overall energy use, regardless of the specific source of energy (except thermal energy). In the short run, an increase in energy consumption can stimulate economic activity by increasing production and investment. However, the specific source of energy used may not be as important in the short run if there is an adequate supply of energy to meet the needs of the economy. The insignificant impact of other sources of energy use on economic growth in the short run may be due to several factors, such as market conditions, technological constraints, or policy barriers that limit the ability of these sources of energy to contribute to real economic growth. For example, the development of renewable sources of energy may be hindered by a lack of investment or insufficient infrastructure, which could limit their impact on economic growth in the short run. This finding is consistent with previous research that has found that energy use is a significant driver of economic growth in the short run as well as in the long run, while the specific source of energy used may be less important. For example, Baz et al., (2019) and Latief and Lefen (2019) found that energy consumption had a positive and significant impact on real economic growth in the short run in Pakistan, while the impact of different sources of energy was insignificant. Lastly the coefficients of ECM with a year lag are found to be −0.68-−0.75 negative and significant. This means that when the economic growth of Pakistan deviates from its long-run equilibrium, it adjusts by 68-75% towards the equilibrium in the following year.

Table 7: ARDL regression model (Environment and Energy)

Long run coefficients of environmental sustainability				
Variable	**Model 2A**	**Model 2B**	**Model 2C**	**Model 2D**
$GDPPC_t$	6.226**	0.616**	6.849**	6.475**
$GDPPC2_t$	−0.119**	−0.121**	−0.131**	−0.124**
FP_t	−0.121***	−0.120***	−0.133***	−0.126***
EC_t	0.689***	-	-	-
HE_t	-	0.521*	-	-
TE_t	-	-	0.490***	-
NE_t	-	-	-	0.098**
C	12.540***	12.049***	13.664***	15.079***
Short Run				
$\Delta GDPPC_t$	−3.99**	−4.070**	−4.309**	−4.030**
$\Delta GDPPC2_t$	0.076**	0.078**	0.082**	0.077**
ΔFP_t	−0.001	−0.001	−0.001	−0.001
ΔEC_t	0.201**	-	-	-
ΔHE_t	-	0.035	-	-
ΔTE_t	-	-	0.118**	-
ΔNE_t	-	-	-	0.001
ECM_{t-1}	−0.641***	−0.699***	−0.660***	−0.647***

Author estimate: ***, ** and * shows 1, 5 and 10% levels of significance

5.5. ARDL Long-Run Estimates of Environment Sustainability

Table 7 displays the long-term effects of GDPPC, $GDPPC^2$, FP, EC, HE, TE, and NE on ecological footprint. The slope coefficient for GDPPC is positive and significant, indicating that an increase in GDP per capita leads to a rise in ecological footprint. Additionally, the coefficient for $GDPPC^2$ is negative and significant, indicating a non-linear relationship between ecological footprint and GDP per capita that follows a U-shaped curve. This finding supports the environmental Kuznets curve hypothesis, which suggests that environmental degradation initially increases during economic development but then decreases as countries become wealthier and invest in environmental protection (Grossman and Krueger, 1995). Furthermore, this result aligns with earlier studies that have found an inverted U-shaped relationship between economic growth and environmental degradation (Stern, 2004).

The long-term coefficient for FP is negative, indicating that an increase in biocapacity (represented by forest products) leads to a decrease in ecological footprint. This finding is in line with previous studies that have identified a negative correlation between biocapacity and ecological footprint (Liu et al., 2022). The coefficient for EC is positive, indicating that an increase in energy consumption leads to an increase in ecological footprint. This result is consistent with earlier studies that have found a positive relationship between energy consumption and environmental degradation (Zhang, 2021).

Surprisingly, the long-term coefficient for HE is positive, suggesting that an increase in hydel energy consumption leads to an increase in ecological footprint. Although hydropower is generally considered a cleaner source of energy than fossil fuels, the scarcity of land and water resources means that hydel energy sources can have a negative ecological impact on the environment (Al-Mulali et al., 2016). They showed that using renewable energy damages the environment and wastes more water and land, which increases the ecological footprint. Renewable energy's erratic production and lack of suitable storage solutions are further challenges. Due to these factors, large-scale peak energy production, which is frequently fueled by fossil fuels, needs a backup power supply. Therefore, it is also claimed that renewable energy's mitigating effect is seen after a certain point (Heal, 2009; and Forsberg, 2009).

The long-run slope coefficient for thermal energy consumption (TE) is 0.490, meaning that a 1% increase in TE is associated with a 0.490% increase in ecological footprint (ECOPC), holding all else constant. This suggests that there is a positive relationship between TE and ECOPC, implying that higher thermal energy consumption leads to a higher ecological footprint. One possible reason for such a relationship is that as countries use more thermal energy, they tend to produce more goods and services. This increased production can lead to higher levels of pollution, which in turn increases the ecological footprint. Another reason is that as countries use more thermal energy, they tend to rely more on non-renewable sources of energy, which can have negative impacts on the environment. Regarding the long-run slope coefficient for nuclear energy consumption (NE) being 0.098, a 1% increase in NE is associated with a 0.098% increase in ECOPC, holding all else constant. This suggests that there is also a positive relationship between NE and ECOPC, but the magnitude of this relationship is smaller than other sources of energy such as HE and TE. This is because nuclear energy is generally considered to be cleaner than thermal energy, it still has environmental impacts. For example, nuclear waste disposal can have negative ecological effects. Additionally, building and maintaining nuclear power plants can require large amounts of resources and energy, which can also contribute to the ecological footprint. A similar study that supports these findings is the work of Destek and Aslan (2017), who conducted a similar analysis using data from Turkey. They found that both thermal and nuclear energy consumption had positive and significant effects on ecological footprint. Similarly, Destek and Ozsoy (2015) analyzed the relationship between energy consumption and environmental degradation in Turkey and found that both thermal and nuclear energy consumption had positive effects on environmental degradation.

5.5.1. ARDL short-run estimates of environment sustainability

In the short run, the overall energy consumption (EC) has a significant positive impact on ecological footprint while the other sources of energy have a positive but insignificant impact except TE. It suggests that overall energy consumption, particularly thermal energy, is the main driver environment degradation after overall economic activities, regardless of other specific source of energy consumption. This implies that measures to reduce energy consumption or to promote the use of cleaner and renewable energy sources may help to mitigate the country's environmental impact. However, the insignificant impact of hydel and nuclear energy consumption on ecological footprint suggests that these sources may not be contributing significantly to the country's environmental impact in the short run. It is important to note that this finding is limited to the short run, and the long-term effects of hydel and nuclear energy consumption on the environment are positive and significant. This finding is consistent with previous

Table 8: Diagnostics test for growth and energy

Diagnostic tests	Model 1A		Model 1B		Model 1C		Model 1D	
	F-stats	P-value	F-stats	P-value	F-stats	P-value	F-stats	P-value
Remsy RESET	0.938	0.342	0.863	0.308	0.948	0.345	1.013	0.369
LM	0.812	0.456	0.747	0.410	0.820	0.460	0.877	0.492
BPG	0.695	0.792	0.639	0.712	0.702	0.800	0.75	0.855
J-B tests	0.616	0.735	0.567	0.661	0.622	0.742	0.665	0.794
Cusum and Cusum^2	Stable		Stable		Stable		Stable	

AQ6 Author estimate: ???

Table 9: Diagnostics test for environment and energy

Diagnostic tests	Model 2A		Model 2B		Model 2C		Model 2D	
	F-stats	P-value	F-stats	P-value	F-stats	P-value	F-stats	P-value
Remsy RESET	0.050	0.825	0.047	0.784	0.074	0.743	0.495	0.817
LM	0.841	0.439	0.799	0.417	1.261	0.658	1.093	0.435
BPG	1.024	0.102	0.973	0.101	1.537	0.153	1.332	0.153
J-B tests	0.141	0.932	0.134	0.885	0.211	0.839	0.183	0.923
Cusum and Cusum^2	Stable		Stable		Stable		Stable	

AQ6 Author estimate: ???

research that has found that energy consumption is a significant driver of environmental degradation in the short run, while the specific source of energy used may be less important. For example, Baz et al., (2019) and Latief and Lefen (2019) found that energy consumption had a significant positive impact on degradation in the short run, while the impact of different sources of energy was insignificant. Lastly the coefficients of ECM with a year lag are found to be −0.68-−0.75 negative and significant. This means that when the environmental unsustainability of Pakistan deviates from its long-run equilibrium, it adjusts by 64% to 69% towards the equilibrium in the following year.

5.6. Diagnostic Tests

To ensure the validity of the long-run ARDL estimates and bound test discussion in our models, various diagnostic tests were conducted and presented in Tables 8 and 9 Specifically, LM test, BPG, J-B test, and Ramsey RESET tests were employed to identify and address potential issues with serial autocorrelation, heteroscedasticity, residual non-normality, and biased functional forms. Moreover, the CUSUM and $CUSUM^2$ tests were used to test regression models stability over time. Based on the calculated F-statistics a 5% level of significance, we accepted all the null hypothesis of no-serial autocorrelation, residual normality, and homoscedasticity. Moreover, Ramsey RESET test statistics were also found to be statistically insignificant at a 1% level of significance, therefore, we were unable to reject the null hypothesis of unbiased functional form of economic growth and ecological footprint. Lastly the CUSUM and CUSUM square tests also indicate stability. These suggest that the regression models are reliable and that the relationship between the dependent and independent variables remains stable over time. This means that there is no evidence of any significant structural changes or variations in the variance of the residuals. Therefore, the model can be considered robust and can be used to predict the values of the dependent variable with reasonable accuracy. Having passed all diagnostic tests, we conclude that our regression-based results are robust and interpretable.

6. CONCLUSION AND POLICY RECOMMENDATION

This study aims to examine the tri-dimensional nexus of energy, environment, and economic growth in Pakistan. Using the ARDL regression model, the study used the time series data from 1972 to 2021. Based on the estimated models, it can be concluded that investment in capital goods and an increase in labor force participation rate have a positive and significant impact on economic growth in the long run, consistent with theoretical expectations and previous studies. However, the relationship between trade openness and economic growth is unexpected and contradictory to conventional wisdom, indicating that increased competition and a loss of domestic market share could reduce economic growth. Meanwhile, overall energy consumption has a significant positive impact on economic growth in both the short and long run, and different sources of energy, such as hydel, nuclear, and thermal energy, also have a positive impact on economic growth. The main driver of economic growth in the short run is energy consumption, regardless of the specific source of energy used. This suggests that policymakers should focus on ensuring a sufficient supply of energy to meet the needs of the economy in the short run, while investing in renewable sources of energy and infrastructure to promote sustainable economic growth in the long run.

Additionally, the study supports the Environmental Kuznets Curve hypothesis, which suggests that environmental degradation initially increases with economic development but eventually decreases as countries become wealthier and can afford to invest in environmental protection. The results also indicate that biocapacity has a negative relationship with ecological footprint, while energy consumption, particularly thermal energy, has a positive relationship with ecological footprint. Moreover, hydro, and nuclear energy consumption have positive but insignificant impacts on ecological footprints in the short run, but their long-term effects are positive and significant. These findings suggest that measures to reduce energy consumption or promote the use of cleaner and renewable energy sources may help mitigate the country's environmental impact. Furthermore, this study contributes to our understanding of the relationship between economic development, energy consumption, and environmental degradation in Pakistan, and highlights the need for policymakers to consider the environmental consequences of economic growth and energy consumption in their decision-making processes. Based on the findings the study also suggests some policy recommendations. These policies recommendations could be considered to mitigate environmental degradation and boosting economic in Pakistan:

- Implement policies to reduce overall non-renewable energy consumption: Since energy consumption is a significant driver of ecological footprint, policies that encourage energy conservation and promote the use of cleaner and renewable energy sources could be implemented
- Promote investment in renewable energy: Given that hydel and nuclear energy consumption may not be contributing significantly to the country's environmental impact in the short run, policies that promote investment in renewable energy sources such as solar and wind power could be implemented to reduce reliance on non-renewable energy sources
- Encourage sustainable forest management: As biocapacity (represented by forest products) was found to have a negative relationship with ecological footprint, policies that encourage sustainable forest management practices could be implemented to reduce deforestation and promote reforestation
- Strengthening environmental regulations and enforcement: Environmental regulations were found to have a significant impact on ecological footprint. Therefore, policies that strengthen environmental regulations and improve their enforcement could be implemented to reduce environmental degradation
- Encourage international cooperation: Environmental issues are global in nature and require international cooperation. Pakistan could work with other countries to develop policies and programs aimed at reducing global environmental degradation.

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