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Integrating non-renewable energy consumption, geopolitical risks, economic development with the ecological intensity of wellbeing: evidence from quantile regression analysis

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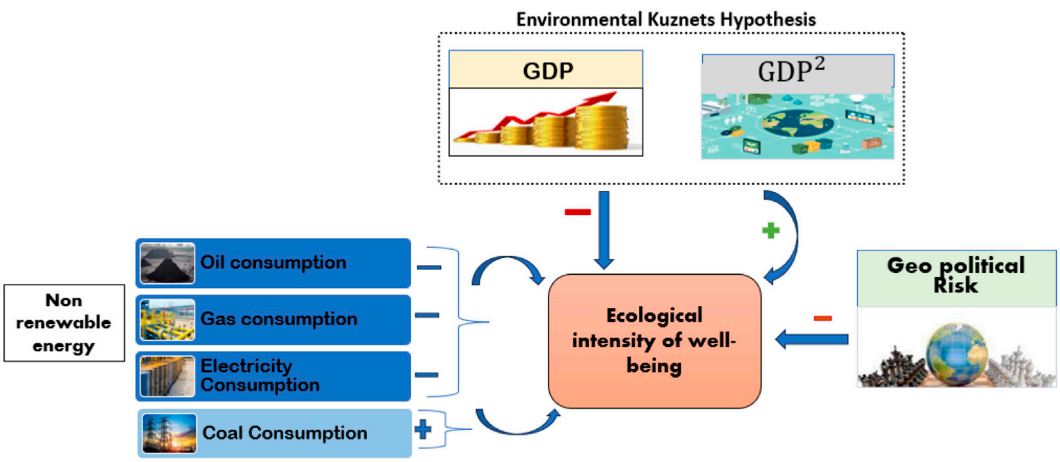
Introduction: This study delves into the intricate relationship between non-renewable energy sources, economic advancement, and the ecological footprint of well-being in Pakistan, spanning the years from 1980 to 2021.

Methods: Employing the quantile regression model, we analyzed the co-integrating dynamics among the variables under scrutiny. Non-renewable energy sources were dissected into four distinct components—namely, gas, electricity, and oil consumption—facilitating a granular examination of their impacts.

Results and discussion: Our empirical investigations reveal that coal, gas, and electricity consumption exhibit a negative correlation with the ecological footprint of well-being. Conversely, coal consumption and overall energy consumption show a positive association with the ecological footprint of well-being. Additionally, the study underscores the detrimental impact of geopolitical risks on the ecological footprint of well-being. Our findings align with the Environmental Kuznets Curve (EKC) hypothesis, positing that environmental degradation initially surges with economic development, subsequently declining as a nation progresses economically. Consequently, our research advocates for Pakistan's imperative to prioritize the adoption of renewable energy sources as it traverses its developmental trajectory. This strategic pivot towards renewables, encompassing hydroelectric, wind, and solar energy, not only seeks to curtail environmental degradation but also endeavors to foster a cleaner and safer ecological milieu.

KEYWORDS

non-renewable energy consumption, environmental kuznet hypothesis, geopolitical risks, economic development, Pakistan



GRAPHICAL ABSTRACT

1 Introduction

One of the major challenges that modern societies face is improving their wellbeing while reducing pressures on their environments. The environmental intensity of wellbeing (EIWB) is an indicator that quantifies the environmental footprint or impact associated with achieving a specific level of human values. The concept of the Environmental Interlinked Worldwide Biosphere has gained increasing importance in recent years as a result of the rising societal value and practices in eco-economic activities. These activities give rise to various environmental challenges, such as climate change, depletion of natural resources, and pollution (Zaman et al., 2017). The statement highlights that our choices regarding canned products, cosmetics, and lifestyle have a broader impact outside our immediate area (Li et al., 2022). The limited availability of resources, the release of greenhouse gas emissions, and the significant ecological impact all indicate the need for doing a cost-benefit analysis and comparison about the environmental costs associated with our energy consumption decisions (Ahmad et al., 2020). To effectively address the complex interconnections between non-renewable energy extraction, geopolitical dangers, economic outputs, and ecological intensities, it is crucial to understand the extensive transformations occurring within the framework of sustainable development. In addition, to establish sustainable foundations within the global energy system, it is imperative to address the requisite problems and dangers correspondingly.

The utilization of finite energy resources is a significant contributing factor to the ongoing global conflict between economic expansion and environmental sustainability. The use of fossil fuels in the production of non-renewable energy sources has significant economic and environmental consequences, both in the short-term and long-term (Zhang et al., 2023a). Energy is a distinctive commodity that plays a crucial role in the advancement of economies, enhancing the quality of life, and ultimately addressing fundamental necessities. However, renewable energy sources, including coal, oil, natural gas, and fossil fuels, are the primary contributors to global energy production. This poses environmental concerns due to the limited stocks of fossil fuels and the growing world population. To conduct a comprehensive sustainability analysis, it is imperative to consider both social wellbeing and ecological stress (Dietz et al., 2012). Furthermore, it is crucial to decarbonize the economy by reducing the consumption of non-renewable energy and adopting sustainable energy sources to promote development and human growth. Coal generates the most amount of CO_2 compared to other fossil fuels, and this is the source of most of the climate changes (Khan et al., 2020). Even though these emissions add to the greenhouse effect and then cause global warming accompanied by the associated ecological disruptions. Energy-related CO_2 emissions inclusive of international organizations are estimated to have reached a historic highest point of 33.1 gigatons in the year 2019 (Energy, 2019). One of the alarming risks of coal mining and extraction is deforestation, habitat destruction, removal of topsoil, and water contamination (Rehman et al., 2021). During the insults air pollution that is propelled by natural gas and coal can be so severe such as respiratory diseases, cardiovascular health issues, and early deaths. The World Health Organization (WHO, 2022) highlights that there are 4.2 million premature deaths linked to outdoor air pollution as stated.

Conversely, oil extraction has detrimental effects on the ecosystem due to practices such as dredging and other approaches (Butler, 2012). Additionally, the combustion of oil in transportation and power generation contributes to the presence of pollutants in the atmosphere. The main pollutants identified in the study conducted by Hannun and Razzaq (2022) were nitrogen oxides (NO_2), sulfur dioxide (SO_2), and particulate matter (PM), among other substances. These pollutants have a detrimental impact on both air quality and human health, as well as causing a decline in individuals' emotional wellbeing. The use of oil leads to environmental degradation, soil and freshwater contamination, and ecological disturbances caused by overspills, tank leaks, and improper disposal practices (Asif et al., 2022). Furthermore, similar to fossil fuels, they also contribute to the exacerbation of environmental degradation. However, it is undeniable that the use of fossil fuels in electric power plants results in the release of greenhouse gas emissions, so impacting

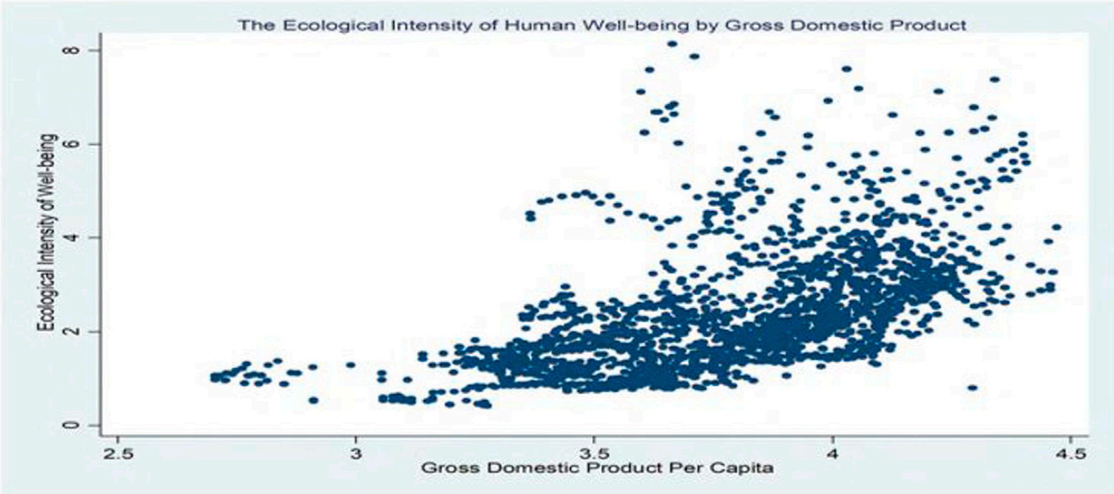


FIGURE 1
EIWB by GDP *per capita* (1989–2013) for developing countries (Source: Irshad et al., 2021).

the environment. According to Brauers (2022), the extraction of natural gas is comparatively less environmentally detrimental than the extraction of oil and coal. However, it still exacerbates various other environmental concerns, such as the destruction of habitats, contamination of water sources, fugitive leaks, and even seismic activity. The continuing utilization of renewable energy sources plays a significant role in enhancing ecological wellbeing by reducing reliance on non-renewable energy sources and implementing ecologically sustainable measures to mitigate climate change. (Osama et al., 2023).

Energy consumption is intricately linked to economic development (Parveen et al., 2020; Khurshid et al., 2023c). It can have both beneficial and bad effects on EIWB. One advantage of economic expansion is the potential for enhanced access to products and services, such as healthcare and education, which can contribute to the improvement of human wellbeing (Niu et al., 2021). Economic growth can lead to the development of eco-friendly technologies and sustainable practices, hence mitigating the adverse environmental impacts of economic activity (Khan et al., 2020; Khurshid, 2023b). Conversely, it has a detrimental effect on EIWB, leading to heightened resource use, deforestation, climate change, and pollution. According to Ahmad et al. (2022) and Khurshid et al. (2023c), the process of economic expansion can potentially contribute to increased urbanization and industrialization, which in turn may lead to the loss of habitats and a decline in biodiversity. The impact of economic expansion on EIWB is contingent upon the regulatory framework in place and the strategies implemented to mitigate its negative consequences. Kuznets's hypothesis posits that during the initial phases, nations give precedence to economic growth and industrialization, resulting in the emergence of pollution and environmental damage. As their revenue rises, they tackle environmental concerns by implementing awareness campaigns, policy interventions, and technical progress. They also allocate resources towards cleaner technologies and regulations (Dinda, 2004; Khurshid et al., 2023d).

Geopolitical risk poses a significant challenge to the Environmental Impact Assessment (EIWB). It is imperative for politicians to carefully evaluate the environmental ramifications of their political choices and devise strategies to mitigate adverse effects. According to Sweidan (2023) and Safi et al. (2023), the presence of geopolitical problems is closely linked to environmental concerns, as distant issues have the potential to generate instability and conflict. Climate change encompasses more than mere environmental concerns, as it exacerbates conflicts between nations and occasionally leads to conflicts over natural resources. The economics and investment in electric vehicles (EVs) and reinvestment can be influenced by various factors (Husnain, et al., 2022). This phenomenon is exemplified by the environmental degradation resulting from political instability and violence, as governments prioritize immediate economic benefits over long-term sustainability. Moreover, geopolitical risk has the potential to impact the availability of natural resources, such as clean water and food, which play a crucial role in determining the overall wellbeing of individuals. Political instability and wars can significantly impact supply chains, leading to inadequate resource acquisition and depletion of key resources for individuals and groups (Zhang et al., 2023b; Khurshid et al., 2023e) Figure 1.

- ➢ The contribution of this research is manifold:
- ➢ The research investigates the extent to which human wellbeing and development are
- ➢ related to the consumption of non-renewable energy and how this links to geopolitical issues. The study focuses on the long-term sustainability of existing socio-economic structures, considering global development disparities and the demands of individual nations. The scope of this study is defined by the inclusion of the following three topics: non-renewable energy consumption, the concept of wellbeing, and the ecological intensity of such wellbeing. Although this concept is not new, we have not found any research that decomposes the effects of non-renewable energy consumption into oil, coal, gas, and electricity consumption on the ecological intensity of wellbeing. Secondly, we analyze and synthesize the concept of wellbeing, drawing upon various streams of literature. It is important to compile a working

definition of this term, as well as potential notions of what constitutes a non-sustainable level of development. This will allow the concept of ecological intensity and wellbeing to be fully understood.

- ➢ Research on Pakistan's biodiversity highlights the importance of understanding how geopolitical challenges can impact conservation efforts. Political upheaval and violence can harm ecosystems and animal populations, necessitating careful consideration of hotspots and protected areas. Transnational issues like border conflicts, water management, and migratory patterns also affect biodiversity preservation. Addressing this research gap can provide valuable insights for policymakers, conservation practitioners, and international organizations to develop strategies for biodiversity conservation in the face of geopolitical challenges.
- ➢ Previous research in Pakistan has explored the relationship between economic growth and environmental degradation. However, there needs to be more research in the specific context of Pakistan regarding validating the Environmental Kuznets Hypothesis and its implications for biodiversity loss. We could address this research gap by conducting a comprehensive study that investigates the impact of economic growth on EWIB.

2 Brief review of prior literature

2.1 Economic development and EIWB

According to the ecological modernization hypothesis, economic progress harms the natural world. Furthermore, extensive research shows that the influence of subsequent economic growth on human wellbeing diminishes once we reach a fair level of wellbeing (Brady et al., 2007). Grossman and Krueger (1995) examined the reduced-form relationship between significant environmental factors and *per capita* income. They could not find any proof that economic expansion causes an ongoing decline in environmental quality. Economic development delivers a first stage of improvement for the majority of metrics. The tipping points for various populations vary but often occur before a nation's *per capita* income surpasses $8,000 (Rosa and Dietz, 2012). According to Dietz and Jorgenson (2014), economic progress has had little impact on EIWB in less developed nations since the early 1970s, while somewhat increasing intensity in wealthier ones. Reid et al. (2005) used the biophysical environment and depended on various ecosystem services to promote human wellbeing by employing economic growth. As a result, people disrupt biogeochemical cycles, harvest biomass, and modify land cover, among other environmental pressures.

2.2 Geopolitical risk and EIWB

The literature needs to sufficiently develop studies on the relationship between GPR and ecological intensity of wellbeing. Recent studies on the environmental effects of GPR include Riti et al. (2022), Husnain et al. (2022), Zhao et al. (2021), and Anser et al. (2021). In the BRICS nations, Riti et al. (2022) found a positive correlation between GPR and environmental degradation. They noticed that the GPR-environment relationship exhibits an aggregation bias. Anser et al. (2021) observed that GPR simultaneously raises CO2 emissions in the BRICS nations. From 2002 to 2019, Tahir et al. (2022) evaluated the effects of terrorism on environmental sustainability and ecosystems in the MENA nations. This study also tested the Environmental Kuznets Curve (EKC) theory. The empirical findings show that since terrorism raises CO_2 emissions, it is bad for the sustainability of the environment. The results also revealed a significant positive link between energy use and CO_2 emissions. Empirically, the results confirmed the MENA region's applicability of the EKC theory.

2.3 Non-renewable energy consumption and EIWB

According to Shahbaz and Dube (2012), using fossil fuels for energy in daily life, manufacturing, emitting considerable amounts of smoke, and using wood as a fuel source all increase CO_2 emissions. Emissions of CO_2 harm various sectors of the economy, such as forestry and agriculture. According to Wang (2021) and others, employing fossil fuels to stimulate economic growth may be successful during the first stages of growth. However, it will not be helpful during the later stages. Wenlong et al. (2023) used the ARDL approach. They discovered that coal transportation and rents both considerably and favorably contribute to the short- and long-term decline of ecological footprints at various quantile ranges. Karlilar and Emir (2023) examine the relationship between fuel usage, renewable energy sources, and ecological impact in India using data from 1995 to 2018. The findings revealed that utilising coal contributes significantly to ecosystem degradation. Majeed et al. (2021) investigated the asymmetric influences of aggregate and disaggregate energy use, economic development, and environmental quality in Pakistan from 1971 to 2014. The data suggested that increased oil use had a detrimental impact on the ecology. Odebayo et al. (2023) use quantile techniques, such as quantile cointegration, quantile causality, and quantile-on-quantile regression, to look at these connections. The study's conclusions indicate that oil consumption, hydroelectric energy use, population density, and economic growth drive most quantiles of environmental deterioration in Turkey.

2.3.1 Concluding remarks

The ecological intensity of human wellbeing focuses on promoting sustainable practices, protecting ecosystems, and valuing nature's benefits for a healthier, more resilient, and more fulfilling future. The literature on economic development, geopolitical risks, and non-renewable energy consumption concludes that these indicators significantly and negatively impact the ecological intensity of human wellbeing. However, existing literature often focuses on isolated aspects of the relationship between non-renewable energy consumption, geopolitical risks, economic development, and ecological wellbeing. There is a lack of comprehensive research that

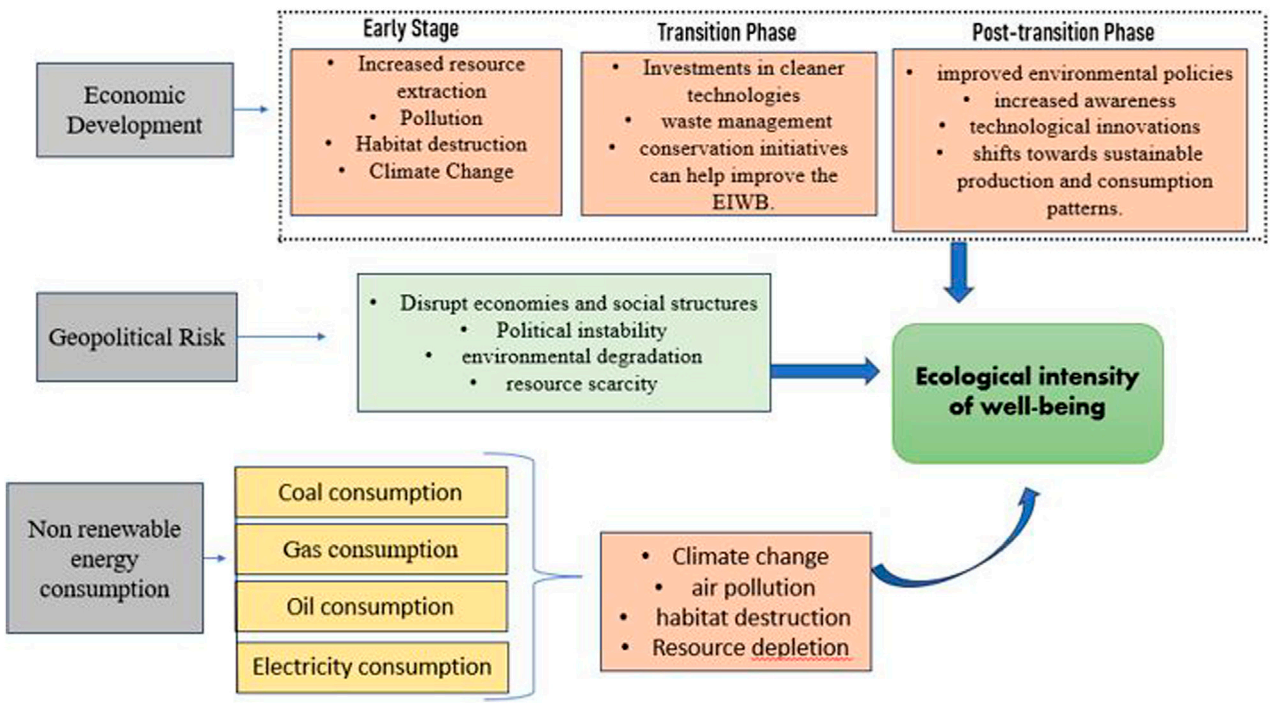


FIGURE 2
Transmission Mechanism of study variables.

integrates these factors to provide a holistic understanding of their interconnections. The current research adds to the literature since it attempts to investigate the combined impact of economic development, geopolitical risk, non-renewable energy consumption, and ecological intensity on human wellbeing. Moreover, the existing literature mostly examines the relationship between these factors in developed countries, overlooking the challenges faced by emerging economies and vulnerable regions like Pakistan. Further research is required to address the specific dynamics and vulnerabilities in these contexts.

3 Methodology

3.1 Conceptual framework

Figure 2 illustrates the relationship between EIWB, economic development, geopolitical risk, and non-renewable energy consumption. Economic development can lead to increased resource extraction, pollution, habitat destruction, climate change, and other ecological impacts that affect the ecological intensity of wellbeing in the early stages of economic growth and development. Environmental regulations, technological advancements, and public awareness initiate a transition phase that involves efforts to mitigate ecological impacts. In this phase, economic growth continues, and societies become more aware of the environmental consequences and consumption patterns. Societies may experience improved ecological wellbeing once they reach a certain level of economic development. The improvement in economic wellbeing could be due to factors such as improved environmental policies, increased awareness, technological innovations, and shifts towards sustainable production and consumption patterns.

Geopolitical risk impacts EIWB by disrupting economies, social structures, and political stability, which can lead to environmental degradation and resource scarcity. Non-renewable energy consumption contributes to climate change, air pollution, habitat destruction, and other environmental degradation, impacting the ecological intensity of wellbeing. Transitioning towards renewable energy sources, improving energy efficiency, and promoting sustainable practices are essential for reducing ecological impacts and ensuring a healthier and more sustainable future for both ecosystems and human wellbeing.

3.2 Variable description and data setting

The following mod can show the variable linkage:

$$\text{EWIB} = f\,(\text{LCC, LEC, LOC, LGAS, LENG, GDP, LGPR, LURB}) \tag{1}$$

The baseline model of our study is specified as:

$$\begin{aligned} EWIB_t = \beta_1 + \beta_2 LCC_t + \beta_3 LEC_t + \beta_4 LGAS_t + \beta_5 LOC_t + \beta_6 LENG_t \\ + \beta_7 LGDP_t + \beta_8 GDP_t^2 + \beta_9 LGPR_t + \beta_{10} LURB_t + \varepsilon_t \end{aligned} \tag{2}$$

Where EWIB is in the ecological intensity of wellbeing, LCC, LEC, LGAS, LOC, and LENG are a log of coal, electricity, gas, oil, and energy consumption, respectively. At the same time, LGDP is the log of GDP

TABLE 1 Description and definition of variables.

Variables	Symbols	Remark/comment	Data source
Ecological Intensity of Wellbeing	EWIB	The author calculates this index by taking data on ecological footprint and child mortality rate	GFN and WDI
Economic growth	GDP	GDP *per capita* (current US$)	WDI
Geopolitical Risks	GPR	Index	www.matteoiacoviello.com
Coil Consumption	LCC	Coal Consumption (metric tons)	Ministry of Energy
Electricity Consumption	LEC	Electricity consumption (GWH)	Ministry of Energy
Energy Consumption	LENG	Energy use (kg of oil equivalent *per capita*)	Ministry of Energy
Gas Consumption	LGAS	Gas consumption (mm cft)	Ministry of Energy
Oil Consumption	LOC	Oil Consumption (tons)	Ministry of Energy
Urbanization	LURB	Urban population (% of the total population)	WDI

per capita, GPR, LURB, geopolitical risks, and the log of urbanization, respectively. According to the simultaneous model, the LGDP (log of GDP *per capita*) and other LCC, LEC, LGAS, LOC, LENG, LGPR, LURB, and other log-transformed variables are applied. These transformations are, namely, of logarithmic, inverse, and square-root ones which allow to give sense to a coefficient and to settle a problem of distribution and scale of a variable. While including the squared term of GDP *per capita* (GDP^2) can permit capturing some anomalous nonlinear relationships between GDP and EWIB, such relationships in GE analysis could be alternatively explained by other cultural factors. Variables and metrics, like LGDP and LCC, are log-transformed to address skewness and heteroscedasticity.

The Ecological Intensity for Human wellbeing is the relationship between environmental pressure and human wellbeing. The authors applied this method at the national level using the child mortality rates *per capita* to the environmental ecological footprint indicator for each country. Almost in every country, research finds the mortality rate of children being monitored and well trusted indicator of prosperity. This renewable energy option is for not only reducing lovers but also the environment and carbon dioxide emissions. This method, founded on the data of the World Bank (2012) has also been employed by a few recent studies in the area of economic measure of the ecological intensity and carbon intensity of human wellbeing (e.g., Dietz et al., 2012; Jorgenson, 2014, respectively). While these aspects resulted, we selected the rate of life expectancy which we present in the article. The *per capita* ecological footprint (Jorgenson and Clark, 2012; Kitzes et al., 2009) constitutes a thorough assessment of consumption-based ecological strain. The Per Capita Ecological Footprint calculates the amount of bio-productive land required for maintaining consumption levels from crops, grassland, pasture, fishing grounds, and forest, as well as the land needed to absorb carbon dioxide emitted by fossil fuels and constructed infrastructures. The footprint includes the space required for built infrastructure (such as roads and buildings) and the land required to absorb the carbon dioxide released during fossil fuel usage. A recent inclusion is the subcomponent of the ecological footprint that deals with nuclear impact. This subcomponent of the nuclear footprint, which only made up a small percentage of the global footprint in 2000, is predicted to be like the footprint of producing the same amount of power using fossil fuels. The ecological footprint is computed by combining importation with domestic production and subtracting exports from domestic production. The ecological footprint is calculated for approximately 600 products, including raw materials and processed goods. Alternative metrics might be used in future research to account for environmental impacts.

Before the analysis can proceed, there is a problem with using a ratio as a dependent variable. A ratio can be dominated by either the numerator or the dominator since their variability and range might differ. The ecological footprint *per capita*'s coefficient of variation (standard deviation/mean) in the current study is 0.355. The infant mortality rate has a coefficient of variation of 0.253, with a range of 124.5–52.8. As a result, the variation in ecological footprint *per capita* (the numerator) exceeds the variation in infant mortality rate (the dominator). Under these conditions, variations in the ecological footprint *per capita* will generate variations in the ratio. To solve this issue, we employ the same strategy developed by New Economics Foundation scholars Dietz et al. (2012), Jorgenson et al. (2014), and Jorgenson (2015). We limit the numerator and denominator coefficients of variation to be equal by including a constant in the numerator that changes the mean without changing the variance. The coefficients of variation for the two variables in our data may be equalized by multiplying the ecological footprint *per capita* by 45.013. As a result, we employ the following metric to assess the ecological intensity of human wellbeing:

$$\text{EIWB} = \left[\left(\text{EF per capita} + 45.01\right)/\text{IMR}\right] \text{x } 100$$

E.F. stands for ecological footprint per person, EIWB for the ecological intensity of human wellbeing, and IMR for infant mortality rate. Following earlier studies (Dietz et al., 2012; Jorgenson, 2014), we multiply the ratio by 100 to scale it.

The current research investigates the relationship between renewable energy sources, economic growth, geopolitical risks, and ecological intensity of wellbeing. This analysis used the annual data series from 1980 to 2021 for Pakistan. The data was driven by considerations of data availability, temporal consistency, and methodological rigor. The primary data sources used in this study are the WDI (World Development Indicators) and the

TABLE 2 Descriptive statistics.

	EWIB	LGDP	LGDP^2	LCC	GPR	LEC	LENG	LGAS	LOC	LURB
Mean	19.460	2.810	7.955	3.709	8.342	4.669	2.631	5.866	7.131	1.516
Median	17.585	2.735	7.465	3.625	8.395	4.695	2.650	5.905	7.200	1.520
Std. Dev	9.889	0.242	1.385	0.330	2.057	0.275	0.055	0.242	0.197	0.036
Skewness	0.571	0.353	0.420	0.459	0.272	−0.596	−0.840	−0.367	−0.957	−0.241
Kurtosis	2.347	1.629	1.679	2.349	2.983	2.382	2.609	1.678	3.004	1.894
Jarque-Bera	3.030	5.159	5.293	2.216	5.520	3.153	5.207	4.003	6.408	5.549
Probability	0.220	0.025	0.017	0.330	0.071	0.207	0.074	0.135	0.041	0.080

Ministry of Energy. Table 1 below presents a detailed description of variables, their assigned symbols, and data sources.

3.2.1 Estimation technique

In addition, using the method of Koenker and Basset, the study used the quantile regression analysis to investigate the relationship of EIWB with Non-renewable energy sources like coal, gas, electricity, and oil consumption along with economic growth, and geopolitical risks. Quantile regression analysis is a useful method in scenarios where the relationship between variables may vary across various parts of the distribution because it provides increased flexibility, robustness, and insights into conditional relationships. Furthermore, this technique defies the limitation on the assumption of the same mistake. The model may be broadly characterized as follows:

$$Y_i = Z_i' \delta_\vartheta + \tau_{\vartheta i} \tag{3}$$

In Eq. 3, Y_i represents the dependent variable, $\tau_{\vartheta i}$ Is the anonymous error term, and δ_ϑ expresses the unacquainted vector regression estimation for the parameter (H × 1). The range of "ϑ" varies from 0 to 1. Eq. 4 can be written in conditional quantile form by ensuring Y_i and Z_i As:

$$Q_\vartheta = \left(\frac{Y_i}{Z_i}\right) = Z_i' \delta_\vartheta \tag{4}$$

In addition, by reducing the appropriate value of "δ," we also measure the function. δ_ϑ Vector as:

$$\left\{ \sum\nolimits_{t:\ \delta_\vartheta > Z_t} \vartheta |Y_t - Z_i' \delta_\vartheta| + \sum\nolimits_{t:\ \delta_\vartheta > Z_t} (1-\vartheta) \| Y_t - Z_i' \vartheta \| \right\} \tag{5}$$

Quantile regression uses a generalized temporal technique or a basic linear technique. As a result, we restrict the scaled absolute errors for each criterion to a reasonable level, such that the weighting of positive and negative residues differs in the given quantity of valuing. As a result, by extending Eq. 2 in the following direction, the interaction of relative variables may be derived as:

$$\begin{aligned} EWIB_t = {} & \beta_1^\vartheta + \beta_2^\vartheta LCC_t + \beta_3^\vartheta LEC_t + \beta_4^\vartheta LGAS_t + \beta_5^\vartheta LOC_t + \beta_6^\vartheta LENG_t \\ & + \beta_7^\vartheta LGDP_t + \beta_8^\vartheta GDP_t^2 + \beta_9^\vartheta LGPR_t\, \beta_{10}^\vartheta LURB_t + \varepsilon_t \end{aligned} \tag{6}$$

In Eq. 6, β_1^ϑ, $\beta_2^\vartheta, \beta_3^\vartheta$, β_4^ϑ, $\beta_5^\vartheta, \beta_6^\vartheta$, β_7^ϑ, β_8^ϑ, β_9^ϑ, β_{10}^ϑ, indicates that the quantile regression estimated coefficients vary from 0.1 to 0.9.

TABLE 3 Results of phillip perron unit root test.

Variable	At level	At first difference	Integration
EWIB	4.723	−3.732***	I (1)
LCC	−0.023	−6.342***	I (1)
LEC	−5.252***	−5.720***	I (0)
LGAS	−2.246	−5.045***	I (1)
LENG	−2.369	−6.512***	I (1)
LOC	−3.612***	−4.708***	I (0)
LGDP	0.053	−6.138***	I (1)
LGDP^2	0.205	−5.813***	I (1)
GPR	−2.872*	−7.021***	I (0)
LURB	−2.895*	−12.856***	I (0)

4 Results and discussion

4.1 Descriptive statistics analysis

The descriptive statistics findings are shown in Table 2 below. The Jarque-Bera test probability values revealed that most variables are not normally distributed. Non-stationary data may have trends, seasonality, or other patterns that change over time. The non-normality of the data can be an indicator that these patterns are not constant and may require special handling in modeling.

4.2 Stationarity test

To identify the stationarity of the variables of each variable, we used a Phillip Perron (P.P.) unit root test. The results (Table 3) confirm that the series is a mix of stationary and non-stationary variables.

4.3 Structural break unit root test

We conducted the Zivot and Andrews (1992) test and discovered that, with a single unknown break, EWIB, GDP, LCC, LOC, LGAC, and LURB exhibit stationarity at both level with intercept and trend. Conversely, LENG and LOC were found to be stationary at first difference. This suggests varying levels of

TABLE 4 Zivot-Andrews Structural Break Unit Root test Results.

	I (0)		I (1)	
	t-stat	Break points	t-stat	Break points
EWIB	−2.661**	2012	−7.083**	2010
GDP	−3.507***	2004	−5.648	2014
GPR	−5.402***	2001	−7.337**	2004
LCC	−3.140*	2010	−7.270**	2014
LEC	−7.337**	2004	−7.563*	2013
LENG	−3.073	1994	−6.983**	2008
LGAS	−4.226**	2003	−6.473**	1999
LOC	−2.775	1995	−4.226	2012
LURB	−8.424*	2001	−9.853**	1992

integration among the series. Further validation using the Zivot and Andrews (1992) test with a single unknown structural break confirmed the robustness of our findings, indicating a mixture of I (0) and I (1) integration among the variables.

4.4 Results of quantile regression estimation

Table 4 presents the results of the quantile regression analysis. Non-renewable energy consumption has many impacts, such as rising temperatures, changing precipitation patterns, and extreme weather events associated with climate change. These have far-reaching ecological consequences, including altered ecosystems, disrupted biodiversity, and increased risks to human health and livelihoods. The current study separates non-renewable energy consumption into four categories: total electricity consumption, coal energy consumption, oil energy consumption, and gas energy consumption. Our results support the claim that LCC significantly impacts the EWIB by 33.9 percent. LEC impacted EWIB negatively and significantly, by 5.636 percent.

Furthermore, LENG has a positive and significant impact of 11.6 percent, while LGAS has a negative and insignificant impact (59.8 percent) on EWIB. Besides, LOC impacts the EWIB negatively and insignificantly, by 37.4 percent. The results show that the adverse indications are quantitatively greater than the positive signs, implying that non-renewable energy use causes environmental deterioration and harms EIWB. Nathaniel and Khan (2020) discovered that non-renewable energy considerably triggers environmental deterioration in ASEAN nations. Destek and Sinha (2020) discovered that growing non-renewable energy usage increases environmental damage.

Non-renewable energy damages environmental quality. According to Chien (2022), the consumption of renewable energy significantly improves environmental quality at all quantiles (0.10–0.90), while the consumption of non-renewable energy only significantly deteriorates it at lower quantiles (0.10–0.40). Previous studies, such as those of Butler (2012) and Hannun and Razzaq (2022), also support the negative impact of oil consumption on EIWB. Brauers (2022) also explains the negative relationship between electricity consumption and ecological wellbeing, pointing out that the generation and consumption of electricity have ecological implications due to the release of greenhouse gases by fossil fuel-based power plants.

TABLE 5 Results of quantile regression estimates.

Variable	Coefficient	Std. Error	t-Statistic	Prob
LENG	0.116	0.058	1.995	0.060
LCC	0.339	0.170	1.990	0.055
LEC	−5.636	1.927	−2.925	0.003
LGAS	−0.598	1.418	−0.422	0.676
LOC	−0.374	3.003	−0.125	0.902
LGDP	−0.302	0.107	−2.824	0.008
LGDP2	0.416	0.136	3.066	0.004
GPR	−0.055	0.122	−2.447	0.006
LURB	9.285	1.363	6.813	0.000
C	−41.385	18.089	−2.288	0.029
Pseudo R-squared	0.932	Mean dep var		19.160
Adj R-squared	0.910	S.D. dep var		5.889
S.E. of regres	1.229	Objective		13.332
Quantile dep. var	17.510	Restr. Objective		171.570
Sparsity	2.529	Quasi-LR statistic		500.596
Prob (Quasi-LR stat)	0.000			

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TABLE 6 Outcomes of estimated quantile process.

Variables	Quantile	Coefficient	Std. Error	t-Statistic	Prob
LCC	0.2	0.318	0.129	2.456	0.020
	0.4	0.695	0.363	1.915	0.064
	0.5	0.377	0.214	1.760	0.088
	0.6	0.202	0.083	2.435	0.021
	0.8	0.816	0.266	3.068	0.004
LEC	0.2	−1.304	0.648	−2.014	0.053
	0.4	−1.231	0.668	−1.843	0.075
	0.5	−1.615	0.933	−1.730	0.093
	0.6	−0.484	0.185	−2.619	0.013
	0.8	−1.103	0.788	−1.398	0.172
LGAS	0.2	−0.431	7.249	−0.059	0.953
	0.4	−0.645	5.431	−0.119	0.906
	0.5	−1.863	5.559	−0.335	0.740
	0.6	−0.255	5.453	−0.047	0.963
	0.8	−10.348	8.004	−1.293	0.205
LOC	0.2	5.684	10.393	0.547	0.588
	0.4	−1.561	7.569	−0.206	0.838
	0.5	−0.748	7.772	−0.096	0.924
	0.6	6.400	7.496	0.854	0.400
	0.8	−2.836	8.299	−0.342	0.735
LENG	0.2	0.679	3.200	0.212	0.833
	0.4	1.819	1.136	1.601	0.119
	0.5	2.972	1.937	1.535	0.135
	0.6	3.629	2.867	1.266	0.215
	0.8	−5.442	36.541	−0.149	0.883
LGDPC	0.2	−2.019	1.482	−1.362	0.183
	0.4	−2.931	1.216	−2.410	0.022
	0.5	−1.220	0.540	−2.260	0.031
	0.6	−1.163	0.793	−1.467	0.152
	0.8	0.317	2.270	0.140	0.890
$LGDP^2$	0.2	2.828	1.860	1.521	0.138
	0.4	1.417	0.529	2.678	0.012
	0.5	0.263	0.105	2.514	0.017
	0.6	0.270	0.160	1.685	0.102
	0.8	−0.291	1.980	−0.147	0.963
GPR	0.2	−0.104	0.144	−0.723	0.538
	0.4	−0.178	0.160	−1.109	0.276
	0.5	−0.194	0.130	−1.489	0.678

(Continued on following page)

TABLE 6 (*Continued*) Outcomes of estimated quantile process.

Variables	Quantile	Coefficient	Std. Error	t-Statistic	Prob
	0.6	−0.211	0.131	−1.605	0.549
	0.8	−0.312	0.210	−1.485	0.147
LURB	0.2	4.511	1.636	2.757	0.001
	0.4	3.583	1.253	2.860	0.000
	0.5	4.958	2.728	1.817	0.000
	0.6	3.650	1.267	2.880	0.000
	0.8	2.562	1.245	2.058	0.000
C	0.2	−8.642	4.138	−2.089	0.045
	0.4	−10.124	4.670	−2.168	0.038
	0.5	−7.407	3.364	−2.202	0.035
	0.6	−14.221	4.905	−2.899	0.007
	0.8	−12.957	4.359	−2.972	0.006

Our findings show that GDP negatively impacts the ecological intensity of wellbeing *per capita*, with a one percent increase in GDP reducing EWIB by 0.302 units. In our model, we also incorporated the quadratic term of GDP because we wanted to know about the impact of economic growth over time. Our results from Table 5 also confirm that if GDP doubles, it can increase EWIB by 0.416 units. These findings support the EKC theory, consistent with earlier research (Knight and Rosa, 2011; Dietz et al., 2012). As a result, developing nations continue to lag in achieving the critical GDP barrier, after which EIWB may decline. According to Irshad et al. (2021), economic expansion favors EIWB, and rising urbanization can also boost EIWB. These data indicate that current modernization practices are less likely to lead to sustainability in underdeveloped nations. Ahmad et al. (2021) discovered that economic expansion reduces biocapacity but raises it until they reach a specific threshold level.

The coefficient of GPR is −0.055 and insignificant, which shows that a unit increase in GPR reduces EWIB by 0.055 units. Geopolitical conflicts can destroy natural resources and ecosystems. Our results are consistent with those of Osama et al. (2023), who found that the impact of GPR on EIWB is negative and statistically significant, with coefficient values of 0.028. Riti et al. (2022), Husnain et al. (2022), and Anser et al. (2021) also support the negative relationship. On the contrary, Sweidan (2021) found that geopolitical risk tends to lower environmental stress levels or promote environmental sustainability.

With a coefficient value of 9.285, urbanization has a strong and favorable influence on EWIB. It implies that a 1% rise in LURB improves EWIB by 9.285 units. Our results agree with those of Irshad et al. (2021), who discovered that increased urbanization could enhance EIWB. According to the ecological modernization idea, as civilizations become more urbanized, environmental quality and related advantages improve (York et al., 2003). These findings contrast those of Ahmad et al. (2021), who reported a negative association between urbanization and biocapacity *per capita*, showing that urbanization is a substantial cause of biocapacity loss in Brazil. According to Chen and Chang (2016), Khurshid et al. (2022a) and Khurshid et al. (2022b), urbanization has significant positive effects at all income levels, indicating that the ecological footprint would increase with the rate of urbanization in a country with high or low income. The pursuit of economic progress by emerging nations will impact the environment. Developed nations may seek to boost their economies through activities that harm the environment.

4.5 Estimated quantile process

Table 6 shows the estimated quantile process results for GDP, GDP^2, GPR, LECC, LEC, LGAS, LOC, and LUBR with a quantile range of (0.1–0.9). The quantile range of all variables demonstrates the enormous influence of various non-renewable energy consumption, GPR, and GDP on the EIWB in Pakistan.

Figure 3 also shows a graphical depiction of the quantile process estimations. It demonstrates the significance of the components on which the influence of ecological intensity of wellbeing is created throughout the cycle. The bold red line represents a rough estimate and a 90% confidence range.

4.5.1 Estimation of symmetric quantile test

Table 7 demonstrates that the Wald test summary Chi-Sq. statistic value of 85.010 is statistically significant at the 1% level, hence the null hypothesis of slope equality across quantiles is rejected. This finding validates the conclusion enforced by Chart 1 and confirms that the connection between the explanatory variables and the dependent variable varies over quantile values. This is relevant because it shows that in cases when the research emphasis is on specific quantiles, linear models can lead to inadequate conclusions as to whether there is a link between the explanatory and dependent variables, and if a link exists these models may suggest a wrong conclusion about the strength of the link. Table 7 also presents the results of the test for symmetry between quantiles. The null hypothesis of this test is that the distribution is symmetric. The test statistic is statistically

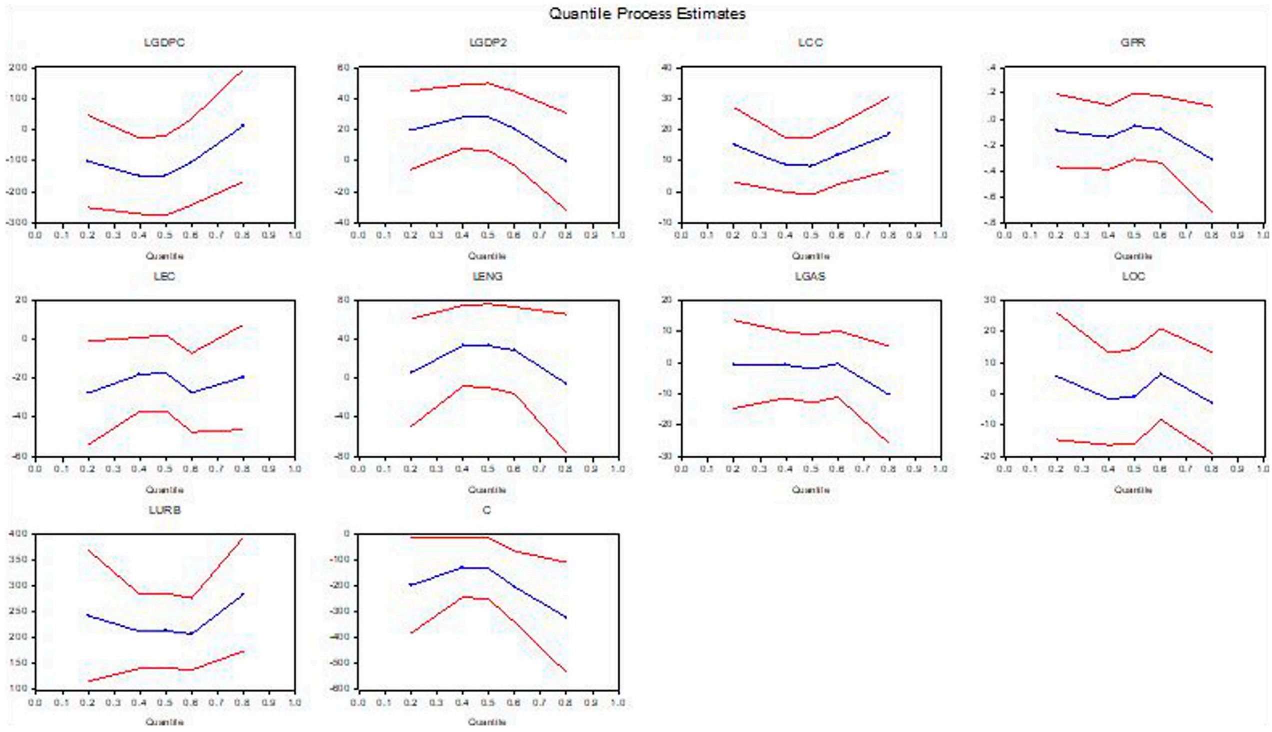

FIGURE 3
Plot of quantile process estimates.

TABLE 7 Quantile slope equality test and symmetric quantile test.

Outcome of slope equality test			
Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f	Prob
Wald Test	85.010	40	0.000
Outcome of Symmetric Quantile Test			
Test Summary	Chi-Sq. Statistic	Chi-Sq. d.f	Prob
Wald Test	918.7132	72	0

significant at the 1% level, which shows significant asymmetry and contradicts the hypothesis of null symmetry between quantiles. These data confirm the diverse influence of the explanatory variables on EWIB.

4.5.2 Estimates of cointegration regression techniques

The cointegrating equation estimations include the application of the Dynamic least squares (DOLS and Fully modified least squares (FMOLS) approaches proposed by Phillips and Moon (1999) and Kao and Chiang (2000) respectively. These techniques seek to estimate the long-run relationship among the variables. DOLS and FMOLS solve the problem of endogeneity and eliminate small sample bias, the application of the FMOLS approach essentially requires that all variables must have the same order of integration and that the regressors must not appear as co-integrated. The current research also applied Fully modified least squares (FMOLS) and Dynamic least squares (DOLS) to expose the linkages among variables. Table 8 reflects the results of FMOLS and exposes the effect of variables LCC (0.683), LEC (−0.346), LENG (0.098), and LGAS (−0.532) on EWIB in Pakistan. From our results, the results of FMOLS, LCC, and LENG positively impact EWIB, while LEC and LGAS negatively impact EWIB.

5 Conclusion and policy recommendation

The research examines the impact of non-renewable energy consumption, geopolitical risks, and economic development on Pakistan's ecological wellbeing, analyzing the components of non-renewable energy like oil, coal, gas, and electricity using quantile regression.

Firstly, we find that coal consumption and total energy consumption positively affect the EWIB, while LEC, LGAS, and LOC negatively contribute to the EWIB. Also, the outcome of cointegration regression analysis through FMLOS and DOLS reveals that LCC and LOC positively affect the EWIB while LEC and LGAS negatively affect the EWIB. Non-renewable resources, used in manufacturing, transportation, and energy production, primarily meet Pakistan's energy needs. However, these resources can lead to biodiversity loss, habitat destruction, pollution, climate change, population decline, and even extinction. Disruptions to ecosystems, such as heavy metal discharge into rivers and pollution from oil extraction, can also negatively impact marine and coastal habitats.

TABLE 8 Outcomes of FMOLS and DOLS.

The outcome of fully modified least square				
Variable	Coefficient	Std. Error	t-Statistic	Prob
LENG	0.098	0.058	1.677	0.104
LCC	0.683	0.170	3.190	0.000
LEC	−0.346	0.117	−2.961	0.000
LOC	0.407	3.003	1.232	0.227
LGAS	−0.532	0.418	−1.272	0.339
LGDPC	−0.306	0.107	−2.866	0.007
LGDP2	0.532	0.236	2.256	0.003
GPR	−0.211	0.122	−1.734	0.093
LURB	5.498	1.063	5.172	0.000
C	−50.948	8.089	−6.298	0.000
R-squared	0.989	Mean dependent var		19.766
Adjusted R-squared	0.986	S.D. dependent var		9.809
S.E. of regression	1.154	Sum squared resid		41.307
Long-run variance	0.478			
Outcomes of Dynamic Least Square (DOLS)				
Variable	Coefficient	Std. Error	t-Statistic	Prob
LENG	0.374	0.158	2.366	0.082
LCC	0.676	0.170	3.968	0.000
LEC	−0.493	0.127	−3.886	0.001
LOC	0.119	0.113	1.051	0.301
LGAS	−1.636	1.418	−1.154	0.257
LGDPC	−0.257	0.107	−2.407	0.022
LGDP2	0.651	0.236	2.762	0.009
GPR	−0.135	0.122	−1.109	0.276
LURB	9.212	1.063	8.667	0.000
C	−43.031	8.089	−5.320	0.000
R-squared	0.950	Mean dependent var		19.460
Adj R-squared	0.937	S.D. dependent var		9.889
S.E. of regression	1.116	Sum squared resid		39.834
Long-run variance	0.630			

Secondly, we found that economic development significantly impacts ecological wellbeing, with impacts varying across quantiles. It can contribute to environmental degradation, with CO_2 emissions being the main cause. The EKC is valid in the case of Pakistan. Thirdly, our analysis uncovers the role of geopolitical risks in shaping ecological wellbeing, with heightened risks amplifying environmental pressures, particularly among countries already experiencing lower wellbeing levels. This underscores the importance of addressing geopolitical tensions and fostering international cooperation to mitigate environmental vulnerabilities.

To promote resilience and sustainability, the study suggests giving priority to renewable energy sources and enhancing energy efficiency in all spheres of the economy. Furthermore, to minimize negative effects, an integrated approach to economic and environmental policy is necessary, integrating strict environmental rules and green growth initiatives. Given the impact of geopolitical concerns on ecological wellbeing, it is important to promote diplomatic efforts and international cooperation to resolve conflicts in the region. Investing in conservation and ecological restoration projects, as well as public awareness and education campaigns, may further support sustainability efforts. By implementing these recommendations, Pakistan can progress towards a future that balances ecological wellbeing and economic development and skillfully manages geopolitical threats to safeguard the environment for future generations.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

NK: Conceptualization, Formal Analysis, Methodology, Software, Supervision, Writing–original draft. CE: Data curation, Funding acquisition, Investigation, Methodology, Writing–review and editing. NA: Methodology, Software, Validation, Visualization, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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